Politechnika Wrocławska

Wrocław University of Technology

"Analysis of the composite manufacturing system based on pultrusion method and the evaluation of the behaviour of beams formed by this process"

Final Degree Project

Degree in Mechanical Engineering

Author: Javier Meléndez Abril

Directed by: Dr Grzegorz Lesiuk

Ana Maria Pedrosa Sanchez

May 2022

Summary

"Analysis of the composite manufacturing system based on pultrusion method and the evaluation of the behaviour of beams formed by this process."

The aim of the project is to analyse precisely the manufacturing system of composite materials based on the pultrusion method and to carry out a detailed study with the Solidworks programme of a beam formed with this type of material. Furthermore, it will be analysed different types of beam profiles and calculate different solutions for different boundary conditions to see exactly how this material behaves in different engineering applications in order to demonstrate all the advantages of this composite material obtained with this manufacturing system.

Streszczenie

"Analiza systemu wytwarzania materiałów kompozytowych w oparciu o metodę pultruzji oraz ocena zachowania się belek formowanych w tym procesie".

Celem projektu jest dokładne przeanalizowanie systemu wytwarzania materiałów kompozytowych metodą pultruzji oraz przeprowadzenie badań w programie Solidworks belki uformowanej z tego typu materiału. Ponadto przeanalizuję różne rodzaje profili belek i obliczę różne rozwiązania dla różnych warunków brzegowych, aby zobaczyć, jak dokładnie zachowuje się ten materiał w różnych zastosowaniach inżynierskich i zademonstrować wszystkie zalety tego materiału kompozytowego uzyskane za pomocą tego systemu produkcyjnego.

Resumen

"Análisis del sistema de fabricación de materiales compuestos basado en el método de pultrusión y la evaluación del comportamiento de las vigas formadas por este proceso".

El objetivo del proyecto es analizar con precisión el sistema de fabricación de materiales compuestos basado en el método de pultrusión y realizar un estudio con el programa Solidworks de una viga formada con este tipo de material. Además, se analizarán diferentes tipos de perfiles de vigas y calcularé diferentes soluciones para diferentes condiciones de contorno para observar exactamente cómo se comporta este material en las diferentes aplicaciones de la ingeniería, con el objetivo de demostrar todas las ventajas de este material compuesto obtenidas con este sistema de fabricación.

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Abbreviations and terminology

FRP	Fiber-reinforced polymer is a strong, lightweight building material that resists corrosion. It's made of a combination of materials that work together for even stronger performance.
GFRP	Glass Fiber Reinforced Polymer
CFRP	An acronym standing for carbon fibre reinforced polymer.
Accelerator	A chemical, usually zinc or cobalt 'soaps', or tertiary amines and sometimes called a promoter, which is added in small percentage to a mixture of thermoset resin and catalyst to speed up the curing reaction at room temperature.
Catalyst	An active reagent often called the hardener, promoter or curing agent which causes thermoset-based matrix resins to cure.
Fillers	These usually consist of fine inert powders which are inorganic in nature added in limited xviii percentage to the matrix to reduce costs. Under certain circumstances they may also enhance certain mechanical and physical properties. Fillers should not be confused with pigments or fire-retardant additives, although they may colour the resin and be advantageous to both properties.
Inhibitors	Chemical additives employed to prolong the storage or shelf-life of thermoset resins, disregarding whether the resin is accelerated or non-accelerated.
Matrix	The component of a composite which surrounds the reinforcement. It gives solid form to the finished component

	and confers its durability to the strength properties of that reinforcement.
Polymerisation	A crosslinking process, building long-chain molecules.
Thermoplastic	Matrices that are capable of being repeatedly softened – and therefore reworked – by an increase in temperature, being restored to the original condition when the temperature is reduced.
Thermoset	Matrices which once changed by polymerisation from the initial viscous liquid condition, become an irreversible, infusible and environmentally resistant insoluble solid.
Anisotropic	Not isotropic, having different properties along axes in different directions.
Elastic limit	Denotes the highest stress, or load, that a laminate is capable of sustaining without permanent stress remaining once that load is released.
Isotropic	Having uniform mechanical properties in all directions
Modulus	A measure of the stiffness or rigidity of a material which is independent of the geometric shape of the component. The numerical value is obtained by dividing the stress by the strain, when a specimen is loaded within its elastic limit.
Composite	A material consisting of two or more different constituents which retain their identity, when combined together to provide properties unobtainable with either constituent separately

Cure	A layperson's term for the time/temperature related molecular crosslinking process, known more correctly as polymerisation, which changes a thermosetting resin from the liquid to solid state, following chemical activation by a catalyst, and an irreversible reaction possibly promoted by the addition of an accelerator
Post-cure	The additional processing of a composites component at an elevated temperature (typically 40–80 °C for several hours, in the case of glass/polyester-based formulations) to ensure a complete theoretical development of the molecular crosslinked structure or cure (polymerisation), of the resin matrix. By this means the full mechanical and physical properties applicable to the particular resin matrix employed are attained.
Release agent	Aqueous or solvent-based polymers, applied by brush or spray to the mould-tool surface, which on drying act as parting-agents to ensure a clean, easy and undamaged removal of the moulding.
Wet-bath	A suitably sized tank holding liquid resin through which the reinforcement passes and during which that reinforcement becomes impregnated with that resin matrix.
Continuous filament yarn	The fibre formed when two or more continuous filaments are blended together into a single continuous strand.
E-glass	A glass fibre developed to have high resistivity and therefore suitable for electrical laminates, which has become the standard reinforcement for the vast majority of commercial components manufactured by the composites industry.

Fibre	Material in the form which has a high length-tothickness ratio and is characterised by flexibility and fineness
Fibreglass	The generic name for typically glass fibre reinforced/ polyester resin composites, although more correctly it refers to glass fibre insulation material.
Reinforcement	Refers to that unchanged, unalloyed portion of the homogeneous composites moulding, which being of a fibrous nature, adds strength to the matrix in which it is subsequently encapsulated.
Roving	An untwisted assemblage of strands.
Yarn	A twisted bundle of strands.
Yield point	The yield point is the point on a stress-strain curve that indicates the limit of elastic behaviour and the beginning of plastic behaviour
Creep	Ratio between stress and total strain after a given time

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1.Project objectives

The aim of this project is to analyse precisely the manufacturing system of composite materials based on the pultrusion method and to carry out a detailed study of different beam profiles against different boundary conditions to show how they behave and to demonstrate the characteristics and advantages that this material and this type of beam could offer to engineering.

1. Accurately analyse the pultrusion manufacturing system.
2. Analyse the different materials (fibres and resins) used in the pultrusion manufacturing system.
3. Evaluate the behaviour of pultruded beams using solidworks.
4. To compare the behaviour of pultruded beams with the common beams used so far in engineering.
5. To present all the advantages offered by this composite material and why we should use it more often in engineering.

2. Introduction

History

When we combine two or more elements we get a composite. The earliest recorded uses of composite materials date back to 1500 BC, when Egyptian and Mesopotamian settlers used a composite of mud and straw to construct best featured buildings.

Later, in 1200 BC, the Mongols invented the first composite bow, which was made of wood, bone and ‘animal glue’. These bows were more accurate and stronger than the earlier ones and enabled the Mongols to secure the military rule of Genghis Khan.

Reasons for using composites

There are many reasons for the wide acceptance of composites by the professional architect, civil and consulting engineer, designer, purchase manager, specifier and other disciplines serving, for example, the aerospace, agricultural, defence, domestic, engineering, industrial, infrastructure, leisure and marine market sectors.

In the following, it will be presented the most outstanding properties of FRP composites:

- High strength at low weight
- Good impact, compression, fatigue and electrical properties
- Excellent environmental resistance
- Ability to fabricate massive one-piece mouldings
- Cost-effective manufacturing processes
- Ability to build in, ex-mould tool, both colour and texture decoration
- Excellent chemical and corrosion resistance
- High ultraviolet radiation stability
- Good-to-excellent fire hardness
- Good structural integrity
- Good thermal insulation
- Ability to attenuate sound
- Respectable abrasion resistance

While all of these features are very good for engineering in general, there is one that stands out above the rest, its adaptability to almost any environment. It means that the physical, mechanical and economic properties of any reinforced plastic composite can be tailored over a wide range to fully meet the required performance specifications.

FRP composites for the construction

FRP composites are made up of reinforced fibres, resins and fillers. Each of these materials plays an important role in the process and in the final product.

In summary, the reinforcing fibres provide the mechanical stress and the resin or polymer functions as a glue, holding the composite together and providing physical properties to the final product. On the other hand, filler materials and additives are used in the process to give special properties to the final product.

Fabrication techniques

In total, there are some 20 well-established techniques, and depending on which one we choose, the quantity, economy, dimensions, shape complexity and mechanical/physical property performance specifications required by the customer for a particular component or application will be met. It will be briefly discussed some fabrication techniques.

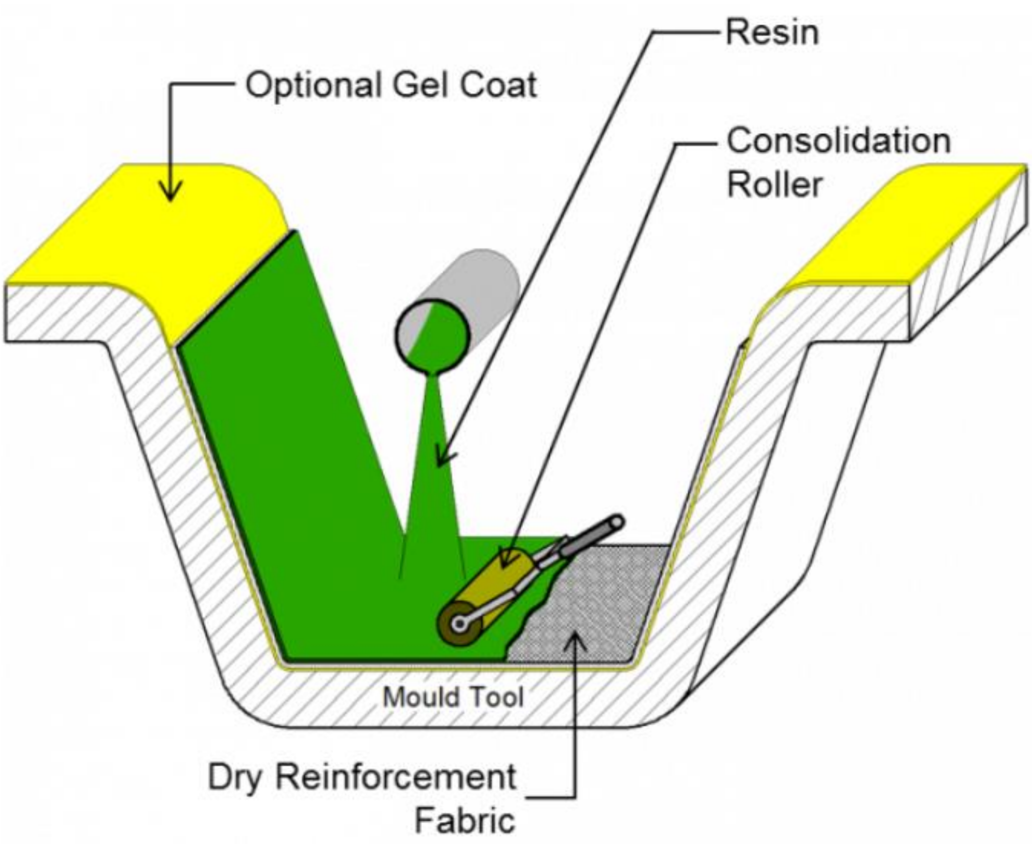


Figure 1 Contact moulding process

Contact moulding is a process, which uses a rigid one-sided mould that imparts the surface finish to one side of the component. The thickness of the composite product is determined by the amount of the composite layers deposited.

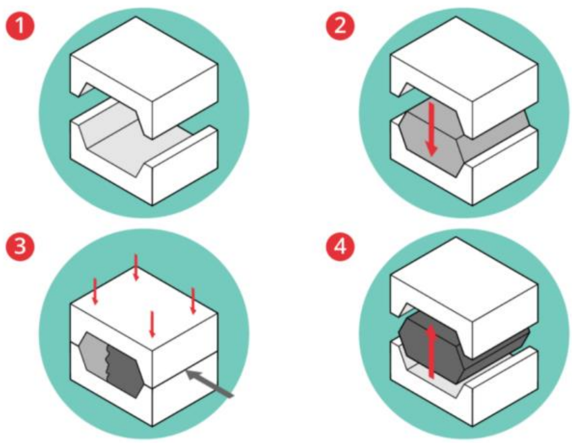


Figure 2 Resin injection process

Resin injection transfer moulding (RTM) is a closed-mould process for manufacturing high performance composite components in medium volumes. Moulds typically consist of matched metal tools into which a dry fibre preform is inserted. The mould is then closed and clamped shut before pumping resin into the tool cavity to thoroughly wet-out the fibres. The tool will often be heated to assist with the curing of the resin. Once the resin is cured, the tool can be opened and the part removed.

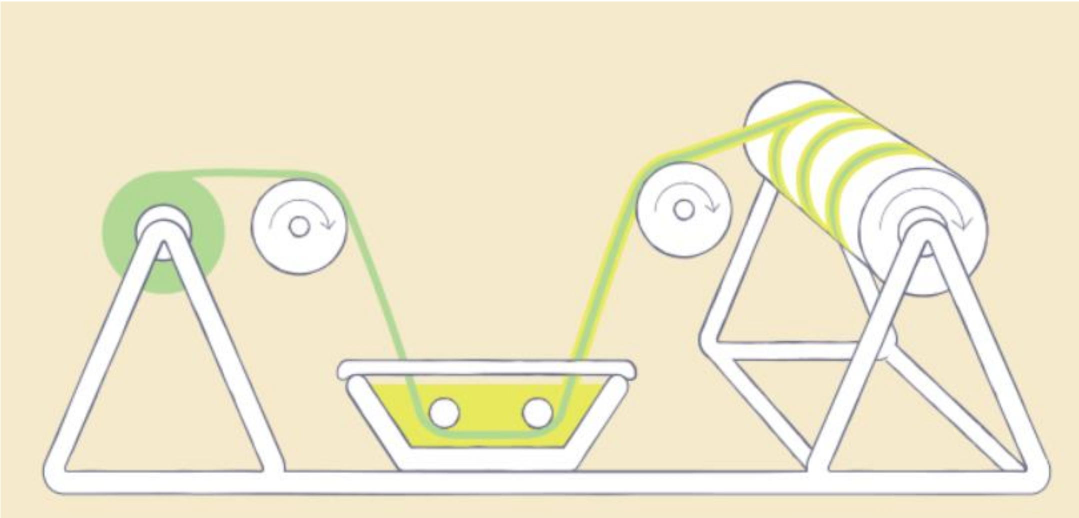


Figure 3 Filament winding

Filament winding results in a high degree of fibre loading, which provides high tensile strength in the manufacture of hollow, generally cylindrical products such as chemical and fuel storage tanks, pipes, batteries, pressure vessels and rocket engine casings. This process allows the production of laminates with a high strength-to-weight ratio and provides a high degree of control over the uniformity and orientation of the fibres. The filament winding process can be used to manufacture highly engineered structures to tight tolerances. Because filament winding is computer-controlled and automated, the labour factor of filament winding is lower than other open moulding processes.

The pultrusion market-place and his future

In particular, pultruded profiles have a much wider field of application than traditional materials such as wood, steel, aluminium and reinforced concrete due to their properties, although their future will depend on many things, above all on their acceptance in engineering. That means it is difficult to change traditions in some people or areas, because it is rare that if you, as an architect, have always used the typical beams, now, you change and incorporate a new material into your field that has not been used enough, which means that there are no real results of the behaviour of pultruded profiles over the years, only results of the tests that the beam has to pass to be used.

There is a process, and in the beginning, all new things in engineering have to go through a time where they are questioned and discussed and where engineers and architects think two times before they are used. Pultruded beams are at this stage, where there are some projects but not enough to really trust. Gradually people will start to rely more and more on these composite materials as their capabilities are proven over the years. To improve the implementation of pultruded beams, first the government has to introduce the knowledge of pultruded profiles in the different degrees of engineering and architecture. It is also recommended that engineers who are familiar with this process write books and disseminate knowledge and research on this subject in order to improve its use in the future.

Talking about the market for pultruded materials, we can say that there are many fields of application. Construction is in terms of volume the area that can benefit the most from this method although it has always been seen as an area where it is difficult to penetrate.

In all areas where we need corrosion resistance we should consider the use of this composite material because these composites have no metals, therefore they do not corrode. In addition, pultruded materials are interesting in the field of electricity because they have great electrical insulating qualities.

Finally, the use of these composite materials in all types of transport has to be considered. They can be useful in sea, land and air transport. Pultruded beams can be useful for example in the structure of a large ship, in the construction of a luggage compartment in a bus or for transporting large amounts of weight in a lorry. They are also very useful in the aerospace sector because pultruded elements are able to withstand high forces despite their light weight.

2.1 Definition of pultrusion method

Pultrusion is a continuous and highly automated process for manufacturing composites with constant cross-sections and this composites are composed of resin, fibres, additives and filling.

The reinforcements are pulled through a resin bath or wet-out where the material is thoroughly coated or impregnated with a liquid thermosetting resin. The resin-saturated reinforcements enter a heated metal pultrusion die. The dimensions and shape of the die will define the finished part being fabricated. Inside the metal die, heat is transferred initiated by precise temperature control to the reinforcements and liquid resin. The heat energy activates the curing or polymerization of the thermoset resin changing it from a liquid to a solid. The solid laminate emerges from the pultrusion die to the exact shape of the die cavity. The laminate solidifies when cooled and it is continuously pulled through the pultrusion machine and cut to the desired length.

2.2 Materials

The purpose of resins is to dissipate loads to the fibre network, maintain fibre orientation, protect the fibre network from harmful environmental conditions such as humidity and high temperature, and also depending on the resin used we have to apply some parameters or others.

When we talk about parameters, we refer to conditions such as temperature, speed, pressure and other parameters to effectively cure the resin to finally obtain a quality product.

There are two main types of polymers used in this field, thermoplastic polymers and thermosetting polymers. The first ones soften, melt and flow when heated, the second ones don’t flow when heated. One of the strengths of composite design is the multiplicity of choices of both polymer types and forms of reinforcement to suit the design.

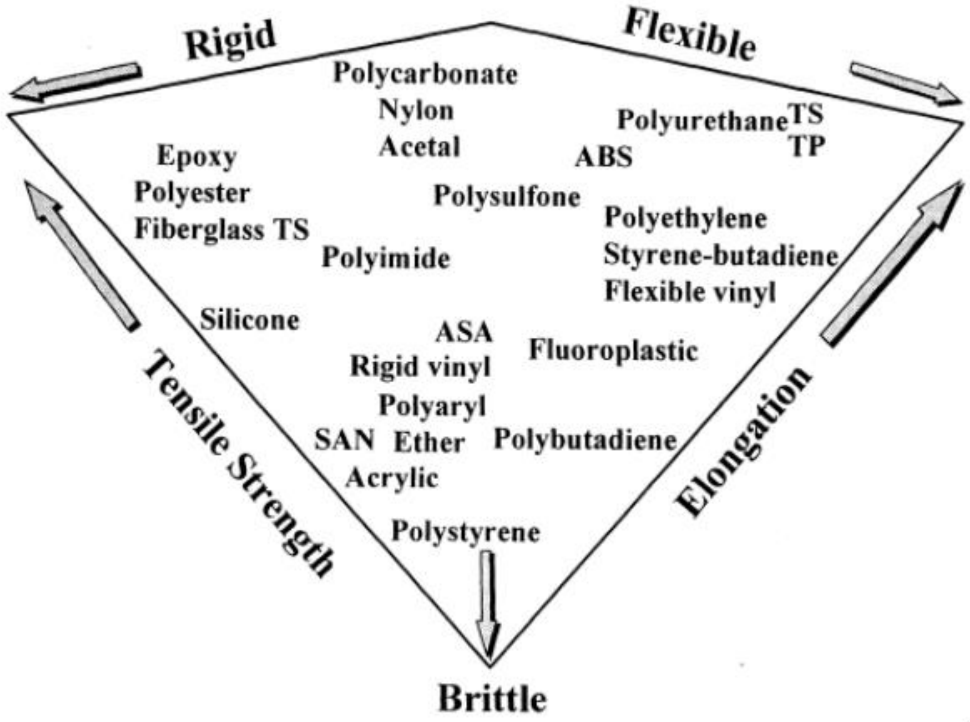


Figure 4 Polymer Scheme

2.2.1 Different resins, how to obtain them and its performances

Phenolic resins

The phenolic resin is a particular class of thermosetting resin made through the condensation of phenol (or phenol derivative) with an aldehyde.

Thermosets, such as phenolic, are fragile at room temperature. Therefore, in applications where good mechanical properties are required, thermosets must be combined with reinforcements to improve these properties.

In fact, composites based on thermoset matrix can replace steel and concrete in some structural engineering applications due to their higher resistance to oxidation than steel and better freeze-thaw than concrete, and moreover phenolic composites can be produced in different and complex shapes. Other reasons for using this material instead of more traditional materials such as metals is that it can be obtained with high strength, stiffness and excellent impact resistance, as well as being able to handle high temperatures and produce little toxic fumes.

In conclusion, the impacts of phenolic compounds on our lives are positive because they can improve safety and reduce costs.

Polyester resins

Metals, ceramics, composites, polymers and other materials have been used as building materials and their availability has enabled human civilisation to increase its standard of living in many ways. In general, composite materials have improved engineering constructions and polyester resins play an important role.

Thermoplastics and thermosets can be manufactured by polycondensation, polyaddition and polymerisation, and in the case of polyesters, which are thermosetting compounds, they are usually synthesised by polycondensation reactions.

Polycondensation or step polymerisation is often used for the production of adhesives, coatings, engineering plastics, fibres, films and many high performance polymers. Polycondensation is the process of forming polymers by combining different monomers and the process is usually accompanied by the release of various low molecular weight by-products (water, alcohol, salt). For polycondensation, the following monomers are characteristic: compounds with molecules of at least 2 functional groups. They are usually divided, for convenience, into three groups:

- Identical functional groups which do not react with each other (diamines)
- Different functional groups that can react with each other and thus form polymers (amino acids)
- Identical functional groups that can react with each other, forming simple polyethers.

Polyaddition is a polymerisation reaction that forms polymers through individual and independent addition reactions. Polyaddition occurs as a reaction between functional groups in molecules with low degrees of polymerisation, such as dimers, trimers and oligomers, to form higher molar mass species.

Polymerisation, is any process in which relatively small molecules, called monomers, combine chemically to produce a very large molecule in the form of a chain or network, called a polymer. The monomer molecules may all be the same, or they may represent two, three or more different compounds. Typically, at least 100 monomer molecules must be combined to produce a product that has certain unique physical properties such as elasticity, high tensile strength, or the ability to form fibres that distinguish polymers from substances composed of smaller, simpler molecules; often many thousands of monomer units are incorporated into a single molecule of a polymer.

Fibre-reinforced polymer composites (FRP) are structural materials that use a polymer as the matrix overlying the reinforcements and it must be said that without these reinforcements (fibres), the polymer would offer relatively poor mechanical properties. There are three main ways of incorporating the reinforcement material (as granular material, as fibres and as layers).

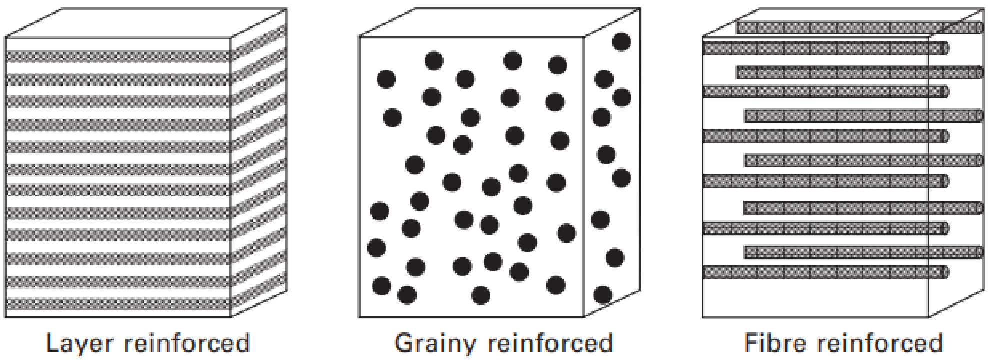


Figure 5 How to incorporate the reinforcement to the polymer

The role played by the reinforcement materials is to provide strength and stiffness to the composite, on the other hand we have the matrix material, which in this case is a polymer that is responsible for covering the reinforcement, preventing wear of the fibres and fixing them in the correct position and also the matrix material distributes the load efficiently.

These composite materials have a peculiarity; they have an anisotropic structural behaviour. This means that they behave differently to loads in different directions in space, and this should facilitate the design of suitable products and structures; however, an adequate knowledge of the strength distribution lines is a prerequisite.

One of the advantages of thermosets is that, before they are moulded, they are liquids with low viscosity, which means that high pressure is not required to process them; furthermore, their processing costs are relatively low. But one of their main disadvantages relates to their reprocessing, as the specific properties of thermosets make them difficult to reprocess by mechanical or chemical recycling.

By way of background, polyester is one of the earliest types of thermosets and is widely used in FRP composites, where its thermosetting properties are very valuable. Between 2000 and 2008, polyester manufacturing in Europe increased rapidly, with an annual increase of 4-5%.

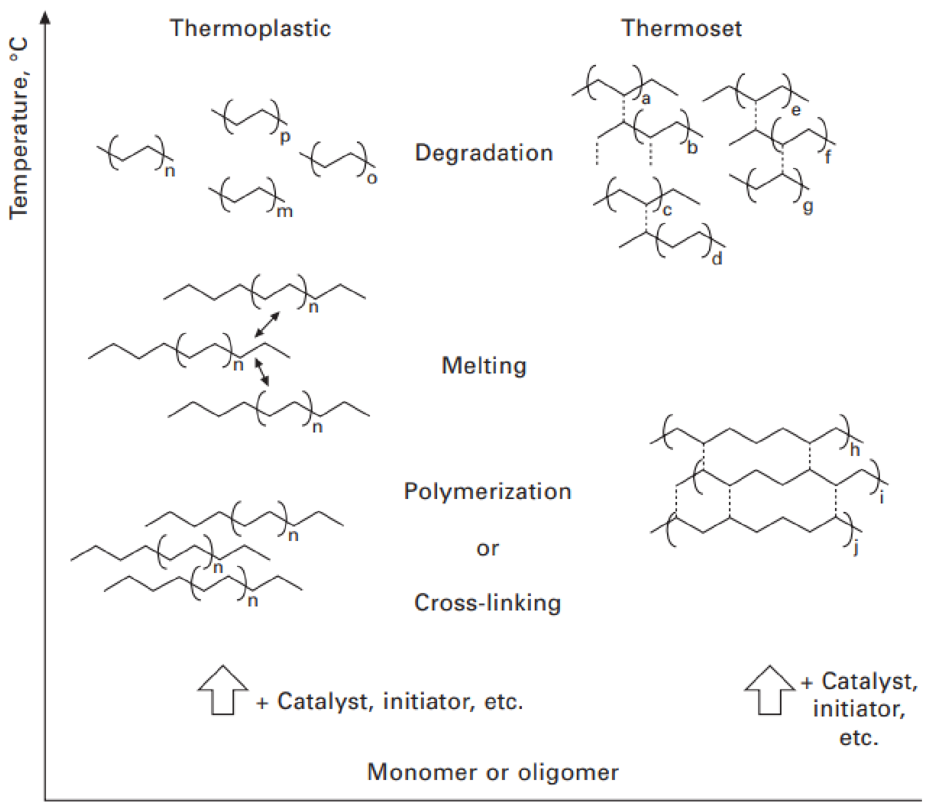


Figure 6 The behaviour of thermoplastics and thermosets against heat

Talking now about the manufacture of polyester-based composites, it is necessary to mention the different methods that exist for their manufacture: hand lay-up, filament winding, sheet moulding, prepreg moulding, resin transfer moulding, vacuum-assisted moulding and pultrusion.

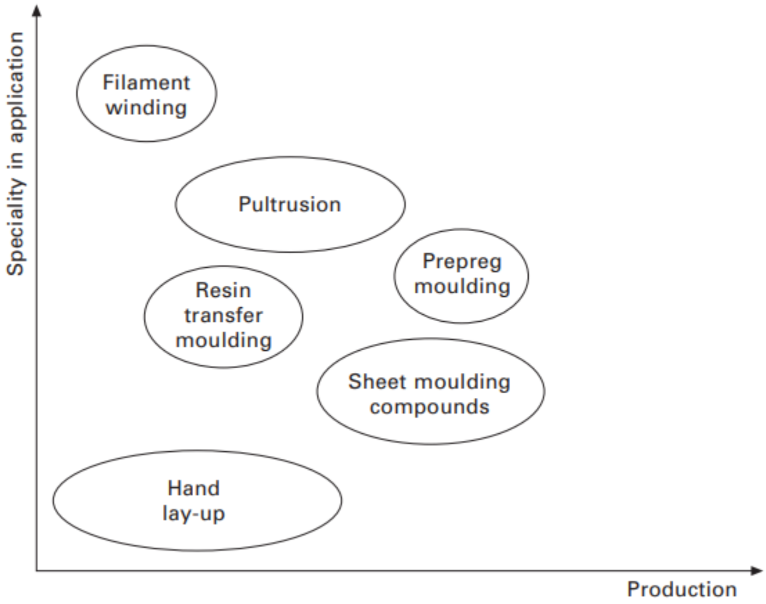


Figure 7 Polyester manufacturing processes

Although there are many methods, it will be explained the pultrusion method for the manufacture of polyester-based composites.

Pultrusion is effectively the only continuous manufacturing method for thermoset composites that allows the production of complex shapes. In the process, the reinforcements are impregnated with a resin that has a particularly low viscosity, and are pulled through a matrix heated to a temperature of 110-160°C, which is the point at which curing reactions occur, and the fibres are permanently tensioned in the direction of the axis during curing. The profile making machines have a speed of 1.5-60 m/h and the die must be subjected to several execution steps at different temperatures, leading to a die length of up to 1.5 m in the case of U- or C-profile production. The profiles have a very high tensile and bending strength only in the axis direction; the critical property is therefore the stiffness and strength in the transverse direction.

Polyesters and their compounds are mainly used in transport, in the shipbuilding industry and in structural materials.

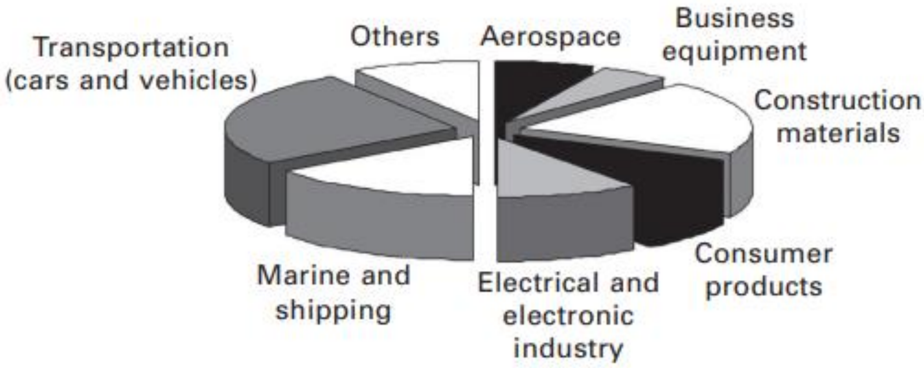


Figure 8 The application of polyester composites in 2009

Vinyl ester resins

In the following, it will be discussed the use of vinyl ester resin as a matrix in polymer composite materials used in civil engineering applications.

The main polymers used in construction are epoxies, vinyl esters, unsaturated polyesters and phenolics. Currently, unsaturated polyesters are the most widely used polymers in construction because they are low-cost materials, easy to process and cure at room temperature.

Vinyl esters are unsaturated esters of epoxy resins and offer similar mechanical and in-service properties as epoxy resins and more or less the same processing techniques as polyester. Due to the lower number of cross-links, a cured vinyl ester resin is more flexible and has a higher fracture toughness than a cured polyester resin, this is the main difference. In addition, vinyl ester has good wetting characteristics and adheres well to glass fibres. In addition to mechanical and chemical properties, they have high acid and alkali resistance, and compared to polyesters, vinyl esters offer lower water absorption and contraction, as well as higher chemical resistance. In fact, vinyl ester resins are commonly used in many applications requiring chemical resistance, such as air and water pollution treatment.

Vinyl ester resins are increasingly used in the construction industry, where special resistance to corrosion and, in general, to exposure to the service environment is required. This justifies the large-scale use of vinyl ester for repair and maintenance purposes, and for the replacement of damaged parts such as bridge decks. Most structural applications, especially in the field of bridge construction, using vinyl ester resin composites are made by pultrusion and are therefore designed and assembled using relatively simple geometric profiles. In this respect, the resins are modified to ensure sufficient strength of the resulting part and effective completion of the curing process.

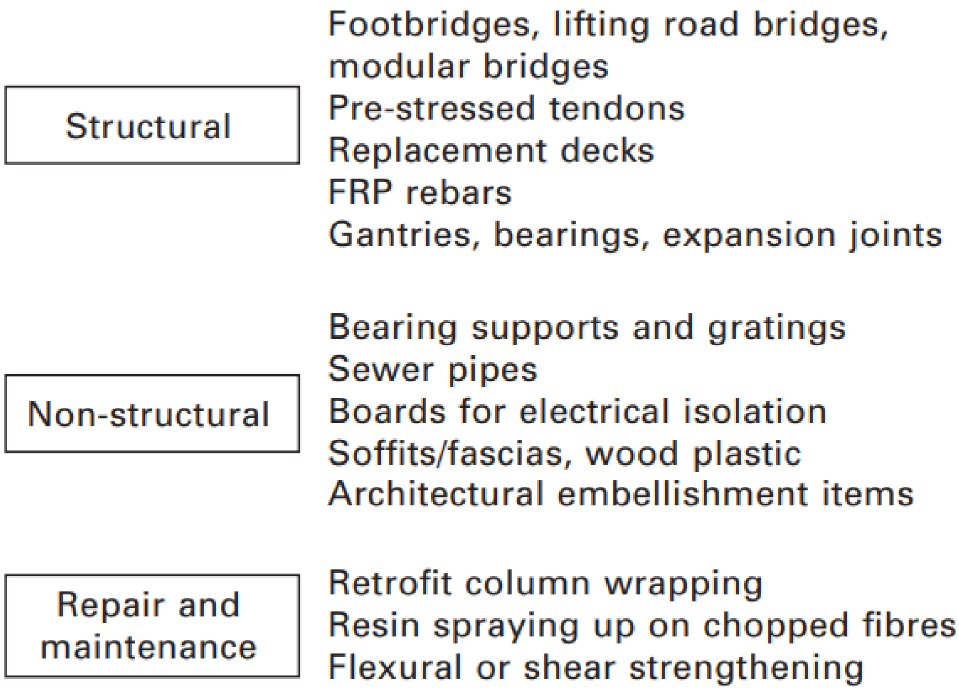


Figure 9 Applications of vinyl ester resin and composites in the construction industry

Epoxy resins

Here it will be discussed epoxy resins as a matrix material in advanced fibre-reinforced polymer (FRP) composites. Epoxy resins have good and versatile properties which I will discuss and demonstrate why it is today considered one of the most important classes of thermosetting polymers.

Although its price is initially more expensive than other matrix materials, this is not the case, because the cost-performance of epoxy is simply excellent. The good performance is due to its better mechanical properties and its higher resistance to humidity absorption and resistance to liquids and corrosive environments than other thermoset polymers, and another excellent property of epoxy is its high electrical resistance and good performance at elevated temperatures. A positive feature is its low contraction during the curing process compared to polyester and vinyl ester resins which retraction is up to 12%.

Finally, the best property of epoxy as a resin is its versatility. It is possible to adapt the final product to a wide number of physical, mechanical and processing properties by modifying the mix of the resin system or by adding specific agents, for example if we need a higher heat resistance we can modify the resin or add some agents to further improve that characteristic.

Curing is defined as the process where properties are changed through chemical reactions, and in the case of epoxy, it consists of two parts, the resin and the hardener. One-part epoxy systems also exist, especially those used in the aerospace and automotive industries. In summary, each epoxy resin contains reactive groups called epoxy groups or rings, and the number of epoxy rings contained in the epoxy resin molecules determines the heat resistance and toughness of the solid state. Basically, the properties of the solid depend directly on the number of epoxy rings it contains, because if it has more rings in the same space, we can say that the density is higher and this conditions some physical properties. In general, tensile modulus, glass transition temperature and thermal stability, as well as chemical resistance, improve with increasing cross-link density, but deformation to failure and fracture toughness are reduced.

The most common epoxy resins are: diglycidyl ether of bisphenol-A epoxy, diglycidyl ether of bisphenol-F epoxy, tetraglycidyl methylene dianiline epoxy, polynuclear phenol epoxy, hydantoin epoxy and epoxy phenol novolac.

The only weak point of epoxy resins is their fragile behaviour, and small amounts of liquid rubbers with highly reactive terminal carboxyl groups are often used to improve this characteristic. But an interesting feature of epoxy resins is their optical properties and over time it has been possible to improve the refractive index of these resins to high levels.

Thanks to its good properties and mainly its versatility, today epoxy resins find application in the following main fields: coatings, electrical and electronic insulation, adhesives and construction and as a matrix for FRP in automotive, nautical and aerospace applications.

Acrylic resins

Finally, it will be presented information about acrylic resins or MODAR which is the trade name given by a UK company.

MODAR resins are basically a urethane-methacrylate prepolymer dissolved in methyl methacrylate monomer which has good characteristics such as low viscosity and high reactivity, two properties of particular importance in the context of pultrusion processing of composites. This means that by using MODAR systems we can obtain high productivity rates in profile manufacturing.

Additional features such as high surface finish quality and toughness can be highlighted, which allow the full potential benefit of the reinforcement to be realised. So we can say that it can develop good mechanical performance and very useful in some applications that we will discuss later.

There are four different grades of MODAR resin which give slightly different characteristics to the final product and these are the low profile grade 826HT, grade 855, grade 865 and grade 835.

The volume fraction, type and configuration of the reinforcements depend on the final mechanical performance required. And in the case of MODAR resins, they can accommodate a wide variety of glass, carbon and aramid reinforcements.

MODAR resins have an advantage in that they can be easily processed on standard and conventional pultrusion machines, but the only thing we have to be more careful about is to limit the distance between the wet bath and the die entrance in order to minimise the evaporation of the MMA monomer.

Within the mechanical properties of pultruded profiles, the fibres are dominant in the final properties of the profile, but if the MODAR resin, has good quality, it provides excellent wetting of the reinforcement due to their low viscosity, which facilitates compatibility between them, resins and fibres, and helps to realise the full potential benefit of the glass reinforcement.

The ability of this resin to provide high productivity, excellent fire safety, very good mechanical performance and high quality surface finish of the profiles has led to its successful use in a number of major projects.

2.2.2 Different fibres and its performances

The mechanical properties of a FRP composite are mainly dependent on the type, amount, and orientation of fibre and also of their ability to adapt with resins.

Aramid fibre (AFRP)

Aramid fibre was developed in 1965 by Du Pont, whose trade name is Kevlar. It is a fantastic material with very good features and performance, but with high costs and manufacturing difficulties that have prevented its increased use in our lives.

Its good characteristics come from its high strength, high tenacity, medium-high modulus and very low density. It is also resistant to low and high temperatures, from -40ºC to 180ºC and is resistant to electricity.

But the best characteristics come from its good behaviour in spite of its low density, that’s means its good strength-to-weight and stiffness-to-weight ratios. In fact, it has such good characteristics at low density that it is used as armour or ballistic protection.

It is expected to grow further in the coming years with improved manufacturing techniques as it can be a major advantage in engineered products.

Carbon fibre (CFRP)

Although carbon fibre was originally not widely used due to its high price, today it is increasingly used in engineering due to recent changes in production process developments and general improvements in the industry that have improved its price to make it more competitive with other materials.

Carbon fibre is a fibre made up of thin filaments 5-10 µm in diameter and composed mainly of carbon. Its properties are close to steel, in fact it has more impact resistance than steel, and it is as light as wood or plastic.

It has several applications and one of them is that it can be used as a small percentage in additions to a glass-reinforced profile, and improve the stiffness performance of that pultruded profile.

Fibre	Density (g/cm^3)	Modulus (GPa)	Strength (GPa)	Specific modulus (Mm)	Specific strength (Mm)
PAN HM 45	1.9	441	1.76	23.2	0.093
PAN HMS	1.86	370	2.75	19.9	0.148
PAN T300	1.76	230	3.2	13.1	0.182
PAN T650/42	1.79	290	4.83	16.2	0.270
Pitch P25W	1.9	160	1.4	8.4	0.074
Pitch P55	2.0	380	2.1	19.0	0.105
Pitch P100	2.15	724	2.2	33.6	0.102

Table 1l Properties of carbon fibre for composites

Glass fibre (GFRP)

Glass fibre is one of the strongest and most versatile materials. In fact, glass fibre (GF) reinforced thermoplastics are used for products where low weight, low cost and high thermo-mechanical properties are required. Glass fibre is the most widely used type of fibre to reinforce thermoplastics, mainly because it increases tensile properties, stiffness and strength and, as I mentioned before, it is one of the cheapest fibres and this justifies the fact that we can find glass fibre in most pultruded profiles.

The amount of fibres matters, and this is justified because research shows that modulus and strength increase with increasing fibre content. To manufacture glass, it is formed by first mixing and then melting together a series of common undifferentiated inorganic minerals.

	A	C	D	E	ECR™	R	S
Density (g/cm^3)	2.46	2.46	2.14	2.57	2.71	2.55	2.47
Fibre modulus (GPa)	73	74	55	72.5	72.5	86	88
UTS (MPa)	2760	2350	2500	3400	3400	4400	4600
Strain to failure (%)	2.5	2.5		2.5	2.5	3	3
Refractive index		1.451	1.47	1.555		1.541	1.524
MoH hardness				6.5			6.5

Table 2 Physical and mechanical properties of a different glass fibres

Basalt Fibre Reinforced Polymer (BFRP)

Basalt fibres are produced by melting basaltic volcanic rocks at a temperature of almost 1400°C and is the latest discovery in the FRP world in terms of fibres and has no less potential than the other fibre types, but it has been less studied and therefore we do not know exactly its full potential.

This bars offer many favourable properties, such as high temperature resistance and favourable behaviour in an acidic environment, high tensile strength and also ease of fabrication. Basalt fibre reinforced polymer bars can be 2.3 times stronger or more, in terms of ultimate strength, than traditional steel reinforcement, however, the modulus of elasticity of traditional steel can be 3.5 times or more than BFRP.

The amount of basalt fibre in BFRP bars is not standardised, but the most commonly used fibre content is in the range of 75% to 90% and the most common resin used in this type of bar is vinyl ester and isophthalic polyester.

As part of the pultrusion process, there is another method of manufacturing BFRP bars called wet-layup, which offers the same mechanical properties as the pultrusion process.

2.3 Fibre reinforced polymers composite in structural engineering

High-performance fibre-reinforced composite (FRP) materials have been widely used in many fields such as architecture, civil engineering or aerospace engineering due to its light weight, high strength, corrosion resistance and design capability. Moreover, due to its superior mechanical and physical properties, it has been widely used in the reinforcement of components and structures, especially in post-earthquake structural repair, although the cost is relatively high in the initial stage, in the later stage of maintenance, the cost is low, so as a summary we can say that pultruded profiles are advantageous in all fields because they provide better results for longer time, which in general terms means less economic costs.

2.3.1 Main properties of pultruded products in structural engineering

Properties

In other points it has been commented the different properties of pultruded profiles and pultruded products in general, but now it will be explained extensively all the properties, good and bad, that have so far been demonstrated and used in different engineering fields.

→ Constant quality and dimensional stability: ease of repair and low tolerances.

→ Low weight: these materials are up to 75% lighter than steel and 30% lighter than aluminium, making them an important alternative when weight reduction is required.

→ Good strength and stiffness with less density. A pultruded composite is stronger and stiffer than steel, simply by making variations in the type and orientation of the reinforcements.

→ Good surface finish.

→ High chemical and corrosion resistance.

→ Good thermal and electrical resistance, they are not electrically conductive and have a thermal conductivity 250 times lower than aluminium and 60 times lower than steel.

→ Maintenance free, due to their excellent anti-corrosion properties these materials do not require any maintenance.

→ Easy design and installation due to their light weight.

→ Magnetic and radio frequency transparent making them ideal for antennas.

→ Flame retardant properties.

→ High creep and fatigue resistance.

Among the disadvantages it’s necessary to name:

→ High difficulty in manufacturing parts that are not one-dimensional and with a constant cross-section.

→ The need for a high-performance (and therefore very expensive) mould with a good finish to avoid future problems in the process, such as preventing the piece from advancing in the process, for example.

→ The speed of the process is relatively low.

→ Problems of adhesion between parts due to the fine surface finish. To obtain high quality joints it is necessary to first prepare the joint through a mechanical and chemical process or to add a peel-ply at the mould entrance.

→ For highly unidirectional pultruded profiles, mechanical joints with high structural requirements are not possible.

Test methods to evaluate the performance of FRP profiles

For evaluating the behaviour of the pultruded profiles before to use them in the real live, it is necessary to expose this profiles to the more difficult conditions, to see and evaluate which would be their performance with a specific boundary conditions. For analyse the performance of the profiles and be sure that the different pieces or buildings are going to support the worst boundary conditions that it can be given in the real live, each profile is analysed with the next procedures.

The main procedures to obtain numbers which allows us to do the correct calculations and therefore the correct dimensioning of the profiles and the materials used are the tensile tests, charpy impact tests, three-point bending test, scanning electron microscope, dynamic image analysis and X-ray micro tomography analysis.

Projects developed with FRP

Figure 10 Construction of a bridge made of FRP composites

In 2015, Warszawa. It was constructed the first Polish road bridge made of FRP composites. It is the longest single-span bridge of its kind in the world

Figure 11 Tank for store corrosive elements

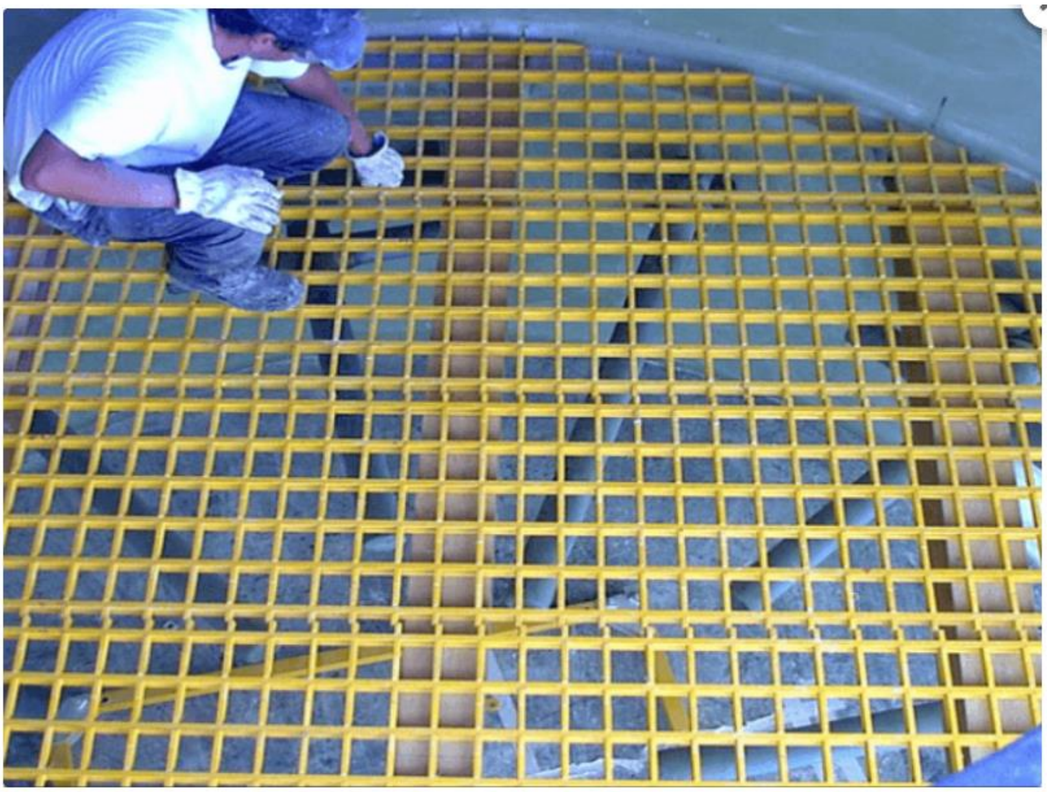


Figure 12 Floor grill in FRP

Figure 13 FRP structure

Figure 14 High chemical resistance FRP pipe

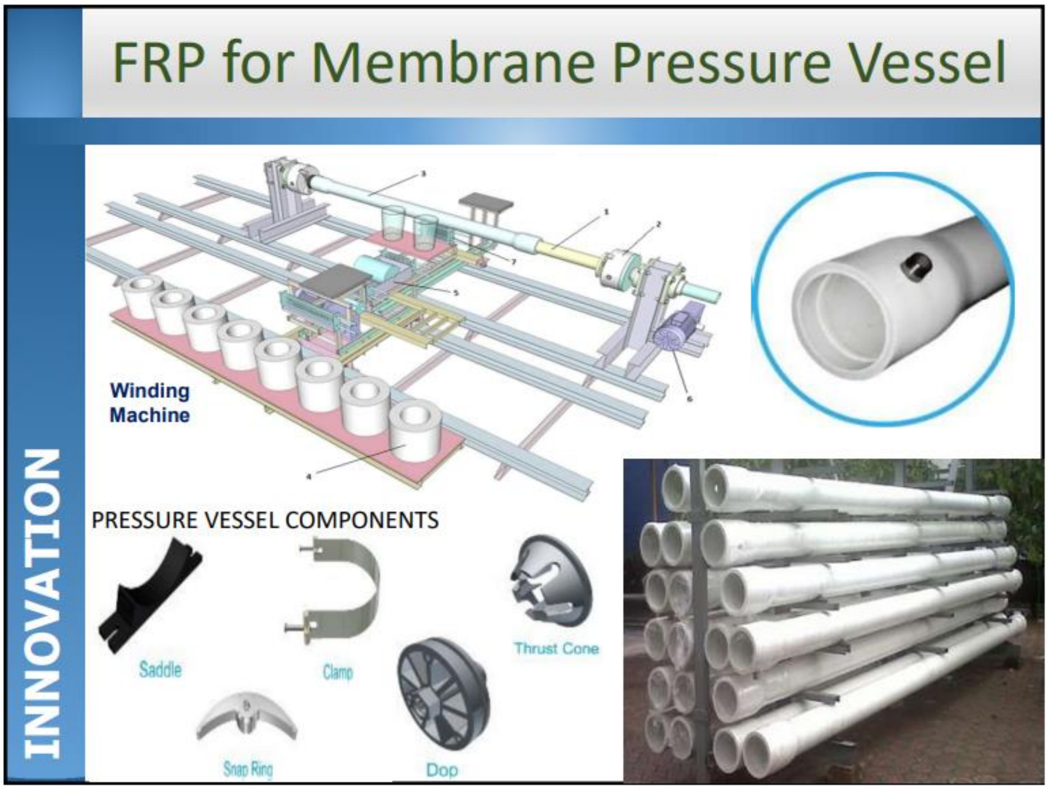


Figure 15 FRP for Membrane Pressure Vessel

Figure 16 Typical airport approach lighting assemblies (Courtesy, Exel Oy, Finland)

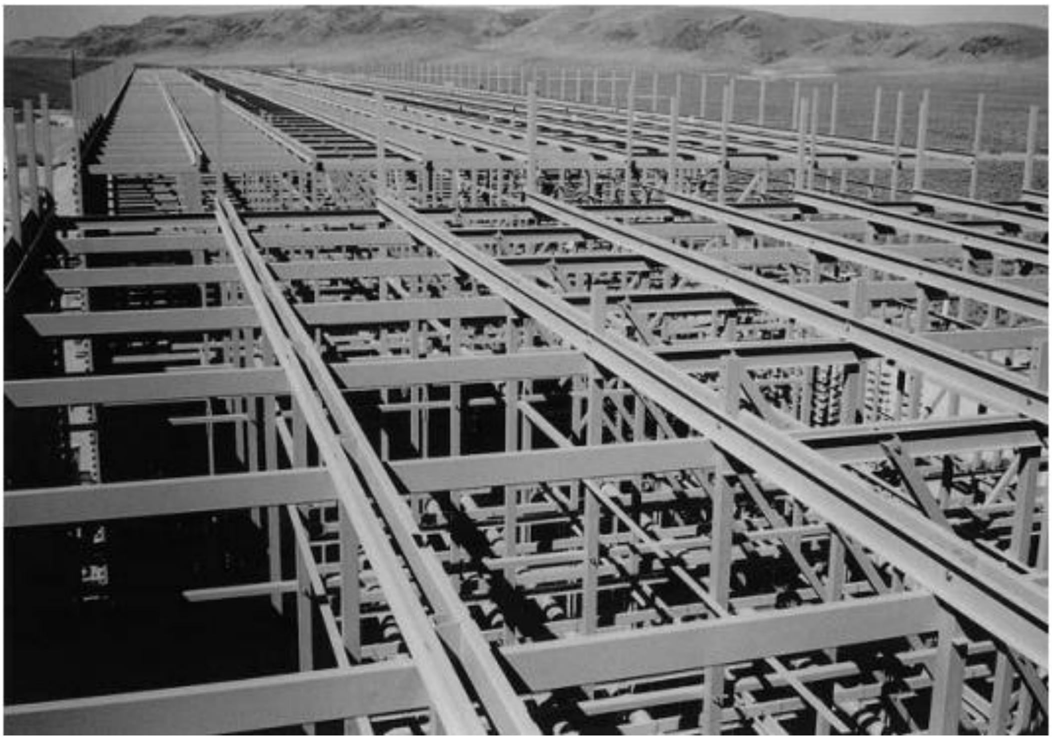


Figure 17 Water cooling tower structure (Courtesy, Bedford Reinforced

Figure 18 'Bio-Plank' TM modular flooring units employed in wáter

Figure 19 LLeida, Spain pederastian Bridge

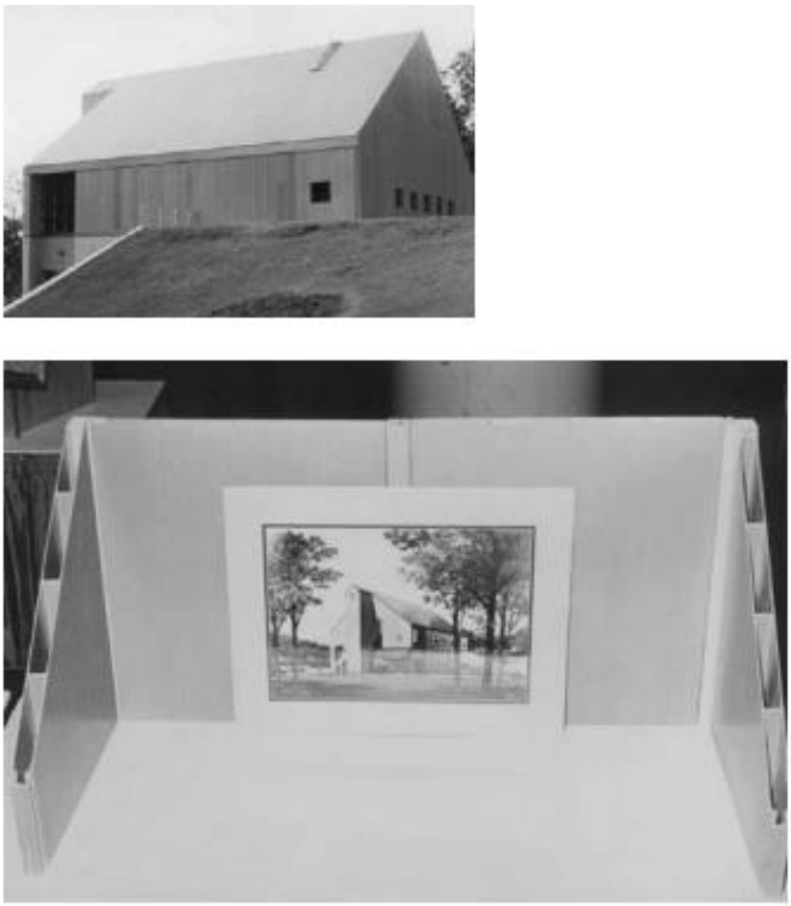


Figure 20 Building constructed from pultruded profiles

Figure 21 Airfoil section

3.Analysis of the manufacturing process

3.1 Manufacturing process

There are a big number of manufacturing processes for composites, generally consisting of placing reinforcement impregnated with a thermosetting resin in the required shape and direction to obtain specific characteristics.

Pultrusion is a continuous, automatic, closed-mould process used to produce continuous, structurally shaped sections of fibre-reinforced plastics and is specifically designed for high volume production, in which case it is very cheap. The process basically consists of pulling the resin-impregnated reinforcements through a high-temperature mould. The function of this high temperature is to cure the resin, resulting in solid profiles with constant geometry.

The reinforcements are impregnated with the resin before entering the mould or it is also possible to inject the resin into the mould.

More than 90% of the products manufactured by pultrusion are made of polyester-glass fibre. With regard to resins, it is necessary to highlight that when high corrosion resistance is required, vinyl ester resins are used and however, when high mechanical and electrical properties are required, epoxy resins are used.

Although the design of the pultrusion machine depends on the final geometry we want to achieve, the process and the machine elements used are basically always the same.

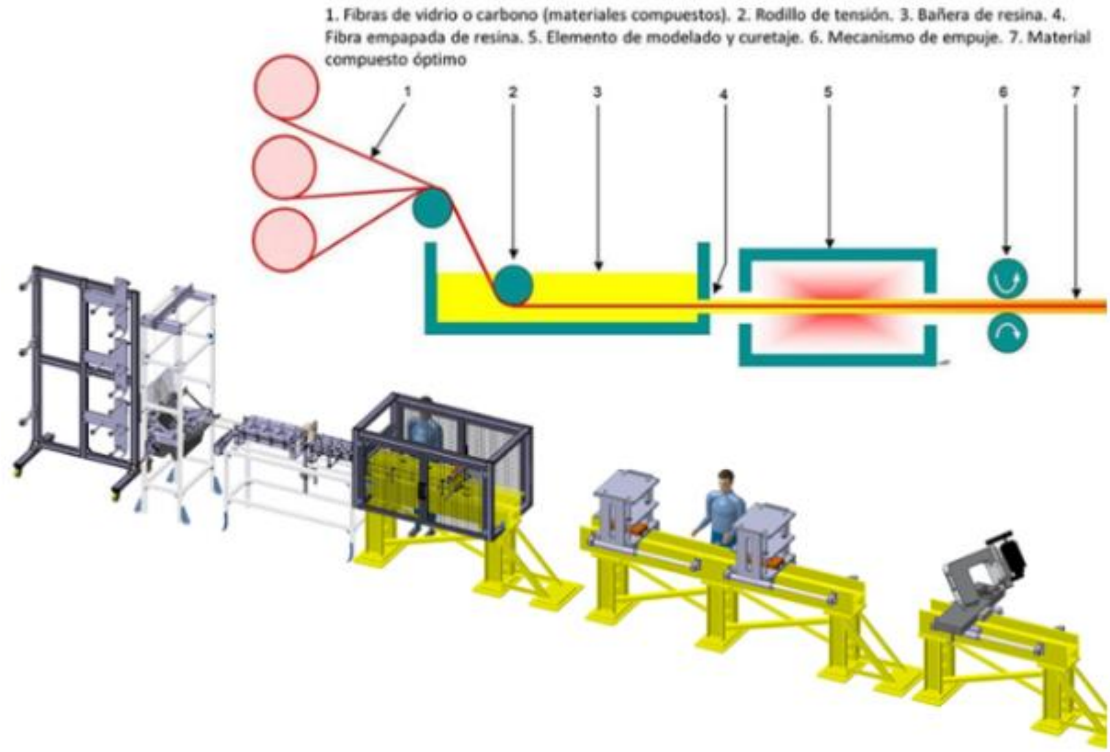


Figure 22 Pultrusion process

In this picture it will showed the stages of the pultrusion process:

1. The yarn fibres

2. Tension roller.

3. Resin impregnator

4. Resin coated fibre

5. Pultrusion die, where the temperature is increased and the resin is cured.

6. Tensile device.

7. Optimus composite material

3.2 Elements of the pultrusion process

It will be presented more extensively the different elements that plays an important role in the pultrusion process.

Yarn dispenser

This is the first stage of the process and is composed of yarn racks, felt dispensers and in some cases it is possible to use winders in order to arrange the fibres in the right shape to be processed.

Resin impregnator

As mentioned before, on the one hand the resin impregnator can be a simple resin bath or on the other hand it can be a resin pressure injector directly into the mould. The function of the resin impregnator is to wet the armature with a substance containing resin, pigments, catalysts and additives to improve the quality of the final product.

Guide plates

The function of the guide plates is to achieve the correct direction of the fibres, to remove excess resin from the fibres, and to provide pre-compaction in order to remove air, moisture and reduce pressure from the main matrix.

Typical materials used for these guides are teflon, ultra-high molecular weight polyethylene, chromium steel and other steel alloys.

Pultrusion die

In this stage of the process, the product (resins and fibres) is heated to high temperatures in order to initiate the curing reaction of the resin as it converts from liquid to solid.

Typically, this device is constructed from machined steel or ceramic which is heated and produces the final profile. Often the die is longer than 1m in length and is heated by an electrical resistance system although there are more systems for doing this.

Traction device

Before the product passes through this stage, a specific space of 3 metres or more is required to facilitate the cooling of the product. This cooling is normally done by air or water and is necessary because after this cooling the product is subjected to a traction load which, in addition to advancing the product, achieves a good compaction with more fibres in the same volume, what means more density and therefore better quality. The mechanism may be a roller mechanism or similar which applies a tensile load to the profile and its speed will depend on the type of resin and the speed of the resin reaction whereby it changes from liquid to solid.

Cutting device

This is the final stage of the process and consists of cutting the profile to the desired length, and usually, the cutting saw is programmed for a better process performance. The saw is made of a hard and resistant material such as diamond carbide.

3.3 Profile design

Nowadays, pultrusion profiles can be classified in two ways: standard or customised profiles.

Standard profiles are those that can be easily found in the catalogues of different manufacturers. These profiles are characterised by their dimensions, specific properties, and their usual uses in engineering.

Customised profiles are those that are manufactured for a specific customer. These profiles usually have a specific design, with specific properties depending on the end use of these profiles.

Usually, after many years of production of some custom profiles, these profiles become standard profiles that are listed by the factory.

Property prediction of the profile

There are 2 main ways to predict the final properties of the final profile if we know previously the properties of the materials that compose this profile, the reinforcement, the resin, the fillers and the additives.

The first way is to use the Rule of Mixtures to know the longitudinal and transverse properties:

Longitudinal $Xc = Vr * Xr + Vf * Xf$

Transversal: $1/Xc = Vr/Xr + Vf/Xf$

Xc = specific property

Vr = resin volume (%)

Xr = resin property (in relation to Xc)

Vf = fibre volume (%)

Xf = property of the fibre (relative to Xc)

Property	E-glass	S-glass	Aramid	Carbon
Density (g/cm^3)	2.6	2.49	1.47	1.77
Tensile strength (MPa)	3450	4585	2750	1900–3100
Tensile modulus (GPa)	72.4	86.9	62.0	227–379
Elongation to break (%)	4.8	5.4	2.3	0.5

Table 3 Typical reinforcement fibre properties

Property	Polyester	Vinyl ester	Epoxy
Density (g/cm^3)	1.13	1.12	1.28
Tensile strength (MPa)	77	81	76
Flexural strength (MPa)	123	138	115
Flexural modulus (GPa)	2.96	3.72	3.24
Elongation at break (%)	4.5	5.0	6.3
Heat distortion temperature (°C)	71	104	165

Table 4 Typical thermoset matrix resin properties

And the second way to calculate the final properties of the profile is to calculate the performance of each individual layer within the laminate that makes up the profile.

Xc = T1 * X1 + Tm * Xm

Where:

Xc = Concrete property

T1 and X1 = Thickness and property of the laminate/reinforcement type (there can be more than two types of reinforcement/laminate in a pultruded profile)

Tm and Xm = Thickness and property of the laminate/reinforcement type (there may be more than two types of reinforcement/laminate in a pultruded profile)

	Roving/ polyester	Woven roving/ polyester	SMC[a] polyester
Glass content (%wt)	50–75	45–60	20–35
Density (g/cm^3)	1.6–2.0	1.5–1.8	1.8–1.85
Tensile strength (MPa)	410–1180	230–240	50–90
Tensile modulus (GPa)	21–41	13–17	9
Flexural strength (MPa)	690–1240	200–270	140–210
Compressive strength (MPa)	210–480	98–140	240–310

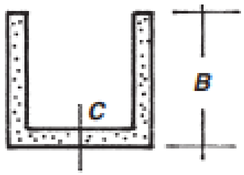
Table 5 Typical laminate mechanical properties

Reinforcement	Fibre volume fraction (%)
E-glass roving	0.62
E-glass chopped strand mat (CSM)	0.38
E-glass continuous filament mat (CFM)	0.28
E-glass woven roving	0.58
Unidirectional carbon cloth	0.66
±45° Carbon fabric	0.56
Kevlar® fabric	0.68

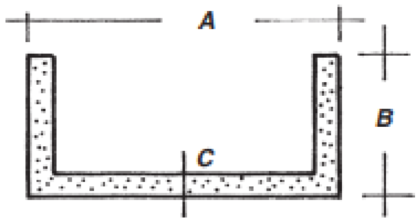
Table 6 Compressibility of reinforcement - volume fraction

Reinforcement	β
Unidirectional	1.0
Bidirectional (woven roving)	5
Chopped strand mat	0.375

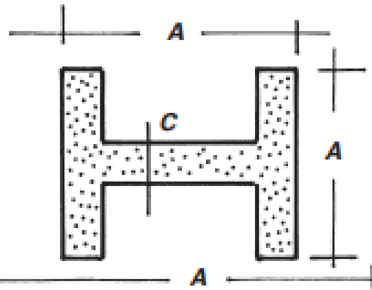
Table 7 Fibre efficiency factors



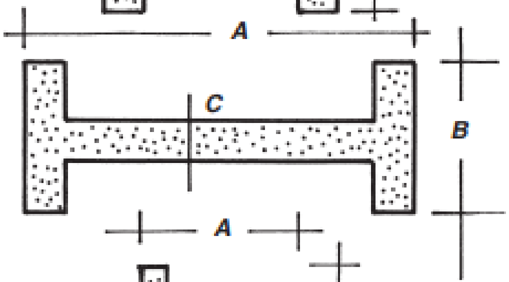
'U' channel, square
20 mm ≤ *A* ≤ 200 mm
0.8" ≤ *A* ≤ 8.0"



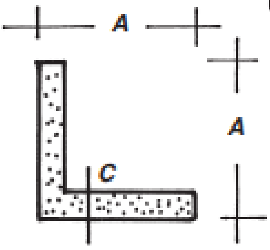
'U' channel, *A* = 2*B*
20 mm ≤ *A* ≤ 200 mm or more
0.8" ≤ *A* ≤ 8.0" or more



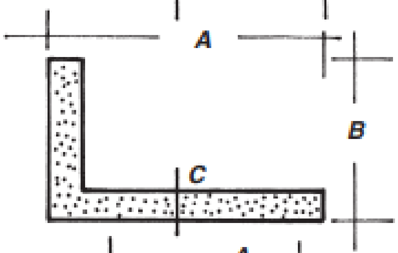
H section beam
50 mm ≤ *A* ≤ 320 mm or more
2" ≤ *A* ≤ 12.5" or more



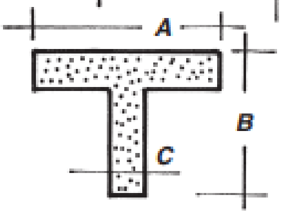
I section beam *A* = 2*B*
50 mm ≤ *A* ≤ 480 mm or more
2" ≤ *A* ≤ 19.0" or more



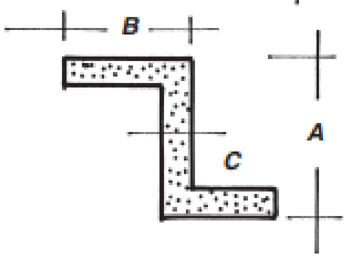
L section, equal leg
20 mm ≤ *A* ≤ 200 mm
0.8" ≤ a ≤ 8.0"



L section, unequal leg, *A* = 2*B*
20 mm ≤ *A* ≤ 200 mm
0.8" ≤ *A* ≤ 8.0"



T section
20 mm ≤ *A* ≤ 200 mm or more
0.8" ≤ *A* ≤ 8.0" or more



Z section, *A* = 2*B*
20 mm ≤ *A* ≤ 200 mm
0.8" ≤ *A* ≤ 8.0"

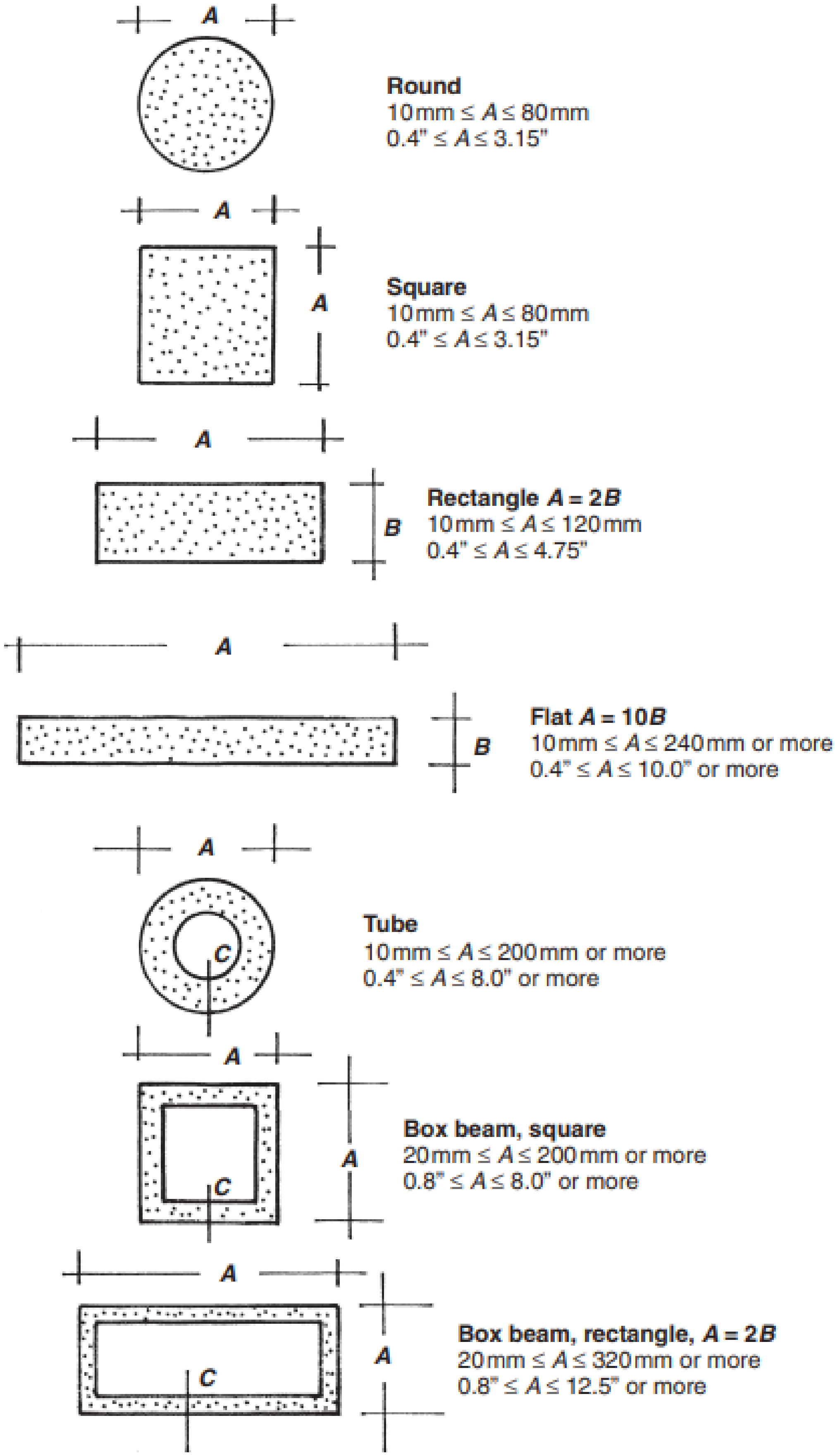


Figure 23 Profiles

Section		Dimension A	Dimension B	Dimension C
Round	(mm)	0.85–27.5	—	—
	(inches)	0.035–1.10	—	—
Square	(mm)	8.0–25.4	8.0–25.4	—
	(inches)	0.30–1.0	0.30–1.0	—
Rectangle	(mm)	8.0–25.4	2.75–25.4	—
	(inches)	0.30–1.0	0.10–1.0	—
Flat	(mm)	6.35–44.0	1.60–9.50	—
	(inches)	0.25–1.75	0.06–0.35	—
Tube	(mm)	6.35–44.0	—	1.25–2.54
	(inches)	0.25–1.75	—	0.05–1.0
Box beam/	(mm)	40.0–51.0	20.0–25.4	3.0–6.0
rectangle	(inches)	1.6–2.0	0.80–1.0	0.12–0.24
U channels	(mm)	11.65–300.0	3.80–51.0	1.75–4.0
	(inches)	0.45–11.75	0.15–2.0	0.65–0.16
I & H sections	(mm)	8.0–102.0	25.4–203.0	7.0–9.5
	(inches)	0.30–4.0	1.0–8.0	0.275–0.375
L angles	(mm)	25.4–83.0	25.4–44.0	3.18–5.0
	(inches)	1.0–3.25	1.0–1.75	0.125–0.20
T section	(mm)	20.0–94.0	16.0–95.25	3.45–5.2
	(inches)	0.80–3.70	0.60–3.75	0.13–0.20

Direction	Dimension	Tolerance
Thickness (mm)	<5	±0.25
	≥ 5	±0.35
Thickness (inches)	<0.2	±0.01
	≥ 0.2	±0.014
Width and depth (mm)	<3	±0.15
	≤ 12	±0.2
	≤ 25	±0.25
	≤ 50	±0.35
	≤ 100	±0.5
	>100	±0.75
Width and depth (inches)	<0.12	±0.006
	≤ 0.5	±0.008
	≤ 1.0	±0.01
	≤ 2.0	±0.014
	≤ 4.0	±0.02
	>4.0	±0.03
Length (mm)	<3	±3
	≤ 6	±6
	>6	±10
Length (inches)	<0.12	±0.12
	≤ 0.24	±0.24
	>0.24	±0.4

Table 8 Dimensions of the profiles

3.4 Manufacture of curved profiles

A few years ago, a German company developed a great method to manufacture curved profiles with very good performance in aerospace applications where they are really most used.

The manufacturing of curved profiles follows a different dynamic, the general process is the same but there is a small change. In the normal pultrusion process, there is a specific device in the whole system that pulls the profile along the mould, but in the case of curved profile manufacturing the mould has to be moved along the profile, with certain parameters such as speed, mould temperature and the function of the angle that the mould is going to follow.

This technology is called radiopultrusion and the only difference that this technology has is the one that it was mentioned before, the device that pulls the profile disappears and the mould has to be displaced along the mould.

Apart from this method there are more methods and in the coming years they will be further developed with the aim of bringing the pultrusion system to other fields of engineering.

4.Comparision of beams formed with FRM and iron

Today, one of the most important materials used for structures is steel, but it is also used in other applications such as tools. Steel is an alloy of iron, carbon and other elements that acts to improve performance depending on the final conditions of use. Alloys of this material give it different characteristics depending on the elements that are mixed with it. Generally, these fusions are made so that the material obtains more hardness, more resistance to wear, greater resistance to impact, greater resistance to corrosion and also an increase in resistance to temperatures.

Specifically, steel is composed of 0.05%-1.7% carbon and can be classified into three groups. The first group is alloy steels which contain higher amounts of elements such as silicon and copper than other steels. The second group is carbon steel, which is the most common and in fact most metal structures are made from this type of steel. And finally the third group is ultra-high-strength, low-alloy steel. This last group is usually cheaper than the rest due to its low alloy levels.

In addition, there are 2 other groups that are also used in engineering such as stainless steel or case hardening steel.

One of the most important characteristics of structural steel is that it is easy to join the different parts together by bolting or welding, which makes this type of structure easy to build.

Steel is isotropic because its mechanical and thermal properties are the same in all directions. Isotropic materials can have a homogeneous or non-homogeneous microstructure and particularly in the case of steel, which exhibits isotropic behaviour even though its microscopic structure is not homogeneous.

In this project it will be analysed the S235 steel. S235 steels are steels whose compositions are governed by the DSTU 8539 and GOSST 27772 standards and are used for the construction of structures with welded and other joints. And now it will be presented their characteristics.

C	Si	Mn	Ni	S	P	Cr	N	Cu
≤0,22	≤0,05	≤0,6	≤0,3	≤0,04	≤0,04	≤0,3	≤0,012	≤0,3

Table 9 Chemical composite (Steel S235)

Thickness	Minimum yield strength N/mm2	Minimum strength limit N/mm2
2,0 – 3,9	235	360
4	235	360

Table 10 Mechanical properties of rolled and wide strip steel sheets (S235)

To analyse FRP composite materials there are two generally accepted material models, the microstructural and macrostructural material models.

Microstructural models take into account the heterogeneity of the FRP material and therefore use the properties of the individual fibre and matrix to analyse the behaviour of the FRP.

In macrostructural models, the individual sheet of a laminated FRP is replaced by equivalent, homogeneous, anisotropic elastic layers. These models consider the average macroscopic material properties of each layer to analyse the behaviour of the laminate.

It has to be said that microstructural models are more accurate and reliable than macrostructural models.

Numerical methods for stress prediction in advanced composite applications are usually classified into FDM (finite difference methods) and FEM (finite element methods).

FDMs use a point approximation and are arguably less accurate.

On the other hand, FEM is probably the only numerical method that can accurately handle and predict the failure loads and stresses in a structural element for almost any geometrical attribute, boundary conditions, prescribed environmental conditions and loading pattern, provided that the model discretisation, boundary conditions and loading are applied correctly.

One of the main disadvantages of FDM compared to FEM is the relatively long time required to establish the solution of the problem using FDM and the less detailed stress data obtained from the solution.

In this project it will be analysed the FRP composite used in beams for construction.

Analysis parameters

In order to compare a beam made of glass fibre composite with epoxy against a beam made of S235 steel, it has been defined the following design parameters.

The profile used is IPE 220 with a length of 5 metres, and in the next steps it will be presented a comparison with this type of beam very used in the construction of structures.

The beam in both cases has a fixed support at one end, and at the other end a force of 3000N is applied in the vertical direction with negative sense according to classical references.

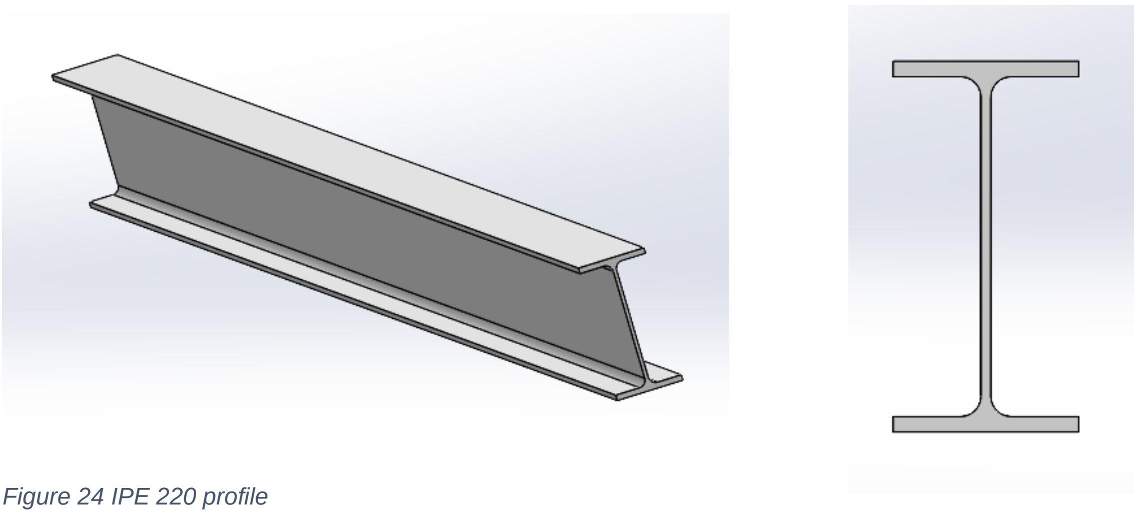


Figure 24 IPE 220 profile

4.1 Evaluation of the performance of pultruded beams by solidworks

In the case of the pultruded beams it has been used S-type fibreglass because of its construction characteristics and in the case of the matrix it has been chosen epoxy resin because it is the most cost-effective of the different resins.

The glass fibre is isotropic and makes up 35% of the composite and the epoxy the remaining 65%.

Properties of this composite

PROPERTIES	**65% EPOXY – 35% FIBER GLASS**
Elastic modulus	3.2 X 10^10 N/m2
Poisson's ratio	2.75 x 10^-1
Shear modulus	1.4 x 10^7 N/m2
density	1.72 x 10^3 Kg/m^3
Tensile limit	1.62 x 10^9 N/m2
Compressive limit	6.6 x 10^8 N/m2
yield strength	1.69 x 10^9 N/m2
Coefficient of thermal expansion	2.78 x 10^-5 /K
Thermal conductivity	9.38 x 10^-1 W/(m*K)
Specific heat	1.51 x 10^3 J/(Kg*K)
Material damping coefficient	4.5 x 10^0 %

Table 11 Properties FRP

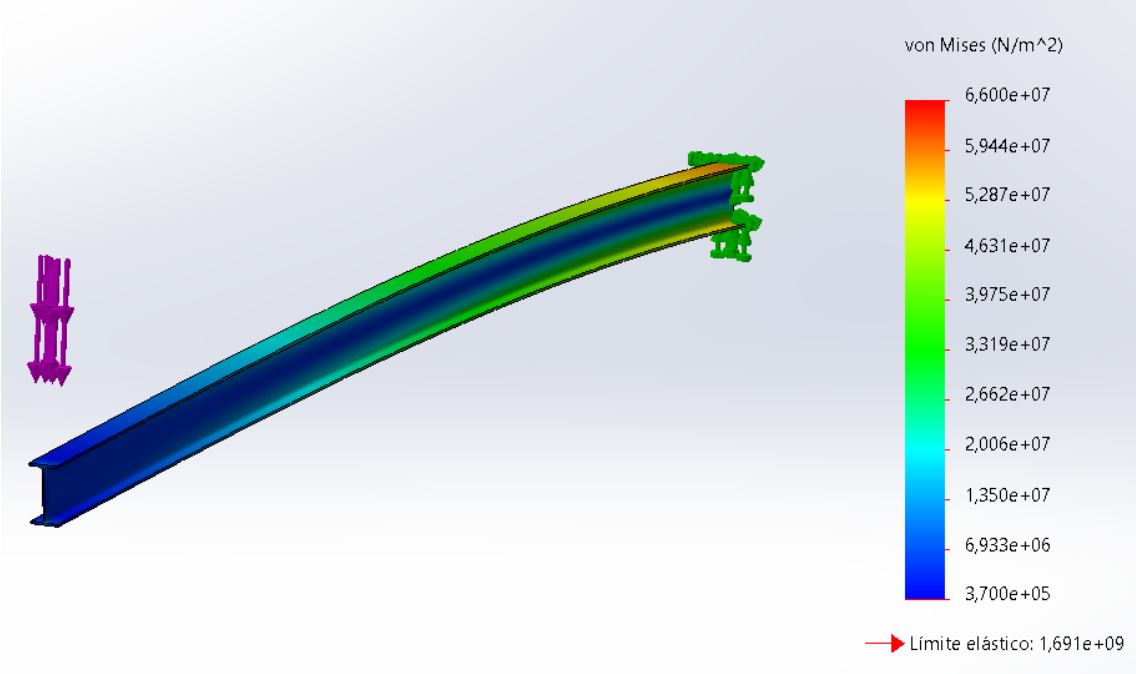


Figure 25 Stresses FRP Beam

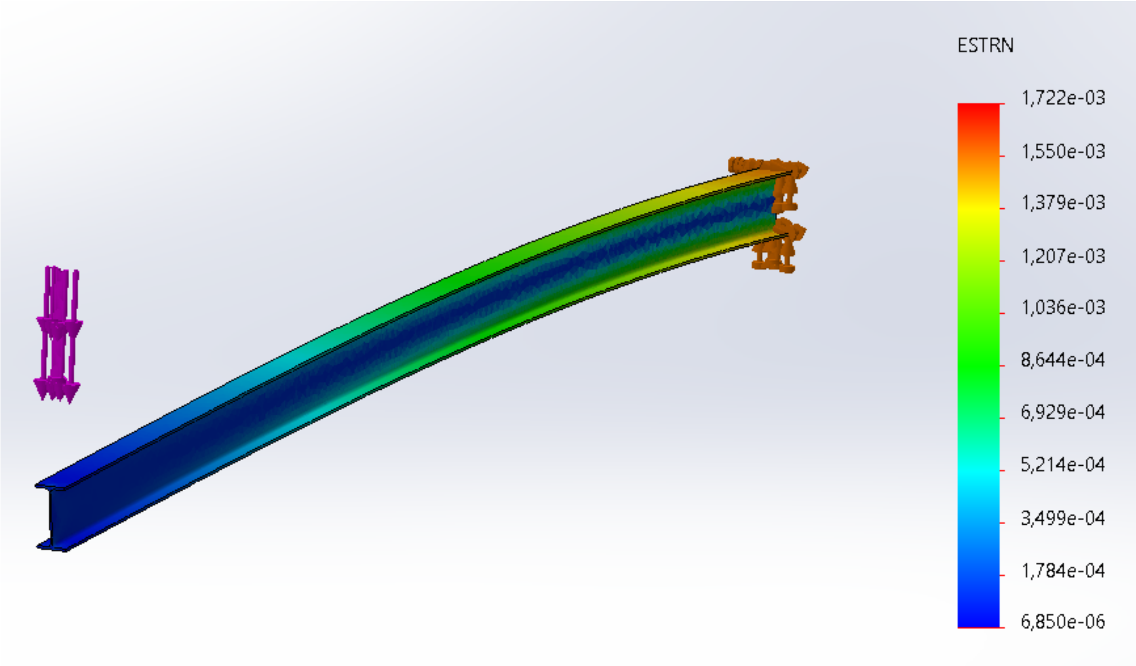


Figure 26 Displacements FRP Beam

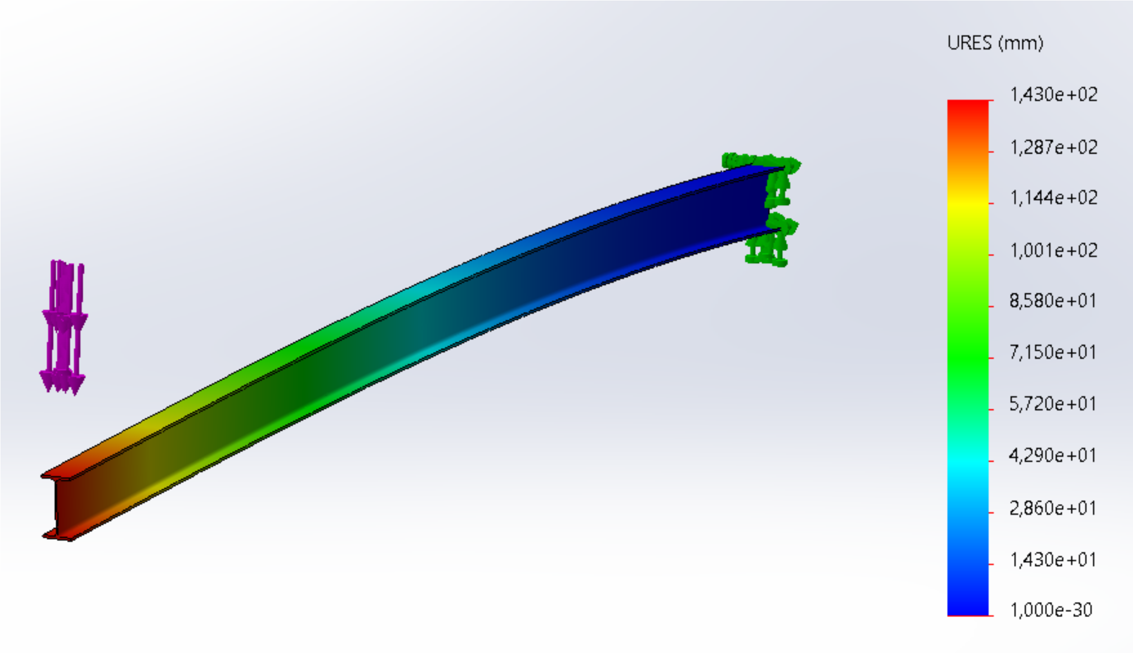


Figure 27 Unitary deformations FRP Beam

4.2 Evaluation of the performance of iron beams by solidworks

It has been chosen an S235 steel beam because it is one of the most commonly used types in construction

PROPERTIES	Steel S235
Elastic modulus	2.1 x 10^11N/m2
Poisson's ratio	0.28
Shear modulus	7.9 x 10^10 N/m2
density	7.8 x 10^3 Kg/m^3
Tensile limit	3.6 x 10^8 N/m2
Compressive limit	N/m2
yield strength	2.35 x 10^8 N/m2
Coefficient of thermal expansion	1.1 x 10^-5 /K
Thermal conductivity	14 W/(m*K)

Specific heat	440 J/(Kg*K)
Material damping coefficient	- %

Table 12 Properties Steel S235

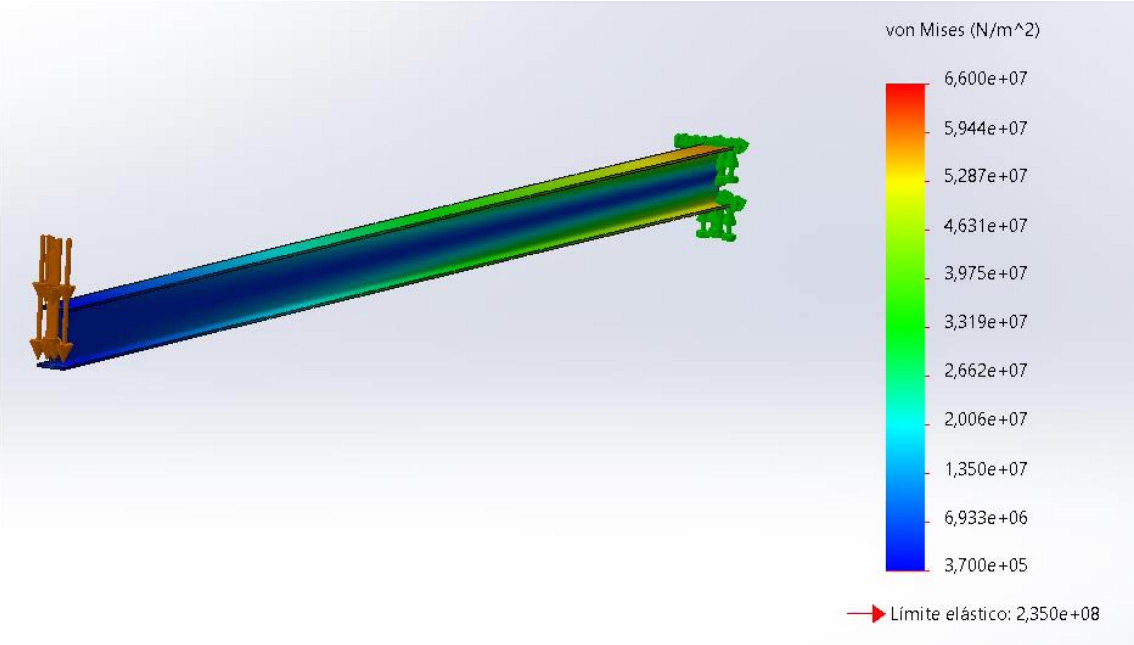


Figure 28 Stresses Steel

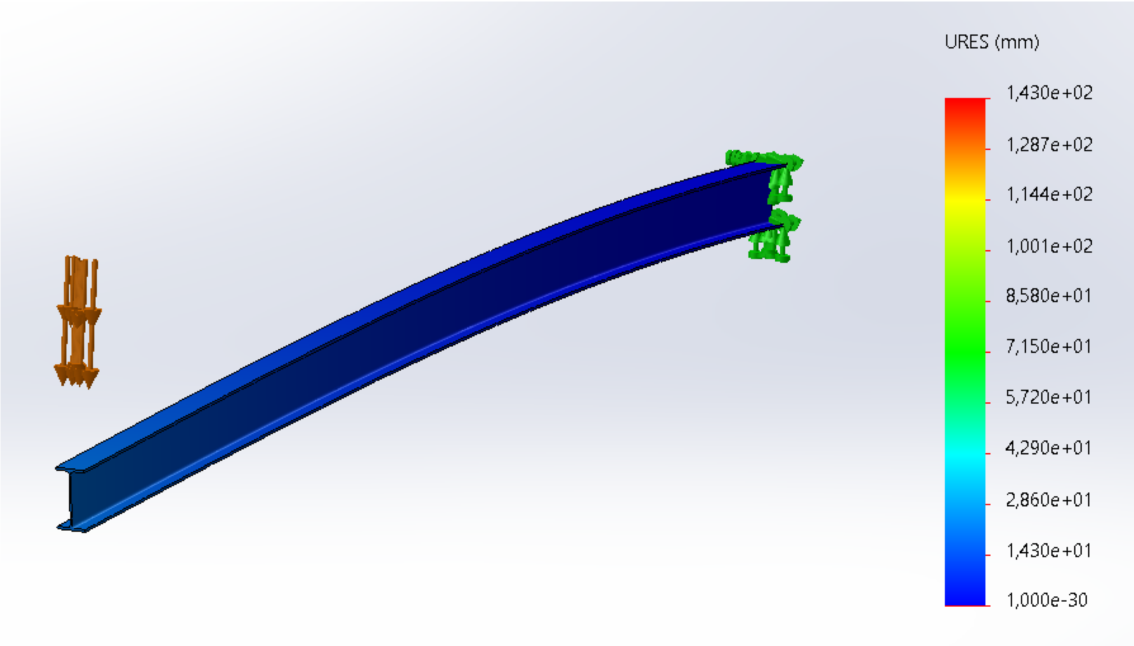


Figure 29 Displacements Steel

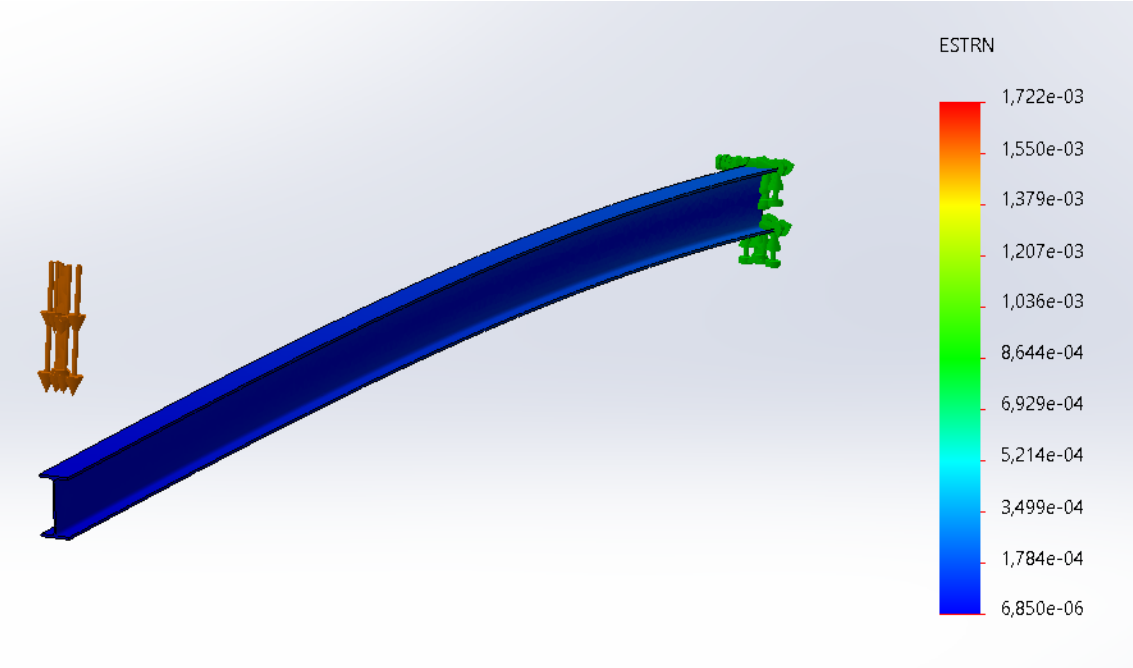


Figure 30 Unitary deformations Steel

4.3 Different methods for assessing the performance of beams

Earlier it has been mentioned the most important tests to analyse the beams and to be able to conclude whether the beams are able to perform their intended purpose, and now it will be explained these different tests in more detail.

Tensile tests

The tensile test is a destructive testing process that provides information on tensile strength, yield strength and ductility. It measures the force required to break the specimen and how far the specimen elongates to that breaking point. Tensile testing of composite materials is generally performed in the form of basic tensile or plane tensile tests in accordance with standards such as ISO 527-4, ISO 527-5, ASTM D 638, ASTM D 3039 and ASTM C 297. These tests produce stress-strain diagrams which are used to determine the tensile modulus.

Charpy impact tests

The Charpy impact test is considered to be one of the most widely used tests to evaluate the relative toughness of a material quickly and economically and measures the energy absorbed by a standard notched specimen when it breaks under an impact load.

This test consists of striking a suitable specimen with a hammer on an oscillating arm while the specimen is held firmly at each end. Then, the hammer strikes in the opposite direction to the notch and finally the energy absorbed by the specimen is accurately determined by measuring the decrease in motion of the pendulum arm.

Three-point bending test

Bending tests are carried out with the aim of obtaining information on the bending behaviour of the material. In the case of fragile materials, the bending strength is determined and in the case of ductile materials, the yield strength, the largest possible bending angle and Young's modulus in the case of elastic deformation can be determined.

This test is carried out on a universal machine by placing the specimen in a place with two supports and bending it by applying a force to one or two load elements. These loading elements move slowly, vertically and with a constant speed, loading the specimen with an increasing load until the specimen breaks or reaches the previously determined deformation. The maximum load reached during the bending test is called the breaking force.

Scanning electron microscope

Scanning electron microscopy (SEM) is a testing process that scans a sample with an electron beam to produce a magnified image for analysis and one of the best advantages of this test is that it is a non-destructive method.

This test is used to great effect in the microanalysis and failure analysis of solid inorganic materials. Electron microscopy is performed at high magnification, generates high resolution images and accurately measures very small features and objects.

X-ray micro tomography analysis

X-ray micro-tomography is a method for the analysis of materials that makes it possible to obtain images of the interior of the sample without destroying it, in high resolution (micrometres) and high contrast, making it possible to produce a three-dimensional reconstruction of the sample, through the impact of the X-rays with the different materials, taking advantage of the contrasts of the densities.

5. Conclusion

In my solidworks analysis it has been shown the analysis of the same type of beam (IPE220) but with two different materials (fibreglass - epoxy and S235 steel) and we can observe that in general the behaviour of the stresses and deformations using the same boundary conditions is very close, but it must be said that FRP is 78% lighter than this type of steel widely used in construction.

Its light weight, corrosion resistance and good mechanical, electrical and thermal characteristics make this composite material a perfect material with many applications in engineering, such as construction and aeronautics.

The advantages are obvious, but it is difficult to incorporate this composite suddenly into society, and for that it is first necessary to show and teach the use of FRP to universities, architects and engineers. Thanks to the corrosion resistance of FRP, if we incorporate this material in the future, companies will not waste time and money on the maintenance of the construction in question and will therefore have more time and money for other important things.

Furthermore, the use of FRP concrete is very common, and there is research (included in the references) that shows that equivalent stresses are reduced with the incorporation of FRP in concrete.

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