POLITECHNIKA GDAŃSKA	Gdańsk University of Technology FACULTY OF MECHANICAL ENGINEERING	

Term Project

Design of industrial material laboratory testing and selection of basic equipment

Projekt przemysłowego laboratorium do badań materiałowych oraz wybór podstawowego wyposażenia.

Student: Javier Martínez Bea

Profesor: dr inż. Krzysztof Krzysztofowicz

ABSTRAC

2.First step of this project is an introduction of quality terms, which must be inherent to a product from the point of view of design, manufacturing and customer satisfaction, with the mention of the different quality models (EFQM Model, DEming Cycle , etc).

In addition, another introduction about accreditation definitions and certification performs, relating their different models to the European standards of accreditation, ISO, which are used for the present project. Approximated prices are quoted but a study of the certification cost in testing laboratory is not widely generated.

3. Material tests are not a new technology, so it´s described a brief historical review of different test types and eminent scientists who have left their mark (Galileo, Mohs, Euler, Hook, etc) .
A study of the state of the art is made, relating testing laboratories with university and large multinationals.
The testing laboratory is not only an entity that provides services, but also a place to keep a series of equipment and ergonomic and safe work space.

4. Material testing.

5. Description of Different non-destructive tests (Visual inspection, with its methodology, ...

6. As in the previous section, the most used destructive tests are described, repeating the previous system.

7. Finally, we analyze an example of an hypothetical company to select the best choice of laboratory. There, a company wants a quality process in its production, so it wants a test laboratory to perform this process. Two types of laboratory can select: its own testing laboratory or outsource an inspection service.

For this, we make an analysis of the different procedures in testing laboratories to know the costs of the tests. In the beginning, it has not tried to obtain budgets of specifically companies that provide these services, so at the end costs were objectify obtained from official prices.

In order to assess the costs of the equipment, here it has been possible to obtain a budget from two companies. In addition to these two budgets, offered prices from the web pages of different manufacturers were used and this led to the valuation of such equipment.

The salary of the laboratory personnel has not been forgotten.

To simplify the visualization of the results, different tables for the calculation process have been used.

KEYWORKS:

ISO, quality, testing, laboratory, Universal Testing Machine, Pendulum Charpy, hadness testing, Brinell, Rockwell, Vickers specimen, magnetic particle testing, destrructive testing, non destructive testing, calibration, verification,

TABLE OF CONTENTS

Note.-for greater practicality will have shortened addresses URLs via the Google htpps://goo.gl program, appearing the links as http://goo.gl/xxxxxx

LIST OF IMPORTANT SYMBOLS AND ABBREVIATIONS.

AOL …………….. Acceptable Quality Level.

ASQ ……………… American Society for Quality.

ASTM ……………..American Society for Testing and Materials.

CEN ……………… European Committee for Standardization.

CWA ………………CEN Workshop Agreement

DIN ………………. Deutsches Institut für Normung .

E ………………….. Young's modulus.

EFQM …………… European Foundation for Quality Management.

ENAC ……………. *Entidad Nacional de Acreditación* (National Accreditation Entity)

Fig. ……………….. Figure.

HBW ……………… Brinell's hardness.

HR ……………….. Rockwell's hardness .

HV …………………Vickers's hardness.

IEC ………………. International Electrotechnical Commission.

IS ………………… International System of Units.

ISO ………………..International Organization for Standardization.

JISC ………………Japan Industrial Standards Committee.

LTPD . ..………… Lot Tolerance Percent Defective.

LPI ………………. Liquid Penetrant Testing.

mm ………………..Milimetres.

MPa ……………… Megapascals (1 Mpa =10^6 N/m^2).

N …………………. Newton.

NDT………………. Non Destructive Testing.

PPE ……………….Personal Protective Equipment.

QMS ……………… Quality Management System.

s ………………….. Secon.

Another symbols

MPa ………………….. Megapascal.

Pa ……………………. Pascal.

ε ……………………… Nominal Stress.

Δl ……………………. Elongation produced by deformation.

σ ……………………… Tensile strength

σ_e ……………………… Tensile Elasticity.

σ_r ……………………… Tensile Resistance.

$\boldsymbol{\rho}$ ……………………… Impact Toughness

b_o ……………………… Test specimen width (Tensile test).

L_o ……………………… Initial test specimen Lenght.

S_o ……………………… Initial transversal area of test specimen (Tensile test).

k ……………………….. Test Specimen Proporcionality coeficient

1. INTRODUCTION, AIMS AND OBJECTIVES.

The objective of the present Term Projec, "Design of industrial material laboratory testing and selection of basic equipment" has an academic nature.

Norton, in his work "Design of machinery" (Norton, 2005) describes the physical principles that govern the natural laws of design and manufacture of machines influence from existing trials in the laboratories and research centres and, therefore, its field of application: kinematics, dynamics, torsion, etc.

In addition, Norton´s work, describes the factors that affect the ideal behavior of those testing machines, such as wear and tear use, method of operation, temperature, etc, and in the development of this Term Projec, it will describe how these factors are considered rules that affect the various tests of materials.

In the international market, there is a wide range of testing machines, which can be found in the different laboratories, public (universities, Governments, etc.) and private. It is proposed, not the design of these machines but the acquisition, merely theoretical, to complete a test laboratory equipment.

Fig. 1.1. Tensile in laboratory testing (https://goo.gl/WVYJzc

New projects include the use of modern technologies as 3D design. It is mean that a parallel work of design software, as (Solid Works®, Autodesk Inventor®, Ansys®) , and commonly testing devices for quality analisys is possible .

Fig. 1.3. SolidWorks®, simulation. (https://goo.gl/9gCCTL

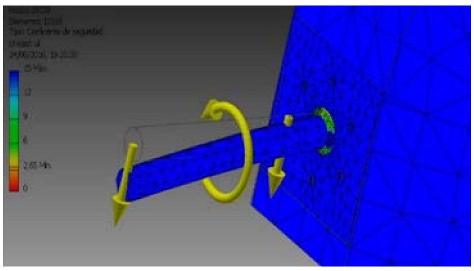


Fig. 1.2. Checking of the safety factor in vertical direction of a piece with Autodesk Inventor®. Handmade.

The use of these tools can serve as the basis for a reliable experimental design in accordance with the requirements or expectations that the customer may have about the product (fig. 1.3) and want to be tested by the laboratory or, also, it is possible to verify that the final product is in accordance with its specifications of design (Fig. 1.4).

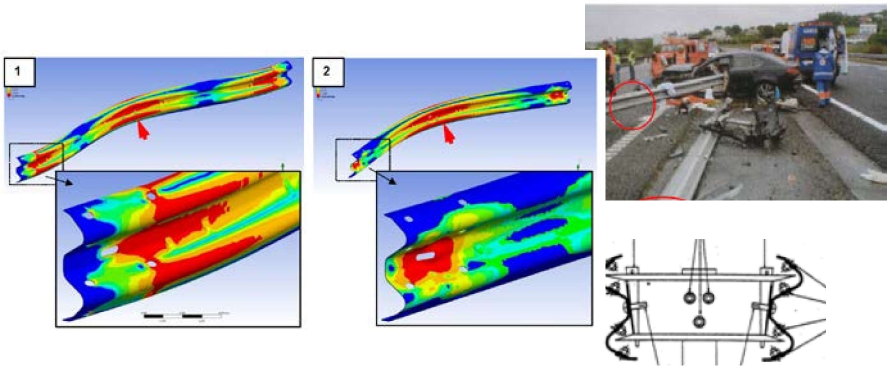


Fig. 1.4. FEM (ANSYS®) test: Tensions over a protection barriers, with (1) and (2) corresponding hardware - only pin and PIN - to validate his behavior in traffic accident. Handmade

The engineer must not only design a product, they must comply with all the standards of quality that the present markets in a globalized world demands. This product must be reliable, durable and, above all, to fulfill the functions for which it is designed and the expectations that the customer expects from him.

Testing laboratory is not only a space equipped with machines and instruments, but it is a workspace where the figure of the Industrial Engineer is key to the performance of different procedures and coordination/direction of the qualified staff working in it.

This Term Project doesn´t try to be a treaty on quality systems and accreditation of test laboratories, although it is necessary to make referrals to these systems and their rules.

To do this, it is necessary a suitable laboratory for the needs of those tests: stress, elasticity, plasticity, ductility, hardness and resistance, creep and fatigue, etc., where there are both teams of mechanical tests, destructive and non-destructive testing, as well as resistance testing equipment in order to use finite elements.

Therefore, it is necessary to provide that laboratory of a series of tools and machines that carry out their function: from basic tools to universal machine testing, hardness testers, etc, as well as the documents necessary to capture the work in the form of reports.

To obtain good levels of quality within the diversity of activities at the companies, conducting measurements and tests on the product at all stages of production, for a correct control is required. Here is where the need for specialised laboratories in control and quality assurance of the product which is intended to incorporate the market, in accordance with the specifications by the customer.

In the market of materials testing laboratories, offer of a broad spectrum of tests on an infinite number of materials from industries such as the automotive, aeronautical, railway, shipbuilding, energy, construction etc, can be found.

Test laboratory not only should be focused at the industry space, the type of tests is associated with the wide range of materials related to those industries (metal ceramics, polymers, concrete, etc.). can also have other purposes.

Fundamentally, there are three types of laboratories:

- Test.
- Teaching.
- Consultancy and research.

Laboratory staff, in addition to the field of teaching, can make reports for individuals and for the Public administration, e.g. courts, to determine that a product is not defective and they can also act as true judicial experts.

Although the Gdansk University of Technology (GUT), which has a scientific and industrial base, has a certified materials testing laboratory; the present project describes a laboratory with basic equipment to provide of a number of services to internal and external customers.

2. QUALITY OF THE PRODUCTS.

2.1. Introduction.

In the beginning, the industries manufactured the final product according to the costumer´s descriptions and they only made an inspection at the end of the production line to ensure the product´s quality. This procedure ensured the product review before sending it to the client. With this test, if products had a failure, the two options were reprocessing of the product, for example, it went to the production line; or otherwise, if the product was not feasible to spreading, the product was considered as waste and a new one was made. Althought this type of inspection could work; it generated high costs for the industry due to reprocessing or manufacturing (Loza Molina, 2010, p. 6).

To avoid the high costs in manufacturing, the product must have a quality control in all the levels. However, what does quality means?

The word quality has different connotations according to the people who employ it, but always underlies a central idea: "the quality of a product is satisfactory when it responds to the needs of the consumer" (Hansen et al, 1987, p. 1).

ISO definition of quality (ISO 9000, 2015, pág. 25): quality is the degree in which a set of inherent object´s characteristics achieves its main requirements. The term "quality" can use adjectives such as poor, good or excellent. In addition, the "Inherent" quality, as opposed to "assigned", means that it exists in the object.

ASQ (American Society for Quality) defines quality control as a set of techniques and activities that are used to achieve the requirements of quality (Loza Molina, 2010).

Quality also means:

- *Quality: jakość* (https://sjp.pwn.pl/, s.f.) *1. "wartość czegoś". 2. filoz. «istotne cechy przedmiotu wyróżniające go spośród innych"*[1]

A summary of the above would be the description of quality as a conformance with the requirements (Crosby, 1996).

Products quality and services include not only their function and performance; they also include the perceived value and the benefit for the customer in order to satisfy the needs, requirements and expectations of the customer. Efficient organizations create and use quality systems, combining the ingredients so Organization's employees can identify, design, develop, produce, deliver, and support the products and services that the costumer desires. Effective quality management systems are dynamic; they have an efficiency adaptability and the capacity to satisfy the needs, requirements and expectations of their customers (Summers, 2005, pág. 35).

Customer means a person or organization that could receive a product or a service required by itself. (ISO 9000, 2015, pág. 20).

---

[1] Quality: 1: The value of something. 2: essential characteristics that distinguish it from others.

Quality control is the basic idea of quality management. Quality control Department is the part of an organization, which is responsible for the verification of products through sampling or inspection with the objective of improving the quality of the product.

The main objectives of quality control are:

1. Satisfiying the customers needs.
2. Determining the quality standards expected by the market.
3. Controlling the processes involved in the production of goods and services, looking for quality.
4. Establishing an order in the interrelationship of the processes of the company.
5. Tracking all the operations.
6. Looking for the production´s processes problems and how to correct and prevent them.

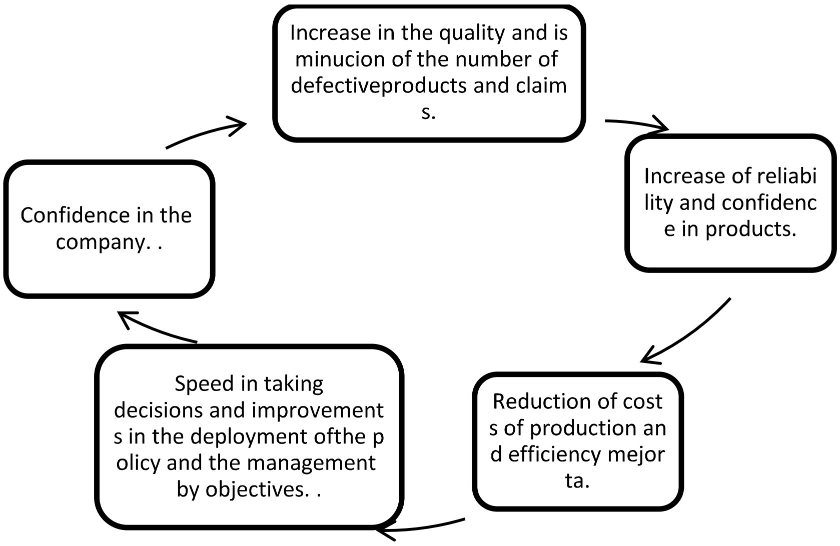


Fig. 2.1. Advantages of quality control. (Handmade)

Kauro Ishikawa understands that "quality control practice is the development, the design, the manufacture and the maintainance of a quality product as the most economical, the most useful and always the most satisfactory product for the consumer” (Ishikawa, 1986).

The quality management may include the establishment of policies and objectives using processes of quality planning, quality assurance, quality control and quality development to achieve optimal levels (ISO 9000, 2015, pág. 21).

Quality of the product is usually synonymous with customer satisfaction, so as to balance the expectations of the customer, the qualities or performance of the product and the final cost.

The process of product or service design is a key phase to guarantee or not of the quality, only if the design process is suitable, it can comply with the requirements of the customer. It is important that the organization or company has the knowledge of the costumer´s needs using a good level of communication (www.fao.org, s.f.).

Fig. 2.2. Total Quality. (Handmade)

All of this creates the total quality concept, which encompasses the approaches of business and production (Ferrando Sánchez & barn Castro, 2008) and focus on the permanent satisfaction of the customer´s expectations. Total quality means the satisfaction of the internal and the external customer and the highly competitive level and continuous improvement of the company.

Last stage in this evolution includes the certification of a system. Certifications consist of documentary and public recognition for a company that follows a standard. There are product or company certifications for quality managers called Quality Management System (QMS).

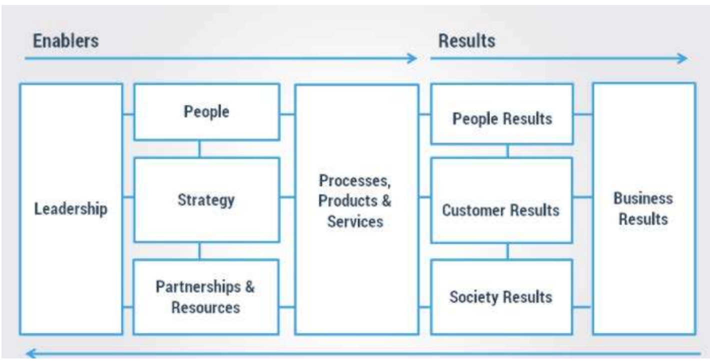


Fig. 2.3. EFMQ MODEL (www.toolshero.com, s.f). (https://goo.g)l/rqqjvQ)

After the QMS, there are models of excellence based on similar principles of the QMS, even they have a different approach. Models of excellence include the so-called model European Foundation for Quality Management, (EFQM) (www.efqm.org, s.f.)[2].

Deming (Japan) (www.deming.org, s.f.) model and the Malcolm Baldrige model can be added to this European model of Total quality (www.asq.org, s.f.).

Fig. 2.4. Deming Cycle

[2] http://www.efqm.pl/

2.2. Accreditation & Certification.

How can quality be credited?

As it has been explained, the companies are able to reach the quality using optimal processes to obtain the maximum costumer satisfaction, and for this objective; companies have looked for the normalization and the standardization systems of these productive processes.

Quality management system (QMS) is a formalized system that documents processes, procedures, and responsibilities for achieving quality policies and objectives. A QMS helps the coordination and control of an organization's activities in order to improve the efficiency and effectiveness basics requirements of the customer using quality standards (www.asq.org, s.f.).

Quality standards is a document, established by consensus and tested by a recognised organization (national or international), that provides, for common and repeated use, the rules, the guidelines or the characteristics for activities and results of quality, with the objective to get an optimum degree of order in the quality context. The quality standards are voluntary technical specifications in which stakeholders had participated and they had been approved within a technical Committee for the standardization of the corresponding Agency (Ministry of economy, n.d.).

Normalization is a set of activities consisting in the development, dissemination and application of standards as a way of establishing productive solutions to repetitive situations (www.aenor.es, s.f.)

Within the European Union, there is the European Committee for Standardization (CEN) who establishes EN standards (www.cen.eu, n.d.). Each member country has its own national centre of representation, as well as in the ISO Committee. There are rules generated by national organizations which do not have application to all member countries of ISO or CEN. The only condition to apply these rules is not be more restrictive than a standard rule of application for all countries, as well as to allow free marked among them.

Fig. 2.5. Polski Komitet Normalizacyjny- CEN

The main international organizations of quality standards are ISO (international standards organization) and IEC (International Electrotechnical Commission).

When a company achieves normalized and quality processes, it will obtain the official recognition from an external organization. This process is certification.

Certification is the activity that allows establishing the conformity of a particular organization with the requirements defined in the standards or technical specifications. A recognized company (e.g. Polski Komitet Normalizacyjny) grants formal recognition to an agency or competent person to carry out specific tasks. Generic rules reflect requirements that apply to any type of organization, such as ISO 9001.

However, it is possible a Division of a company, a production plant or a product line certification.

Accreditation is the established on an international scale tool to generate confidence about the performance of a very particular type of organizations called Conformity Assessment Authority.

Accreditation: an approved authority (EA, European Accreditation) formally recognizes that an organization is competent to perform a particular task. The specific requirements of the activities are standards, as the ISO 17025, which control the technical competence of laboratories.

The base of accreditation testing laboratories is the evaluation of the quality conformity system that complies with the administrative and technical requirements of a quality standard reference. Requirements for accreditation that must perform a testing or calibration laboratory have been continuously adapted to international standards (Hernández Guzmán, et al, 2001, pág. 14).


Polski Rejestr Statków

APPROVAL CERTIFICATE
ŚWIADECTWO UZNANIA

This is to certify that
Zaświadcza się, że

Laboratorium Badań Materiałów
Wydziału Mechanicznego Politechniki Gdańskiej
Katedra Mechaniki i Mechatroniki
80-233 Gdańsk, ul. Gabriela Narutowicza 11/12
POLAND

has been approved in accordance with the requirements of Polski Rejestr Statków S.A. (Publication 56/P), to perform:
uznano zgodnie z wymaganiami Polskiego Rejestru Statków S.A. (Publikacja 56/P) do wykonywania:

fatigue testing of metals
badań metali na zmęczenie
technical examination of the ropes, chains and slings
prób i badań lin, łańcuchów i zawiesi
Charpy impact test and drop weight tear test (DWTT)
prób udarności sposobem Charpy'ego oraz próby udarowej spadającym ciężarem
static tests and examination of loose gear and interchangeable components
prób statycznych i badań osprzętu zdejmowalnego i osprzętu do podwieszania ładunku
tests of mechanical properties of metallic materials, details of constructions and connections
badań własności mechanicznych metali, elementów konstrukcji oraz złączy
tests for fatigue crack growth rates and the determination of plane strain fracture toughness
badań prędkości wzrostu pęknięcia zmęczeniowego oraz określanie odporności na pękanie w płaskim stanie odkształcenia

Head of Laboratory / *Kierownik Laboratorium* **Wiktoria Wojnicz** First issue / *Pierwsze wydanie* **1978-05-16**

The Approval Certificate is valid, provided the conditions stated overleaf are complied with.

Certificate No. / *Nr świadectwa* **TT/83/710405/16** Expiry date / *Data ważności* **2019-04-30**

Issued at/Wydano w

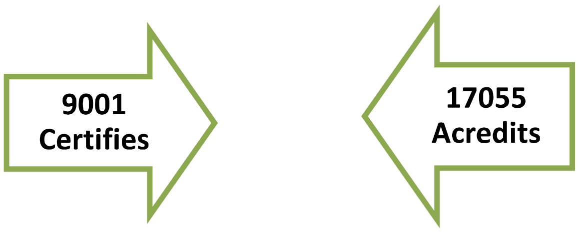
Gdańsk, 2016-04-01 C/040/01 Signature/Podpis

Polski Rejestr Statków S.A.
al. Gen. Józefa Hallera 126
80-416 Gdańsk, Poland
Tel. +(48) 58 346 17 00
Fax +(48) 58 346 03 92
e-mail: mailbox@prs.pl
www: http://www.prs.pl

Continued overleaf/Ciąg dalszy na odwrocie

1/2

Fig. 2.6. Certification of the Laboratory of Materials. Department of Mechanics and Mechatronics. Faculty of Mechanical Engineering Gdansk. https://goo.gl/Ly8BxR



2.3. The ISO standards.

ISO means International Organization for Standards. This organization, with headquarters in Geneva, has developed quality management systems (QMS) and the series 9000 has been approved in more than 100 countries (Besterfield, 2009, pág. 93) beginning in 1979 from the formation of a technical Committee with representatives from 20 Nations.

ISO standards are regulations established by the organization responsible for design, enactment and monitoring the international standards of production, marketing and communication industries in all sectors in order to facilitate the international exchange of products and services, by providing a clear set of requirements for quality systems.

ISO standards are not binding; they are not enacted or promoted to establish their mandatory normative compliance. States or supranational agencies have the choice of establishing laws acording with them, and companies are free commitment to adopt them.

Adopting in the industry processes ISO standards adds an unquestionable value to activities, processes and to the products or services. In addition, no matter the size product or service and the type of organization, public or private; they can be used by organizations for internal application and certification,

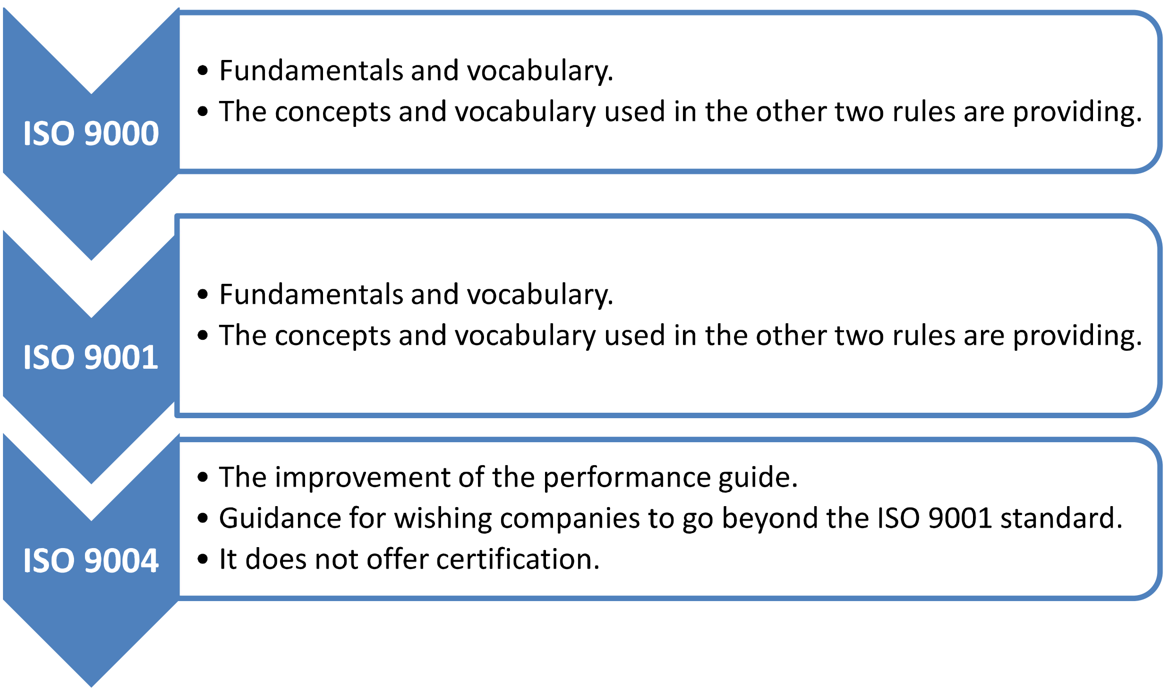


Fig. 2.7 (http://sklep.pkn.pl/pn-en-iso-9000-2015-10p.html)

2.3.1. ISO 17025.

The norm ISO 17025 (ISO 17025, 2017) is an international standard developed by ISO in which requirements for testing and calibration laboratories are established. Although this standard has many aspects in common with the ISO 9001 standard, its main objective and its competence accreditation of testing and calibration, is distinguished from the previous one by the corresponding entities.

This ISO divides into management requirements and technical requirements.

Some examples of management requirements are: the creation and control of documents, job control non-compliant, corrective and preventive actions, control of records and internal audits, etc.

the technical requirements category includes factors such as the the laboratory capacity to generate technically valid results.Also, it have procedures relating to staff and their training, facilities and media environment, laboratory methods of testing, equipment, traceability measures, sampling, handling of items of testing and assurance of the quality of the results, etc.

Fig. 2.8. Evolution Rules. Handmade and www.intedya.co (Sagrado et al, 2005, pág. 10)

Specifying general requirements for the competence, impartiality and consistent operation of the laboratories and being applicable to all organizations that develop laboratory activities, regardless of the number of staff, is the main objective of this standard (ISO 17025, 2017, pág. 9).

2.3.2. Other ISO standards.

The ISO family is not only the cited standards in previous points and as an example of "members" of that family, here, there is a list of ISO standards used in the project:

Table 2-1. ISO family

EN 1330-10	*Non-destructive testing. Terminology. Part 10: Terms used in visual testing.*
ISO 17025	*General requirements for the competence of testing and calibration laboratorios*
ISO 10228-1	*Non-destructive testing of steel forgings. Part 1: Magnetic particle inspection.*
ISO 10228-2	*Non-destructive testing of steel forgings. Part 2: Penetrant testing.*
ISO 10228-3	*Non-destructive testing of steel forgings. Part 3: Ultrasonic testing of ferritic or martensitic steel forgings.*
ISO 10228-4	*Non-destructive testing of steel forgings. Part 4: Ultrasonic testing of austenitic and austenitic-ferritic stainless steel forgings.*
ISO 12076	*Non-destructive testing. Essays by penetrating liquids. Vocabulary.*
ISO 12707	*Non-destructive testing. Magnetic particle testing. Vocabulary*
ISO 13018	*Non destructive testing. Visual testing, regulates the general principles*
ISO 1330-1	*Non-destructive testing. Terminology. Part 1: List of general terms.*
ISO 1330-2	*Non-destructive testing. Terminology. Part 2: Terms common to the methods of non-destructive testing.*
ISO 14556	*Steel. Charpy V-notch pendulum impact test. Instrumented test method*
ISO 148-1	*Metallic materials. Charpy pendulum impact test. Part 1: Test method*
ISO 148-2	*Metallic materials. Charpy pendulum impact test. Part 2: Verification of testing machines*
ISO 17640	*Non-destructive testing of welds. Ultrasonic testing. Techniques testing levels, and assessment.*
ISO 17707	*Non-destructive testing. Magnetic particle testing. Vocabulary.*
ISO 18490	*Non-destructive Testing. Evaluation of vision acuity of NDT personnel*
ISO 18563-2	*Non destructive testing. Characterization and verification of ultrasonic phased array equipment*
ISO 3059	*Non destructive testing. Penetrant testing and magnetic particle testing. Viewing conditions.*

ISO 3452-1	*Non-destructive testing. Penetrant testing. Part 1: General principles.*
ISO 3452-2	*Non-destructive testing. Penetrant testing. Part 2: Testing of penetrant materials.*
ISO 3452-3	*Non-destructive testing. Penetrant testing. Part 3: Reference test blocks.*
ISO 3452-4	*Non-destructive testing- Penetrant testing, Part 4: equipment*
ISO 3452-5	*Non-destructive testing. Penetrant testing. Part 5: Penetrant testing at tempera tures higher than 50 degrees C*
ISO 5577	*Non-destructive testing. Ultrasonic testing. Vocabulary.*
ISO 6506-1	*Metallic materials. Brinell hardness test. Part 1: Test method*
ISO 6507-1	*Metallic materials. Vickers hardness test. Part 1: Test method.*
ISO 6508-1	*Metallic materials. Rockwell hardness test. Part 1: Test method*
ISO 6892-1	*Metallic materials. Tensile testing. Part 1: Method of test at room temperature.*
ISO 6892-2	*Metallic materials. Tensile testing. Part 1: Method of test at elevated temperatura.*
ISO 7500-1	*Metallic materials. Calibration and verification of static uniaxial testing machines. Part 1: Tension/compression testing machines. Calibration and verification of the force-measuring system.*
ISO 7500-2	*Metallic materials. Verification of static uniaxial testing machines. Part 2: Tension creep testing machines. Verification of the applied forcet.*
ISO 9712	*Non destructive testing. Qualification and certification of NDT personnel.*
ISO 9934-1	*Non-destructive testing. Magnetic particle testing. Part 1: General principles.*
ISO 9934-2	*Non-destructive testing. Magnetic particle testing. Part 2: Detection media.*
ISO 9934-3	*Non-destructive testing. Magnetic particle testing. Part 3: Equipment.*

There are an infinite number of relations between ISO standards and different materials: plastic, ceramic, concrete, etc. This made an impossible list creation for all of them.

2.4. Other quality systems.

Although European ISO standards are commonly used, in a globalised world it is possible to find other international agencies with test methods.

DIN (Deutsches Institut für Normung) is the technical standard for the quality assurance in industrial and scientific products in Germany (www.din.de, s.f.). They represent the development regulations of German products in industry, science and public institutions.

ASTM (American Society for Testing and Materials) (www.astm.org), founded in 1898, is a non-profit organization, which provides a forum for the development and publication of voluntary consensus standards, applicable to the materials, products, systems and services.

DIN Deutsches Institut für Normung

ASTM INTERNATIONAL

Fig. 2.9. DIN - ASTM. https://goo.gl/iNThUc; www.astm.org

CWA (CEN Workshop Agreement), they are reference standards that have general recognition for electronic products. CEN Workshop Agreement (CWA) is a document published by CEN in at least one of the CEN three official languages (CEN).

A CWA is an agreement developed and approved in a CEN Workshop; the latter is open to the direct participation of anyone with an interest in the development of the agreement. There is no geographical limit on participation; hence, participants may be from outside Europe. The development of a CWA is fast and flexible, on average between 10-12 months.

CWA does not have the status of a European Standard. It involves no obligation at national level. CWA may not conflict with the European Standard; if a conflicting EN is subsequently published, the CWA shall be withdrawn (CEN).

The Japan Industrial Standards Committee (JISC) is an organization attached to METI. It is in charge of surveying and deliberating on industrial standards and it offers searchable databases on its website, but they are in Japanese (EU-Japan Centre, s.f.).

3. DESIGN OF THE TESTING LABORATORY.

The laboratory is a physical space equipped with various necessary machines, equipment and instruments to make experiments, scientific or technical nature work. In these spaces, the environmental conditions are controlled and normalized according to the type of tests; this way of work tries to avoid the alteration of measurements or results obtained by strange influences (Peñafiel Pilco, 2014, pág. 3).

3.1. State of the art in testing laboratories.

The materials testing is not new in the history of man since the domain of these materials allowed humanity to cover their basic needs, from the age of Stone to the Iron age, until the present day with the manufacture of polimeric materials, compounds, adhesives, etc.

Egyptians and Greeks had empirical observation rules for the resistance of the construction materials. Leonardo da Vinci performed a test of traction wires of different lengths to determine the best length to carry on a load. Part of this activity led to the birth of metallurgy and systematic study of the behavior and the strength of materials.

Galileo also made observations about the fragility of the materials, developing the theory in which a column or Obelisk with higher length fail easily due to its own weight.

Theory development was a simple tensile test in which specimens were columns of different lengths and thicknesses with a basket of sand load. He concluded that the resistance of an element with uniaxial stress applied was due to the cross-section of the body and not its length. This resistance is called “absolute resistance to fracture” (Urrea Mariño, 2014, pág. 4).

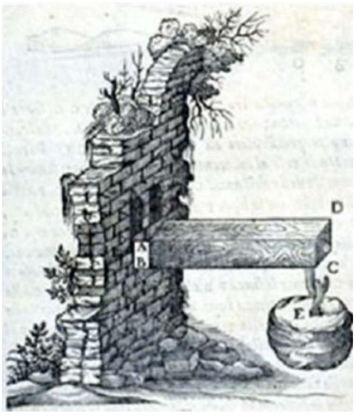


Fig. 3.1. Representation of the cantilever beam test practiced by Galileo (Urrea Mariño, 2014), pag 5

It is possible to find notch hardness tests since 1722. In 1822 hardness tests were introduced; this type of test, known as the Mohs scale, measured the width of a surface scrap done with a diamond material. In the year 1900 Brinell determined a hardness test widely used today.(www.buehler.com, s.f.).

The Preußische Königliche Mechanisch-Technische Versuchsanstalt (Prussian Royal Laboratory for Mechanical Testing) within the Königliche Technische Hochschule (Royal Technical University) in Berlin in 1871 was the predecessor of today's Federal Institute for Materials Research and

Testing (BAM). The organisation's mission was to guide mechanical material tests and other tests that are of general scientific and public interest (BAM, s.f.) .

Next examples are scientists whose contribution to the science of the materials are undeniable:

Robert Hook discovers the so-called "law of Hooke" in the seventeenth century; it relates the deformation with the modulus of elasticity of each material.

Euler predicted that a column with compression force would sag, Young related the deformation of a column with its applied forces and Castigliano determinated the displacement of an elastic structure due to the forces acting on it.

Poisson studied the relationship between transverse deformation and axial deformation of a structure with axial loads acting on it. This relationship is the Poisson module.

Focusing on the mechanical testing topic, the first mechanical tests equipments were developed in England and from there, they spread to the rest of Europe and America. Zwick Roell® was one of the first companies who, in 1836, developed equipment to perform stress tests.

In 1896, Russell introduced the concept of energy fracture as an evaluation parameter. He proposed a pendulum test method but Charpy in 1901, proposed a variation of the initial method and the pendulum adopted his name.

At the academic level, testing material laboratories born around the departments of materials science, with its different variations in each University or Polytechnic Center, expanding their infrastructure to cover techniques of chemical testing, metallographic, mechanical or thermal analysis and thermomechanical analysis.

Nowadays it can be possible find many testing materials laboratories as public administration with university students and private nature laboratories associated to large multinationals. New laboratories development grows together with a wide range of testing devices like universal testing machines, hardness testers, Charpy pendulus, etc. Athough this devices have a relatively high price, they enable the easily creation of testing laboratory.

From the academic point of view, testing materials laboratory, covered by the quality inherent to a University Center, must join the value of students engineering training, research and development of new materials with the benefit of its portfolio or its external costumer's services expansion.

The following table shows a list of centers, both public and private, equipped with Material Testing Laboratories:

Table 3-1. Material testing laboratories. Handmade

Laboratory	Country	Web
Massachusetts Institute Of Technology[3]	USA	https://goo.gl/RCWphY
Queen Mary University Of London (School of Engineering and Materials Science	UK	https://goo.gl/GFu1T3
The Univsersity of Sheffield. Engineering	UK	https://goo.gl/JLftd3
Norges Teknisk-Naturvitenskapelige Universitet (NTNU)	Norway	https://goo.gl/9oDwXP
Univsersität Stuttgart	Germany	https://goo.gl/dZcdjy
Siemens	Germany	https://goo.gl/ay4fJd
Bundesanstalt für Materialforschung und -prüfung (BAM)	Germany	https://www.bamn.de
Gdansk Univsersity of Technology. Faculty of Mechanical Engineering	Poland	https://goo.gl/kKeukZ
Institute of Aviation	Poland	https://goo.gl/2GL2uZ
AGH Univsersity of Sciencie and Technology, Krakow	Poland	https://goo.gl/JXeWCy
Polytechnic University of Valencia	Spain	https://goo.gl/xMgdXV
Polytechnic University of Madrid	Spain	https://goo.gl/u3tTWF
Polytechnic University of Sevilla	Spain	https://goo.gl/SCuUkD
Polytechnic University of Cataluña	Spain	https://goo.gl/GiB3ih
FIDAMC	Spain	https://goo.gl/17Eeti
Applus laboratories	Multinational	https://goo.gl/ZonXdZ
SGS	Multinational	https://goo.gl/ou2wiK
Eurocontrol	Multinational	https://www.eurocontrol.es

[3] MIT charge USA$ 25/h for mechanical tests on 5984 and 4206 INSTRON equipment.

3.2. Laboratories.

3.2.1. Previus requirements.

The layout of the laboratory should have a design with efficiency criteria. For example, even taking into account that it may be necessary some space between the procedures for technical or safety reasons, the distance that students and instructors must travel to develop the different activities within the laboratories should be as short as possible,.

Fig. 3.2. Testing laboratory example. (https://goo.gl/gsxUL2)

The laboratory and its operation facilities, activities, equipment or products, as well as the technical conditions or safety requirements according to its purpose must comply applicable country Safety Regulations. Technical conformity evaluation procedures, adopted prevention measures, coverage of the risks derived from the activity of the facilities or the use of the products including environmental impact studies, equipment conditions, address of work, execution, assembly, conservation and maintenance of industrial facilities and products must comply the country Safety Regulations also.

In addition, requirement of subscribing professional civil liability insurance by the involved construction management, execution, assembly, conservation and maintenance of industrial facilities and products teams or companies in the project, it will be necessary when a direct and specific risk to the health or safety of the personnel is possible. The required guarantee must be proportionate to the nature and extension of the covered risk.

The installations, equipment and industrial products must be constructed or manufactured in accordance with the corresponding regulations provisions, which may establish the obligation of periodic inspections to check their operation and state of conservation or maintenance.

3.2.2. Personnel.

For the present Project, a design of a laboratory will perform for external customer. This hypotetically company is a manufacturing industry, so the laboratory should be exclusively design for company´s procedures.

In a laboratory, internal or external personnel staff can influence the activities and tests so they must act impartially, be competent and work according to the system of management of the laboratory standards (ISO 17025, 2017, pág. 14).

The staff is going to be perform by the minimum number of person; in this case, they will be three: An Industrial Engineer as head of the laboratory and two assistants, with powers to perform the job.

3.2.2.1. Personnel qualification.

As a rule, all laboratory internal or external staff, which can influence laboratory activities, must act impartially, be competent and work in accordance with the laboratory's management system. It is necessary for each function that influences the results of laboratory activities, including the requirements of education, qualification, training, technical knowledge, skills and experience, laboratory documentation. (ISO 17025, 2017, pág. 14)

The knowledge about techniques, equipment, procedures and materials of the experienced personnel who performed the inspections must be accredited according to different ISO standards such as ISO 9712, 2012, *Non destructive testing. Qualification and certification of NDT personnel.*

The Levels:

- *Level I: Accreditation of an Inspector prepared to perform, according to written instructions and equipment calibration, testing and evaluation of results that determine the acceptance or rejection of the material under study. Level III inspector should teached him and he must gain experience as an apprentice.*

- *Level II: Accreditation of an Inspector prepared to adjust and calibrate the equipment, to interpret and evaluate the results according to codes, standards and specifications. He must be available to prepare written instructions, organize and prepare reports about the results obtained. He has to work as inspector of level I for a period of time.*
- *Level III: It is the highest level and it certifies that the inspector is enable to perform forming techniques and procedures, interpret codes, standards and specifications, and select the testing method for a specific application. He have large practical experience in technology of materials, manufacturing processes and the most common non-destructive techniques. He is responsible for the formation and training of level I and level II inspectors. To achieve accreditation level III it is necessary to have worked before as Apprentice level I and at least one or two years as level II (Rodríguez González, 2012, pág. 23).*

3.2.3. Architectural space.

Every laboratory must have a design with efficiency criteria, prioritizing safety conditions. In addition, the laboratory has to accommodate the staff that works in it, with offices, test areas, warehouses, changing rooms, etc. and the equipment with which it is equipped.

For its design and development, two initial situations, although theoretical, can divided the general project:

1. That an existing space be available and assigned to the test laboratory function.
2. That a new building has to be made.

The specifications provided by the customer will serve as the base for the laboratory design in the choice and distribution of the testing machinery or equipment.

Even if the volume of work is always the same, the company evolution may require application of different changes in the relative importance given to the different types of analysis. In addition, advances in instrumentation and procedures can alter space needs. For this reason, a dynamic laboratory with modifiable spaces is the best choice to perform this project.

The basic requirements of laboratory space are not standardized; they depend on the installed equipment, the established processes and the number of people who will work in the development of tests.

Physical space to develop the processes of tests must be enough for any activity. There is a consideration of minimum space per person about approximately 3m2 and each activity capable of influencing others must be isolated, using walls or other methods, in order to prevent cross contamination.

Dimensions specifications of the devices are in the next table:

Table 3-2 Dimensions specificactions.

Test	***Definition***	**Dimensions**			**Weight**
		Height	**Length**	**Width**	
Tensile Test	Universal test device IB-mt4-1000	600 mm	500 mm	150mm	75 Kg
	Axial Extensiometer	15 cm	10 cm	5cm	550 gr
Impact Test	Charpy Pendulum	2150 mm	750 mm	500mm	
	Broaching machine for notching test pieces for Charpy e Izod tests		241 mm		690 gr
Hardness Test	Durometer Sauter HMO	135 mm	83 mm	24mm	228 gr
Visual Analysis	Borescope PCE-VE-800	200 mm	110 mm	50 mm	
	Motic Microscopio BA310 MET trinocular microscope	240 mm	465 mm	508 mm	12,7kg
	Magnifying glasses 2x a 15X Schweizer	18.3 cm	8 cm	6.5 cm	
Penetrant Liquids	Spray penetrant 400 ml Würt	30 cm	30 cm	20 cm	
	Spray revelador 400 ml Würt	30cm	30cm	20 cm	
	Spray Developer 500 ml Würt	30cm	30cm	20 cm	
Magnetic Particle Test	CJE-200 Magnaflux Testing Machine	200 mm	250 mm	25 mm	2.9 kg

Finally, the assumption of physical location is inside the main building of the factory; it will be in one of its lower floors with general dimensions of 20x17x4.75m.

In the following sketch, there is a proposition of the space:

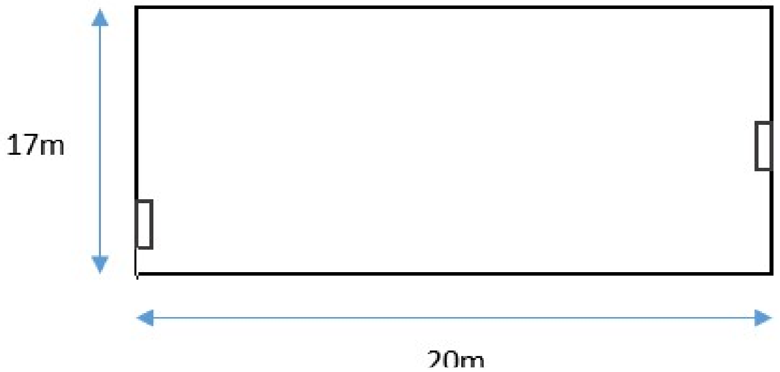


Fig. 3.3. Space laboratory

With the basic information of dimensions and equipment, based on the above description and the sketch of the physical space available for the implementation and adaptation of the Laboratory, the equipment purchased and the necessary furniture will be adjusted as follows.

The charpy pendulum machine must be placed in a specific area since it requires a special section for the operation. The movement of the machine and the security reasons of the personnel make necessary the machine isolation in a proper room.

This division will be made with lightweight aluminum walls, forming a subdivision area of 7x5 m^2.

By subtracting the area of Charpy pendulum ´s room to the total laboratory area, there remains an area of 305m^2, which does not require anything in particular as far as the rest of the test are concerned and this will be where the remaining equipment will be adapted.

The larger equipment, like the universal testing machine, will be placed in the opposite corner of the Charpy´s machine room. The selection of this distribution try to avoid vibration´s influence of both machines.

Testing machines have two meters from the walls to have a degree of security in possible maintenance tasks.

For the rest of the equipment, inspection for penetrating liquids, magnetic particles and visual inspection, depending on the dimensions of test devices must find the right position.

Since all of them are small equipment, they can operate in any sector, outside or inside the laboratory. Some laboratory tables will be chosen for the preparation of the trials, depending on their needs.

The selected tables are four laboratory tables with metal surface and cabinet, placed in two rows of two tables whose model BT-6 METAL LOCKER 1500 has the measurements of 850x1200x600 mm (www.estanteriasmetalicas.biz, s.f.).

The basic equipment is easily stored in cabinets and drawers. On the other hand, some instruments, such as strain gauges, magnifying loupes or the borescope, are included into storage cases kits.

For storage, three Multi-purpose Wardrobe cabinets of 1800x800x400 mm are located between the Charpy and the Universal machine.

Two workbenches with 6 tool drawers are placed near the tables where the tests perform and they have half a meter distance from the tables on both sides, with their back next to the wall; the model used is BT-5900 of 840x900x600 mm (www.estanteriasmetalicas.biz, s.f.).

Due to there is enough area for working test, it is decided to make a small office for the head of the laboratory in order to place the records of the tests and the specific documentation organized in cabinets and drawers.

Like the Charpy pendulum´s room, a separation is designed based on aluminum walls with transparent plastic windows. The room has an area of dimensions 5x7m^2.

Finally, the distribution of the laboratory defines as:

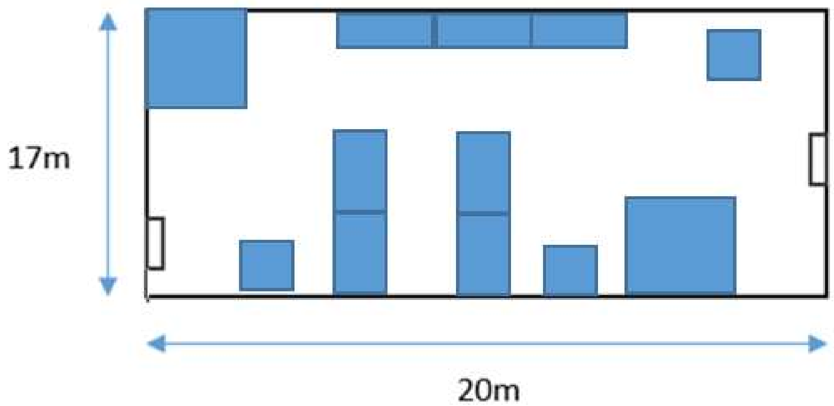


Fig. 3.4. Distribution of the laboratpry

3.2.4. Electrical installation.

The laboratory area must have a stable electrical system that allows the equipment be powered by electricity from the central network.

In addition, an extra contribution of energy will be necessary, since the Universal testing machine works with a high voltage of 380V. This system achieves with UPS (Uninterruptible Power Supply) equipment that is independent of the normal power supply network.

The UPS will be three phase, with 220 / 380V output voltages and the laboratory load will define the net-power. The UPS network will be powered directly from the main network.

The networks must be fully identified as a normal network and UPS network because only the universal machine device can be connected to it.

Table 3-3. Electrical installation for the testing laboratory

EQUIPMENT	ELECTRICAL INSTALLATION REQUIREMENTS
Visual Inspection--Boroscope	Battery-Recharged with 220V
Penetrant Liquid—Black light	110V
Magnetic Particles--Yoke	220V
Tensile test--Universal Machine	380 V Power 11KVa

3.2.4.1. The lighting system.

The lighting system of the laboratory should be established according to the work that will perform inside.

For example, the limit set for the tests with penetrating liquids and magnetic particles (ISO 3059, 2013) will be at least 350 lx but for some cases it should reach 1000 lx.

The specification of moderate level is 500 lx which is enough for most activities.

The light installation will consist of an emergency light, only used when the primary lighting equipment fail. For this reason, the emergency lighting accessories must be powered from an independent power source and comply with the complementary applicable technical instructions.

3.2.5. Segurity Rules.

Fire protection will be available, so the laboratory will have the required number of portable fire extinguishers by the applicable regulations, guaranteeing the safety and evacuation of the people who work there.

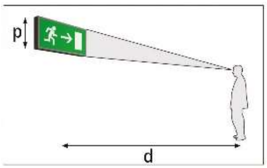


Fig. 3.5. https://goo.gl/WbKfA1

In order to perform the tests by the personnel in charge of the tests, with the enough safety and hygiene measures at work, the essential protection equipment will be available. Here are detailed.

Fig. 3.6. PPE (https://goo.gl/e3Ti9Z)

Table 3-4. Types of Test and Segurity Rules

TYPE OF TEST	SEGURITY RULES
Visual Inspection	There is no one
Penetrant Liquid	Hands Protection, Glasses, Respiratory Protection.
Magnetic Particles	Hands Protection, Glasses, Respiratory Protection.
Ultrasonic	There is no one
Tensile Strenght	Hands Protection, Glasses
Charpy Test	Hands Protection, Glasses

3.2.6. General concepts.

The laboratory must have access to the required equipment (including measuring instruments, software, measurement standards, reference materials, reference data, reagents, consumables or auxiliary devices) for the proper performance of the activities that can influence the results. (ISO 17025, 2017, pág. 16).

Documentation must ensure that all requirements are active when non-permanent control equipment is use. A procedure for the handling, transportation, storage, use, planned maintenance and ensurance proper operation of the equipment is necessary in order to prevent contamination or deterioration.

To provide a valid result, before being installed or reinstated for its service, the laboratory must verify the specified requirements of the equipment. In addition, the equipment must be also achieved the required accuracy of the measurement and / or the uncertainty measurement.

Regarding the calibration of the measurement equipment, it must be calibrated when:

- *Accuracy or uncertainty measurement affect the validity of the reported results.*
- *The calibration of the equipment is required to establish the metrological traceability of the reported results.*

Three elements which constitute the testing laboratory:

1. *The laboratory, as physical work space where machines, tools, furniture, etc. remain.*
2. *The personnel working in the laboratory.*
3. *Machines and basic tools to perform the tests of materials as well as necessary software.*

Which kind of product test is going to be offered to potential customers is another question and it will determine the size of the designing laboratory.

A) Non destructive testing:

- Visual Inspection.
- Penetrating fluids.
- Magnetic Particles.
- Hardness tests.

B) Destructive testing:

1. *Mechanical properties of materials: traction,[4] compression, torsion and shear.*
2. *Charpy impact tests.*

[4] Given the nature of the Term Project only has described the tensile test

Nowadays, using software for the study of the structures and parts behaviour is possible through finite element programs, for example in the field of automotive, road traffic, etc.

3.2.6.1. Equipment for the testing laboratory.

It is obvious that a laboratory can use an infinite variety of equipment more or less sophisticated. This equipment should be use with the same purpose, but it can be generically divided in two sections:

- *Basic Equipment*
- *Special Equipment.*

In the first group there are basic tools: mechanical keys: flat, layered tube, automatic, torx, etc.; (hammers, screwdrivers: mixed, philps, slotted, pz/pozi, torx, etc.), drills, rules, etc.

In Appendix II described the testing machines and their price.

4. MATERIAL TESTING.

4.1. Introduction.

When an industrial material that must fulfill a certain function is choosed, knowledge of physical and technical characteristics is essential in order to understand what kind of efforts and loads it could resist.

Fig. 4.1. Failure of a crankshaft (https://goo.gl/R52GBv)

Classical Mechanics already explains that solid system will remain undeformable when a determined system of forces is applied to him, but this is not true. Any real body with acting forces has a deformation, in a higher or lower degree, although such deformations are not immediately detectable. If the magnitude of the applied forces increases, the deformations also gradually increase until a break moment. This explains properties knowledge for correct design and use of the materials importance has for manufacturers or consumers.

In the introduction, the project´s purpose has been defined as the laboratory design and it will have the necessary equipment to perform the different tests that can be performed on materials, in order to achieving the requirements of potential costumers. However, quantity and types of tests in the project will be a small number.

4.2. Materials testing.

Industry works with all the range of materials, including metals and ferrous alloys and metals and non-ferrous alloys, polymers (plastics and synthetic rubbers), ceramics, composites and electronics (semiconductor).

Mechanical properties of materials defines their production and use. External loads of any type and nature and the material behavior are linked, since any external applied force creates a material deformation in order to counteract this perturbation. So mechanical properties and the main ability of forces and deformations transference and resistance of materials have an attachment.

Although the limit of design has been, for many years the maximum elastic deformation of the material, from the point of view of resistance, the material was not permanently deformed. Currently, better understanding of the material behaviour and the basis of calculation allow controled and acceptable deformations.

Some examples of material mechanical properties are: stress and strain, elasticity, plasticity, ductility, toughness and resilience, hardness, creep and fatigue.

Material tests obtain mechanical properties measurements from metals, ceramics, or plastics under various conditions. Specifying the suitability of materials for various applications needs the obtained data. A full- scale or small-scale model of a proposed machine or structure may be tested and investigators may construct mathematical models from knowed material characteristics to design products (Encyclopedia Britannica, s.f.).

The tests of these materials can be classified in different ways:

- According to the piece utility after the realization of the test: destructive and non-destructive.
- According to its thoroughness: scientifical, where numerical of certain physical quantities are checked, or technological, where properties values of a given material are are checked.
- According to their nature: metallurgical, chemical, mechanical or physicical.
- Depending on the speed of forces application: static and dynamic.

In conclusion, the different kind of tests will allow, in addition to the properties knoweldge of the materials, the future behavior evaluation of an element and the determination of possible failure causes, as well as the most suitable material selection for each application and, in our case, the performance of customer requirements.

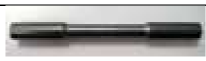
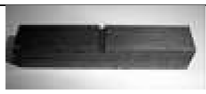
4.3. Test specimens.

In order to perform a material test we need a sample of it, generally in the form of a test specimen. The element where the mechanical test is performed in order to know the mechanical properties of the materials is the test specimen. Test specimen can be a part, a scale model of a piece or a piece of the machined material. According to the performed test, different types of test tubes are used (neetescuela.org, s.f.).

Machining or blank pressing or casting a sample from the product is the usually procurement test specimen obtaining way. However, products of uniform cross-section (sections, bars, wires, etc.) and test pieces (cast iron and non-ferrous alloys) may be tested without being machined. (ISO 6892-1).

Each test specimen has a characteristics shape depending on the type of test. Thus, tensile tests have flat or cylindrical shape with flanged ends for faster connexion by the jaws of the testing machine specimens. Compression tests have generally cylindrical or prismatic shapes; for the bending tests are used supported beams; cutting tests use cylindrical shape test specimens for metal materials and prismatic shape test specimens for wood materials and torsion tests are performed with hollow or solid cylindrical test specimens. The case of polymeric matrix materials has flat test specimens.

Table 4-1. Types of specimens (Gómez, s.f.)

Type	Figure
Test piece for tensile flat test 80x10x2	
Test piece for tensile flat test 100x10x25	
Specimen for tensile test ø12x111xø0,8	
Specimen for tensile test ø16x175xø12	
Specimen for tensile test ø25x1505xø10	
Specimen for impact - Charpy Test	

Specimen for impact - Charpy Test without notch	
Prototypes under plane.	

Application of different standards to specify their characteristics is common to all of them.

5. NON DESTRUCTIVE TESTING (NDT).

As its name suggests, the non-destructive tests cause imperceptible or no damage in the test sample in the evaluation of materials properties. They do not permanently alter physical, chemical or mechanical material properties. The determination of the integrity of a material, component or structure uses these non-invasive techniques.

Non-destructive tests perform the investigation of qualitative defects levels, cracks, pores and inclusions, the quantification of their dimension and their service time indicator. They realize all of these services without providing any deterioration in the qualified pieces (Ferrer Giménez et al, 2003, pág. 189).

In addition, they are commonly used for the inspection of materials after transformation processes (casting, forging, welding...) and for the inspection of materials or parts in service. International standarts regulate them; as an example the ISO: 10893-1:2011 “*Non-destructive testing of steel tubes -- Part 1: Automated electromagnetic testing of seamless and welded (except submerged arc-welded) steel tubes for the verification of hydraulic leaktightness”*.

These tests are very frequent, since they increase their number according to the progress of scientific knowledge and new instrumentalization allows its application with reliability.

Different types of test can be found and grouped in:

- Surfaces tests methods use for the detection of surface discontinuities.
    - Visual test method.
    - Penetrant liquid testing.
    - Magnetic particles testing.

- *Volumetrics tests methods use for the detection of superficial and internal discontinuities:*
    - Ultrasonis testing.
    - Radiography testing.

In general, the NDT advantages and disadvantages are:

Table 5-1. Applicability of the various techniques NDT. Homepage and Rodríguez González, 2012, pág. 14.

METHOD	***TYPE OF DEFECT***	***ANALISED MATERIAL***	***DON´T ALLOW THE DETECTION OF***
Liquid penetrant	*Surface*	*Metallic and non-metallic materials*	*Internal defects and porous materials*
Ultrasonic	*Internal*	*Plates, pipes, welded and forged materials*	*Materials with high attenuation*
Magnetic Particles	*The surface and subsurface*	*Ferromagnetic materials*	*Non-ferromagnetic materials and internal defects*
Radiology	*Internal*	*Welded and metal castings materials*	*metal castings materials with more than 400mm thicknes*

The effectiveness of locating a certain type and size of defects quantifies the effectivity of a non-destructive inspection, although it must keep in mind that there is only the guarantee that the examined piece has not a defect of a certain kind; it may not be free of defects.

The use of conditional probability quantify the possible results of the inspection. In the inspection of a samples series, probability of making a correct decision when one of the pieces is accepted or rejected calculation is possible. (Rodríguez González, 2012, pág. 22).

5.1. Testing of materials by visual inspection.

5.1.1. Object.

The object of this procedure is to establish the systematics for non-destructive testing by visual inspection. This procedure verifies the compliance of a material using the human view, with the addition of helpfully tools. Experienced and well-trained personnel has high chances of detecting and fixing problems, avoiding unnecessary costs.

The ISO 13018, 2016 *Non destructive testing. Visual testing*, regulates the general principles. It describes the general principles for visual inspection, direct and indirect type, in the case of specified product requirements checking procedure (for example: state of the surface of the piece, alignment of the surfaces faced, shape of the piece).

5.1.2. Scope.

Checking the quality of the surfaces, during and after the process of making parts, detecting damage by abrasion, mechanical, corrosion and discontinuities in unions such as welding, sealed, etc. is the scope of Visual inspection.

Visual inspection is essentially non-destructive testing because it does not cause damage in materials.

Light is physical agent and this inspection uses the power of the visible portion of the electromagnetic spectrum. The human eye or a visual inspection system can detect changes in the properties of light, after contacting the inspected object.

Mirrors, amplifiers, fiberscopes, borescopes and Visual Tools or other accessories, can reinforce the detection.

5.1.3. Generalities.

Visual inspection is the oldest, the most used technique of NDT, and it has the lowest price because the method uses the human eye to establish the criteria for acceptance or rejection of a material. The inspector shall be determine, according to previously established codes and standards, qualitative and quantitative criterion aspects.

The used instruments for reinforcing the vision and the distance or access between the inspector and the object of study can divide the Visual inspection into two groups:

Fig. 5.1. Inspección visual (Polytechnic University of Cartagena, s.f.)

a) Direct visual inspection: Visual inspection performs without interruption of the optical path between the operator's eye and the tested area. The inspectior can use additional instruments as mirrors, lenses, endoscopes or optical fibers (ISO 13018, 2016, pág. 6). In general, direct visual inspection can perform as long as the access to the area allows a distance lower than 600 mm between the human eye and the tested surface with an angle equal or bigger to 30 ° in relation to the surface.

b) Indirect visual inspection: Visual inspection performs with interruption of the optical path between the operator's eye and the area tested. Indirect visual inspection includes the use of photography or video camera, automatic systems and robots (ISO 13018, 2016, pág. 6).

This type of inspection is very usually in the industry; internal verification of devices, stationary turbines, heat exchangers, conections of pieces and valves, for example, need that method.

5.1.4. Visual Inspection Trial Procedure.

5.1.4.1. Staff and required equipment.

Personnel that performs this test must know the use of standards, rules, specifications, equipment, and procedures of this inspection. They also must know the manufacture procedurements and the testing element rules of use. Statisfactory vision is necessary for the performance of this inspection as Standart ISO 9712, 2012 specifies.

Personnel can use some tools in order to upgrating the discontinuity inspection:

1. Magnifying lenses or magnifying glasses: usually they have increases of 5X and 10X, at most for studies called macroscopic. They have a low cost and cover a wide range of inspection.
2. Systems of chromatic interference or systems with polarized light: They determinate chromatic patterns discontinuities areas using polarized light on a reflecting surface. Porcelains or glazed coatings inspections are examples of this.
3. Borescopes (endoscopes): In difficult places to reach or in high-risk areas, indirect visual inspections use this equipment. Widely disseminated in the new techniques of Visual Inspection, mainly because they allow the observation of the interior part of an element without disassembling all the components.
   Boroscopes are frequently used in the inspection of gas turbines, aeronautical structures, nuclear reactors, internal parts of automotive engines and driving lines.
4. Information and training: For an accurate interpretation of the possible indications generate by the discontinuities, the Visual inspection technique requires a large amount of information about the inspected element characteristics.

5.1.4.2. Visual Inspection Requirement.

- Perform a 6 or 12 monthly visual acuity test to all personnel who will perform Visual Inspection.
- In some cases, it would be very important to perform a chromatic discrimination test in order to checking the personnel´s capacity to color variations or chromatic tones detection. This test is only done once, because they can produce genetic alterations that are not correctable.
- Inspector's knowledge of the inspected element characteristics and the types of detected discontinuities by this technique.

5.1.4.3. Test Procedure.

The first considered technique of an element inspection is this technique in order to make an evaluation. Visual inspection, depending on the type and the possible discontinuities of the inspected element, can detect different irregularities:

- Detection of surface anomalies such as scratches, excess roughness and areas not covered by paint or coating.
- Detection of fractures, porosity, corrosion and other cracks.
- Checking dimensions.
- Detection of strange objects.
- Location of failures.

5.1.4.4. Results.

After performing the main visual inspection test, the following results of the analysed parts to be tested are usually obtained:

- General evaluation of a tubular element, tool or component.
- Premature detection of possible defects before they reach the critical size.
- Detection of manufacturing errors.
- Obtaining information of the defect conditions in the inspected elements.

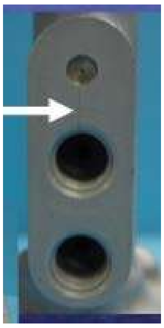


Fig. 5.2. Visual inspection of manufactured materials. (https://goo.gl/84PR5B)

As limitations, it is necessary to emphasize that this method only allows evaluation of superficial conditions, only with the use of an effective illumination source and depending on the easily access to the inspected surface.

5.1.4.5. Different Procedures.

The laboratory personnel should follow the Manual of Instructions or Recommendations made by the manufacturer in order to facilitate the development of the test and the use of the different tools already described.

5.1.5. Test report.

The report of the test must contain at least:

- Reference to the used standard:
- Identification of the piece to be tested
- Specified material
- Test specimens Location and address manufacturing place
- Test results, including at least:
    - Types and measurements of founded defects.
    - Sketch of the piece to indicate the location of the defect.
    - Final resolution to adopt.

5.2. Liquid penetrant inspection testing.

5.2.1. Object.

This method pretends set systematics for the realization of non-destructive tests using penetrant inspection La Norma ISO 3059, 2013, collects the *Non destructive testing. Penetrant testing and magnetic particle testing. Viewing conditions.*

5.2.2. Generalities.

The test by penetrating liquids uses the capillary phenomenon; it is a non-destructive examination procedure and allows the localization of discontinuities such as cracks, folds, creases, porosity and lack of fusion, open to the surface of the pieces surface.

It mainly applied to metallic materials, but it is also used with other materials to control characteristics as reaction to test products and excessively porosity (parts of castings, forgings, welding, ceramics, etc.).

The search and interpretation of the defects performs by visual examination need control from the standard (ISO 3059, 2013, pág. 6).

The standard ISO 3452-1, 2013, specifies a test method by liquid penetrant used to detect discontinuities such as cracks, folds, creases, porosity and lack of fusion, open to the surface of the material to examine.

It is mainly applied to metallic materials, but it can also be used with other materials to condition that are inert to test products and are not excessively porous (parts of castings, forgings, welding, ceramics, etc.).

The advantages and limitations description of this method are in the following table:

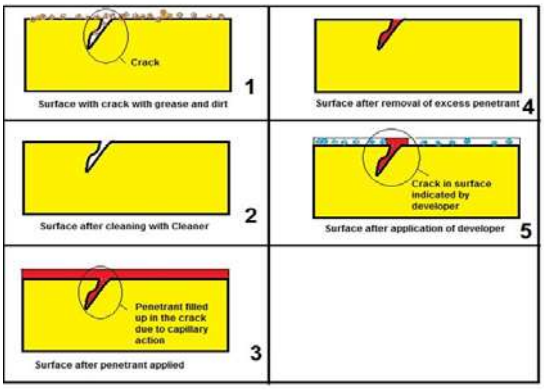


Fig. 5.3. Stages of dye penetrat testing (https://goo.gl/VazL52)

Table 5-2. Advantages and disadvantages of the trials not penetrant.

Advantage	Disadvantage
It is a simple method.	It only detects open discontinuities.
It has no limitation by the size of the workpiece.	The defect must not be filled with foreign material. It must always be clean.
It adapts to the inspection in small parts manufacturing processes.	The surface of the material must be impermeable to the penetrating liquid.
It cannot be reduced to a minimum equipment, resulting in an economic test.	Products used as piercing should not attack the inspected material.
It offers the maximum sensitivity for very fine cracks.	The temperature must lie in a certain range.
There are penetrating different types and compositions, which allows adoption to different types of materials and conditions.	Presents problems of cleaning after inspection to be difficult to remove from threads, grooves, holes and rough surfaces.
Detecting defects, what ever your shape and orientation.	This test type depends on much of the skill of the person performing the inspection.
	It does not provide a permanent record of the non-destructive test.

5.2.3. Scope

Scope of these tests is the inspection of non-ferromagnetic metals (aluminum and its alloys, stainless steels, copper, bronze, brass, etc.) Penetrating liquids can also inspect ferromagnetic metals (carbon and alloy steels, etc.) but it is usually more advantageous to use the method of non-destructive testing of magnetic particles, which is much more sensitive in these materials (Serrano, s.f., pág. 2). This is a quick test without the need for alternative energy that, given its characteristics, can performs in remote and difficult to access places.

5.2.4. Test Procedure.

5.2.4.1. Required equipment.

There are different products for liquid penetrate inspection: solvents, penetrating excess Remover (except for method A) and developer. Only approved product families should be used (ISO 3452-1, 2013, pág. 9).

5.2.4.1.1. Penetrate Inspection Fluid.

The penetration or capillary capacity of the liquids depends mainly on the wettability properties (contact angle between liquid and solid: (α)), surface tension (T) and viscosity (μ).

An optimum penetration capacity achieves if a liquid has high surface tension, small contact angle (less than 90 °) and low viscosity.

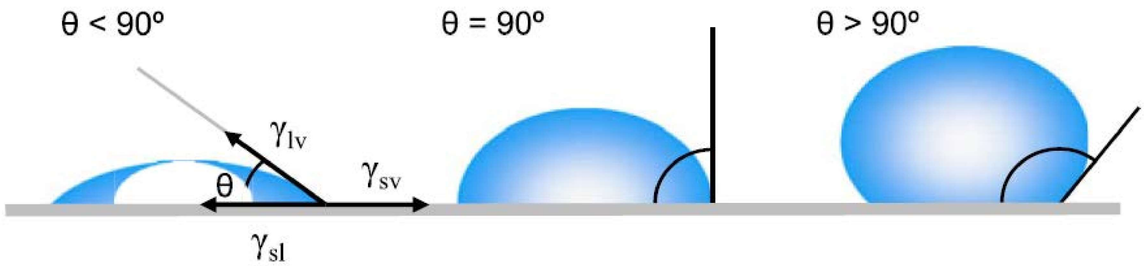


Fig. 5.4.Contact angles formed by sessile liquid drops on a smooth homogeneous (Yuan et al , 2013, pág. 4)

5.2.4.1.1.1. Characteristics of penetrant liquid.

Penetrating liquids must have at least the following characteristics:

- Power of easy penetration.

- Low evaporation capacity.
- Easy cleaning.
- Colors to get contrast with the background.
- Ease to leave the fine openings when the developer is applied.
- When the cleaning of first penetrant liquid performs, the liquid should not be dragged from inside openings.
- It must not chemically attack the test material.
- It must have no smell.
- It must be stable under storage and handling conditions.
- It should not be toxic.
- It must not be flammable.

The use of standard blocks allows the calculation of the sensitivity levels for the penetrating liquids, also the families division performs in two types depending on standard blocks (ISO 3452-3, 2013, pág. 7):

- Type 1: standard blocks used to determine the sensitivity levels of penetrating products families by color contrast and fluorescent
- Type 2: standard blocks used for the periodic evaluation of the behavior of penetrants families by color contrast and fluorescent.

5.2.4.1.1.2. Clasification of penetrant liquid.

A) By the type of color:

- Colored penetrating liquids: they contain a red dye that provides high contrast against the white developer background. They can be observed under natural light.
- Fluorescent penetrating liquids: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation. They have very high sensitivity and should be used on surfaces with very low roughness.

B) By the procedure used for its excess elimination:

- Self-emulsifying Penetrants: they can be removed from the material using water alone..
- Penetrants post-emulsifiable: they are removed with water but after the application of the emulsifier to the penetrant. They are soluble in water once they have been emulsified.

- Penetrants removable with solvents: they are not soluble in water.

Advantatges and disadvantatges explanations in the choosen liquid are in the next table:

Table 5-3. Advantages and limitations in the selection of the penetrating LPI.

Autoemulsionable Fluorescent Penetrant	
Advantage	**Disadvantage**
- *Fluorescence gives you a very good visibility.* - *You can wash it directly with water.* - *Good for a wide range of discontinuities. It can be used on rough surfaces.* - *Economy of time in the process.*	- *Excessive washing can reduce sensitivity.* - *It may affect the sensitivity of the anodized.* - *It may affect the sensitivity of the chrome.* - *It is not suitable for shallow discontinuities.* - *Precise camera obscura, with black light for observation.*
Postemulsionable Fluorescent Penetrant	
- *Fluorescence gives you very good visibility. I* - *It has high sensitivity for small discontinuities and I could detect open and small depth discontinuities.* - *Its penetration time is short. It can be used with parts anonizadas or chrome.* -	- *It is not directly washable with water enforcement of the emulsifier lengthens the time of trial.* - *Difficult to apply in rough materials.* - *Difficult cleaning in inaccessible areas.* - *It can be flammable.Precise camera obscura, with black light for observation.*
Penetrating colored	
- *It can be used in laptops.* - *The black light for observation is not required.* - *It can be used in parts in the not permitted the use of water for washing.* - *It can be used in parts anonizadas. It is very sensitive to small discontinuities.*	- *It can be flammable.* - *The signs are less visible than those obtained with penetrating fluorescent.* - *Difficult to apply in rough parts, such as castings in sand.*

Table 5-4. Testing products General Information (ISO 3452-1, 2013, pág. 10)

Penetrant liquid		Solvent-removal		Developer	
I	Fluorescent Penetrant	A	Water-Washable	a	Dry powder
II	Penetrating colored	B	Penetrants post-emulsifiable, Lipophilic	b	Water Soluble
II	Penetrant mixture (fluorescent penetrant and colored)	C	Penetrants Solvent Removable – Level 1, halogenated – Level 2, not halogenated – Level 3, Special application	c	Water Suspendable
		D	Penetrants post-emulsifiable, Hydrophilic	d	Nonaqueous Type 1: Fluorescent (Dry developers for level I)
		E	Water and Removal-Washable	e	Nonaqueous Type 2: Visible Dye (Dry

					developers for level II and III)
				f	Special Applications
In some specific procedures, it is necesary special products with technical characteristics of inflamability, sulfur quantity, halogens, sodium and other pollutants and other types of pollutants. ISO 3452-2. [a] The level C is not in the group.					

Table 5-5. Testing products Specific Information. (ISO 3452-2, 2014, pág. 8)

Penetrant liquid		Solvent-removal		Developer	
I	Fluorescent Penetrant	A	Water-Washable	a	Dry powder
II	Penetrating colored	B	Penetrants post-emulsifiable, Lipophilic	b	Water Soluble
II	Penetrant mixture (fluorescent penetrant and colored)	C	Penetrants Solvent Removable – Level 1, halogenated – Level 2, not halogenated – Level 3, Special application	c	Water Suspendable
		D	Penetrants post-emulsifiable, Hydrophilic	d	Nonaqueous Type 1: Fluorescent (Dry developers for level I)
		E[a]	Water and Removal-Washable	e	Nonaqueous Type 2: Visible Dye (Dry developers for level II and III)
				f	Special Applications
[a] Method E has the application relationship. Penetrant Liquids of level A have the same qualification as Penetrant Liquids of Level E.					

5.2.4.1.2.1. Solvent-removal.

They require the use of a solvent to remove the penetrant from the material.

5.2.4.1.2.2. Developer.

The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so an inspector can see it.

They consist of a very fine powder, usually white color, which must extend over the examined surface when the removal of the penetrant is completed. Thanks to it, a color contrast generates and determinates the retention areas.

One of its main characteristics is a great capacity of absorption, allowing the extraction of the remaining penetrant in the discontinuities.

5.2.4.1.2.2.1. Characteristics of the Developer.

The properties that developers must have in order to perform their function are the following:

Fig. 5.5. Liquid penetrant kit (https://goo.gl/unegLu)

- Physically, the grain of the dust from which it is formed must be very fine, achieving a great dispersion and definition of the penetrant, in addition to achieving a thin and uniform layer on the piece to be tested.
- They must have absorbent properties to perform drying action.
- They must be able to cover the bottom of the inclusions.
- Their application should be fast and the simple.
- It must be easily removed once the inspection is complete
- It must be chemically inert.
- It must not be toxic or smell.

5.2.4.1.2.2.2. Clasification of the Developer.

A) The developers are classified in four types:

a) Dry powder developers.
b) Developers suspension of dust in the solvent.
c) Developers suspension of dust in water.
d) Developers dissolved in water.

The evaluation must performs as correctly as possible and with minimum levels of contrast and visibility so, before the selection of the most indicated developer, a series of general rules must be taken into account in order to make an adequate choice of the developer.

- Use aqueous or non-aqueous wet developers with very fine finish and well-polished surfaces.
- On very rough surfaces, use dry developers because wet developers create accumulation in the irregularities as not uniform surfaces.
- Wet developers are suitable in processes of large series of parts in automatic processes.
- In pieces with acute notches (threaded bolts, etc.), wet developers should not be used, since developer accumulations could occur in these areas.
- On rough surfaces that have been tested with wet developers, it is difficult to re-inspect again.

5.2.4.1.2.2.3. Application of Developer.

The application of the developers can be diverse and most common methods are:

- By immersion.
- By air gun.
- By brush.
- Sprinkling with the hand.
- With electrostatic gun.

5.2.4.2. Test Procedure.

Before starting the Penetrating Liquids tests, it is convenient to take into account the following information:

1. Define the characteristics of the discontinuities and the level of sensitivity. If discontinuities are relatively large or their sensitivity is between low and normal level, it is recommended to use visible penetrants; but if the discontinuity is very thin or a high or their sensitivity is between high or very high level, it is recommended to use fluorescent penetrants.
2. Surface to inspect. If it is a rough surface, as a welded joint or a cast part, a penetrating liquid removable with water should be used. However, if the surface is smooth and polished, it is preferable to use a removable penetrant with solvent.
3. The type of inspection depends on the required sensitivity in the analysis. According to the level of importance of the analyzed piece, a more or less sensitive test will perform:

    - For detection of discontinuities of approximately 0.012 inch, a fluorescent penetrant, removable by post-emulsification and a dry developer.
    - For detection of discontinuities of approximately 0.100 inch, a contrasting penetrant, removable by water and a developer in aqueous suspension.

4. Finally, post-emulsificable penetrant is use in a required high quality inspection.
5. If the examined material is stainless steel, titanium or aluminum (for aeronautical components, for example) or nickel alloys (monel), then the penetrants should have a very rigid control of contaminants: as halogenated compounds (derivatives of the fluorine, chlorine, bromine, iodine) or sulfur (sulfates or sulphides). If there are residues of them, they can cause fractures or material fragility. All suppliers of high quality products provide a certificate of purity of their products at no additional charge.

It is usually a seven-stage process:

a) Surface cleaning (degreasing etc)
b) Application of a penetrant liquid (dipping, spray, brush)
c) Removal of excess penetrant (solvent, water)
d) Application of developer
e) Inspection of test surface (visual, television camera)
f) Post-inspection cleaning (anti-corrosion solutions).
g) Evaluation of the indications.

5.4.2.2.1. Pre-cleaning of the test surface.

It is important that the surface is free of any type of contaminant such as dust, grease, oxides, paint, among others, that may intervene in the penetration of penetrating liquid at discontinuities, which may hinder the procedure and affect the test result. That is why the surface to be examined and adjacent areas in an area of at least 25 mm must be free.

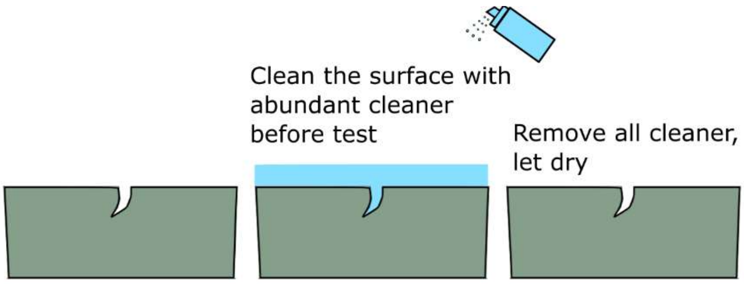


Fig. 5.6. Cleaning of the workpiece (https://goo.gl/ZcnnLf)

For the cleaning of the surface, the choice of method is important, taking into account the type of material and the type of surface contamination.

For this, both mechanical and chemical agents can be used, as long as the latter do not affect the material to be tested. Degreasers and ultrasonic cleaning methods can also be used.

- *Mechanical medium: grinding, machining, etc.*
- *Chemical agents: detergents, organic solvents, pickling solutions and paint thinners.*

After the preparation and cleaning of the surface, it must be completely dry and free of residues of any of the products used in its cleaning, drying can be done by natural or forced evaporation with hot air.

5.4.2.2.2 Penetrant Fluid Application.

There are several ways to apply the penetrating liquid on the surface to be examined, in order to detect any discontinuity or fissure:

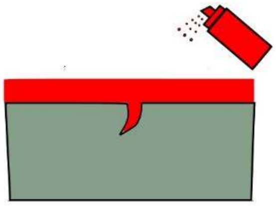


Fig. 5.7. Apply penetrant (https://goo.gl/uKSTr8) and handmade

- By immersion: used in elements of small dimensions, consists of immersing them in a container full of penetrating liquid.
- By spraying: it consists of placing pulverized penetrating liquid to the surface to be examined, by means of a jet of air at low pressure.
- With brush: unlike the spray technique, this method consists in placing the penetrating liquid specifically on the surface to be examined, thus reducing the penetration consumption and the cleaning time.

Given any chosen method, the entire surface to be examined should be completely covered with a uniform layer of penetrant and kept long enough to achieve maximum penetration.

Generally penetration times are recommended by the manufacturer. It should be considered that these times are minimum and it should be controlled that the penetrant remains humid in this lapse.

The temperature of the penetrant and the surfaces to be examined should be between 16ºC and 52ºC.

5.4.2.2.3. Excess Penetrant Removal.

This phase of the method is the most important and after the dwell time has elapsed, the excess liquid penetrant is carefully removed from the surface to avoid removing any of the captured penetrant from the flaw or defect.

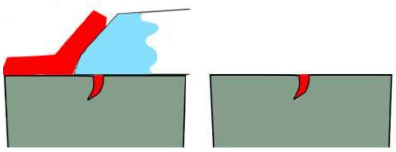


Fig. 5.8. Remove excess of penetrant from surface. (https://goo.gl/ZcnnLf) and handmade

The manner of removal will depend on the type of penetrating liquid used:

Method A - Water Washable: penetrants can be removed from the part by rinsing with water alone. These penetrants contain an emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone.

Water washable penetrants are sometimes referred to as self-emulsifying systems.

Method B - Post-Emulsifiable, Lipophilic: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.

Method C - Solvent Removable: they require the use of a solvent to remove the penetrant from the part.

Method D - Post-Emulsifiable, Hydrophilic: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.

When using the water-washable or post-emulsifiable methods, the part is placed in a low-temperature oven and allowed time to dry before applying the developer.

5.4.2.2.4. Drying.

After the movement of the excess of penetrant, the pieces under examination need to dry carefully. The temperature used to dry parts after the application of an aqueous wet developer or prior to the application of a dry powder or a nonaqueous wet developer, must be controlled to prevent drying in the penetrant in the flaw. Depending on the used type of penetrant, the test procedure will be:

- For water-washable or post-emulsifiable penetrants: the surface will be dried by the use of rags or with forced circulation of hot air without exceed 52 ° C.
- When waterborne developers are used, absorbent materials will not be used for drying.
- For removable penetrants with solvent: the surfaces will be dried by normal evaporation, drying materials or forced air circulation.

5.4.2.2.5 Application of Developer.

In this phase, with the application of the revealing substance will generate a colored line in the discontinuity (fissure) on the tested surface.

The developer will be applied as soon as possible, after the removal of the penetrant and drying of the surface.

Whichever used method, a thin and regularly distributed layer of developer over the entire surface will be applied.

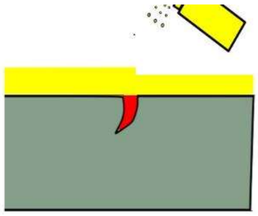


Fig. 5.9. Aply developer (https://goo.gl/ZcnnLf)and handmade

Two types of developers can be used with fluorescent penetrants:

- Dry developers: Applied by a soft brush, with manual spray, with a gun or by immersion. This developer can not be used with colored penetrants.
- Wet developers: They are a mixture of a solution or suspension of a powder in water or in a volatile solvent, and they are applicate by dipping, brushing or spraying.

5.4.2.2.6. Inspection.

The visual inspection can start after the preparation of the surface by the stages previously explained. A carefully observation of the test surface is made in search of possible indications of defects or discontinuities once the applied developer application and the time required by the developer for the absorption of the penetrant have elapsed.

Fig. 5.10 Final inspection liquid penetrant. Handmade and https://goo.gl/aqvTB2

Depending on the type of liquid penetrant used in the test, cracks or inclusions indications will manifest themselves in a different way:

- Colored Penetrants: in this type, the discontinuity manifests by the color contrast, usually red, on the white background of the developer layer.
- Fluorescent Penetrants: the observation must perform in a dark area; the examined surfaces must be with filtered black light illumination. The black light lamps must remain connected for heating for a time of 5 minutes before the observation.

5.4.2.2.7. Clean Surface.

The final step in the process is cleanning the part of the surface to remove the developer from the parts that were found to be acceptable.

5.2.5. Results.

After basic stages of the test have been perform, in the final checking part all the indications are a consequence of material tested defects.

The defining criteria results will depend strictly on the experience and training of the inspector in charge, as well as the reference standard.

For the qualification of the indications, inspector will attend the following advertisements:

a) Evaluation of all the indications will be in accordance with the acceptance rules or in the reference standards.
b) Any discontinuity open to the surface will be an indication.
c) The possible irregularities in the machining and other surface conditions can lead to false indications
d) If there are extensive fluorescence or colored areas, they may mask indications of discontinuities so the examination will not be acceptable, these areas should need a new cleaning process and inspection will perform again.

5.2.5.1. Classification of Discontinuities.

1. It will be possible to classify the discontinuity form according to the following criteria:
2. Round indications: Those that have a circular or elliptical shape. Porosities on the surface origin them by moisture welding cords, craters at the end of the cord, etc. Normally they are not in an isolated form; they are in form of small or large groups depending on the intensity of the defect.
3. Continuous linear indications: Cracks of corrosion under stress, cracks of a defective cooling in a heat treatment, cracks of contraction of welding, etc.
4. Discontinuous linear indications: Also, some of the previous causes and characteristics of material folds, sheets of lamination, lack of bonding in welds, etc., origin them.
5. Grouped indications: When the adjacent indications are in a distance less than the largest dimension of the smallest indications.

5.2.6. Different Procedures.

The laboratory personnel will use the Manual of Instructions or Recommendations made by the manufacturer of the penetrant and its accessories in order to perform the tests together with the standard and the present procedure.

5.2.7. Test report.

The report of the test results must contain at least:

- Reference to the used standard.
- Identification of the tested piece.
- Specified material.
- Characteristics of the used penetrant liquid and its complements
- Situation and direction of the place of execution of the test samples.
- Test results, including at least:
  - Types of found defects and their measurement.
  - Sketch of the piece in order to indicate the location of the defect.
  - Final resolution to adopt.

5.3. Ultrasonic testing.

5.3.1. Objetc.

The objective of this procedure is to establish the non-destructive system for elements inspection by ultrasound procedures. According to the particular standard applied to each test, the internal defects of the pieces detection performs at room temperature.

Note that there are several ISO standards for different tests: ISO 17640, 2011 ISO 17640: Non destructive testing of welds. Ultrasonic testing.Techniques, testing levels, and assessment; ISO 18563-2,) Non destructive testing. Characterization and verification of ultrasonic phased array equipment, Part 2: Probes; ISO 16946 Non-destructive testing. Ultrasonic testing. Specification for step wedge calibration block, etc.

Fig. 5.11. Detection of a crack in a test tube. (Rodríguez Paredes, 2014, pág. 66)

5.3.2. Generalities and Scope.

Ultrasonic inspection is a non-destructive testing method of surface and internal discontinuities detection using the introduction of high-frequency waves into the inspected material and measuring the propagation of sound in the medium that constitutes the piece to analyze. It has the peculiarity of being very sensitive to the detection of critical discontinuities, such as cracks, lack of fusion in welds, etc. but this method has application in all types of materials.

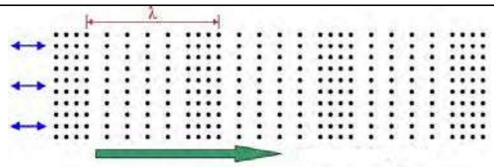
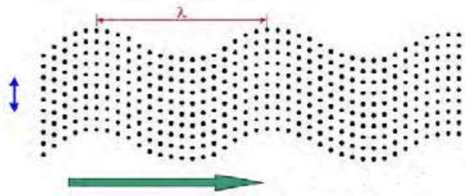
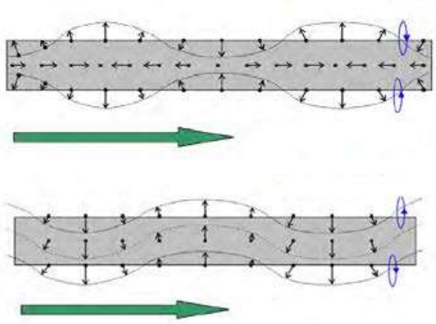
The sound transmits through an elastic medium by waves. In an empty space, the sound is not possible, since there are no particles of matter that can vibrate. In the air, for example, a sound´s wave displaces a discrete volume of air around its neutral position. These mechanical movements in matter, periodically repeated for a certain time, are characterized according to the number of oscillations per second of a given material particle. That is its frequency (in cycles / second or Herz).

Ultrasonic waves have a frequency higher than 20 KHz and they are not audible by people, so ultrasounds are waves of the same nature as sonic waves, therefore they are transmited at the same speed in the same medium but with a higher frequency. The frequency band used in material quality control extends between 0.2 and 25 MHz.

Fig. 5.12. Range of frequencies. Homemade and https://goo.gl/Rg9TF7

There are several types of ultrasonic waves depending on their equilibrium positions in relation to the different trajectories and the applied mechanical energy.

Table 5-6. Wave type. Homemade and (Rodríguez González, 2012)

Longitudinal waves: the pressure is perpendicular to the surface of the material and the oscillation of the particles takes place in the same direction of the wave propagation	
Transverse waves: It occurs when the direction of oscillation of the particles is perpendicular to the direction of propagation of the ultrasonic wave.	
Superficial or Rayleigh waves; They are obtained in thin materials, whose thickness is of the order of the wavelength as, for example, sheets and tubes.	

Materials have a boundary surface or contour in which ultrasonic propagation is altered, so when the material is surrounded by an empty space there is no transmission of ultrasonic waves because they need the presence of a material medium. In this case, the wave, when it reaches the edge, returns in the same way.

Reflection occurs when the limit surface is smooth and dispersion occurs when it is rough. In the case dispersion, wavelength terms of the incident beam must measure irregularities of the surface. Incidence of waves can be normal and angular as the standard explains.

5.3.3. Test procedure.

The ultrasonic test works with the similitude of a discontinuity presence or a change in the density of the material acting as a reflector of high-frequency propagations.

Three groups can classify the different objectives of an ultrasonic test on a structure or component performance (Castillo Niño, 2006, pág. 25):

a) Defectology: it includes detection tests, identification and evaluation of discontinuities, heterogeneities, impurities, etc., produced in manufacturing or in service life.
b) Metrology: it covers the related techniques of thickness in pipes, containers, etc., measurement; very widespread in applications of corrosion control.
c) Characterization: they allow conclusions about the nature or state of the material by measuring parameters such as acoustic speed or attenuation.

This testing method has many advantages:

- High penetration power, which allows identification of discontinuities in large thickness.
- High sensitivity of the test, allowing detection of very small discontinuities.
- It achieves greater capacity than other non-destructive testing methods of position of external discontinuities, estimating their shape, orientation, dimension and nature determination.
- It needs only one testing element surface to perform the analysis.
- Instantaneous indication of discontinuities.
- Equipment portability.

Regarding its disadvantages:

- Manual tests require highly qualified personnel due to the large number of critical decisions that the operator has to make.
- Irregular or rough samples have difficult inspection.
- Calibration of test system and determination of certain defects characteristics require the use of standards or reference samples.
- It is necessary to use a couplant liquid between the scanning equipment and the inspected sample.

5.3.3.1. Required equipment.

Ultrasonic measuring equipment consists of a transducer, which converts the electrical energy into mechanical and vice versa, a pulse generator, which transmits a short electrical discharge and a Couplant liquid, in addition to a reference standard (Appendix II).

Fig. 5.13. Ultrasonic flaw detector. (https://goo.gl/Z9Priq)

Signal on the oscilloscope shows its reflected distance, but the signal really is the propagation response speed of the very high frequency sound wave traveled through the inspected material.

5.3.3.2. Test Method.

Before beginning to perform ultrasonic tests, inspector must know the transducers and the basic description principles of ultrasound propagation. Inspector must have the required qualification and certification of Norma ISO 9712, 2012.

Depending on the type of coupling between the transducer and the tested element, method can be:

a) By direct contact. The transducer locates on the surface of the element with a couplant liquid between them.
b) By immersion, local or total. The element is immersed in a container with liquid, which acts as a coupler. This type of test is easier to perform; the scan is faster and with a single transducer can perform tests with any angle of incidence.

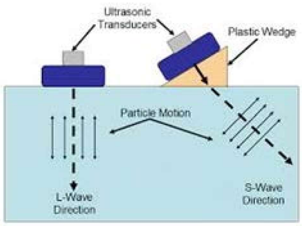


Fig. 5.14. Types of coupling. (https://goo.gl/DEc2tY)

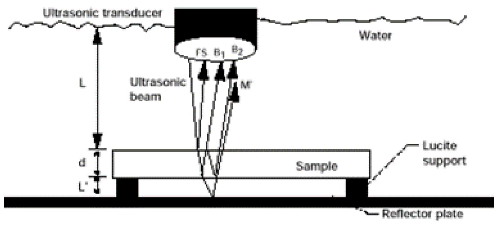


Fig. 5.15. Immersion test. (https://goo.gl/rEirJe)

Depending on the movement of the transducer through the surface, test can be:

c) Manual test. Direct contacts predominate and in most of them the pulse-echo technique.
d) Automatic test. Immersion tests predominate in this type.

5.3.3.2.1. Ultrasonic Pulse-Echo Method.

This type of manual test, which employs portable ultrasonic scanning equipment, uses the reflected sound defects evaluation. The piezoelectric head works as both emitter and receiver. It uses only sound impulses since received energy is weaker than emitted and operation by continuous sound is not possible.

An electrical impulse of very short duration generates a similar ultrasonic wave; immediately, while the wave is still propagating, the same oscillator (piezoelectric head) is ready for reception. The wave penetrates the material until a total or partial reflection takes place.

Fig. 5.16. Testing pulse echo. (https://goo.gl/n7x4SA)

Its advantage is a great speed of executing the test, although it also has as a disadvantage analyzing false indications or variations of the acoustic coupling, usually due to human errors.

5.3.3.2.2. Resonance Method.

Based on the frequency measurement of resonance by reflection (formation of standing waves) and it is use for thickness measurement in elements of parallel surfaces. Each thickness has a resonance frequency due to the superposition of the incident waves with those reflected in a limit interface and it must be taking into account by formation of standing waves. This superposition results in the appearance of nodes and crests in which the pressure is zero and maximum respectively.

If in a sample of parallel surfaces of a certain thickness "e", an ultrasonic beam of continuous excitation with a wide frequency spectrum propagates, the corresponding oscillations with a sub-multiple thickness of the sample half-wavelength will be reinforced. The rest of oscillations become weakly and standing waves will form a phenomenon of resonance.

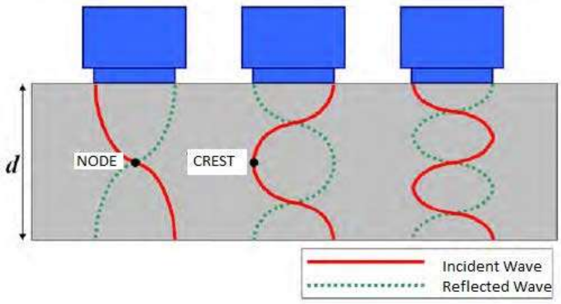


Fig. 5.17. Resonance metho. Homemade and (Rodríguez González, 2012, pág. 61)

The knowing distance between a consecutive node and a crest corresponds to a half-wavelength. With this knowledge and the performance of resonance measurement corresponding to the resonance frequency, the thickness of the piece is easily obtained.

5.3.3.2. Test procedure.

The type of test depends on the type of transducer, but, in general, the procedure will be as follows:

1. Equipment initial calibration according to the inspected element type. Every two hours or each transducer change inspectors should done calibration in order to eliminate performing inspection, equipment and used test mistakes.

2. Preparation of the inspected element surface with the purpose of guaranteeing a perfect coupling between the transducer and the piece.
3. Application of the couplant liquid on the inspected surface. The material necessities determine the most appropriate type of couplant.
4. Coupling of the transducer with the surface of the inspected element. Selection of themost appropriate test depends on the need of the element because there are different types of test.

Fig. 5.18. Calibration block. (https://goo.gl/Xnjr4p)

5. Performance of the inspection. Inspectors must guide the transducer in different orientations to find possible discontinuities in the inspected element. Here, the determination of inspection positions, thickness zones and any other relative form of inspection is done.

In most cases, inspection equipment shows:

- A peak corresponding to the emission pulse.
- A succession of small peaks due to superficial imperfections of the faces.
- Eventually a peak due to the echo of a discontinuity.
- A peak due to the background echo.

6. Interpretation and record of the obtained results. It is very important to have the record of the obtained results with the discontinuities and their locations for a subsequent inspection, after some correction process.

5.3.4. Results.

Ultrasonic data can be collected and displayed in a number of different formats. The three most common formats in the NDT world are A-scan, B-scan and C-scan presentations. Each presentation mode provides a different region evaluation of the inspected material. Modern computerized ultrasonic scanning systems can display data in all three forms simultaneously (NDT Resource Center, s.f.).

Representation Type A (Scan A). Representation where the time is on the horizontal scale and the amplitude of the reflected signal is on the vertical scale. Normally a rectified image of the echo is obtained.

Scan-A image can obtain information about the dimensions of the heterogeneity, the located depth, the divergence of the ultrasonic beam and other characteristics. It is also used to determine wall thicknesses in pipes, tanks, vessels or other metal structures.

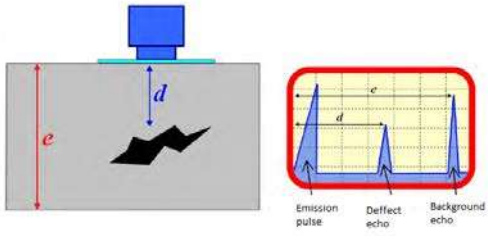


Fig. 5.19. Scan-A picture. Handmade and (Rodríguez González, 2012)

Representation Type B (Scan B). It is the graphic and two-dimensional representation of the obtained thickness. A cross-sectional view of the examined piece is obtained, so any heterogeneity of the material gives a limit surface indication.

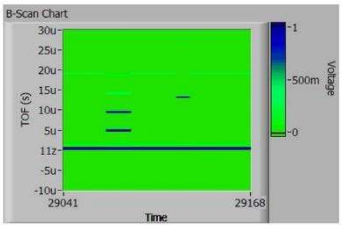


Fig. 5.20. B-Scan. (https://goo.gl/xPH4yT)

Representation Type C (Scan C). A three-dimensional representation of the thicknesses is obtained. There is a plan view of the test piece with the shape and location of the heterogeneity, since in this case any discontinuity results in the absence of indication, although it does not provide any type of information about the depth.

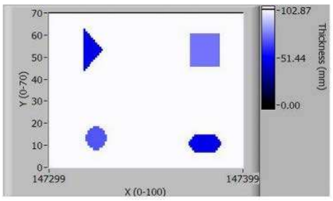


Fig. 5.21. C-Scan. https://goo.gl/xPH4yT)

5.3.5. Different procedures

In order to facilitate the development of the test, the personnel of the Laboratory will use the Manual of Instructions or Recommendations made by the manufacturer of the device and its accessories together with the standard and the present procedure.

5.3.6. Test report

The report of the test results must contain at least:

- Reference to the standard used.
- Identification of the tested element.
- Specified material.
- Situation and address of the place where the test specimens were made.
- Results of the test, including at least:
    - Type of found defects and their measurement.
    - Sketch of the piece in order to to indicate the defect´s location.

- Final adopted resolution.

5.4. Hardness testing.

Although test specimens may suffer damage, this type of tests has non-destructive classification because the damage of test specimens in test is little or non-appreciable.

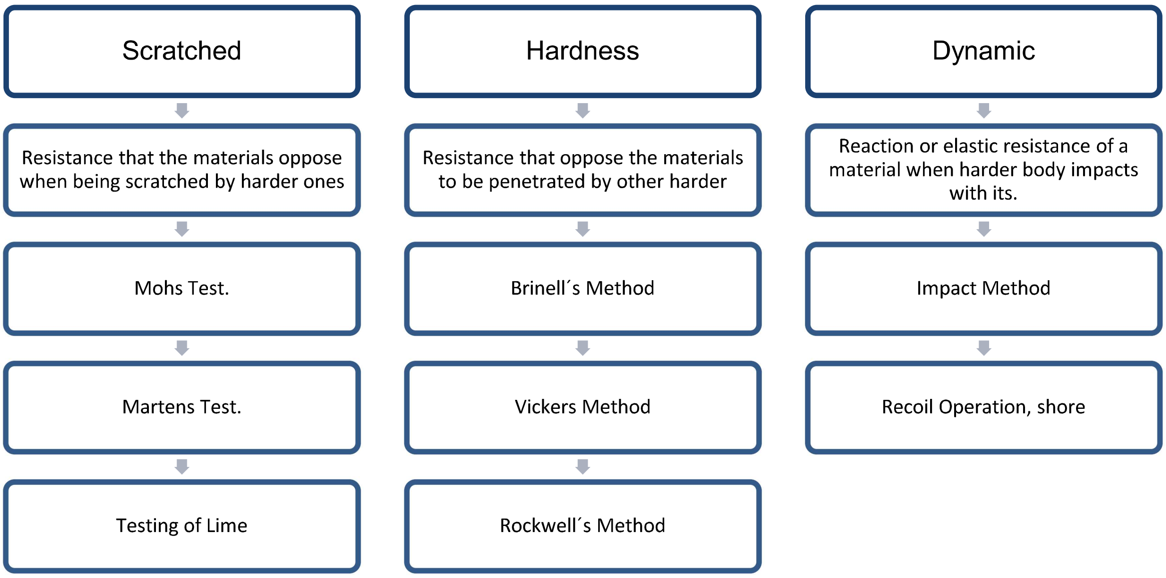
These tests are included in the following Standards:

1. *ISO 6506:* Metallic materials. Brinell hardness test. Part 1: Test method.
2. *ISO 6507:* Metallic materials. Rockwell hardness test. Part 1: Test method.
3. *ISO 6508:* Metallic materials. Rockwell hardness test. Part 1: Test method.

5.4.1. Object

Determination of the characteristics and the knowledge of the subjected treatment done of the material is the main purpose of a hardness test.

Table 5-7 Main hardness testing. Handmade and https://goo.gl/JSB1go



There are several types of tests, which determine the hardness of a material: Leeb, Shore, Knoopetc. But this project is going to explain the most common.

The usually machine for this type of tests is the durometer. Each of the different tests need a certain type of these devices due to their differences but looking for the same purpose.

Fig. 5.22. Durometer of Leeb (https://goo.gl/wj74BJ)

Method´s explanation of the general and particular systematic procediment is the main object of this part of the project. Each of the three hardness tests, according to theirs standards, perform with a particular systematic procedure:

1. The Brinell hardness test (ISO 6509-1, 2014) consists of the diameter measurement of the mark obtained with a tungsten or tungsten carbide ball of 1, 2.5 5 or 10 mm of diameter. The ball develops a force, F, from 1 kgf to 3000 kgf in a period of time measured in seconds. Larger samples with a large or irregular grain structure such as, for example, forged or cast materials uses this type of method.

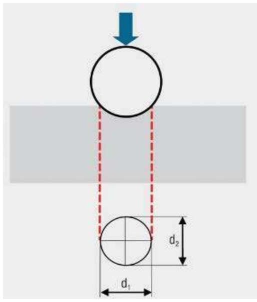


Fig. 5.24. Ensayo Brinell (https://goo.gl/U2nJw1)

2. The Vickers hardness test (HV) (ISO 6507-1, 2005) (normal and microhardness) calculation depends of the diagonal length measurement of a mark made by a pyramidal diamond indenter. The angle at the apex between opposite faces is measured in the surface of the sample material in the point of force application, F. The durometer has loads from 10 Kgf to 100 Kgf in order to evaluate all types of solid materials, and is suitable for a wide range of applications in a period of time measured in seconds.
3. The Rockwell (HR) hardness test (ISO 6508-1, 2016) depends on the depth of the indentation penetration. Its application has a preload of 10 Kgf, which is considered as the zero level of penetration. Measurements of volumetric hardness has scales A, B and C and also for surface hardness it has scales T and N. Due to the relatively high loads use, it is usually limited to geometries of larger samples.

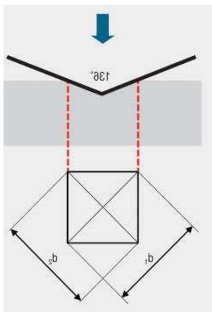


Fig. 5.24. Vickers testing (https://goo.gl/U2nJw1)

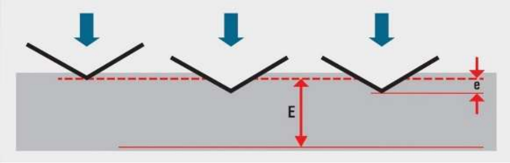


Fig. 5.25. Ensayo Rockwell
(https://goo.gl/U2nJw1)

In addition, this type of test has different variants:

- Rockwell C, A and D hardness scales, with diamond cone.
- Rockwell hardness scales B, E and F, with steel ball.
- Rockwell N surface hardness scales with diamond cone.
- Rockwell T surface hardness scales with steel ball.

5.4.2. Scope.

Application of this method of hardness calculation is possible on any type of metal or alloy. A mark created with a penetrator incision of a certain geometry and the thickness of this mark determines the material resistance.

Three basic characteristics perform the existing methods for measuring hardness:

- The shape of the tool used (penetrator).
- The conditions of load application.
- The way to hardness calculation (definition).

The method choice to determine the hardness depends on factors as:

- Type of sample.
- Dimensions of sample.
- Thickness of sample.

5.4.3. Generalities.

Hardness is a matter property and one of the most widely methods for the quality selection of metallics materials.

The hardness test is relatively simple and provides a high yield, because it does not require the destruction of the sample. Another of its most significant characteristics is its ability to evaluate the properties of the different material micro structural components.

Creation of traces on a surface due to the resistance that a material presents to the penetration defines the hardness test. The smaller mark obtained in normalized conditions, the harder tested material.

Penetrator is a main part of the device used in the performance of tests. Generally, it has a spherical, pyramidal or conical shape and is made of a much harder material than tested material, such as hardened steel, diamond or tungsten sinter carbide.

5.4.3.1. Brinell hardness test (ISO 6506-1).

In the Brinell hardness test, the penetrator press the surface of the tested material with a very hard steel ball or tungsten carbide, generating an impression of a spherical cap which is a portion of the penetrating sphere.

The Brinell hardness is proportional to the obtained ratio division of the test load by the surface mark area of the curve.

$$HBW = \frac{2\,F}{\pi \cdot D^2\left(1 - \sqrt{1 - \frac{d^2}{D^2}}\right)} \qquad (1)$$

The mark is spherical with a radius of half indentation sphere diameter. In practice, the calculus of Brinell number is directly taken from a table, using the comparison of the imprint diameter value.

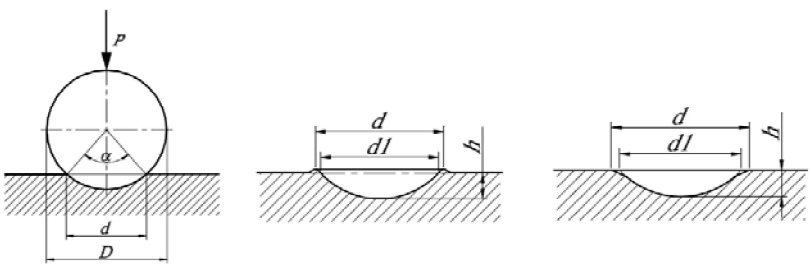


Fig. 5.26. Left: Basic scheme of a Brinell hardness test. Center: Craterizacion in the indentation. Right: Depression in the indentation

The nomenclature uses for the designation of the Brinell hardness test is HBW. Hardness value supplemented by an index shall preceded these identification letters, and they must indicate test conditions in the following order:

a) Diameter of the sphere in mm.

b) Number that represents the test load in kgf.

c) The duration of the applied test load, in seconds, if it is different from the specified time.

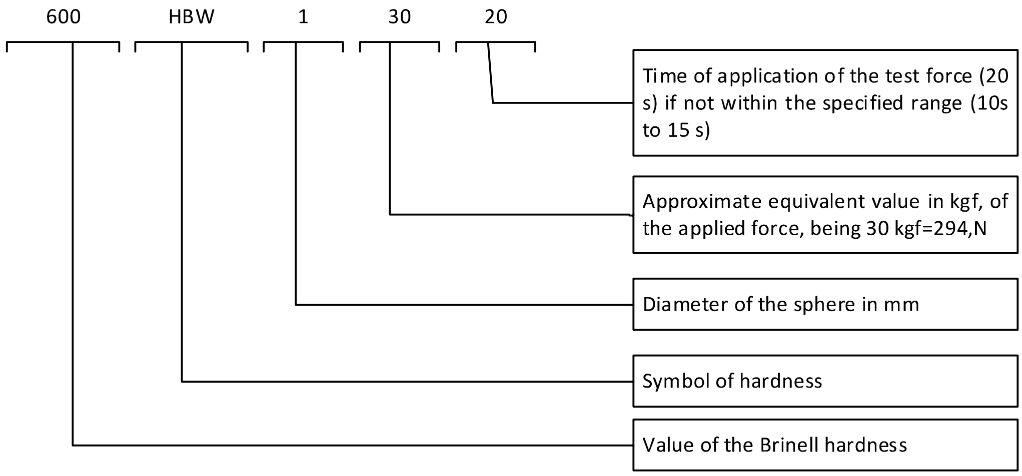


Fig. 5.27. Example. ISO 6506-1 and handmade

5.4.3.1.1. Required equipment.

1. Test device, it must apply a predetermined test force or different force values in a range between 9.807 N and 29.42 kN.
2. Indenter, a polished sphere of tungsten carbide.
3. Measurement device for the mark´s diameter.
4. Test piece: The surface of the specimen must allow an accurate determination of the mark´s diameter; therefore it will present a smooth surface, free of oxides, foreign matters and free of lubricants. Its thickness must be at least 8 times the depth of the mark.

5.4.3.1.2. Test Report.

1. The test performs at room temperature between the ratio of 10ºC and 35ºC. The tests at different temperatures will perform under controlled conditions with temperature limits of 23 ± 5ºC.

2. The performing loads of the test are specified in Fig. 44. For each type of mark diameter size "d", this should remain between the values 0.24D and 0.6D. If this is not the case, the indication of the quotient between the diameter of the mark and the diameter of the indenter (d / D) should be in the Test report. As an example, for steel and cast iron C = 30 with a 10 mm ball, a test load of 3000 kg is applied.

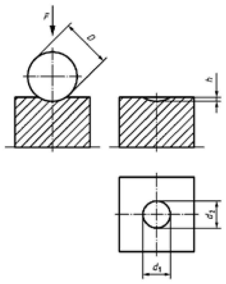


Fig. 5.28. Start of test (ISO 6506-1)

3. The diameter of the sphere should perform as large as possible, in order to test the largest representative area.
4. Test specimen should remain on a rigid support, with both surfaces in contact clean and free of any foreign material. The recommendation is that test faces specimen should be as flat and parallel as possible; must be polished and during its preparation should avoid any kind of heating that can introduce tensions.
5. Place the indentation sphere in contact with the test surface and apply the test load in a direction perpendicular to the surface, avoiding shakes, vibrations or displacements. Increase the load until the stipulated value.
6. The limit time between the initial load application and total test load performance shall not be less than 2s or greater than 8s.
7. The time of testing load is between 10 and 15 s. For some materials, with a longer application of the load, the time must have a tolerance of ± 2s.
8. The test should not be influenced by external factors; therefore, protection of test device from influential shocks or vibrations is important.
9. Distance from the end of the test specimen to the center of the trace must have a minimum of two and a half times the diameter of the trace. The distance between the centers of two adjacent tracks must be at least three times the average diameter of the mark.
10. To guarantee the correct calculation of the hardness, the measurement of the mark diameter is in two perpendicular directions, taking the arithmetic average of both readings.

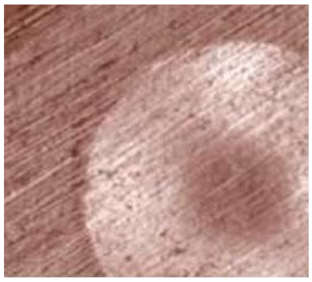


Fig. 5.29. Footprint left in the material in a Brinell test (San Buenaventura University, 2002, pág. 13)

Arithmetic average for the diameter of the mark: $d = \frac{d_1+d_2}{2}$ (2)

Diameters of the mark with a measurement of 90º (en mm). $d_1;\ d_2$ (3)

Table 5-8 Test for different conditions of test forces (ISO 6506-1)

Hardness Symbol	**Sphere Diameter D mm**	**Load-Diameter relationship 0,102 x F/D^2**	**Testing Force value F N**
HBW 10/3 000	10	30	29 420
HBW 10/5 500	10	15	14 710
HBW 10/1 000	10	10	9 807
HBW 10/500	10	5	4 903
HBW 10/250	10	2,5	2 452
HBW 10/100	10	1	980,7
HBW 5/750	5	30	7 355
HBW 5/250	5	10	2 452
HBW 5/125	5	5	1 226
HBW 5/62,5	5	2,5	612,9
HBW 2,5/187,5	2,5	30	1 839
HBW 2,5/62,5	2,5	10	612,9
HBW 2,5/31,25	2,5	5	306,5
HBW 2,5 15,625	2,5	2,5	153,2
HBW 1/30	1	30	294,2
HBW 1/10	1	10	98,07
HBW 1/2,5	1	2,5	24.52
HBW 1/1	1	1	9,807

5.4.3.2. Vickers *hardness test* (ISO 6507-1, 2005*).*

Determination of Vickers hardness test is similar to the Brinell since its obtainment performs from the quotient of the load applied by the surface of the mark. However, in this case, a small charge is used and the penetrator is a diamond with the shape of a pyramid.

In order to test performance, a diamond indenter with a straight pyramid shape, square base and with a predetermined angle between the opposite faces at the apex, press against the surface of the test specimen with a test force F.

Next step is the measurement of the diagonal length that the mark has remained on the surface when it stops the force. Angle of the Vickers penetrator adapted a common way as Vickers numbers coincide with Brinell.

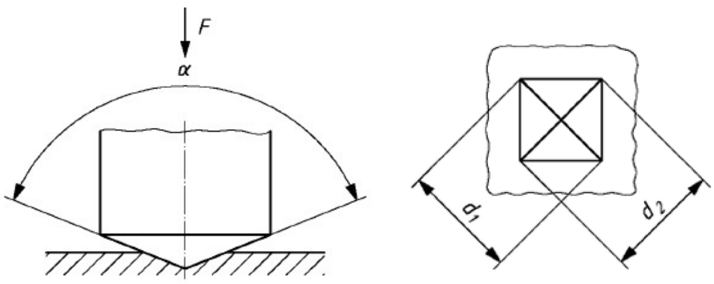


Fig. 5.30. Start of test (ISO 6507-1, Pag. 8)

Results of Vickers hardness are proportional to the quotient division of the test force between the faces areas of the mark, which is a straight pyramid of square base, with the same angle at the indenter vertex.

$$\text{Hardness Vickers } HV = \frac{F}{d^2} \quad \frac{Test\ force}{Area\ of\ the\ footprint} \tag{4}$$

Nomenclature designation of Vickers hardness test is HV. An index indication of test conditions and hardness value shall preceded HV identification letters in the following order:

a) Number of test load in kgf.

b) Duration of the test load application in seconds.

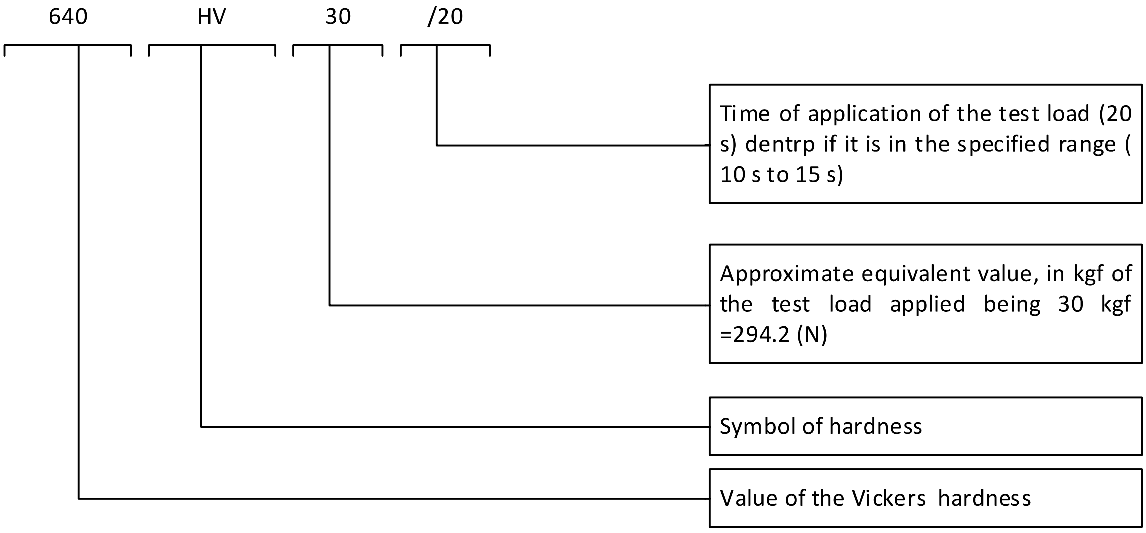


Fig. 5.31.Example Vickers hardness

5.4.3.2.1. Required equipment.

1. Test machine with testing load application level in the specific limits.
2. Indenter: a diamond with a straight pyramid shape with a square base.
3. Measurement device for diameter of the mark calculation. Its specifications are in the International Standard ISO 6507-2.
4. Test specimen should have a smooth surface, free of oxidation rust, foreign matters and free of lubricants.

The thickness of the specimen must be at least one and a half times bigger than the length of the diagonal of the tread.

In Vickers micro hardness tests, selection of special measurements such as polishing or electro polishing appropriate to the characteristics of the material is possible when the small depth of the mark occurs.

5.4.3.2.2. Test Report.

1. The test performs generally at room temperature in the range of 10ºC and 35ºC. The tests with different temperatures will have controlled conditions with temperature limits of 23 ± 5ºC.
2. The used test forces are in Table 3.
3. The test specimen should remain on a rigid support, with both surfaces in contact. Both supports must be clean and free of foreign matter.
4. Displacements do not occur during the test, so test specimen must supported on the rigid structure.
5. Placing the indentation sphere in contact with the test surface and applying the test load in a perpendicular direction to the surface. Next, the load will increase until the stipulated value level without vibrations or displacements.
6. The limit time between the initial load application and the total test load shall not be less than 2 s and not more than 8 s. In the hardness tests of at low strength and micro hardness this time should not exceed 10 s. Test load maintains its level between 10 and 15 s, but for some materials with a longer application of the load, the time must have a tolerance of ± 2s.

    a. For specific materials, test application time must be between 10 and 15 s and the use of this time must be in the report and in the part of the hardness designation.
    b. In these cases, the approach speed of the indenter must not exceed 0.2 mm / s. Indenter should contact the specimen at an average speed between 15 µm / s and 70 µm / s in the microhardness tests.

7. External factors should not influence the test; therefore, protection of test device from influential shocks or vibrations is important.
8. Type of tested material conditions:

    a. The minimum distance from the end of the test specimen to the center of the mark:
    b. For steels, copper and copper alloys: distance must have a minimum of two and a half times the average length of the mark´s diagonal.
    c. For light metals, lead, tin and their alloys: distance must have a minimum of three times the average length of the mark´s diagonal.

9. Type of tested material also conditions the distance between the centers of two adjacent tracks:

a. For steels, copper and copper alloys: distance between centers must be at least three times the average length of the mark´s diagonal.
b. For light metals, lead, tin and their alloys: distance between centers must have a minimum of six times the average length of the mark´s diagonal.

10. Measure the length of the two diagonals and determine the value of the Vickers hardness taking the arithmetic average of both values. For flat surfaces, difference between the measures of the two diagonals should not be more than 5%. In any other case, final report must have a reference about it.

Table 5-9 Strength of test ranges.

Testing Force Range F N	**Hardness Symbol**	**Relationship**
F ≥ 49,03	≥ HV 5	Vickers Hardness Test
1,961 ≤ F < 49,03	De HV 0,02 hasta < HV 5	Vickers Hardness Test with Low Force
0.098 07 ≤ F < 1,961	De HV 0,01 hasta < HV 2	Vickers micro-Hardness Test

Table 5-10. Test forces

Hardness Test [a]		**Hardness Test with Low Force**		**Micro-Hardness Test**	
Hardness Symbol	Nominal Value of force, F N	Hardness Symbol	Nominal Value of force, F N	Hardness Symbol	Nominal Value of force, F N
HV 5	49,03	HV 0,2	1,961	HV 0,01	0,098 07
HV 10	98,07	HV 0,3	2,942	HV 0,015	0,147
HV 20	196,1	HV 0,5	4,903	HV 0,02	0,196 1
HV 30	294,2	HV 1	9,807	HV 0,025	0,245 2
HV 50	490,3	HV 2	19,61	HV 0,05	0,490 3
HV 100	980,7	HV 3	29,42	HV 0,1	0,980 7
[a] Nominal Tests with high forces can performs until 980,7 N					

5.4.3.3. Rockwel hardness test (ISO 6508-1, 2016).

As in the Brinell test, hardness is determined according to the degree of penetration in the tested piece by a penetrator´s action with a static load.

Although this type of Hardness test differs from the previous one in the loads level, they have smaller penetrators, so the mark will be smaller and less deep and it can be a steel ball or a diamond cone. It is possible visualization of the Hardness value directly from the indicator´s dial of the device, without the use of formulas.

An indentator performs this test. It has determined size and shape depending on the type of tested material. It press against the sample´s surface in two different strength levels according to the specified conditions. First, specified preliminary force is applied and the initial penetration depth measured. Next step is the application and removement of an additional specified force, returning to the preliminary force. Final penetration´s depth is measured and the Rockwell hardness value comes from the difference, h, of the final and initial penetration depth and their two constants N and S loads:

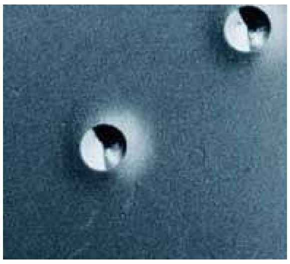


Fig. 5.32. Footprint in material under Rockwel testl. (San Buenaventura University, 2002, pág. 10)

$$\text{Rockwell´s Hardness } N - \frac{h}{S} \tag{5}$$

The following nomenclatures establish the different types of tests according to the Rockwell hardness scales:

- HR symbol describes the Rockwell hardness for the scales A, C and D, it preceded by the hardness value and completed with an identifying letter of the scale.
- HR symbol describes the Rockwell hardness for the scales B, E, F, G, H and K , it preceded by the hardness value and completed with an identifying letter of the scale and a letter for the type of indented sphere S for steel and W for carbide.
- HR symbol describes the surface Rockwell hardness for the N scale, also preceded by the hardness value and followed by a number of total load, and the letter N.
- HR symbol describes the Rockwell hardness for the T scale, it preceded by the hardness value and followed by a number of total load and the letter T indicative of the scale. This type also has a letter according to the indenter type: steel (S) or carbide (W).

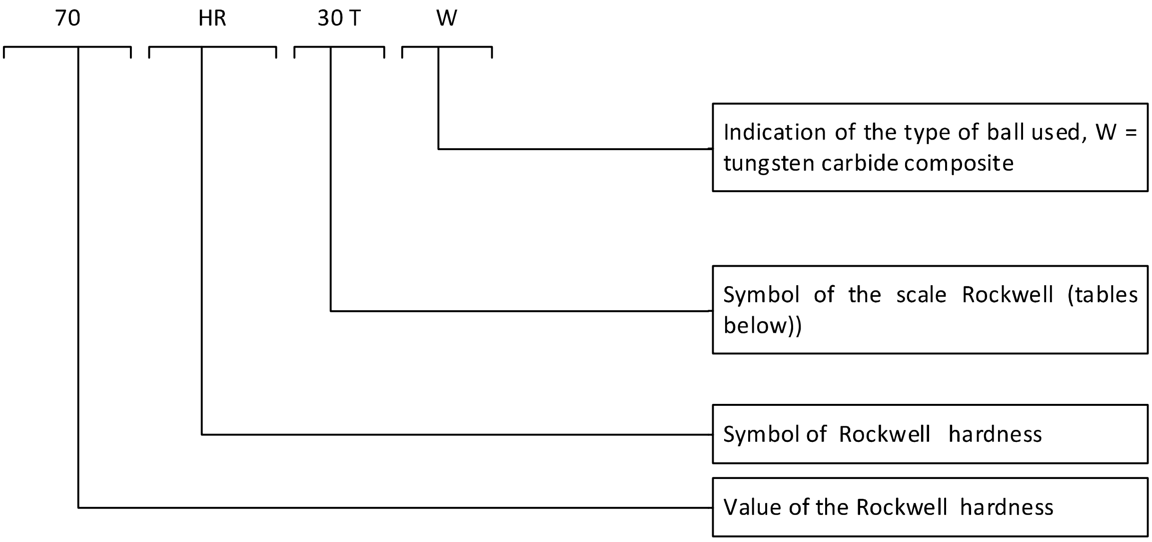


Fig. 5.33. Example. Handmade and ISO 6508-1.

Table 5-11. Normal Rockwell scale hardness. Handmade and ISO 6508-1, 2016, pag 8

Normal Rockwell hardness test	Symbol of hardness Unit	Type of Indenter	Preliminar forcé F_o	Total forcé F	Scale constant S	Scale constant limit N	Range of application (normal Rockwell hardness scales)
A	HRA	Diamont cone	98,07 N	588,4 N	0,002 mm	100	From 20 HRA to 95 HRA
B	HRBW	Ball 1,587 5 mm	98,07 N	980,7 N	0,002 mm	130	From 10 HRBW to 100 HRBW
C	HRC	Diamont cone	98,07 N	1,471 kN	0,002 mm	100	From 20 HRC[a] to 70 HRC
D	HREW	Diamont cone	98,07 N	980,7 N	0,002 mm	100	From 40 HRD to 77 HRD
E	HRFW	Ball 3,175 mm	98,07 N	980,7 N	0,002 mm	130	From 70 HREW to 100 HREW
F	HRGW	Ball 1,587 5 mm	98,07 N	588,4 N	0,002 mm	130	From 60 HRFW to 100 HRFW
G	HRGW	Ball 1,587 5 mm	98,07 N	1,471 kN	0,002 mm	130	From 30 HRGW to 94 HRGW
H	HRHW	Ball 3,175 mm	98,07 N	588,4 N	0,002 mm	130	From 80 HRHW to 100 HRHW
K	HRKW	Ball 3,175 mm	98,07 N	1,471 kN	0,002 mm	130	From 40 HRKW to 100 HRKW

[a]The corresponding range of application can be extended to 10 HRC if the surfaces of the diamond cone and tip spherical they are polished to a depth of at least 0.4 mm.

Table 5-12. Superficial Rockwell hardness scales. Handmade and ISO 6508-1, 2016, pag 8

Superficial Rockwell hardness test	Symbol of hardness Unit	Type of Indenter	Preliminar forcé F_o	Total forcé F	Scale constant S	Scale constant limit N	Range of application (normal Rockwell hardness scales)
15 N	HR15N	Diamont cone	29,42 N	588,4 N	0,001 mm	100	From 70 HR15N to 94 HR15N
30 N	HR30N	Diamont cone	29,42 N	980,7 N	0,001 mm	100	From 42 HR30N to 86 HR30N
45 N	HR45N	Diamont cone	29,42 N	1,471 kN	0,001 mm	100	From 20 HR45N to 77 HR45N
15 T	HR15TW	Ball 1,587 5 mm	29,42 N	980,7 N	0,001 mm	100	From 67 HR15TW to 93 HR15TW
30 T	HR30TW	Ball 1,587 5 mm	29,42 N	980,7 N	0,001 mm	100	From 29 HR30TW to 82 HR30TW
45 T	HR45TW	Ball 1,587 5 mm	29,42 N	588,4 N	0,001 mm	100	From 10 HR45TW to 72 HR45TW

5.4.3.3.1. Required equipment.

1. Testing machine: it must apply the different test forces for some or all of the Rockwell hardness scales, as shown in tables 1 and 2.

2. The penetrator.

2.1. Spherical-conical diamond penetration: the tip has an angle of 120 ° and a radius of curvature of 0.2 mm. Certified Diamond penetrators must perform next uses:

1. Normal Rockwell diamond scales only.
2. Superficial Rockwell diamond scales only.
3. Normal and superficial Rockwell diamond scales.

2.2. Penetrator ball, it must be composed of tungsten carbide and have a tip diameter of 1,587 5 mm or 3,175 mm

3. Measuring device with measuring capacity of the mark´s diameter.

4. Test specimen must have a smooth surface, free of foreign materials (lubricants, dust, etc.) unless other specification use. The thickness of the tested layer must be at least 10 times the depth of the permanent mark for dial indenters.

5.4.3.3.2. *Test Report.*

1. The test performs at room temperature between the ratio of 10ºC and 35ºC. The tests at different temperatures will perform under controlled conditions with temperature limits of 23 ± 5ºC.
2. Test specimen should remain on a rigid support, with both surfaces in contact. Both supports must be clean and free of foreign matter so displacements do not occur during the test.
3. Preliminary load F0 must remain meanwhile the indentor is in contact with the test surface. Vibrations or displacements are not allow in the device until the applied load reaches the stipulated value.
4. Time between the application of the preliminary load and the followed load must not exceed 3 s.
5. Place the measuring device in its position of data collection and without vibrations or oscillations; increase the load from F0 to F not in less than 1s or in more than 8 s.
6. The test load F must be maintained for a period of 4 ± 2 s. Subsequently, eliminate the additional test load F1 and, after a period of stabilization and maintaining the load F0, take the measurements of the final reading.
7. For the calculation of the Rockwell hardness value, the depth of the permanent trace h is used, which is obtained according to tables 9 and 10.
8. External factors should not influence the test, therefore it is important to protect the test device from shocks or vibrations that could perform an error in the test result.
9. The distance between two consecutive mark centers should be at least 4 times the diameter of the mark, but not less than 2 mm. Distance between the center of the mark to the end of the test specimen must be at least two and a half times the diameter of the mark, but not less than 1 mm.
10. For the correct test procedure, it is necessary a series of checks when more than 24 h have elapsed since the last test, and after each change, removal or replacement of the indenter or the support of the test specimen, and the first two results must be discarded due to such changes.

5.4.4. Different Procedures.

In order to facilitate the development of the test, Laboratory personnel will use the Manual of Instructions or Recommendations made by the manufacturer of the device and any additional complement together with the Standard and the procedures described.

5.4.5. Test Report.

The test report of the results must contain at least:

- Reference to the standard used:

    - Brinell: UNE / EN ISO 6506-1
    - Vickers: UNE / EN ISO 6507-1
    - Rockwell: UNE / EN ISO 6508-1

- Identification of the testing piece.
- The different test temperature if it is not in the limits (23 ± 5ºC).
- Obtained result.
- Additional requirements to the standard.
- Details of any incident that may affect the result.

5.5. *Magnetic particle Testing.*

5.5.1. Object.

Magnetic particle testing is used for the testing of materials, which can be easily magnetized. This method is capable of detecting open to surface and just below the surface flaws. ISO 9934-1, 2016, Non-destructive testing. Magnetic particle testing. It can also detect discontinuities just below the surface, but its sensitivity decreases rapidly with depth.

5.5.2. Scope.

Applying the test by magnetic particles, surface and sub-surface discontinuities (cracks) detection is the main objective. This is achieved by the magnetization of the element to be inspected and it will only be possible in ferromagnetic materials: iron, steels, nickel, cobalt and most of its alloys.

Thus, it is not applicable to non-ferromagnetic materials: alloys of aluminum, copper, magnesium, lead, titanium and austenitic stainless steels.

Magnetic particle testing is usually selected when a fast inspection is required.

The ideal situation obtained in the magnetic particle examination is the one that provides the greatest sensitivity for the smallest discontinuities.

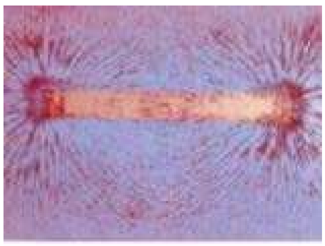


Fig. 5.34. Field lines for a magnet (https://goo.gl/nAuZs6)

5.5.3. Generalities.

The basic principle is test specimen magnetization by using a permanent or an electromagnet or by passing electric current through or around the specimen. The magnetic field thus introduced into the specimen is composed of magnetic lines of force. When the piece presents a zone in which there are perpendicular discontinuities to the lines of the magnetic field, the distortions or poles attract the magnetic particles that interrupt the uniform flow of the lines of force.

When sprinkling magnetic particles on the aforementioned magnet, these would be attracted by the poles created by the crack, giving an indication of the area of the defect due to its accumulation. Some of magnetic particles are forced to leave the magnet, which is called flow leakage.

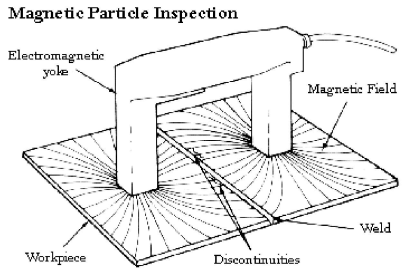


Fig. 5.35. Magnetic particle inspection. (https://goo.gl/9h1TA2)

It is possible to use multidirectional magnetization to search for discontinuities oriented in any direction.

Factors that affect the detection or identification of defects:

- Direction and intensity of the field.
- Form, size, orientation and depth of the defect.
- Surface condition of the piece.
- Characteristics and application of the magnetic particles (dry and wet way): size, shape, color, magnetic properties, etc.
- Magnetic characteristics of the piece to be tested: the minimum requirement is ferromagnetic material type, but in addition, the retentivity of the material is also important in the case of applying the so-called residual method.

5.5.4. Classification of materials by their magnetic characteristics.

Based on the principle of magnetic particle inspection, materials can be classified according to their behavior when a magnetic field appears.

a) Ferromagnetic: they are materials strongly attracted by a magnetic field. (They are ferromagnetic, elements such as iron, nickel, cobalt and gadolinium, oxides such as magnetite, and some alloys such as Heusler (30% of Mn and 70% of Cu) and Permalloy (22% Fe, 78% Ni).

b) Paramagnetic: They are materials slightly attracted by a magnetic field, which are platinum, aluminum, chromium, potassium, tin, etc.

c) Diamagnetic: materials that are not attracted by a magnetic field, which are silver, lead, copper, mercury, etc.

5.5.5. Test procedure.

5.5.5.1. Required equipment.

Many different varieties of standard magnetic particle test equipment are available for industrial use. ISO Standard 9934-3, 2015 describes three types of magnetic particle test equipment:

- Portable or transportable equipment.
- Fixed installations.
- Specialized testing system for testing components continuously as a series of processing stations located sequentially in order to form a process line.

Fig. 5.36. Magnetic yoke (https://goo.gl/mQnz3e)

The equipment for magnetization, demagnetization, lighting, measurement and monitoring is also described.

It´s not enough to have the appropriate equipment, but also to choose the most effective method that ensures the best inspection of the tested parts.

They mainly consist of:

- Magnetic yoke: it is a metal element in the shape of a "U" with a coil around the horizontal bar, which transports the electric current. They are usually made of low-retentivity sweet iron. There are two types: Magnetic permanent yoke and electromagnetic yoke.
- Coil: In this case a pre-wound coil of few turns is used to create longitudinal field in the part where placed within it. As an induced current sensor, formed by one or multiple windings of the conductor and used for the longitudinal inspection of parts, thanks to this mode of operation, the transverse fissures in axes and cylinders can be easily detected.

Fig. 5.37. Longitudinal magnetization coi. (https://goo.gl/HKLHb9)

- Magnetc prods: The magnetization is often done with contact points in the inspection of large pieces, too big to place in a bench between heads. In this method, the pass of the current is directly through the piece, in a localized area.

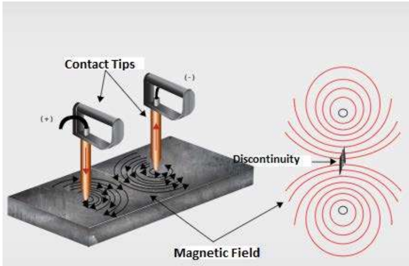


Fig. 5.38.Single points of contact. Homemade and https://goo.gl/JGpWsR

This technique is commonly used in large foundries and welds, since prods are easy to handle and portable, so they are very convenient in field inspection of large tanks and welded structures. It also presents a great sensitivity to subsuperficial defects, more than any other technique.

In addition to this equipment, it is necessary the knowledge of the different basic components operations.

5.5.5.1.1. Magnetic particles products.

Standard ISO 9934-2, 2015 classifies the magnetic particle products in two types:

- Suspensions of magnetic particles.
- Powders.

These products, generally, consist of finely divided ferromagnetic oxide particles, which may have spheroidal or elongated shape. There are three different types of magnetic particles that differ from each other according to several characteristics:

a. Dry particles. They are the most used and are a mixture of elongated particles and small and fine particles. Fine particles help mobility and sensitivity, while long particles help to shape long indications.
b. Wet visible particles. They are usually smaller than those used in the dry method. Usually they are in a range of 1 to 25 µm, while the dry particles are in the range of 100 to 1000 µm.
c. Fluorescent particles in suspension.

The selection of these types of particles focus on the following considerations, depending on the discontinuity of the tested piece:

- Type of discontinuity: For sub-surface discontinuities, the dry method is the most sensitive.

- Size of the discontinuity: the suspended particle method is the most suitable for shallow particles.

Another factor in the selection of the particle type is the dispersing agent used for the propagation of the particles in the medium. The magnetically particles can apply on the surface as dry particles or as a suspension in a liquid, such as water or oil:

- Dry method-Dry magnetic particles: they use air as a dispersing medium.
- Wet Method-Wet magnetic particles: they are prepared commercially in paste or powder to perform a dissolution. Water produces corrosive phenomena in the piece that the oil does not, but the use of oil releases toxic and flammable vapors that the use of water does not generate.

5.5.5.1.1.1. Characteristics of magnetic particles.

The most important ferromagnetic properties of magnetic particles descriptions are below:

- High Permeability: This property allows particles to be specifically attracted where the discontinuity forms a visible indication.
- Low Coercive Force: With this property, it is possible to ensure the accumulation of the particles on the test surface, making the application of the technique easy.
- High visibility and contrast: The procurement of these properties depends on the selection of a suitable particle color (white, black, red, blue and yellow.) Color selection is due to the surface of the tested element and the lighting ambient conditions.

In theory, particles whose magnetic permeability is as large as possible must have coercive force and retentivity as low as possible.

5.5.5.1.1.2. Size.

All the particles present, from the beginning, a characteristic in common; all of them will be finely divided particles of the order of microns. This diversity of sizes, from thicker to slender, they will have an effect on the inspection of the tested pieces.

5.5.5.1.1.3. Shape.

The particles forms have a range from elongated particles to spherical particles, moving on multiple intermediate forms. This will also generate an effect on the detection sensitivity of the discontinuities:

As the particles tend to align in the direction of the force lines, we will look for mixtures of particles with different shapes. A solution in which a compromise between the fluidity and the production of acceptable indications is achieved.

5.5.5.1.1.4. Visibility and contrast.

It is possible generation of an optimal contrast using several options of magnetic particles in the surface of the piece:

- Under visible light: It is feasible the use of pigmented magnetic particles with different types of colors: gray, white, black, yellow and red. The particles will have a pigmentation whose color ensures a good contrast with the color in the surface of the studied piece. Another option is painting the surface of the piece with a suitable paint, in order to increase the contrast.
- Under black light (wavelength of 365mm = 3650 Å, lamp preheated for 5 min.). The use of fluorescent magnetic particles require a smaller accumulation of them over the discontinuity, even with a lower contrasting color.

Fig. 5.39. Wet magnetic particles (https://goo.gl/nAuZs6)

5.5.6. Test Report.

Before Magnetic Particles inspection, it is necessary to take into account the following data:

- Condition of the surface of the material and the type of discontinuity to detect.
- Metallurgical and magnetic characteristics of the material inspected. The type of current, the use of particles and the method of the residual remaining magnetism elimination in the piece will depend on this.

The procedurement of the test consists of four fundamental phases:

1) Preparation and cleaning of the surface to be tested.

2) Magnetization of the piece.
3) Application of magnetic particles.
4) Inspection, Identification and Interpretation of discontinuities.
5) Demagnetization of the piece.
6) Post-inspection cleaning.

5.5.6.1. Preparation and cleaning of the surface to be tested.

During the test, the sensitivity determination degree of the defects inspection depends on the cleanliness of the tested surface.

The examined surface and adjacent areas should be cleaned of any remaining water, oil, grease or any other contaminating substance to not interfering with the magnetic particles possible alignment on the defects.

5.5.6.2. Magnetization of the element.

There has to be a choice made between continuous method (dry or wet) and residual.
There is a need of strict control and check on the choice of magnetizing current, direction of the field and values of current.

Standard ISO 9934-1, 2016 establishes the following magnetization techniques:

1) *Transmission of electric current through the piece:*

- Axial current flow.
- Current flow between electrodes.
- Induced current flow.

2). Magnetic flow transmission through the piece:

- Central conductor.
- Adjacent conductors.
- Fixed installation.
- Portable electromagnet (Yoke).
- Rigid coil.
- Coil formed by flexible cable.

5.5.6.3. Magnetic particles application

Once the magnetization has been performed, the magnetic particles will be applied as a developer that will allow the identification of the leakage fields originated by the discontinuities (defects), thanks to their alignment around them.

Depending on the route to be used, a different preparation of the particles will be required:

- *In dry way no preparation is required, but its use is direct.*
- *In the case of the wet method, it is necessary to prepare a solution of adequate concentration.*

5.6.3.4. Inspection, Identification and Interpretation of the indications.

Once the magnetic particles have been applied to the magnetized piece, the next step will be the inspection of the piece. Inspection is done visually, using visible light if the particles are colored or black light if the particles are fluorescent.

Fig. 5.40. Fluorescent, wet particle method (https://goo.gl/79PNQo)

The objective of this visual inspection is the detection of the indications generated by the leakage fields, when the particles accumulate and align around the defects.

If imperfections are found in the inspection, the correct interpretation of the indications is made, attributing to each one their real cause and establishing what type of imperfection it is, distinguishing them with certainty from the false or irrelevant indications.

5.6.3.5. Demagnetization of the element.

After submitting a magnetic field to any ferromagnetic material, these present, as it disappears, a residual or residual magnetic field whose intensity depends on the retentivity of the material.

This magnetic field can be very small in soft metals, but in very hard metals, this field can be similar to a field of permanent magnet.

The process of demagnetization will not always be necessary depending on the time of this process and the cost, however there are cases in which it is necessary to demagnetize the pieces after the magnetic particle test.

All the existing procedures are based on the hysteresis cycles and, in any case, it proceeds by subjecting the piece to an alternating magnetic field, produced by a coil through which an alternating current circulates, whose intensity gradually decreases until it is canceled. For demagnetization to be effective, it is necessary to make sure that the initial field is strong enough to overcome the coercive force and thus invest the or initial residual of the piece.

Fig. 5.41. Demagnetizer portable (https://goo.gl/iYXLAo)

5.6.3.6. Post-inspection Cleanning.

At the end of the inspection and demagnetization phases, cleaning operations may be necessary. It is very important to focus the cleaning process in the parts where the magnetic particles may interfere in subsequent processes or service requirements.

The most common techniques of post-inspection cleaning are:

- Use of compressed air: eliminates unwanted accumulations of dry magnetic particles.
- Drying of wet particles and subsequent removal by brush or compressed air.
- Elimination of wet particles using solvents.
- Other techniques, as long as they do not interfere with the requirements of the piece.

5.5.7. Results.

When the interpretation and evaluation of the indications perform, the following factors should be taken into account:

1. Appearance, definition, direction and form of the indications.
2. Evaluation of the size and extension of the indications.
3. Knowledge of the different types of possible defects.
4. Knowledge of the material type.
5. History of processes of the affected piece or area (type of machining, heat treatment, etc.)
6. Use of previous experience in similar pieces.

For the evaluation and qualification of the indications, it is important to take into account:

a. Evaluation of all indications in the acceptance rules plans or in the reference standards.
b. Any discontinuity open to the surface will generate an indication. However, irregularities in machining and other surface conditions can create false indications.

c. In case of extensive fluorescence or colored areas, which may mask indications of discontinuities, the examination will not be acceptable. These areas will perform a cleaning process and examination again.

The classification of the different defects in the tested pieces depends on the type and form of generated discontinuity:

- Cracks, defects and superficial heterogeneities: they occur in clearly defined indications when their plane is perpendicular to the lines of force of the magnetic field.
- Continuous linear indications: cracks or fissures of corrosion under stress, cracks of a defective cooling in a heat treatment, cracks of contraction of welding, etc.
- Round indications: those of a circular or elliptical shape. Originated due to porosities on the surface, which can be caused by moisture welding cords, craters at the end of the cord, etc. Normally they are not usually presented alone, but forming small or large groups depending on the intensity of the defect.
- Discontinuous linear indications: they origin can be by some of the previous causes as characteristics of material folds, sheets of lamination, lack of bonding in welds, etc.
- Grouped indications: when the adjacent indications are separated by a distance less than the largest dimension of the smallest indications, they are considered as a single indication.
- Cracks, defects or sub superficial heterogeneities.
- Of cylindrical morphology: with indications of more diffuse edges, due to the smaller obstacle that they offer to the lines of force of the magnetic field.
- Spherical morphology: they give rise to poorly defined indications, so they are difficult to detect. They come to define cavities, pores and globular macro-inclusions.

According to the different types of defects that cause them, indications importance divides them into two different groups:

1. Relevant indications.

- Cracks and streaks: shrinkage cracks, quenching cracks, grinding cracks, fatigue cracks or cracks due to corrosion.
- Others: forging folds, cracking of friction surfaces, expansion cracks, stress corrosion cracks and seams.
- Macro-inclusions.
- Typical welding defects, such as: melting faults, penetration faults, aligned slags and porosity.

2. No relevant Indications.

They are indications not created by heterogeneities or discontinuities of the material. They are usually diffuse and not very well defined. However, they may mask relevant indications, so they should be eliminated as much as possible. They generally disappear when the piece is demagnetized and magnetized again, using lower values of magnetizing current. Different possible causes of non-relevant indications can include:

a. Use of excessive magnetizing current
b. Existence of sensitive permeability differences in different areas of the piece. A very usual example is due to the configuration and geometry of the piece, which produces "constrictions" in the force lines, for example in the edges, corners and abrupt changes of section.
c. Contact of two pieces with different degree of magnetization. This is due to contact surfaces friction of both parts, producing a very slight distortion of the magnetic field of the pieces. Magnetic Field remains once separation of pieces occurs and the accumulation of magnetic particles performs. It is the well-known magnetic writing effect.

3. False indications.

Due to particles accumulations by gravity in the superficial irregularities of the piece. They are easily recognizable because it is easy to spread them by means of a light blow.

In certain cases, it is possible the repetition of a detected defect in the tests, but always using the same product, equipment and method as when the discontinuity was detected.

5.5.8. Different Procedures.

In order to help the development of the Charpy test by the Laboratory personnel, they will use the Manual of Instructions written for this test, as well as any other recommendation made by the equipment manufacturer

5.5.9. Test report.

The report of the test results must contain at least:

- Reference to the standard used: UNE EN ISO 9934-1

- Situation and address of the place where the test samples were made.
- Identification of the tested piece.
- Specified material.
- Time of the test procedure (for example, before or after the heat treatment, before or after the final machining).
- Characteristics of the equipment to be used (particles, type of magnetization, etc.) and their complements.
- Detection products used and contrast paint if it has been used.
- Surface Preparation.
- Conditions of the visual examination.
- Test results, including at least
    - Type of found defects and their measurement.
    - Sketch of the piece to indicate the defect´s location.
    - Final resolution adoption.

6. DESTRUCTIVE TESTING.

The speed of Destructive testing creates two groups:

Static test: speed of applied forces to the material does not affect the results of the test. The active force on the piece is constant: hardness testing (Mhos, Martens) scratch lime hardness testers (Brinell, Vickers, Rockwell) penetration, tensile stress, creep, torque, compression, bending and buckling.

Dynamic test: speed of applied forces to the material plays a decisive role in the results of the test as impact tests and fatigue resistance tests. This type of testing is destructive test material because it has only one use; for other use, it will not have the same evaluating properties in their same limits or beyond.

6.1. Tensile test.

In previous sections, the importance of material characteristics knowledge and working forces and loads applications has been described in order to design the working material space without excessive efforts and breakage produces. The mechanical behavior of a material is a reflection of the relationship between its deformation response to an applied force or load.

Fig. 6.1.Spear of a trailer https://goo.gl/t1qmV9

6.1.1. Object.

The objective of this procedure establishes the following system to perform tensile tests of metallic materials according to ISO 6892-1 "Traction Test Methods at Ambient Temperature". This method describes the relationship between the behavior and changes suffered by different materials with the different critical points of the stress-strain diagram after holding extreme loads.

6.1.2. Scope.

The tensile test (destructive test) is simulative, is one of the most important, simple and cheap tests of the mechanical tests and it is very standardized.

Tensile tests perform in metallic materials (aluminum and steel specimen). There are different standards to control it DIN 53455, ISO/DP 527, ASTM.

The test, progressive axial stress or increasing tensile load applies to a specimen test of different material type until the breaking point, is able to determine the material properties at room temperature. Samples are fixed to the testing machine by wedges, screwed fixings, clamps, etc., which must allow axial stress to optimize the transmission of forces.

This method estimates next material characteristics:

- Modulus of elasticity (E);
- Elastic limit (σ_e);
- Maximum stress or tensile strength σ_r;
- Elastic and plastic energies associated with the tensile deformation process.

- Ductility or break deformation (percentage of final relative elongation), observing the break at the end of the test;
- Percentage of tightness of the test specimens as well as the tenacity: material´s limit energy absorption before fracture.

Table 6-1. Example of shear modulus of elasticity and at room temperature and Poisson coefficient for several metals and alloys (Callister, 1995, pág. 118)

Metal or alloy	Modulus of elasticity		*Shearing Module*		Poisson coefficient
	$psi \cdot 10^6$	$MPa \cdot 10^4$	$psi \cdot 10^6$	$MPa \cdot 10^4$	
Aluminio	10,0	6,9	3,8	2,6	0,33
Cobre	16,0	11,0	6,67	4,6	0,35
Niquel	30,0	20,7	11,0	7,6	0,31
Acero	30,0	20,7	12,0	8,3	0,27
Titanio	15.5	10,7	6,5	4,5	0,36

6.1.3. Generalities.

The test performs with the use of universal test machine (Appendix I) when the displacement of mobile clamp at a selected speed with the application of the selected load generates forces in a test specimen of circular section, the most usual, or square section, fixed between the mobile clamp and another fixed clamp.

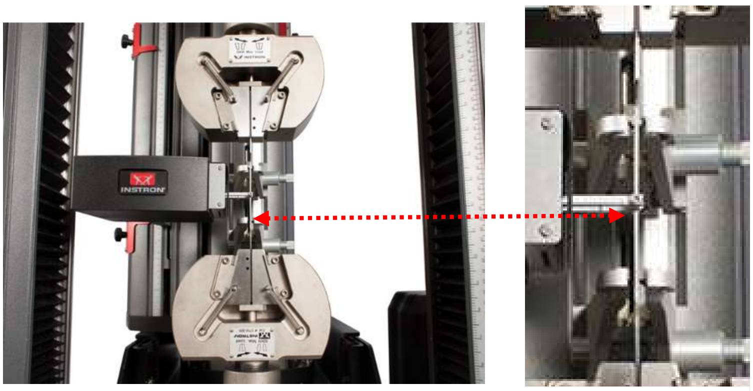


Fig. 6.2. Universal Testing Machine: Jaws and traction test specimen. Retrieved from: https://goo.gl/2WvXs6

The strain rate of the sample, (eg, 1.6 mm / min), the speed of the sample (eg, 1.15-11.5 MPa / s), the speed separation of the testing machine´s clamps, duration of the test or movement of the head (Monsalve Jaramillo) can define the speed of the test.

Final results obtained by the load cell connected to the fixed clamp give the form of a stress graph called "Deformation stress diagram” when fracture of test specimens is studied.

The test performs at room temperature, between 10 and 35 ° C, unless otherwise specified. The tests, under controlled conditions, should perform at a temperature of 23 ± 5ºC. Inspectors must record and report the testing values if the test and calibration do not perform in the range of established limits between the temperatures of 10 ° C and 35 ° C. In case of a significant temperature gradient during the test and / or calibration phases, the measurements uncertainties can be increased and established outside the tolerated conditions.

Standard ISO 6892 2 specifies a method for the tensile test of metallic materials at temperatures above room temperature.

The corresponding standards rules determine the different values of the specific characteristics of each material, changing, for example, the values of the Modulus of Elasticity or the Shear Module in the test of different materials test specimens.

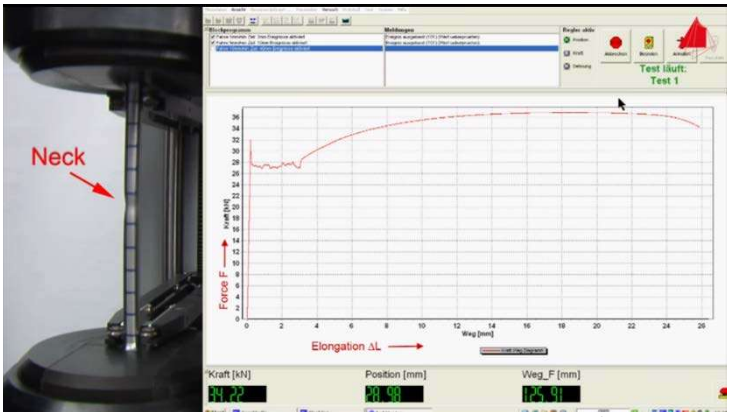


Fig. 6.3. Traction and graphical test. Retrieved from https://goo.gl/T5696N

Shape of the specimen is also normalized as it influences the testing properties. During the test, the narrowest region of the center, S0, confines deformation´s value and although this section can be variable along the length, it is correlated with the length of the test specimen, l_0. The applied standard also defines the K value and it use a model type:

$$L_0 = K\sqrt{S_0} \quad (6)$$

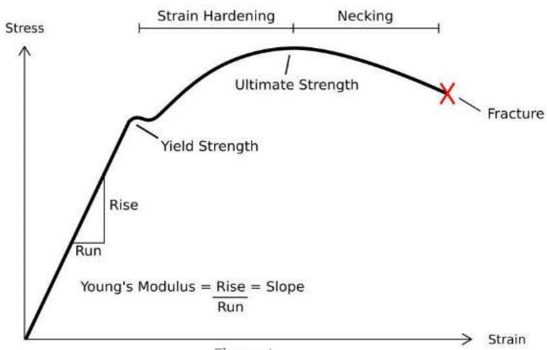


Fig. 6.4. Deformation strain diagram. Retrieved from https://goo.gl/dS6UPb

The attached figure represents the four phases of the test specimen, from the beginning to its rupture: Elastic period, fluency period, plastic period and stricture period.

When material can recover its original form in the moment of deforming force action ceases is the elastic period. The deformation degree of a structure under an axial load depends on the imposed stress.

In the period of creep, which corresponds to the boundary limit between the elastic zone and the beginning of the plastic zone, the elongations increase without an increasing force. The phenomenon of creep begins where a level of stress performs plastic deformation. Some tensile test curve don´t allow the clearly visualization of the yield strength, so forces with permanent unitary longitudinal deformation of 0.2% define by common agreement the yield point.

The plastic phase starts from the upper yield point until an extreme value of stress called maximum stress or tensile strength. Maximum stress is the tensile structure limit of force.

Finally, the stiffening period begins after the breaking stress point. Without an increasing stress, specimen lengthens until breaking moment due to the dislocations movement in its sliding planes, cracking and finally breaking. The relative variation of the specimen cross section during this last phase is the stiffening.

6.1.4. Test procedure of tensile strenght.

6.1.4.1. Types of specimen.

Requirements of used test specimen as test samples must accordance with the international standards of the different materials. Machining a sample of the material from a molded sample is the method of test specimen obtainment. In order to obtain comparable test results, the test specimens must be geometrically similar.

6.1.4.1.1. Area of the initial cross section.

Test specimens have standardized shapes and dimensions according to the tested material and the standards. The measurement of the tests specimen's dimensions should use an enough number of perpendicular cross sections to the longitudinal axis in the central area for the calibrated length.

Type of product		Corresponding Annex
Sheets — Plates — Flats	Wire — Bars — Sections	
Thickness a	Diameter or side	
$0,1 \le a < 3$	—	B
—	<4	C
$a \ge 3$	≥4	D
Tubes		E

Fig. 6.5. Main types of test pieces according to product type (ISO 6892-1 pág. 9)

The area of the initial cross-section S_o is the average of the cross-sectional area and must be calculated from the measurements of the appropriate dimensions.

The different types of sections can be classified into:

- Circular section.
- Square section.
- Rectangular constants over its entire length.

- Annular.
- Other forms.

Even with different sections and working areas, the test specimens have one characteristic in common: they have extremities with a larger section for an easy attachment to the machine, as well as to avoid breaking the specimen at this fixation point.

6.1.4.2. Test Report.

6.1.4.2.1. Sample preparation.

The test specimens should held by suitable instruments such as wedges, screwed fixings, jagged jaws or gagged handles, allowing optimal transmission of axial forces.

Preparation of the sample: there are two ways to fix the specimens to the machine depending on the type of test specimen´s surface:

a) Machined samples: if they have different measurements, they must incorporate a transition curve between the grippers and the parallel length.

In the case of initial parallel length (Lc), or in no transition curve case, the length between the clamps must be always bigger than the initial free calibration length. The test specimen´s extremities can adapted to the clamping devices of the testing machine.

b) Non-machined samples: distance between the clamps and the calibration marks have a reasonable measure, so the free length between clamps must be enough.

Large thickness tests use cylindrical specimens and thin thickness tests use specimens with flat sections.

6.1.4.2.2. Marking of the initial calibration length L_0.

Each calibration extremity should be marked with marks or strokes. Any type of notches are not allow, as they would influence a possible premature fracture.

Marks should have an accuracy of ± 1%. When the test uses proportional test specimens, the value from the initial length between points can round the nearest multiple of 5 mm. In the case of a

10% lower measurement difference between the marked length and the calculated length of L_o, length multiple of 5 mm it uses.

If L_c, the length of the calibrated part, is bigger than the initial length between points, several points must mark the limit of different lengths between the overlap points.

6.1.4.2.3. Calibration of the load measuring system of the test machine.

There are four classes of test machines according to the maximum values of the applied ranges and their calibration procedures:

The following table shows, as an example, the characteristic values of the force measurement system for each class of the machine scale:

Table 6-2: Characteristic values of the Force system value. Handmade and ISO 7500-1, 2015, pág. 17

Scale level of the device	**Maximun allowed value %**				
	Relative error				**Relative Resolution**
	Indication	**Repetitivity**	**Reversibility**	**zero**	
	q	*b*	*v*	f_0	*a*
0,5	± 0,5	0,5	± 0,75	± 0,05	0,25
1	±1,0	1,0	± 1,5	± 0,1	0,5
2	± 2,0	2,0	± 3,0	± 0,2	1,0
3	± 3,0	3,0	± 4,5	± 0,3	1,5

Being:

- *q:* Relative error of the force measurement indication system of the Test machine (%)
- b: Relative error of the force repeatability measurement system of the test machine (%)
- v: Relative error of the force reversibility measurement system of the test machine (%).
- f0: Relative zero error of the force measuring test machine system (%).
- a: Relative strength resolution indicator of the test machine (%).

6.1.5. Testing rate.

Determination of the ductile and test resistors

1. Superior ductile resistance (RdH): it is the stress value when the first reduction of load is observed. Separation rate of the machine´s crossheads must be as constant as possible

from the elastic range to the superior ductile resistance; in addition, the values must remain into the stress range.

Table 6-3. Stress rate (ISO- 6892-1)

Modulus of elasticity of the material *E* MPa	Stress rate $\dot{R}$ MPa s^{-1}	
	min.	**max.**
<150 000	2	20
$\geq$150 000	6	60

2. Lower ductile resistance (RdL): minimum value of stress during plastic ductility.

In order to determine the lower ductile resistance, the stress rate during ductility of the parallel length of the test specimen must be between 0.00025s-1 and 0.0002 5 s-1, keeping the stress rate in the parallel length as constant as possible. The maximum values in the table above should not never exceed the stress rate in the elastic range.

3. Upper and lower ductile resistance: If it is possible the calculation of both values at same test, the conditions for determining the lower ductile resistance are in section 1.
4. Test resistance (non-proportional stress) defined as the stress at which a non-proportional extension is equal to a specified percentage of the calibration length of the extensimeter, and total resistance (total extension), defined as the stress at which the total extension is equal to the specified percentage of the extensimeter calibration length, (Rp and Rt). Working in the plastic range, stress rate should not exceed 0.002 5 s-1 until test resistance.
5. Tensile strength (Rm): the maximum load stress. This value is the next step after the ductility test strength properties determination. Test rate increases in a lower value of 0.008 s- 1.
6. Only for the tensile strength measurement in the test, the rate must not exceed 0.008s-1 during all the time.

Determination of the percentage elongation (L-L0) after the fracture (A): using a measuring device with enough resolution and precision, the two fractured pieces of the sample joins with aligned axes.

Determination of the total percentage elongation at the maximum load (Agt): determination of the stress performs with the use of an extensimeter at the maximum load-stress.

$$A_{gt} = \frac{\Delta l_m}{L_e} \cdot 100 \quad (7)$$

Determination of the test Resistance, non-proportional extension (Rp): Obtained from the load-extension diagram. The total load corresponding to the test resistance divided between Initial cross section of the test specimen is obtained with parallel line to the straight part of the curve with a 0.2% distance placed to obtain the crossing with the curve.

Determination of the test resistance, total extension (*Rt*): It is determined with the use of a parallel line to the axis of ordinates (axis of the load) at an equivalent distance to the total percentage extension described in the load-extension diagram. Analogously to the previous section, the crossing point with the curve and the division between the initial cross section of the test specimen determinates the result.

Verification method of the remaining resistance (*Rr*): Removing an applied force in the sample for 10 or 12 seconds, with the same value of to the specific stress, and checking that the remaining extension or elongation is lower than the specified percentage for the initial calibration length performs the verification.

Determination of the percentage reduction of area (*Z*): Test fragments are carefully recomposed and their axes are aligned. The area of the minimum cross section after the fracture, Su, should be measured with an accuracy of ± 2%. Percentage of the initial percentage reduction in area defines the difference between S_u and S_0.

6.1.6. Different Procedures.

Tensile test can use a different variety of Tensile Testing Machines.

For tensile tests with computer controlled testing machines, the test should provide analogical signals not addressed by the software results. If analogical results are not possible, the manufacturer of the machine should provide untreated digital data with information about how it has been obtained and processed by the software. This data should be in basic units of the international system with the relationship of the force, the elongation, the speed of separation of the clamps, the time and the dimensions of the specimen (ISO 6892-1, 2016, pág. 46).

Fig. 6.6. Universal testing device Ibertest IBMU4 (https://goo.gl/HKg162)

In order to help the development of the test by the Laboratory personnel, they will use the Manual of Instructions written for this test, as well as any other recommendation made by the equipment manufacturer.

*6.1.7. Test report***.**

The report of the testing results must contain:

- Identification of the test sample
- Specified material
- Type of test specimen
- Reference to the used standard.
- Test results, including:

  - Resistance values in MPa.
  - Values of percentage elongation to 0.5%
  - Percentage reduction of the area to 1%

6.2. Charpy pendulum impact test.

Although static tensile tests allow the knowledge of metal resistance and deformability when progressive effort acts in test specimen, these properties vary depending on the nature of the loads and the working conditions.

In many cases the factors that affect the destruction of the piece must be considered according to the practical use of the mechanism or structure to which it belongs. If the metal experiences successive dynamic stresses (fatigue) or static stresses at high temperatures (creep), the origin of the fracture is the decreasing of the resistance.

In contrast, some failures happen in elements with instantaneous exterior effects or variations of loads when they do not accept plastic deformations, even in those metals considered as ductile, so, the analysis of metal behavior by shock or impact experiences is important.

6.7. Fatigue (https://goo.gl/KAThkT)

The static tensile test (Appendix I) offers correct values of the metal ductility, but it is not necessary to determine its degree of tenacity or fragility under variable working conditions. On the other hand, the shocking test determines the material capacity to absorb instantaneous loads by cracking the material after an impact in a certain area; this capacity is resilience.

Resilience does not offer a definite property of the material but it constitutes a comparative index of its plasticity respect to other tests in identical conditions, this is the reason to control its different influential factors.

Using this test, verification of a machine or structure failure due to fragility under the conditions imposed by its use, especially when the pieces experience stress concentration, by abrupt section changes, incorrect machining, filleting, etc., or verification of the correct thermal treatment of the tested material are possible.

6.2.1. Object.

Determination of the energy absorbed performing a test of bending by impact of metallic materials is the main objective of this procedure. Also, studying how temperature influences the tenacity, classifying the type of test specimen fracture after the impact and determining the amount of energy dissipated in the moment of the pendulum impact are additional objectives. Shock resistance is a measure of the material tenacity; it defines as the absorption energy ability before fracture appearance. High value of static tensile strength or breaking resistance does not necessarily indicate the working capacity of this material with acting loads.

Fig. 6.8. Charpy testing. (https://goo.gl/GFyRyF)

Although there are two methods of testing, the Charpy method and the Izo method, originally from Anglo-Saxon countries, this project will describe the first one because its use is more extended (Kirschenbaum, 2006, page 45).

For certain materials and certain specific applications, the present test has specific standards or particular conditions as ISO standard (ISO 148-1:2016).

6.2.2. Scope.

Impact tests determine the ability of a material to endure instantaneously applied loads. Results are only used for comparative purposes with other identical conditions tests.

Test performances by two types of test specimens with different types of notch: U- notch or V-notch. Both test specimens, called Charpy test specimens, experience the direct impact of a mass-pendulum on a specified area, notched zone, and the energy absorption of the piece in the impact is calculated.

The Charpy pendulum test has industrially uses as a high performance test to establish pass or fail policies due to specific characteristics in materials necesities.

Since the breaking energy in the flexion due to the impact of certain metallic materials is different according to the temperature, test performs at a specific temperature.

6.2.2.1. Generalities.

Fracture of test specimen, notched at its midpoint and supported at both ends, by an impact of an oscillating pendulum-mass under certain previously established conditions performs the Flexion Test by shocking on Charpy test specimen.

Charpy pendulum method transforms the initially potential energy of the hammer, when it remains in an elevated position, in kinetic energy and later in the cracking energy of the test specimen.

The fracture energy of the specimen creation appears by the variation between the initial and final position of the pendulum before the impact and after the impact.

Fig. 6.9. Charpy pendulus cracked specimen (Ibertest)

The energy absorption in the break derives from the height difference of the pendulum before and after the impact:

$$\Delta E = m \cdot g \cdot \Delta h \qquad (8)$$

Where:

- m: mass of the piece.
- g: gravity´s acceleration.

The amount of absorbed energy before the fracture conditions impact tenacity, reaching higher levels with higher energy. Impact tenacity can be calculated as:

$$\rho = \frac{E}{S} \tag{9}$$

Where:

- E: Energy absorbed by the fracture.
- S: Section of the test specimen in the place of the notch.

6.2.2.2. Types of fracture in the material.

In the test material, different types of fracture can perform:

a) Ductile fracture: in this type of fracture, the test specimen has a previous plastic deformation characterized and distinguished by a change in the geometrical structure of the specimen at the breaking point. This produces a no coincidental joining of the surfaces when the fracture of the two pieces of the broken specimen join again.

From a microstructural point of view, the plastic deformation occurs by sliding dislocations in its sliding planes and, if the number of sliding dislocations turns out sufficiently high, the microscopic shape of the specimen changes.

b) Fragile fracture: in this type of fracture, the specimen has a cleanly fracture without microscopic geometry change. By joining test specimen fragments, test specimen has the same geometrical shape before the Charpy test.

From a microstructural level, de-cohesion of the crystalline network occurs. Energy used in the fracture it uses now in the formation of new junction grain surface. This process requires less energy than plastic deformation.

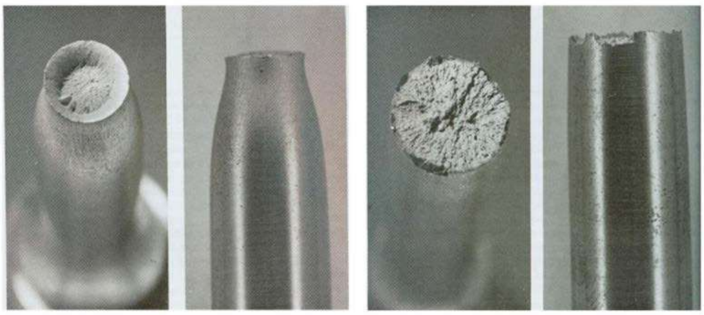


Fig. 6.10. Fracture ductile and brittle fracture (https://goo.gl/NFXAku)

6.2.3. Test procedure.

6.2.3.1. Required equipment.

6.2.3.1.1. Specimens.

Test specimen has 55 mm length with a square cross section of 10 mm on each side of standardized dimensions.

If the standard test specimen material is other than the material under test, one of the specimens must be replaced by one with a reduced section of thickness of 7.5 mm, 2.5 mm, 5 mm or less.

One possible solution of prior machining to heat treatment problem is a surface machining of test specimen, including the realization of the notch.

6.2.3.1.1.1. Geometry of the notch.

The most important physical factor of the specimen will be the notch. The broaching machine creates the notch at the midpoint of test specimen length and it has two models:

a) V- shape of 45º, 2mm deep with a background radius of the notch of 0.25 mm.

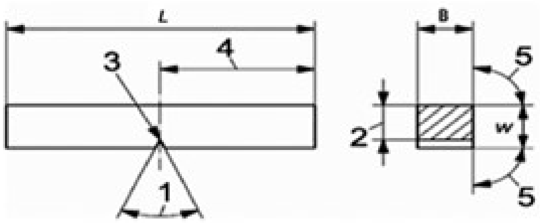


Fig. 6.11. The V notch geometry (ISO 148-1:2016, pág. 18)

b) U-shaped of notch 5 mm deep, with a background radius of the notch of 1mm.

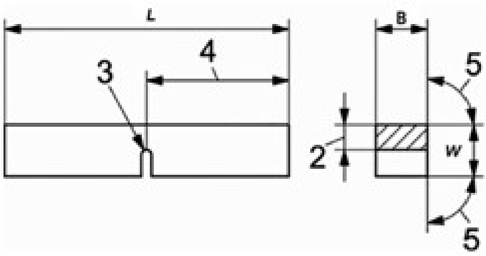


Fig. 6.12. The U notch geometry. (ISO 148-1:2016 , pág. 18)

The notch should not have machining marks that could affect the energy absorbed, especially in the rounded area of the notch bottom. The symmetry plane of the notch must be perpendicular to the longitudinal axis of the test specimen.

6.2.3.1.1.2. Marking of the specimens.

Any face with no contact with the supports, the anvils or the firing pin of the machine can have the marks of the test specimen and the marking process will not have effects in the energy absorption due to plastic deformation and surface discontinuities.

6.2.3.1.1.3. Tolerance of the specimens.

The tolerances on the test specimen's measurements are established in the following table:

Table 6-4. Applied Tolerances to the specific dimensions of test specimen. From ISO and handmade (ISO 148-1:2016 pág. 19)

Dimensions	**Symbol and Number**	**Test Specimen V-shape of notch**			**Test Specimen U-shape of notch**		
		Nominal Dimension	**Tolerance and machining process**		**Nominal Dimension**	**Tolerance and machining process**	
				Tolerance Type[a]			**Tolerance Typea**
Lenght	L	55 mm	± 0,60 mm	js15	55 mm	± 60 mm	js15
Width	W	10 mm	± 0,075 mm	js 12	10 mm	± 0,11 mm	js 13
Thickness	B	10 mm	± 0,11 mm	js 13	10 mm	± 0,11 mm	js 13
Standard test Specimen Test Specimen with reduced section Test Specimen with reduced section Test Specimen with reduced section		10 mm 7,5 mm 5 mm 2,5 mm	± 0,11 mm ± 0,11 mm ± 0,06 mm ± 0,05 mm	js 13 js 13 js 12 js 12	10 mm 7,5 mm 5 mm -	± 0,11 mm ± 0,11 mm ± 0,06 mm .	js 13 - - -
Angle of the notch	1	45º	± 2º	-	-	-	-
Ligament	2	8 mm	± 0,075 mm	js 12	5 mm	± 0,09 mm	js 13
Notch radiius	3	0,25 mm	± 0,025 mm	-	1 mm	± 0,07 mm	Js 12
Position of the notch (centered)	4	27,5 mm	± 0,422 mm[d]	js15	27,5 mm	± 0.42 mm[d]	Js 15
Angle between the plane of symmetry of the notch and the longitudinal axis of the test piece		90º	± 2º	-	90º	±2º	-

Angle between the adjacent longitudinal planes of the specimen	5	90º	± 2º	-	90º	±2º	-
*Surface roughness l^b^*	NA	< 5µm			< 5µm		

a According to ISO Standart 286-1.
b The specimens should have a surface roughness better than Ra 5 µm, except at the ends.
c If a different thickness (2 mm or 3 mm) is specified, tolerances must also be specified.
d For machines that have automatic positioning of the specimen, it is recommended a tolerance of ± 0.165 mm instead of ± 0.42 mm

6.2.3.1.1.4. Test Device.

In the performance of a standardized test, the machine conditions of 300 ± 10J correspond to a nominal energy or the available energy possessed by the machine using standard test pieces.

Energy absorption designated in these standard conditions as:

- KU for specimens with U notches
- KV for specimens with V-notch

For any other type than the standardized width of the test specimen Test Results variation is possible.

6.2.3.1.1.4.1. Striker.

The most important part of the test machine is the so-called striker. Same tests with different strikers models provide different results in the performance of each test, so the laboratory personnel must specified in the report the use of 2-mm or an 8-mm striker ´s geometry. The striker radius indication performs by a subscript of the following table:

Table 6-5. Symbol and unit designation. Handmade and (ISO 148-1:2016, pág. 9

KV_2	V-Notch test specimen with 2mm Striker
KV_8	V-Notch test specimen with 8mm Striker
KU_2	U-Notch test specimen with 2mm Striker
KU_8	U-Notch test specimen with 8mm Striker

6.2.4. Test Report.

The operation mechanism of the test performs with the strike of the pendulum in one curved movement. Test specimen breaks due to the energy transfer from the pendulum.

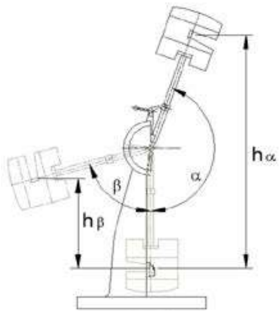


Fig. 6.13. Charpy testing (https://goo.gl/8tQAhF).

1. Placement of the test piece. The test piece place is on the anvils or supports of the test machine, so symmetry plane of notch does not separate more than 0.5 mm from the symmetry plane of the same. The edge of the hammer-pendulum should strike the opposite face of the notch.

2. Impact on the piece. By actuating the mechanism that holds the hammer-pendulum in its initial elevated position, it releases and hits the piece on the opposite side of the notch by the gravity effect.

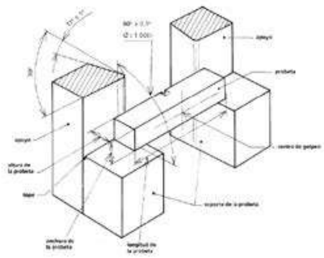


Fig. 6.14. Scheme of the specimen and the support brackets

6.2.4.1. Parameters to be taken into account for the test.

The height of the pendulum mass controls the generated impact energy using a different position of the fixing system in the pendulum installation.

6.2.4.1.1. Temperature.

- If the product´s standard does not specify another test temperature, it will perform at 23 ± 5 ºC.
- At a different temperature than room´s temperature, it will be between 0º and -60ºC
- If the costumer specifies a certain temperature, new temperature will have a tolerance of ± 2ºC.

Conditioning the test specimen at a different temperature from the normalized test performs with the immersion of test specimen in a medium that allows temperature control following the preparation conditions as established in ISO Standard 148-1 for a estimated period of time to reach the specific temperature

In these different temperatures conditions, others than normalized temperatures, test specimen must break in new conditions before 5s after removing it from the conditioning medium. The exception is possible if the difference between the ambient or instrument temperature and the temperature of the specimen is less than 25 ° C; in this case the transfer time of the test specimen must be less than 10 s.

6.2.4.1.2. Incomplete rupture of the specimen.

In the case where deformation of test specimen performs but a crack is not achieve, the absorption energy can not be determined.

In this case, an indication will be necessary in the report with a description of the applied energy for the non-broken test piece.

6.2.4.1.3. Strangling of the specimen.

In the case where a specimen cannot be remove from the initial positioning site after performing the test; the result is not going to be useful.

The pertinent indication will be made in the report for the subsequent verification of the machine in terms of damages that may have affected its calibration status.

6.2.5. Different Procedures.

In order to help the development of the Charpy test by the Laboratory personnel, they will use the Manual of Instructions written for this test, as well as any other recommendation made by the equipment manufacturer.

Fig. 6.15. Instron® Manual (https://goo.gl/xHjyjh)

6.2.6. Test report.

The obtained report must contain at least the next information:

- Reference to the standard, in this case ISO 148-1 2016.
- Type and measurements of the test specimen.
- Type of striker´s geometry and radius.
- Identification of the test specimen (type of material, number of casting, etc.)
- The direction of the sample and orientation of the test specimen.
- Nominal energy of the pendulum.
- Temperature at which the test is performed.
- The energy absorbed by the test specimen.

7. FINAL CONCLUSIONS OF THE PROJECT.

Fig. 7.1. Visual inspection ((Martínez Leal, 2016, pág. 80)

After the descriptions of quality concepts and its company's improvement implication analysis, the small study of the state of the art of the testing laboratories, the design of the laboratory, the description of different types of tests, non-destructive and destructive, and calculation of the equipment costs (appendix xx) the cost evaluation of the tests is necessary in order to determine if a manufactory company can afford its own testing laboratory or outsource these tests (outsourcing) to improve its finances and the quality of its products.

The laboratory costs of quality certification are not calculated as it has already explained in various points of this Project. However, in the consulted bibliography (ENAC[5]), link is approximately 6000 euros and an additional annual costs of maintaining the accreditation of 2000 euros.

7.1. Viability of the project for a company.

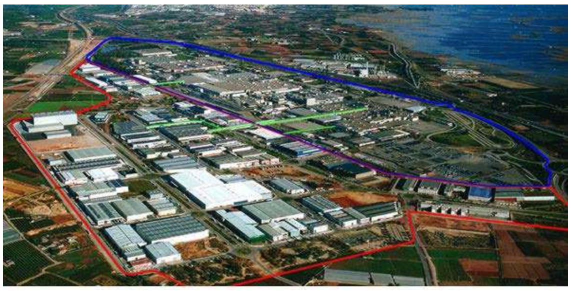


Fig. 7.2. Business Park Juan Carlos I and Ford factory. Valencia Spain. (https://goo.gl/RTyaX9).

The main assumption is a company, whose commercial name is Valencia Products, which manufactures a certain number of components in the automotive auxiliary industry.

The managers of the company want an expansion of their design and manufacture gears production and the performance of the quality control of them. They are considering two ways of quality control: the profitability of a laboratory of own testing or the test performance in an external laboratory.

This company, Valencia Products, requires a report of its own testing laboratory or external laboratories economic profitability based on the following requirements:

[5] https://goo.gl/dw1r8H

1. Control of basic material:

   a) Tensile test to know the mechanical properties (elongation, elastic limit or breaking load of the material).
   b) Charpy pendulum test to know the measure of tenacity.
   c) Hardness test.
   d) Detection of internal defects: Ultrasonic Test.

2. Control of the finished product:

   a. Surface defects: Visual Inspection test.
   b. Crack detection: Penetrating Liquids test.
   c. Hardness.

The volume of production for this Project is constant and uniform over a year.

Given the size of the factory, the manufacturing technology acquired and the number of employees, the production level is set at a number of 20000 gears in batches of 200 per month, which means 240000 gears per year[6].

The raw material for the manufacture is steel, in form of cylindrical shafts with different diameters divided in 25 batches per month[7] including all used diameters.

Prices of the equipment have already been calculated in the Appendix II. The managers of the company informs that the factory has spaces for the installation of the laboratory, so space of the laboratory should not be added in the final cost.

Also the number of performed tests influences the selection of the laboratory.

Table 7-1. Steel batches

Steel batches	
Month	**Year**
25	300

[6] https://goo.gl/oyr41h

[7] In 2011 steel consumption in Poland was 11 millions of tons (Economic and Commercial Office of the Embassy of Spain in Warsaw, 2012)

Table 7-2. Gears Production

Product[8] (units)		Batches	
Month	**Year**	**Month**	**Year**
20000	240000	200	2400

1. Steel batches decides the control of the raw material.
2. Gears batches decides the control of the final product.

7.1.1. Number of pieces to quality inspection and quality levels.

Obviously, the manufactured product, gears, must have an Acceptable Quality Level (AQL). The UNE 66020-1, 2001 sampling standards will be applied, and the AQL is the quality level that represents the worst tolerable average of the process when a continuous series of batches are sending for sampling acceptance. Normal type of inspection is going to be performed.

In order to determine the number of pieces tested in each of the two cases and the economic cost of these tests, a simple sampling is chosen and two tables are used (UNE 66020-1 (ISO 2859-1), 2001):

Table 7.3 depends on the inspection levels and batch size and gives the entry code in the second table (Table 7.4.). This second table, using the size of the previous obtained code, determines the size sample, the values of the acceptance numbers (maximum number of defects allowed in the sample) and the rejection number (number of defects that if it is reached suspends the inspection and leads to reject the lot), for each AQL.

7.1.1.1. Steel batches.

For a typical sampling of a normal level (II) inspection on a batch of 25 units, from Table 2.4 is deduced that the assigned code is C. With this code, Table 2.5 indicates that a sample must have 5 elements.

[8] Number of different types of gears.

Table 7-3. Sample size codes according to UNE 66020-I

Tamaño		Niveles de inspección especiales				Niveles de inspección generales		
		S1	S2	S3	S4	I	II	III
2	8	A	A	A	A	A	A	B
9	15	A	A	A	A	A	B	C
16	25	A	A	B	B	B	C	D
26	50	A	B	B	C	C	D	E
51	90	B	B	C	C	C	E	F
91	150	B	B	C	D	D	F	G
151	280	B	C	D	E	E	G	H
281	500	B	C	D	E	F	H	J
501	1200	C	C	E	F	G	J	K
1201	3200	C	D	E	G	H	K	L
3201	10000	C	D	F	G	J	L	M
10001	35000	C	D	F	H	K	M	N
35001	150000	D	E	G	J	L	N	P
150001	500000	D	E	G	J	M	P	Q
más de	500001	D	E	E	J	N	Q	R

Table 7-4. Sample Sizes (Normal Inspection)

Letra código tamaño de la muestra	Tamaño de la muestra	Nivel de calidad aceptable (NCA), en porcentaje de elementos no conformes y no conformidades por 100 unidades (inspección normal)																									
		0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑
E	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑	↑
F	20	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑
G	32	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑
H	50	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑
J	80	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	125	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	200	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	315	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	500	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	800	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	1 250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	2 000	↑	↑	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

Table 7-5. Batches of steel and examined components

Batches of steel and examined components			
Monthly Batches	**Monthly examined components**	**Annual Batches**	**Annual examined components**
25	5	300	60

7.1.1.2. Gears batches.

For a typical sampling of a normal level (II) inspection on a batch of 200 units, from Table 7.6. is deduced that the assigned code is G. With this code, Table 7.7 indicates that a sample must have 32 elements.

Table 7-6. Sample size codes according to UNE 66020-I

Tamaño		Niveles de inspección especiales				Niveles de inspección generales		
		S1	S2	S3	S4	I	II	III
2	8	A	A	A	A	A	A	B
9	15	A	A	A	A	A	B	C
16	25	A	A	B	B	B	C	D
26	50	A	B	B	C	C	D	E
51	90	B	B	C	C	C	E	F
91	150	B	B	C	D	D	F	G
151	280	B	C	D	E	E	G	H
281	500	B	C	D	E	F	H	J
501	1200	C	C	E	F	G	J	K
1201	3200	C	D	E	G	H	K	L
3201	10000	C	D	F	G	J	L	M
10001	35000	C	D	F	H	K	M	N
35001	150000	D	E	G	J	L	N	P
150001	500000	D	E	G	J	M	P	Q
más de	500001	D	E	E	J	N	Q	R

Table 7-7. Sample Sizes (Normal Inspection)

Letra código tamaño de la muestra	Tamaño de la muestra	Nivel de calidad aceptable (NCA), en porcentaje de elementos no conformes y no conformidades por 100 unidades (inspección normal)																									
		0,010	0,015	0,025	0,040	0,065	0,10	0,15	0,25	0,40	0,65	1,0	1,5	2,5	4,0	6,5	10	15	25	40	65	100	150	250	400	650	1 000
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2														↓	0 1		↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3													↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5												↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8											↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	
E	13										↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑		
F	20									↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑			
G	32								↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑						
H	50							↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑							
J	80						↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑								
K	125					↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑									
L	200				↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑										
M	315			↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑											
N	500		↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑												
P	800	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑													
Q	1 250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑														
R	2 000	↑		1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑															

Table 7-8. Batches of gears and examined components

Batches of gears and examined components			
Monthly Batches	**Monthly examined components**	**Annual Batches**	**Annual examined components**
200	32	300	384

7.1.2. Calculation of test costs in external laboratories.

In order to continue with the study of the economic viability of test laboratory, external laboratory cost is calculated. Knowing the marking fees and consulted various laboratories:

7.1.2.1. Control of raw material (Batches of steel) and the finished product (Batches of gears.).

For the analysis of the raw material, four tests are selected to control the material.

Table 7-9. Costs of Raw material test and their source pages.

Test type	Cost €	Source
Complete tensile test [9]:	72,46	https://goo.gl/3WHfAm
Pendulum impact test of 300 J	8,05	https://goo.gl/3WHfAm
Brinell or Vickers Hardness	16,10	https://goo.gl/3WHfAm
Ultrasonic test	20,60	https://goo.gl/LkfTmZ

In the final steps of production, the raw material has been transformed and, before the arrival of the product to the final production step, another control analysis must to be done.

For this analysis, three test are selected:

[9] Smelting or machining of test species 48, 31 € hour technical.

Table 7-10. Costs of finished product test and their source pages

Test type	Cost €	Source
Visual test	50,07	https://goo.gl/ULwuGD
Penetrant Liquid test	50,07	https://goo.gl/ULwuGD
Ultrasonic test	20,60	https://goo.gl/LkfTmZ

Table 7-11. Costs of performing tests due to the ratio of analysis.

Test type	Cost	Raw material	Finished material	Total Tests	Monthly Cost	Annual Cost
Complete tensile test	72,46	5	0	5	362,3	4347,6
Pendulum impact test of 300 J	8,05	5	0	5	40,25	483
Brinell or Vickers Hardness	16,1	0	32	32	515,2	6182,4
Ultrasonic test	20,6	5	32	37	762,2	9146,4
Visual test	50,07	0	32	32	1602,24	19226,88
Penetrant Liquid test	50,07	5	32	37	1852,59	22231,08
SUBTOTAL				**148**	**5134,78**	**61617,36**
TOTAL (15%[10])					5904,997	**70859,964**
Average Monthly cost for piece **39,90 €**						

Above table shows the price of each one of selected tests, as well as the average cost of the test/piece equal to 39, 90€.

[10] Management costs, technical assistance costs, opening of file costs and preparation of the report costs, which increases the total costs by 15% must added to these costs.

7.2. Cost analysis in own test.

In this part of the project and example of laboratory design is going to be developed.

First assumption is going to be the hypothetical company, called Valencia Products, who plays the role of customer.

Second assumption is the physical place for the test laboratory. Valencia Products Company has a factory so it is assumed that the facilities already exist. Building has capacity for the design laboratory itself and for warehouses, with all the basic systems as wiring systems, water systems, etc.

Third assumption relates with the company´s modulus costs in administration, fiscally, cleaning, water and electricity system, etc. Costs represent 9.25% of the calculated final costs.

7.2.1. Costs of Laboratory Personnel.

The same person will realize the role of Technical Director and Headmaster of Quality.

In the personnel stuff, there will be two laboratory assistants with a technician skills and trained in Level II of NDT, for the tests performed in the laboratory. Also they will perform administrative tasks.

Table 7-12. Personnel cost

Role	Monthly salary (12month)€ [11]	Annual salary	Working hours in a month[12]	Working hours in a year[13]	Cost of a Monthly Hour €
Technical Director, Headmaster of Quality [14]	2500	30000[15]	144	1736	17,36
NDT Technic Level II and administrative[16]	1750	21000	144	1736	12,15
Total	**4250**	**51000**	**288**	**3472**	**29,51**

[11] Net Salary

[12] Taking into account 12 months (bottom note)

[13] 217 work days in a year of 8-hour per day (without weekends, holidays and holidays)

[14]He has more than one year of experience in Level III, as well as a degree as an industrial engineer.

[15] Industrial junior engineer (https://goo.gl/8jmDMS)

[16] More tan one year of experience.

7.2.2.1. Previously considerations

The objective of this project is not to perform an accounting study of the manufacturing cost of gears. Neither is it not going to appear the additional unit cost that consumer needs to increase in their products due to the quality tests; but it is necessary some economical definitions to perform the economic profitability of the laboratory.

In the first step of production design, main characteristics of the production process as uninterrupted, continuous and uniform production, as well as with general average costs, are asumed.

Expenditure is a concept of financial accounting and it refers to the operations relationship with goods and services acquisitions for consumption, as well as in the production process or as for other people, depending on the activity of the company (primary, industrial, commercial or service) (Aragón Izquierdo, 2011) .

In addition, expenditure is a concept also related to legislation accounting, since it is in financial accounting where this term is widely used.

The cost is the measure and the value of the necessary material consumptions for the productive activity. Material consumptions are called inputs consumptions, which produce some outputs products in the productive activity.

In the investment, one part of the expense is not consumed in the economic process, so is still maintained in the company to be used in subsequent exercises (for example, buildings, facilities or machinery). However, in each fiscal year, it is necessary to calculate the part of the investments that are actually consumed in the productive process (amortization).

Amortization is the accounting reflex of depreciation. This operation determines the decrease of the economic value, or depreciation, suffered by the fixed assets during the fiscal year.

In this project, it is use the so-called constant amortization type of amortization. This amortization consists of applying a constant amortization fee, equal every year. Here, the calculation of the useful life of the asset performs with the next formula:

$$Annual\ quota = \frac{Amortization\ base}{Useful\ life} = \frac{Acquisition\ price - Residual\ value}{Useful\ life}$$

For each device of the equipment, a useful life and a residual value have been calculated at the end of their use. (Table 7-13).

7.2.2.2. Equipment costs[17].

The equipment is divided into two parts, basic equipment and special equipment

The basic equipment is all the material use in a usually way; screwdrivers, hammers, etc. Final cost of these materials can be included in the common expenses of the company.

Total investment of Basic Equipment is supposed as 2593, 06 € (Appendix II).

The special equipment includes those machines and elements specifically designed for testing procedures.

The total investment of Special Equipment is 112639, 3 €.

Investment estimation has an amortization period reflected in the following tables:

Table 7-13. Amortization of each device.

Equipment	Purchase price €	Useful life (years)	Residual value €	Constant amortization €
Universal testing machine	91361	10	25000	6636,1
Pendulum impact test	48000	10	12000	3600
Durometer	1770	5	300	294
Boroscope	6474,9	5	1500	994,98
Visual Test	4821	5	1000	764,2

Penetrant liquids have a special operation characteristic; with each quit of penetrant liquids five tests can be performed.

7.2.3. Costs of Testing procedures

To quantify the price of performing tests, two assumptions must be made:

[17] Equipment will calibrated every 2 years or when any anomaly appears in them. An accredited laboratory or national official institute will be in charge.

- Fixed costs of the laboratory personnel.
- Fixed costs of the equipment.

Fixed personnel costs are 4250 euros per month (Table 7-12). The two hired people perform a monthly salary of 144 total hours each one, with an average price of 29, 51 euros per hour.

The equipment costs have their description in the previous section (Table 7-11)

On the other hand, before the general analysis of the testing cost, total time is quantified in the following table:

Table 7-14.

Testing Type	Time	Raw material	Finished product	Total Tests	Total Time
Hardness	0,5	0	32	32	16
Tensile test	0,5	5	0	5	2,5
Ultrasound	2	5	32	37	64
Visual test	0,5	0	32	32	16
Penetrant liquid	1	5	32	37	37
Charpy Pendulum	1	5	0	5	5
Total employee time				**148**	**140,5**

Main conclusion of this table is that used time for the tests must be lower than the monthly workingday of the two technicians in charge of them.

Knowing the fixed monthly costs (salary + amortization + general expenses) and the number of pieces tested monthly (148), deduction of cost per unit is:

Table 7-15.

Personnel Salary €	4250	
Montly amortization costs € [18]	1333,32	
General Costs (9, 5%)	1460,	
Pieces	148	
Unity testing cost		38,58

[18] Including Penetrant Liquid tests

7.3. Sum up Conclusions.

Due to the above calculations, there is the following average costs per tested piece (independently of the piece type and test):

- External laboratory; *39,90 €/pieza*
- Own laboratory: *38,58 €/pieza*

To sum up, in the theoretical case it is more profitable for the copany to own a personal laboratory.

In addition, there is a ratio of free working hours, equal to the monthly workday of a technician. This possiblility can be used to increase the number of tests until equalice the number of hours.

7.3.1. Other considerations:

As an additional value, the use of internal laboratory means, despite the initial investment, a reduction in the costs of the management system by not having to depend on external companys. Also, test Laboratory increases the competitiveness of the company and it could be associated with a product research and development of new products.

Future work will involve the possibility of a stately, regionally or European grant for the company.

European Union offers to the industry, for the creation of employment, promotion of competitiveness, training of researchers and research to the company different types of grants.[19]

Fundusze Europejskie
na innowacje

Fig. 7.3. https://goo.gl/HPmRvF

[19] https://goo.gl/mW9BwC

BIBLIOGRAPHY

1. AEND. (n.d.). *END. Magnetic partcles. Level II. ISB: 84-95428-72-5.* Asociación Española de Ensayos No Destructivos.
2. Aragón Izquierdo, P. (2011). *Cost analysis carried out on the tests carried out in concrete and steel building control laboratories.* Polititechni University Valencia.
3. BAM. (n.d.). *Bundesanstalt ür Materialsforshung und-prüfung*. Retrieved 4 12, 2018, from https://www.bam.de/Navigation/EN/About-us/Experience-BAM/BAM-History/bam-history.html
4. Benitez Herreros, J. A. (2011). *Study of the evolution of the speed of ultrasound in varying degrees of moisture concrete specimens.* Universidad Politécnica de Madrid.
5. Besterfield, D. H. (2009). *Quality Control. ISBN: 10: 0135000955* (8ª ed.). Prentice Hall.
6. Callister, W. D. (1995). *Materials Sciencie and Engineering. An Introduction. ISBN: 9788429172539.* Spain: Editorial Revente.
7. Castillo Niño, A. (2006). Design and implementation of a process and the system of quality management for inspection by ultrasonic carbon fiber parts. Spain: Cádiz University.
8. CEN. (n.d.). *European Committee for Standardization.* Retrieved 4 18, 2018, from A CEN Workshop Agreement (CWA) is a document published by CEN in at least one of the CEN three official languages.
9. Chang Nieto, G., & Pérez Avendaño, D. (2017). *Laboratory guides. Material resistance. ISBN: 978-9583746-071-1.* Colombia: Unimagdalena.
10. Crosby, P. B. (1996). *Quality is free: The Art of Making Quality Certain.* McGraw-Hill.
11. De máquinas y herramientas. (n.d.). *http://www.demaquinasyherramientas.com*. Retrieved 4 29, 2018, from http://www.demaquinasyherramientas.com/herramientas-de-medicion/boroscopio
12. Dudley, D. W. (n.d.). *Handbook of practical Gear Design.* Technomic Publishing.co.inc.
13. *Encyclopedia Britannica*. (n.d.). Retrieved 3 22, 2018, from https://www.britannica.com: https://www.britannica.com/technology/materials-testing
14. EU-Japan Centre. (n.d.). *www.eu-japan.eu*. Retrieved 4 20, 2018, from www.eu-japan.eu: https://www.eu-japan.eu/government-procurement/tendering-process/japan-industrial-standards-jis
15. Ferrando Sánchez, M., & Granero Castro, J. (2008). *Calidad Total. Modelo EFQM de excelencia. ISBN: 9788496743601* (2ª Ed. ed.). FC Editorial Confemetal.
16. Ferrer Giménez, C., & Amigó Borrás, V. (2003). *Materials technology. ISBN: 84-9705-363-X.* Valencia, Spain: Polytechnic University of Valencia.
17. Fundiciones_Gómez. (n.d.). *http://www.fundicionesgomez.com*. Retrieved 4 12, 2018, from http://www.fundicionesgomez.com/epages/ea7741.sf/es_ES/?ObjectPath=/Shops/ea7741/Categories/%22Probetas%20de%20Laboratorio%22

18. Gómez, F. (n.d.). *http://www.fundicionesgomez.com*. Retrieved 4 12, 2018, from http://www.fundicionesgomez.com/epages/ea7741.sf/es_ES/?ObjectPath=/Shops/ea7741/Categories/%22Probetas%20de%20Laboratorio%22
19. Hansen, B. L., & Ghare, P. M. (1987). *Quality Control and Application.* Madrid: Diaz Santos S.A.
20. Hernández Guzmán, A., Fabela Gallegos, M. d., & Martínez Madrid, M. (2001). *Quality and accreditation systems applied to testing laboratories.* Instituto Mexicano del Transporte, Secretariat of communications and transport, México, DF. Retrieved 3 15, 2018
21. *https://sjp.pwn.pl/*. (n.d.). Retrieved 3 17, 2018, from https://sjp.pwn.pl/
22. Ishikawa, K. (1986). *What is total quality control? The japanese way.*
23. ISO 13018. (2016). *Non-destructive testing. Visual testing. General principles.* AENOR (European Standard).
24. ISO 1330-2. (1999). *Non destructive testing. Terminology. Part 2: Terms common to the non-destructive testing methods.* AENOR (European Standard).
25. ISO 148-1. (2016). *Metallic materials. Charpy pendulum impact test. Part 1: Test method.* AENOR (European Standard).
26. ISO 17025. (2017). *General requirements for the competence of testing and calibration laboratories.* AENOR (European Standard).
27. ISO 17640. (2011). *Non destructive testing of welds. Ultrasonic testing.Techniques, testing levels, and assessment.* AENOR (European Standad).
28. ISO 18563-2. (2017). *Non destructive testing. Characterization and verification of ultrasonic phased array equipment.* AENOR (European Standard).
29. ISO 3059. (2013). *Non destructive testing. Penetrant testing and magnetic particle testing. Viewing conditions.* AENOR (European Standard).
30. ISO 3452-1. (2013). *Non-destructive testing. Penetrant testing. Part 1: General principles.* AENOR (European Standard).
31. ISO 3452-2. (2014). *Non-destructive testing. Penetrant testing. Part 2: Testing of penetrant materials.* AENOR (European Standard).
32. ISO 3452-3. (2013). *Non-destructive testing. Penetrant testing. Part 3: Reference test blocks.* AENOR (European Standard).
33. ISO 5577. (2017). *Non-destructive testing. Ultrasonic testing. Vocabulary.* AENERO (European Standad).
34. ISO 6507-1. (2005). *Metallic materials. Vickers hardness test. Part 1: Test method.* AENOR (European Standard).
35. ISO 6507-1. (2016). *Metallic materials. Rockwell hardness test. Part 1: Test method.* AENOR (European Standard).
36. ISO 6509-1. (2014). *Metallic materials. Brinell hardness test. Part 1: Test method.* AENOR (European Standard).

37. ISO 6892-1. (2016). *Metallic materials - Tensile testing - Part 1: Method of test.* AENOR (European Standard).
38. ISO 7500-1. (2015). *Metallic materials. Calibration and verification of static uniaxial testing machines. Part 1:.* AENOR (European Standard).
39. ISO 7500-1. (2015). *Metallic materials. Calibration and verification of static uniaxial testing machines. Part 1:.* AENOR (European Standard).
40. ISO 9000. (2015). *Quality management systems. Fundamentals and vocabulary.* AENOR (European Standard).
41. ISO 9513. (2012). *Metallic materials. Calibration of extensometer systems used in uniaxial testing.* AENOR (European Standard).
42. ISO 9712. (2012). *Non destructive testing. Qualification and certification of NDT personnel.* AENOR (European Standard).
43. ISO 9934-1. (2016). *Non destructive testing. Magnetic particle testing. Part 1: General principles.* AENOR (European Standard).
44. ISO 9934-2. (2015). *Non-destructive testing. Magnetic particle testing. Part 2: Detection media.* AENOR (European Standard).
45. ISO 9934-3. (2015). *Non-destructive testing. Magnetic particle testing. Part 3: Equipment.* ANEOR (European Standard).
46. Kirschenbaum, J. M. (2006). *Foundations and Essays on Metallic Materials., ISBN: 950-00-0457-6.* Argentina: Ministry of Education, Science and Technology - National Institute of Technical Education.
47. Loza Molina, C. A. (2010). Proposal for a system of quality control in the production processes of a metalworking company. *Tesis*. Lima, Perú: University of Applied Sciences from Peru.
48. Martínez Leal, J. (2016). *Implementation of technological operations, for the generation of spur gears, in multi-axis CNC machining center.* Bogotá Faculty of Mechanical Engineering.
49. Ministerio de Economia, I. y. (n.d.). *ww.comercioo.gob.es*. Retrieved 3 17, 2018, from http://www.comercio.gob.es/es-ES/comercio-interior/Registros/Empresas-de-ventas-a-distancia/Preguntas-frecuentes-(en-general)/Paginas/Control-de-calidad.aspx
50. Monsalve Jaramillo, H. (n.d.). Steel tensile test. Retrieved 4 22, 2018, from https://issuu.com/daniela.a.s/docs/protocolo-lab1-traccion_en_acero
51. Navarro, M. (n.d.). *https://w3.ual.es/*. Retrieved 3 18, 2018, from https://w3.ual.es/~mnavarro/Tema%206%20%20Elasticidad.pdf
52. NDT Resource Center. (n.d.). *https://www.nde-ed.org*. Retrieved 05 02, 2018, from https://www.nde-ed.org/EducationResources/CommunityCollege/Ultrasonics/EquipmentTrans/DataPres.htm

53. neetescuela.org. (n.d.). *https://neetescuela.org*. Retrieved 4 11, 2018, from https://neetescuela.org/probetas-segun-el-ensayo-mecanico/
54. Norton, R. L. (2005). *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines. ISBN-0 07 247046 1.* USA: McGraw-Hill.
55. Norton, R. L. (n.d.). *Diseño de Maquinaria* (4ª ed.). México: McGraw Hill.
56. Peñafiel Pilco, C. A. (2014). Design and implementation of an operation and maintenance manual for the laboratories of strength of materials, metallography, non-destructive tests and thermal treatment of the Faculty of Mechanical. Ecuador: Higher Polytechnic School of Chimborazo.
57. Polytechnic University of Cartagena. (n.d.). *www.dim*. Retrieved 4 29, 2018, from http://www.dimf.upct.es/: http://www.dimf.upct.es/personal/jb_a/presentacion_end.pdf
58. Prat, P. (2006). Constitutive Equations. Elasticity and Plasticity. Barcelona, Spain: Universidad Politécnica de Cataluña. Retrieved from https://portal.camins.upc.edu/materials_guia/250131/2012/Elasticitat-Plasticitat.pdf
59. Rivera Romero, B., & Ferrer Margalef, F. (2015). *Use of the concept of metrological traceability by calibration laboratories.* ENAC-CEM.
60. Rodríguez González, C. (2012). Automated detection of defects in metal parts by means of non-destructive testing with ultrasound. Santander, Spain: University of Cantabria.
61. Rodríguez Paredes, E. (2014). Study of the effectiveness of the trial of ultrasound for inspection of structural steels to 37 - 24 is of quality SAE 1020. Chile: Austral Universy of Chile.
62. Sagrado, S., Bonet, E., Medina, M. J., & Martín, Y. (2005). *Practical manual of quality in laboratories: approach ISO 17025 (2ª ED), ISBN: 84-8143-440-X.* Spain: AENOR Ediciones.
63. San Buenaventura University. (2002). Mécanica de Solidos: Prácticas de resistencia de materiales. Bogotá.
64. Serrano, R. (n.d.). *http://www.raquelserrano.com.* Retrieved 5 2, 2018, from http://www.raquelserrano.com/wp-content/files/ciencias_t8.2_particulas_magnticas.pdf
65. Serrano, R. (n.d.). *www.raquelserrano.com*. Retrieved 4 27, 2018, from http://www.raquelserrano.com/wp-content/files/ciencias_t8.3_liq_penetrantes.pdf
66. Spanish Center of Metrology. (2012). *International vocabulary of metrology , basic and general concepts and terms associated. NIPO: 074-13-004-1* (3ª ed.).
67. Stiopin, P. (1968). *CDU: 620.10.605.21-60 Resistance of materials.* Moscow: MIR.
68. Summers, D. C. (2005). *Quality management.* Prentice Hall.
69. UNE 66020-1 (ISO 2859-1). (2001). *Sampling procedures for inspection by attributes. Part 1: Sampling schemes indexed by acceptance quality.* ANERO (Euopean Standard).
70. UNE 66-020-73. (1973). *Characteristics of inspection and reception.* AENOR (European Standard).

71. Urrea Mariño, M. (2014). Design of a reconfigurable bank for conduct of clinmical teaching of torsion and bending. *Tesis*. Mexico: National Autonomous University of Mexico.
72. Wolniak, R. (n.d.). *Wyokorzystane punków krontoli jacósci do poprawy procesu produkcyjnego*. Retrieved 3 17, 2018, from www.ptzp.org.pl/files/konferencje/kzz/artyk_pdf.../t2_0340.pd
73. Woman, J. (2011). *http://www.nationalboard.org.* Retrieved 4 27, 2018, from http://www.nationalboard.org/index.aspx?pageID=164&ID=374
74. *www.aenor.es*. (n.d.). Retrieved 3 17, 2018, from http://www.aenor.es/aenor/aenor/perfil/perfil.asp#.VfbTgtLtlHw
75. www.asq.org. (n.d.). *www.asq.org*. Retrieved 3 17, 2018, from http://asq.org/learn-about-quality/quality-management-system/
76. www.buehler.com. (n.d.). Retrieved 4 12, 2018, from https://www.buehler.com/Spanish/history-of-hardness.php
77. *www.cen.eu*. (n.d.). Retrieved 3 17, 2018, from https://www.cen.eu/Pages/default.aspx
78. www.corrionpedia.com. (n.d.). Retrieved 4 30, 2018, from https://www.corrosionpedia.com/definition/980/resilience
79. *www.deming.org*. (n.d.). Retrieved 3 17, 2018, from https://deming.org
80. *www.din.de*. (n.d.). Retrieved 4 8, 2018, from www.din.de.
81. www.efqm.org. (n.d.). *www.efqm.org*. Retrieved 3 17, 2018, from http://www.efqm.org/
82. *www.estanteriasmetalicas.biz*. (n.d.). (E. Metálicas.biz, Producer) Retrieved 5 30, 2018, from https://www.estanteriasmetalicas.biz/ES/Articulos/5506/mesa_de_trabajo_superficie_met%C3%A1lica_con_armario_inferior_bt-6_metal_locker_1500_azul_830x1500x730
83. *www.fao.org*. (n.d.). Retrieved 3 21, 2018, from http://www.fao.org/docrep/w6864e/w6864e0d.htm
84. *www.toolshero.com*. (n.d.). Retrieved 3 17, 2018, from https://www.toolshero.com/quality-management/efqm-model/
85. Yuan, Y., & Lee, T. R. (2013). *Contact Angle and Wetting Properties. ISBN: 978-3-642-34242-4.* Springuer.

LIST OF FIGURES

LIST OF TABLES

I APPENDIX. TESTING MACHINES.

Measurer of environmental conditions.

The tests performed in accordance with regulations, such as the ISO, should have the ambient temperature specified in each one of them.This is very important and the laboratory should maintain control and registration of environmental conditions in order to not affect the quality of the results, through the use of temperature measuring instruments.

Fig. I.1. Temperature measuring instrument (https://goo.gl/FXGJ9L)

***1. Microscope and magnifying glasses*.**

A microscope or binocular loupe will perform a 3D, stereoscopic or with relief view. Besides its evident utility in the visual inspection of materials test, microscope develops the job as magnifying glasses. The microscopes function is aid for the calibration and verification of the different equipment, according to the application standarts for each type of test. One example in a Charpy pendulum test where it is used to verify the test specimen's measurements, looking for specimens with no-standardized dimensions and verifying that they are within the tolerance range.

It is composed of a binocular head with two magnifying eyepieces, normally wide focus or large field model, a fixed magnification objective selectable or a zoom system, a stand or column stand by which the optical assembly moves up or down, a foot or base that incorporates the plate with clips and finally a lighting system.

Fig. I.2. Trinocular microscope Motic (https://goo.gl/2BuR8W)

2. Boroscope.

It is a device with the same principles as a medical endoscope, which allows visual inspection (NDT) in no-accessible areas such as turbines, motors, etc. In the general sense, the borescope is an optical instrument of low magnification (3x to 4x), usually of small diameter (<20 mm) and relatively large in terms of total length, often 50 to 100 times its diameter. These dimensional limitations influenced the optical design of a borescope; the precision requirements of the optical components and the high level of image quality that is generally necessary. Although they have the same function, the borocope provides a clearer and more complete view than fibroscopes.

Fig. I.3. Boroscopio flexible (https://goo.gl/MdkkZy)

There are different models as rigid (with oscillating or semi-prism prism with a fiber optic bundle) and flexible (De máquinas y herramientas, s.f.).

2.1. Calibrators.

For END tests by visual inspection, instruments such as rulers and scales, calibrators and micrometers, welding calibrators (bridge cam), have the function of measure the fillet of the same, etc.

Fig. I.6. Calibrator Bridge Cam (https://goo.gl/ovqFEc)

Fig. I.6. Galga Socket Wells (https://goo.gl/772ecJ)

Fig. I.6. Galga Hi-Lo (https://goo.gl/9Sqv41)

3. Penetrant liquids.

As already said, this NDT method allows locating and detecting surface discontinuities, even in complicated geometry pieces. Although this method only detects surface discontinuities, it is an effective, reliable, quick and easy test to apply to a wide variety of materials, as well as being relatively inexpensive (Prices).

The method consists of a liquid application with a certain color on the surface of the inspected piece; the liquid enters into the discontinuity and after cleaning the surface in order to eliminate the excess of penetrant a developer is applied. Developer acts as a substance for contrast the penetrant color lodged in the discontinuities when they absorb it, creating a visible indication or mark of the discontinuity.

Although there are automated systems for testing large series of products, it is usual to present the three types of liquids (eliminator, penetrant, developer), either in kit or in individual spray.

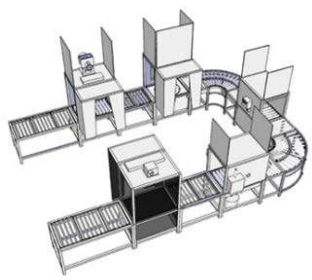


Fig. I.7. Test facility with penetrant liquids (https://goo.gl/xEV59J)

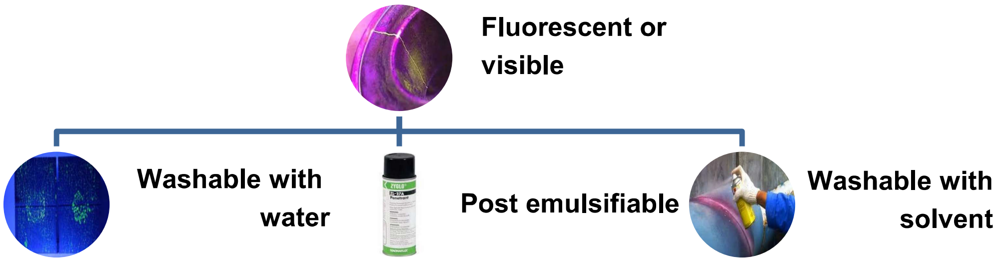


Fig. I.8. Types of penetrant testing.

4. Durometers.

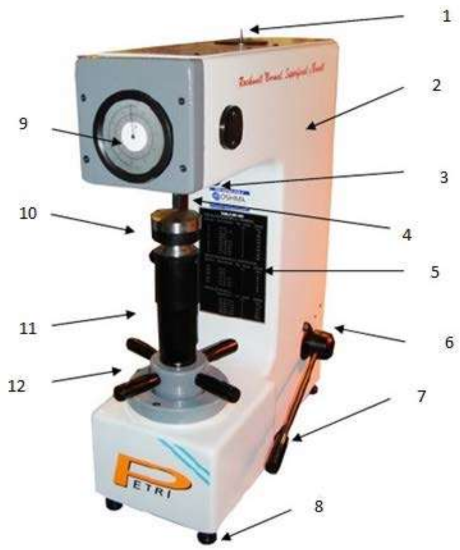
The durometers are measurement devices used, as the name suggests, to determine the hardness of materials.

Durometers work by applying a load, which will depend on the scale used (Rockwell, Vickers, etc) on the surface of a material. The type of tested material and the type of the normalized penetrator that will leave a mark on the material perform the election of the load. Once the load on the material ceases, the depth of the left mark is measured.

The market offers a widely variety of durometers as desktop type, portable, rigid, etc, with a different test scales (Examples: Vickers HV0.01 to HV50: Rocwell Hr15t to Hr45n).

Thay can perform the test with a basic operation, where laboratory inspector can check the results by using cameras or even from fully automatic operation.

.



1	Preload
2	Body
3	Zero adjustment of the dial indicator
4	Penetrator bearing shaft
5	Quick guide of equipment configuration
6	Hydraulic Pump Regulation
7	Load application lever
8	Leg control
9	Comparator clock
10	Support for measured pieces
11	Lifting screw
12	Lifting wheel

Fig. I.9. Petry durometer (https://goo.gl/hBPDJH)

Fig. I.12. Durometro UCI PCE-3500 (https://goo.gl/wRZZ75)

Fig. I.11. Tipos de puntas normalizadas para ensayos Brinell. (San Buenaventura University, 2002, pág. 13)

Fig. I.10. Rockwell test blocks (https://goo.gl/FTMhbk)

In addition, these equipments have additional standardized test patterns, in order to obtain maximum accuracy and efficiency in the durometers verification.

5. Ultrasonic testing equipment.

The propagation of ultrasound test uses an equipment that consists of a system of waves emission and reception and a system for measuring the time and / or speed of transmission of those waves.

In point 5, the multiple applications of this type of NDT test create a big family of ultrasonic test devices, from small portable devices for manual tests to large automatic machines. Althoug all of them have common basic components:

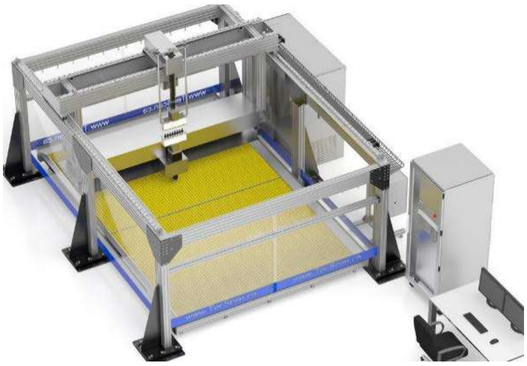


Fig. I.13. Machine ultrasonic inspection of surface for aeronautics (https://goo.gl/7fV41g

- Generator of electrical impulses: emits pulses to the emitting probe.
- Probes: performs the conversion of electrical impulses into mechanical impulses.
- Amplifier: receives and registers the electrical impulses from the receiver probe.
- Electronic timer: it measures the time elapsed between the emission and the reception of an electrical impulse by chromometer of direct digital reading intervals, or by an oscilloscope, which shows the first front of the impulse respect of a suitable time scale. It offers the possibility to examine the shape of the impulse wave.
- Calibration block: serves to provide a standardized data for the measurement of speed. Using this component, the emission and measurement equipment adjust itselft to the measure of the indicated tare.

Ultrasonic test equipment uses the piezoelectric effect (put in definition) so the main elements of the devices are usually a piece of polarized material with electrodes attached to two of their opposite faces.

When an electric field is applied along the material, alignation of polarized molecules with the field occurs and an induced dipole in the crystal structure appeares. This molecule alignment causes a dimensional change, called electrostriction. In turn, the opposite action can occur, that is, the production of an electric field when a dimensional change occurs.

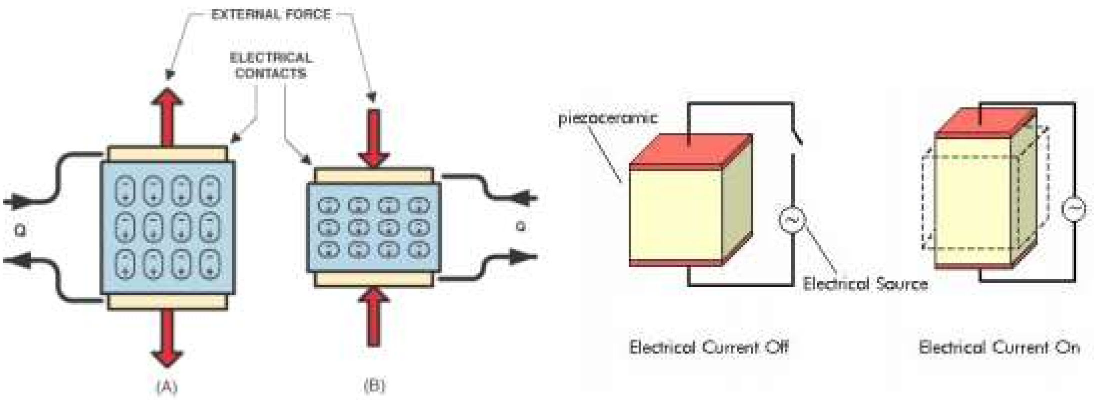


Fig. I.14. Piezoelectric element schema. (https://goo.gl/Gafyne)

The probe applies the electrical impulses generated by the equipment and transforms them into mechanical pulses of very short duration. These are transmitted to the examined piece, where they propagate and reflect on the opposite surface or on the defects that may appear in its path.

These reflected pulses are picked up again by another probe and, by inverse piezoelectric effect, pulses become electrical impulses with the same frequency. They generate the necessary information about the test with their analisys and recorder in the equipment by the amplifier. The necessary information about the incidents of the Ultrasonic impulses through the material includes the length and measurements of internal discontinuitis (Benitez Herreros, 2011, pág. 48).

5.1. Probes.

The Probes are the elements in direct contact with the piece of the test.

Probe is an electro-acoustic device that generally incorporates one or more transducers, which main objective is emission or reception of ultrasonic waves (ISO 5577, 2017, pág. 21). Transducer is the active element of the probe that allows the conversion of electrical energy into acoustic energy, and vice versa. Some factors, such as mechanical and electrical construction, affect the behavior of the head structure. The mechanical construction includes parameters such as radiation surface, encapsulation and connection.

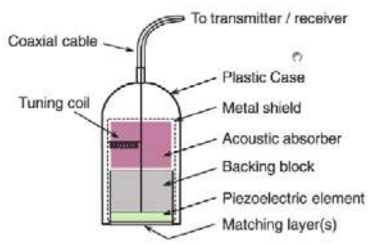
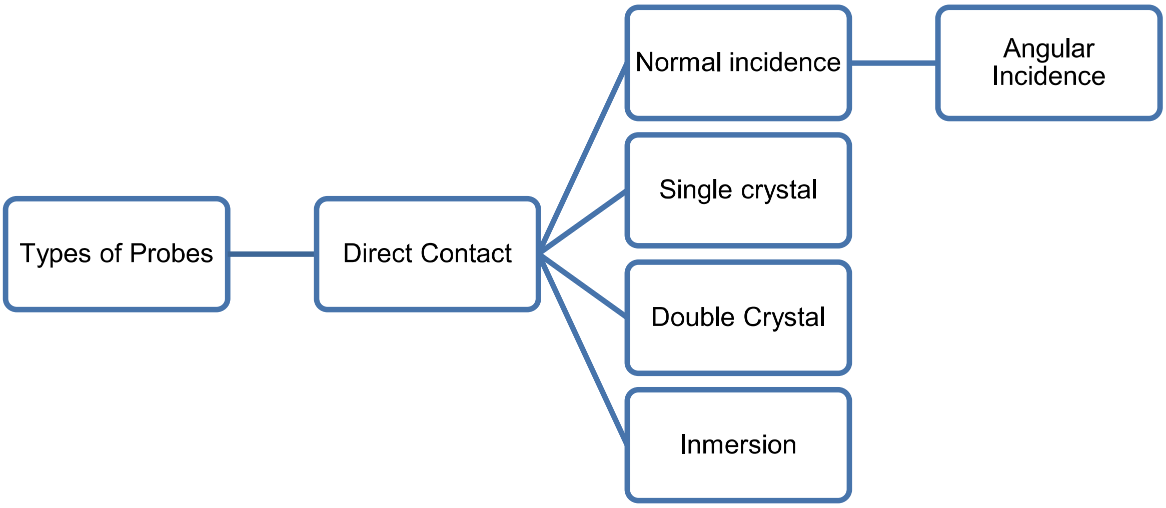


Fig. I.15. Transducer (https://goo.gl/ArUoJw)



Application of coupling liquid is necessary in order to eliminate the thin layer of air between the probe and the surface of the inspected element, since the air presents a high acoustic impedance that would hinder the transmission of the ultrasonic beam.

Fig. I.16. Couplings for Ultrasound Olympus. (https://goo.gl/QHJh6e)

For a correct test procedure using ultrasound method, the inspection should not start without a first adjust of the equipment-probe set. This set should be adjusted each time there is a fundamental variation in the inspection, such as changing the probe or the quality of the material to be tested.

This adjustment uses calibration blocks as reference patterns. They can be a block or set of blocks with artificial discontinuities and / or known thicknesses which are used to calibrate ultrasound equipment.
The calibration blocks must have the same physical, chemical and structural properties as the inspected material.

6. Equipment for magnetic tests.

As a rule, the design of the equipment must follow all international, European, national and local regulations that include health, safety, electrical and environmental requirements.

6.1. Portable electromagnets (Yoke).

It is a metal element with the shape of and "U" and a coil around the horizontal part, which transports the electric current. They are usually made of low-retentivity, sweet iron, and there are two types: permanent magnets and electromagnetic magnets.

a) Permanent magnets: Used to generate magnetic field in environments where electric arcs are not allowed (for example in explosive atmospheres) or electric sources are not available. This type of yokes has the following limitations:

- *Large areas or parts cannot magnetized with sufficient intensity; due to this, fissures do not generate visible indications.*
- *The density of flow cannot generate variations.*
- *If the magnet is very strong, later it is difficult to detach it from the piece.*
- *The particles can adhere to the magnet and to the piece at the same time, masking the indications.*

b) Electromagnetic Yokes: They consist of a winding on a U-shaped body made of soft iron, usually silicon electrical steel with fixed or articulated legs that used to vary the contact distance and to adapt to different geometries of the piece.

Its biggest difference with permanent yokes lies in the fact that the electromagnets allow the connection and disconnection of the system, which makes it easy to separate them from the test piece at the end of the test.

Fig. I.18. Magnetization of a piece with the yoke (Goñi Córdoba, 2015, pág. 78)

Fig. I.18. Magnetization by contact tips. (https://goo.gl/Dp2vbi)

The yoke can be designed to work with direct current (DC), alternating current (AC) or both. When the yoke works using AC, a large penetration of the field occurs. Meanwhile, when the yoke works with DC, magnetic field is concentrated mainly on the surface of the piece, which allows a good sensitivity for surface discontinuities over a wide area.

Inspection of large pieces to place a yoke is often done with contact tips. The current throughs the piece directly to a localized area using the tips because they have great mobility and easy handling. Besides its versatility easily detection of defects using the magnitude and orientation variance of the magnetic field.

6.2. Coils

The coil is as an induced current sensor, formed by one or multiple conductor wirings and used for the longitudinal inspection of parts. Thanks to this mode of operation, transversal cracks in shafts and camshafts can be easily detected. These coils are movable and they can be directly used in the inspection place in rail maintenance, aeronautics, automotive and in trucks and tractors shafts.

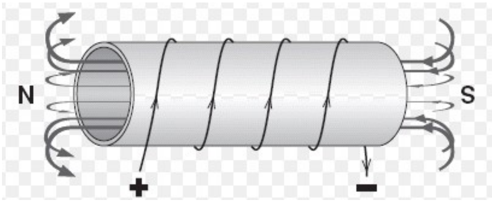


Fig. I.19. Coil (https://goo.gl/vrZGBR)

For large parts, the coil can be assembled by winding up the cable around the piece with several turns, generating a field inside the coil with the same direction of lines of force produced by each portion of the conductor. The higher the number of turns a coil has, the greater the magnetizing power.

There are many types of magnetic test instruments as fluoroscent powders and magnetic particles of color, with different mediums: aerosols, concentrated, and in various methods: dry, wet, etc.


Fig. I.20. Fluorescent magnetic particles (https://goo.gl/MkgCAa)

7. Universal testing machine.

The first universal testing machine was built in Philadelphia, USA, by engineer Tinius Olsen, in 1880, The device allowed tensile and compression tests with a maximum load capacity of 40,000 (lbf). The first tensile test in a universal machine was performed in sheets for manufacturing boilers of steam engines (Urrea Mariño, 2014, pág. 6) and whose success led to the development of machines to test torsion, bending, hardness and impact

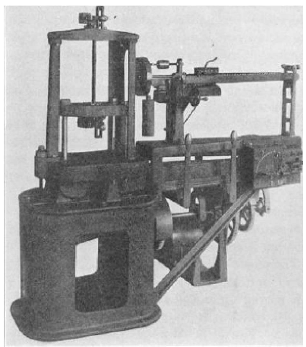


Fig. I.21. Primera máquina universal de ensayos. Olsen. 1880 (Urrea Mariño, 2014, pág. 6)

As it was seen in point 6.1 this type of machines checks the resistance of different types of materials as main function. It applies controlled loads on a test specimen of pre-established dimensions measuring graphically the deformation, as well as its rupture load.

Currently there are several models in the market divided by their type of testing material and by their characteristics: maximum strength (eg, 2 kN to 2 MN), analog, computerized, of one or double column, vertical or horizontal, types of accessories, traction speed, etc.

Fig. I.22. a) Electromechanical universal test machine (https://goo.gl/oAcX4D); b) Universal test machine / single column / double column / numeral control. AMETK (https://goo.gl/38LhLM); c) Universal Testing Machine With Environmental Chamber. Gester (https://goo.gl/j6gUAR)

The main parts of a Universal Testing Machine are:

1. Hydraulic piston of double effect and great route.
2. Top plate of the test frame: acts as structural closure.
3. 4 Columns of high rigidity to ensure a homogeneous distribution of axial forces.
4. Upper traction hydraulic head, guided in its displacement.
5. Remote control for opening and closing the hydraulic jaws and piston positioning.
6. Bottom jaw: mounted in series with the loading card.
7. Charge card.
8. Bottom plate, frame closure and structure base.

Fig. I.23. Elaboración propia y https://goo.gl/GXneNt

As shown in the figure and in the description above; Universal Test Machines in general are composed of a crosshead that moves vertically up or down, applying a controlled force of traction or compression on the test specimen to be evaluated.

The manufacturers of this type of machines also provide customers with a series of solutions for data acquisition and auxiliary devices in addition to other elements to perform various tests. Some examples of auxiliary products are digital programs or softwares, and accessories such as extensometers, screws, fork clamps, rotating hooks, etc.

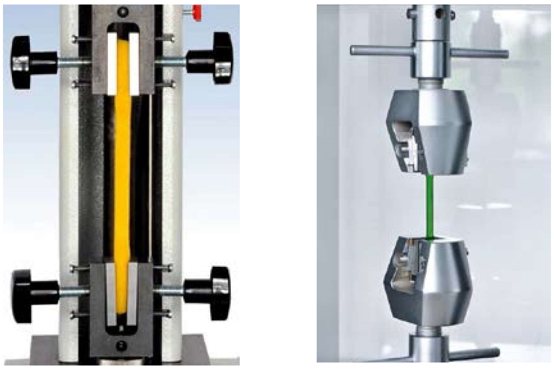


Fig. I.24. Screw and wedge clamps Test® https://goo.gl/zpdGWw

7.1. Extensometer.

The standard ISO 9513 defines them as a strain strain equipment to measure the displacement or deformation on the surface of a specimen (ISO 9513: 2012, page 8).

They are sensors used to measure the stretching or deformations around a point. Using Hooke's law and with the knowledge of material deformation and modulus of elasticity, it is possible the measurement for stress-strain and tensile tests.

Fig. I.25. Extensometer (https://goo.gl/oWwrFh)

8. Charpy´s Pendulum.

The Charpy pendulum is a rotating arm with a hammer at its end. A test specimen of the tested material, which has previously a U or V notch, is hitting it with the pendulum in order to know the energy that can absorb the material without breaking.

This pendulum, of mass m, is in an initial height, h1, so it has a certain potential energy at the beginning of the test. When the test started, the pendulum released and after hitting the test specimen and breaking it, continues with its rotation, reaching a final height h2, so it will have a new potential energy.

The energy that has absorbed the test piece will be the difference of initial and final potential energies.

If the specimen does not break and the pendulum stops, it is necessary to increase the potential energy of the pendulum by two methods: increasing the mass or increasing the initial height.

1.- Interlocking device of the maza
2.- Maza.
3.- Impact hammer
4.- Impact hammer
5.- Engine with clutch and brake
6.- Pendulum shaft
7.- Anvils
8.- Support of the specimens (Charpy)
9.- Checking the leveling zone
10.- Leveling screws
11.- Pendulum body
12.- Control panel and reading results
13.- Proximity sensors
14.- Clamping arm position of trial

Fig. I.26. Pendulum impact test IBERTEST Serie PIB (https://goo.gl/ERK5v1)

In order material reactions in severe conditions, the Charpy method uses test specimens with standard dimensions as a measure of tenacity, and deformation speeds recommended by the standards from 5 to 5.5 m / s.

8.1. Broaching machine.

This machine can mechanise the notchs of the specimens, in particular for those used in the Charpy pendulum tests. It is a multiedge cutting tool with a brush, a shaft with multiple teeth, which cuts the material progressively. The geometry of the brush is the same as the notch shape of the test specimen, with a V or U form.

Fig. I.28. Horizontal Broaching Machine (https://goo.gl/nntgKG)

Fig. I.27. Brochas (https://goo.gl/HoRRYz)

However, the characteristics of some materials make the broaching operation not recommended. In these cases, it must be replaced by others methods, such as rectification of shape.

II. APPENDIX. Economic Costs.

In section 2 of this Project, there are references about the company's quality, quality certification and the accreditation of laboratories. In addition, some explanations appeared about tests products or materials of these companies and the ISO standards topics.

However, this Project is going to develop the evaluation costs of the different elements used in the tests that have been developed in the previous sections but the laboratories costs of certification will not be taking into account.

Basic Equipment		
	Price €[20]	Fuente
6"/152mm High Precision Rule	67,34	https://goo.gl/MXT7kf
Traditional External Micrometer	119	https://goo.gl/DrCXjC
Baker Dial Calipe	98,40	https://goo.gl/3pfwVz
mechanical keys	69,95	https://goo.gl/4xHk3s
Drill	189	https://goo.gl/xWoDyt
Screwdriver	6,95	https://goo.gl/xHeE2W
Tool Cart	99	https://goo.gl/T3XgXB
Rubber Hammer	2,95	https://goo.gl/fjXBfr
Metal bristle brush	4,22	https://goo.gl/SgfRQk
Kit for welding inspection[21]	998,25	https://goo.gl/8KT8hq
Computer Asus K541UA i7	639	https://goo.gl/rNMXPU
Printer HP LaserJet	299	https://goo.gl/VMKp6p
Total	2593,06 €	

[20] Unitary Cost

[21] Full welding gauge Hi/Lo, gauge Socket Welds, gauge Foillet/Rincón, Micrometer, mirror, etc.

Special Equipment		
Definition	**Price €**	**Source**
Universal test device[22] IB-mt4-1000	87188	Appendix IV
Instrumented control table	614	Appendix IV
Axial Extensiometer	3559	Appendix IV
Charpy Pendulum	48000	Appendix V
Broaching machine for notching test pieces for Charpy e Izod tests	2153	https://goo.gl/v3yMm7
Durometer Sauter HMO	***1770***	*https://goo.gl/7sH1kx*
Borescope PCE-VE-800	6479	https://goo.gl/KefUUq
Motic Microscopio BA310 MET trinocular microscope	4436	https://goo.gl/PfuPfu
Magnifying glasses 2x a 15X Schweizer	385	https://goo.gl/hroC8P
Spray penetrant 400 ml Würt [23]	19,95	https://goo.gl/kertyK
Spray revelador 400 ml Würt	16,80	https://goo.gl/kertyK
Spray Developer 500 ml Würt	18,55	https://goo.gl/kertyK
TOTAL	**112639,3**	

Other type of Equipment[24]		
Definition	**Price €**	**Source**
CJE-200 Magnaflux Testing Machine	600	https://goo.gl/WXgqvL
Fluorescent magnetic particles	15,98	https://goo.gl/49R9B7
Magnifying glasses 2x a 15X Schweizer	385	https://goo.gl/hroC8P

[22] For the universal testing machine and for some of the equipment, a cost assumption has been requested from manufacturers. Only one company has been answered (in Spanish, about the Ibertest Universal Testing Machine and auxiliary components).

[23] They allow realizing five tests.

[24] NDT equipment reference.

Training (It is assumed that the laboratory personnel have such training)

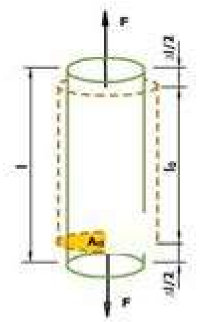
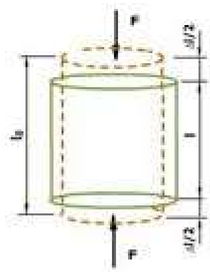
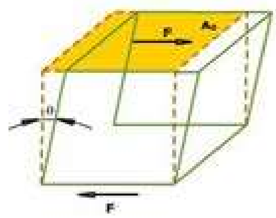
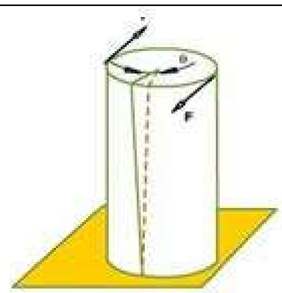
Type of degree[25]	Price €
Líquidos penetrantes Level I	710
Ultrasonic Level I	1312
Ultrasonic (thickness Level I)	1084
Visual Inspection Level II	1255
Penetrant Liquids Level II	1255
Ultrasonic Level II	1564

[25] http://www.aend.org/cursos.php

III. APPENDIX DEFINITIONS.

Mechanical behavior of a material is the relationship between an applied force and its reaction as a deformation and, so it is necessary to know what types of efforts can act on the materials as well as the concepts of tension and deformation.

Table III-1. Types of efforts to which a material may be subjected. Handmade and https://goo.gl/RE1WYA

Traction: It is the effort to which a body is subjected by the implementation of two forces acting in the opposite direction and which tend to stretch it, increasing its length and decreasing its section. A traction force produces an elongation and deformation positive linear.	
Compression: It is the effort to which a body is subjected by the implementation of two forces acting in the opposite direction and which tend to compress it decreasing their length and increasing its section. A compressive load produces contraction and negative linear deformation.	
Cut or shear or shear stress: is the effort that supports a part when on her act two forces in opposite direction and not aligned and tend to cut it.	
Torque: It is force that produces a momentum around the axis.	

Artificial discontinuity Discontinuities such as holes, slots or notches, introduced in a piece by machining or other process.

Capillarity The description of capillarity is the action by which the surface of a liquid, where it is in contact with a solid, is raised or lowered depending on the relative attraction of the molecules of the liquid for each other and for those of the solid.

Default: Element with a discontinuity rejected in the quality test by the minimum requirements of a code, standard or specification.

For the Standard (ISO 9000, 2015, page 26) it means: Non-compliance related to an intended or specified use. Any disagreement of the product unit with the required prescriptions.

The defects are divided into (UNE 66-020-73, 1973, page 2):

- *Critical defect: The one that reason and experience probably leads to unsafe conditions for its use or maintenance.*
- *Main defect: The one that, without critical level, can cause a failure or breakdown.*
- *Secondary defect: The one that does not reduce the utility of the product for its defined purpose.*

Deformation (ε) The deformation (ε) in the shaft or test specimen is the ratio between the final shape or size of the structure respect to its initials measures.

$$\varepsilon = \frac{l_1 - l_0}{l_0} = \frac{\Delta l}{l_0} \quad (10)$$

Where Lo is the original length before applying the load, and Li the instantaneous length. Sometimes li-l0 expression is Δl and it refers to elongation ratio. The deformation does not have units, although sometimes it expresses as meter-by-meter or as a percentage (value of the deformation by 100).

Discontinuity. Any irregularity detected in a piece by some test method. They become, therefore, into a defect

Ductility Ductility is another important mechanical property and is a measure of the degree of plastic deformation that materials achieve until fracture. A quantitatively expression of ductility is by the percentage relative elongation, or by the percentage of area reduction.

$$\%EL = \left(\frac{l_f - l_o}{l_o}\right) \cdot 100 \tag{11}$$

$$\%RA = \left(\frac{A_f - A_o}{A_o}\right) \cdot 100 \tag{12}$$

Elastic and plastic deformation. Depending on the type of material, size and geometry of the object, and the forces applied, various types of deformation may result.

During the tensile tests, when uniaxial force applies to a test piece, deformation occurs. If the composed material returns to its original dimensions when the force or load ceases, this process is called as elastic deformation. In elastic deformation, once the forces are no longer applied, the object returns to its original shape.

On the other hand, if the material is deformed to a point where the deformation stays even after removal of the applied forces, it is said that there is a plastic deformation.

Hardness. From the point of view of physics, hardness is a property that all materials have and consists of the level of force between the molecules that make them. It is the ability of the material to prevent any other object or substance for penetrating or compromise its surface.

The definition of hardness is different from mechanical strength, which is the resistance of the material to be deformed.

In the industrial area, they use hardness as a magnitude to resistance capacity or weight resistance of materials.

Magnetism. That is the physical phenomenon associated with the attraction of certain materials, by means of which materials exert force of attraction or repulsion on and other materials. Magnetic forces are produced by the movement of charged particles like electrons, while indicating the intimate relationship between electricity and magnetism.

When they subjected to an external magnetic field, their magnetic characteristics suffer a degree of distortion and change. Depending of the level of changes, that materials are classified into three groups: diamagnetic, paramagnetic and ferromagnetic.

To explain the behavior of magnets and electromagnets, the main process starts from the idea that a large number of infinitely small magnets, called magnetic domains, forms all bodies.

Said magnets or domains are initially in disorder in such a way that their total magnetic resultant is null.

A material capable of being magnetized orients its magnetic domains when it is near a magnet or an electric current, generating the so-called total magnet.

The magnetization will consist of the ordering process through which various submicroscopic regions of a material are oriented predominantly in one direction.

Resilience

Resilience is the property of a material to absorb energy when a force of bending, stretching or compression deforms it elastically and release that energy upon unloading. This must occur before its plastic deformation, without the creation of a permanent deformation to its original shape.

It is important to note that resilience and toughness are two very different terms. Resilience is the ability of a material to deform elastically. Toughness is the ability of a material to absorb energy not only from elastic deformation, but from plastic deformation as well. When testing the resilience of a material, it will be possible to use it after the testing is complete. Testing the toughness of a material, however, is usually destructive (www.corrionpedia.com, s.f.).

The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without creating a permanent distortion.

$$U_R = \frac{1}{2}\sigma_0\varepsilon_0 = \frac{1}{2}\sigma_0 \cdot \frac{\sigma_0}{E} = \frac{\sigma_0^2}{2E}\left(\frac{J}{m^3}\right) \quad (13)$$

Tenacity. Tenacity explains the behavior of the mineral when applied load tries to deformed or broken it. It is a material's strength, force per unit area at failure, divided by the material density.

When testing for brittleness, one should scratch the specimen with a harder mineral or material, and see if the mineral leaves a fine powder.

Tensile strength (σ). The tensile strength in the shaft or test specimen is the quotient between the average uniaxial force, F, and the original cross section, So.

$$\sigma = F / So \qquad (14)$$

The units of Tensile strength measurements are Pascal (Pa), although results are usually expressed in Mega-Pascals (MPa). Mega-Pascals express the surface in mm2 because these units are more coherent for the sections from the pieces.

Other definitions

In the use of the different standards for the practice of tests on materials, it is possible finding definitions to perform tests and checking if the results reflected in the report are correct, regardless of the result of them.

Calibration. In the use of the different standards for the practice of tests on materials, it is possible finding definitions to perform tests and checking if the results reflected in the report are correct, regardless of the result of them.

Calibration is the checking activity, by comparison the accuracy of a measuring instrument with a standard. As has been said, the tests are performed by machines, and calibration may also include adjustment of the instrument to bring it into alignment with the standard.

The calibration is defined as: "operation that under specified conditions establishes, in a first stage, a relation between the values and their associated measurement uncertainties obtained from the measurement standards, and the corresponding indications with their associated uncertainties and, in a second stage uses this information to establish a relationship that allows obtaining a measurement result from an indication (Spanish Center of Metrology, 2012, page 37)

Although the different ISO standards include their own definitions depending on the test, it can define the calibration as the set of operations carried out by competent personnel. These laboratory personnel have the purpose of verify or affirm that the device satisfies all the requirements of the regulations or specifications.

Verification of the calibration can perform, independently, by external companies, giving the accreditation in accordance with the requirements of Standards such as IO 9000 and ISO 17025.

Metrological traceability: Metrological traceability is: "the property of a measurement result by which the result can be related to a reference through an uninterrupted and documented string of calibrations, each of which contributes to the uncertainty of measurement (Spanish Center of Metrology, 2012, page 38).

This main property allows comparison of the measured Results to each other, regardless of the place and time in which they were made. With this procedure, the universal acceptance and the reduction of the potential technical barriers to trade (Rivera Romero & Ferrer Margalef, 2015) become easily.

The method of Metrological Traceability consists of a documented chain of calibrations up to a reference (measurement pattern, practical realization of the definition of a unit of measurement or a measurement procedure) by means of documented procedures. Finally, units of the results of measurement are in the units of the International System of Units (IS) (Rivera Romero et al, 2015, page 5) becoming universal measurements.

Uncertainty of measurement: The statistical parameter characterizes the dispersion of the values. It attributed to a measurement from the used information and it includes components from systematic effects, such as components associated with corrections and values assigned to patterns, as well as the uncertainty due to the definition. Sometimes the estimated effects are not correct but they are treated as components of uncertainty. Some examples of this parameter can be:

- *As a standard deviation, in which case it is called a typical measurement uncertainty (or a multiple of it)*
- *As a semiamplitude of a range with a given coverage probability (Spanish Center of Metrology, 2012, p. 3. 4).*

The evaluation groups of the measurement accuracy are two types, called A and B.

- *Type A: The purpose is to identify the main sources of inconsistency in the measures.*
- *Type B: It can be associated with published and recognized values; to the value of a certified reference material; obtained from a calibration certificate; obtained from the accuracy class of a verified measuring instrument; etc.*

Identification of the main inconsistency sources in the measures is the purpose of the measurement uncertainty analysis.

Uncertainty of the results.

The definition of Uncertainty is the state of information deficiency and it is related to the understanding or knowledge of an event, its consequence or its probability (ISO 9000, 2015, page 29).

Industrial process generates product specifications with product tolerances based mainly on the product requirements. Product specifications also are due to the performance of the measurement machine of testing processes. These tolerances incorporate a contribution due to the uncertainty of the measurement and it would not be appropriate to make any additional concession for this uncertainty.

Due to this approach, it is important that the individual components of the machine operate within tolerances.

ibertest
Desde 1970

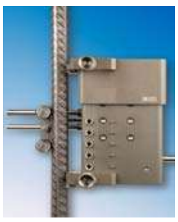
Oferta

Empresa	*UNIVERSIDAD POLITÉCNICA DE VALENCIA*	**Fecha**	13/04/2018
Dirección	E.T.S.I. Industriales Camino de Vera s/n Valencia	**Nº Oferta**	10-2018-134
Teléfono			
Contacto	*Javier Martínez Bea*		
e-Mail	jamarbe1@etsii.upv.es		
Su Ref.	--		
Nuestra Ref.	Fernando Alvir lfalvir@ibertest.es		

Pos.	Ref.	Cant.	Descripción	P. Unit. (€)	P.Total (€)
1		1	**IB-MT4-1000** Máquina universal, servohidráulica, para ensayos de tracción, compresión, flexión, cizalladura, etc, sobre materiales metálicos y no metálicos. Totalmente automática, con control en lazo cerrado y manejo por ordenador Capacidad: 1000 kN. Sistema de medida de fuerza: **célula de carga de alta precisión tracción-compresión** Clase 0,5 según EN ISO 7500-1 desde el 1 al 100 % de su capacidad. Mono espacio 4 columnas guías de acero endurecido Carrera del pistón: 600 mm. Transductor de desplazamiento: encoder Resolución 1µm Distancia libre entre columnas: 700 x 400 mm Distancia libre entre cabezales de tracción (incluyendo carrera del pistón): 700 mm Alimentación : Trifásica a 380 V + Neutro y toma de tierra. 50 Hz. *Otras alimentaciones bajo demanda.* ***Incluyendo:*** **Calibración en IBERTEST y emision de certificado por parte de nuestro laboratorio de calibración acreditado.**	87.188,00	**87.188,00**
2	121-101318	1	**Canal de extensometría** Para extensómetros con principio de medida basado en **bandas extensométricas** *NOTA: extensómetro no incluido* ***Accesorios incluidos***	Included	**Included**
3	--	1	**Sistema de protección de la electrónica de control.** Filtro para prevencion de perturbaciones en la red electrica de alta frecuencia.	Included	**Included**
4		1	**Cabina de protección del grupo hidráulico** Estructura en perfiles de aluminio Cerramiento en chapa de acero perforada y ciega en función de las necesidades de visibilidad y rerfrigeración	incluido	**Included**
			SOFTWARE-HARDWARE		
5	115-100003	1	**Software WinTest32** Diseñado para su uso en máquinas universales de ensayos para compresión, tracción, flexión, plegado, cizalladura, etc, sobre todo tipo de materiales: metales, plásticos, maderas, hilos, cuerdas, textiles, materiales compuestos, etc. Para trabajar bajo sistemas operativos Windows® de 32 bits y 64 bits. Desarrollado específicamente para máquinas universales de ensayos IBERTEST con las siguientes funcionalidades principales: · Configuración y programación de ensayos bajo norma · Desarrollo automático del ensayo con visualización en pantalla en tiempo real. · Generación automática de informes personalizables tras el ensayo. · Realización de cálculos indirectos automáticos · Herramientas de análisis de datos y estadísticas, · Generación de gráficos y exportación de datos a formatos ASCII o CSV, etc.	Included	**Included**

S.A.E. IBERTEST
Ramón y Cajal, 18-20
28814 Daganzo de Arriba – Madrid – España
Tel:+34 91 8845385
Fax:+34 918845002
info@ibertest.es - www.ibertest.com

ibertest

Pos.	Ref.	Cant.	Descripción	P. Unit. (€)	P.Total (€)
6	135-100080	1	**Ordenador de última generación tipo ALL in ONE: con pantalla tactil y sistema oper** *Con este ordenador de última generacion y pantalla táctil, podrán trabajar comoda e intuitivamente mediante su pantalla tactil o de forma "tradicional" mediante el teclado y raton incluidos.* ***Configuración mínima:*** - Procesador Intel i5® de cuarta generación. - 4 GB RAM. - 500 GB de disco duro SATA. - DVD+/-RW 8x. - Pantalla táctil de 19,5" con resolución 1600x900. - Windows 10 Profesional - Teclado y ratón inalámbricos. - Adaptador Intel® Dual Band Wireless-AC (WiFi) + Bluetooth	Included	**Included**
7	111-100573	1	**Mesa de control instrumentada** Incluye parada de emergencia y conexiones eléctricas para ordenador y periféricos	614,00	**614,00**
			ELECTRÓNICA DE CONTROL		
8	111-101333	1	**Sistema de control tipo MD2**. Principales características: Tiempo de cierre de bucle de control: 1 ms Frecuencia de muestreo : 1kHz (1000 lecturas/segundo) Resolución: 180.000 puntos reales Hasta 4 canales síncronos Conexiones a PC vía USB 2.0 o Ethernet	Included	**Included**
			UNIDADES DE CONTROL REMOTO (OPCIONAL)		
9	111-1000LM	1	**UCRB: mando para control remoto básico.** Permite movimiento del pistón . Apertura y cierre independiente de mordazas hidráulicas. Posicionamiento fijo en el marco de ensayos	Included	**Included**
			DISPOSITIVOS DE ENSAYO		
10		1	Cabezales de tracción hidráulicos IBHC-1000: con sistema de cierrre en cuña Capacidad máxima: 1000 kN.	Included	**Included**
			Superficie de amarre :100mm (longitud) x150mm (anchura) **Juego de portamordazas para las siguientes mordazas**	Included	**Included**
11		1	Mordazas planas para probetas de 0-45 mm de espesor y 0-10mm de diámetro	Included	**Included**
12		1	Mordazas en V para probetas cilíndricas Ø 10-30	Included	**Included**
13		1	Mordazas en V para probetas cilíndricas Ø 30-60	Included	**Included**
			EXTENSOMETRÍA		
14	121-100007	1	**Extensómetro axial modelo IB/MFA20**	3.559,00	**3.559,00**
			Altamente recomendado para ensayos sobre barras de acero corrugado Pinzable manualmente sobre la probeta. No precisa soporte externo. Principio de medida: bandas extensométricas Debe ser retirado antes de rotura. Clase 0,5 según EN ISO 9513 Base de medida Lo estándar: de 50 mm a 100 mm en pasos de 5 mm Máxima deformación medible: 20 mm Dimensiones de probetas: · Planas: desde 15 a 30 mm de anchura y desde 1 a 30 mm de espesor · Redondas: diámetros desde 4 a 30 mm Fuerza de actuación: 150 cN Peso 470 g		
			SERVICIOS		
15	115-100009	1	**Sistema de Telediagnosis para máquina IBERTEST en GARANTÍA** Mantenimiento a distancia "on line" a través de internet. Incluyendo cuota de alta en el servicio y 5 horas de conexión gratuita, a consumir durante el periodo de garantia de la máquina. Pasado este periodo puede solicitarnos cotizacion para la renovacion de este servicio. ***NOTAS***:	Incluido	**Free of charge**

ibertest

Pos.	Ref.	Cant.	Descripción	P. Unit. (€)	P.Total (€)
			Para garantizar un servicio de calidad, el usuario debe disponer de un servicio de ADSL con velocidad de conexión superior a 3 Mb. El control del tiempo consumido se computará mediante fracciones de 15 minutos.		
15		1	**Transporte, montaje y puesta en marcha** Trabajo a realizar por un técnico especialista de IBERTEST. **Incluye los siguientes servicios:** · Transporte hasta su laboratorio mediante camión, servicio concertado puerta a puerta. · Entrenamiento en el manejo del sistema (cursillo de hasta 4 horas de duración). · Certificado oficial de calibración en fuerza, según UNE-EN-ISO 7500-1, emitido por nuestro Laboratorio de Calibración Acreditado por E.N.A.C., realizado con instrumentos calibrados y con trazabilidad a patrones internacionales.		No incluido

CONDICIONES DE VENTA

Precios: NETOS en EUROS (€) para mercancía posicionada EXW Daganzo de Arriba (Madrid). IVA 21% no incluido, se cargaría en factura.

Plazo de entrega*: 60 días aprox, a partir de la recepción de su pedido en firme y de nuestra confirmación al mismo por escrito.
* El plazo de entrega será confirmado en el momento del pedido y estará sujeto a la carga de trabajo en nuestra fábrica.
** Agosto no incluido debido a cierre de fabrica por periodo vacacional.

Validez: 30 días

Forma de pago: A convenir

S.A.E. IBERTEST
Ramón y Cajal, 18-20
28814 Daganzo de Arriba – Madrid – España

Ph:+34 91 8845385
Fax:+34 918845002
info@ibertest.es - www.ibertest.com

V APPENDIX

Má

Precios pendulo Recibidos x

Javier M B
Buenas tardes. Gracias por su información. Como indique en anterior correo es.

Soto, Isidoro
para mí

Buenas Javier

Te comento precio incluyendo; instalación, software, formación, calibración y

Péndulo 750J 98.000€
Péndulo 450J 58.000€
Péndulo 300J 48.000€

Saludos / Best regards / Mit herzlichen Grüßen