A study on drying shrinkage and creep of recycled concrete aggregate

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Abstract

Although it is not a new material, in the last years the recycled aggregates of concrete RCA have had a great progress and are highly valued because of being friendly with the environment, multiple studies find feasible their use in structural concrete but when it is intended to be used in singular structures or prefabricated pieces that require high performance levels an exhaustive evaluation of its properties dealing with deformation and durability are needed.

The paper presents an experimental study on drying shrinkage and creep of recycled concrete at constant standard ambient conditions, 8 concrete mixtures with 2 water/cement ratio (0,5 and 0,65) and 4 substitution levels of natural coarse aggregates by recycled concrete aggregates (0%, 20%, 50% and 100%) were used and the influence on this two important time-dependent deformations of recycled concrete were examined in conformity the ASTM C 512 for creep and UNE 83-318-94 for shrinkage. The effects of recycled concrete aggregates on the mechanical properties were analyzed and coefficients and recommendations to fit design are provided. The experimental results showed that the recycled aggregate have a significant effect on the overall elastic properties of concrete, the creep and drying shrinkage increases considerably, as the substitution level increases, without a lineal relation with the elasticity modulus variation when high performance concrete is used.

Keywords: Recycled concrete aggregate, elastic modulus, creep, drying shrinkage.

1. Introduction

Drying shrinkage of concrete is the decrease in the concrete volume occurring at constant temperature with moisture exchange with the environmental medium, which occurs without stress attributable to actions external to the concrete. The beginning of this phenomenon is the contact of concrete with drying environment (relative humidity less 98%). The time dependant increase of strain in hardened concrete at sustained stress is defined as creep.

Many authors agree that the RCA content influence negatively the concrete strength with decreases up to 15% (Sanchez) [9] and the difference is more notorious in the elastic modulus decreases up to 30% as RCA content increases (Nishbayashi and Samura) [7] (Ravindrarajah and Tam) [8] and some results more pessimistic decreases up to 50% (Hansen et al) [4]. Time-dependent deformations of recycled concrete are increased in 15% - 60% as RCA content is increased, ought to the great content of adhered mortar (Gomez) [3], (Hansen) [5]. While for design strength concrete 30 MPa the shrinkage is notable only when the RCA contents exceed 50% (Limbachiya and Leelawat) [6].

Time-dependant deformation tests are complicated because of the multiple factors that have influence on them and the long time they take, time that normally the designer does not have so estimations based on the elastic properties have to be done, for example the elastic modulus to 28 day of age. This paper focuses on the influence of replacement of natural aggregates by recycled concrete aggregates on drying shrinkage, creep and the relation between elastic properties and time-dependant properties of mixtures of recycled concretes at W/C of 0.5 and 0.65.

2. Materials and methods

2.1. Materials

In the present study, Portland cement (CEM I 42,5 N/RS) was used. Natural coarse aggregate CA (10/20 mm), CA (4/10 mm), and Natural fine aggregate FA limestone were used.

Recycled coarse aggregate RCA (4/20 mm) was used. The aggregates properties are given in Table 1. Additive super-plasticizer Sikament 500 was used in the eight different concrete compositions (mix proportions are given in Table 2).

Material	Dry density (kg/m^3)	Ssd density (kg/m^3)	Absorption 24h (%)	LA coefficient (%)
CA (10/20)	2467	2673	0.98	27.8
CA (4/10)	2622	2659	1.42	31.96
RCA (4/20)	2338	2460	5.19	40.22
FA (0/4)	2460	2540	3.22	

Table 1. Aggregates Properties

Material	Recycled aggregate replacement level							
	0%		20%		50%		100%	
Cement (kg)	380	275	380	275	380	275	380	275
Water (kg)	190	179	190	179	190	179	190	179
FA (0/4) (kg)	714	843	744	878	709	849	714	868
CA (0/4) (kg)	882	752	665	565	414	350	0	0
CA (0/4) (kg)	122	226	92	170	57	105	0	0
RCA (0/4) (kg)	0	0	189	184	471	455	874	830
W/C	0.5	0.65	0.5	0.65	0.5	0.65	0.5	0.65
Plasticizer (%)	0.7	0.7	0.8	1	1.1	1.5	1.5	2

Table 2. Mixtures Composition

2.2. Creep and shrinkage test

Creep test was made in conformity to ASTM C512 [1], and Shrinkage in conformity to UNE 83-318-94 [10]. Drying shrinkage evaluated in prismatic specimens and creep in cylindrical specimens of concrete both at constant ambient conditions (T=20ºC, RH=50%) and moisture conditions unsealed (drying shrinkage and total creep) were used. The prismatic specimens for the shrinkage test have 350x100x100 mm^3 section, the cylindrical specimens for the creep test have a diameter 150x300 mm section, subjected to uniaxial loading to approximate 35% of compressive strength determined on cylinders stored for 28 days in a wet room (fc_{28}) (See Table 3)

Creep and shrinkage test were carried in the temperature and humidity controlled test chamber in which the temperature range between 5ºC – 45ºC and relative humidity range between 30% - 100% can be analyzed.

One day after casting, the cylinders (creep and compressive strength), prism (shrinkage) were demoulded and they were cured 28 days and fixed with their measurement device.

The creep deformations were measured constantly by means of strain gauges, the creep strain was obtained from the total strain subtracting the elastic strain and the strain at the same age of the corresponding unloaded specimen. More details of the measurement device and the loading equipment of the creep test are described in Ref [2]. The shrinkage deformations were measured at time 1, 2, 3, 7 days and weekly until the end of the test by means of Demec mechanical strain gauge.

3. Results and discussion

From the test results of the present study corresponding to 28 days results, is proved that the concrete mix composition on the time-dependent deformations have high influence.

Concrete	Fc_{28}		Fc_{120} (MPa)	E_{28}		
	(MPa)	Rel.		(MPa)	Rel.	1/ $E_{28\ rel}$
0.5-0%	49.4	1	54.8	36678	1	1
0.5-20%	49.0	0.99	54.2	33566	0.92	1.09
0.5-50%	47.1	0.95	53.8	31376	0.86	1.17
0.5-100%	43.2	0.87	54.1	28891	0.79	1.27
0.65-0%	41.6	1	45.7	35204	1	1
0.65-20%	40.5	0.97	45.1	33186	0.94	1.06
0.65-50%	38.8	0.93	44.8	30775	0.87	1.14
0.65-100%	35.8	0.86	44.8	26214	0.74	1.34

Table 3. Hardened Concrete Properties

3.1. Drying shrinkage

Drying shrinkage test results of unsealed specimens w/c ratio 0.5 and 0.65 stored at standard climatic conditions are presented (Fig. 1 – 4). The measurements started after the curing period finished (28 days), it corresponds to the moment when the internal RH started to drop. Fig. 1 shows that the drying shrinkage of the 'recycled'-specimens is constantly larger than the shrinkage of the reference specimens. This higher shrinkage is related to replacement of natural aggregates by RCA. Drying shrinkage increases and the rate of drying decreases as the RCA content increases (See table 4).

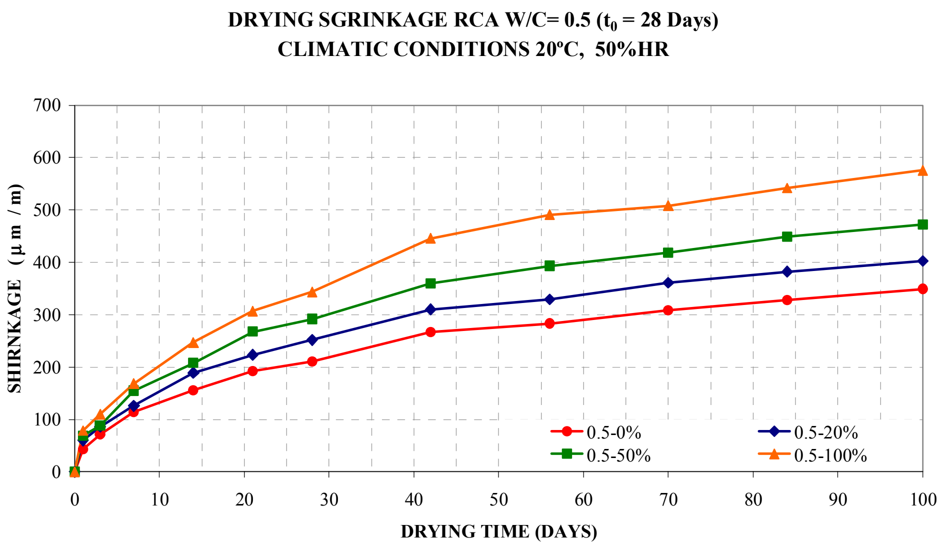

Figure 1. Drying shrinkage recycled concrete aggregate w/c ratio 0.5.

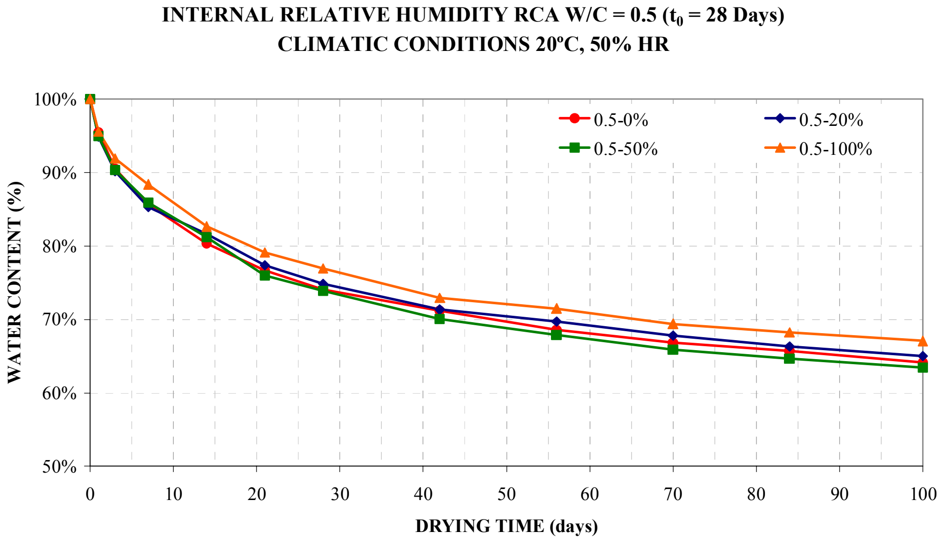

Figure 2. Lose water recycled concrete aggregate w/c ratio 0.5.

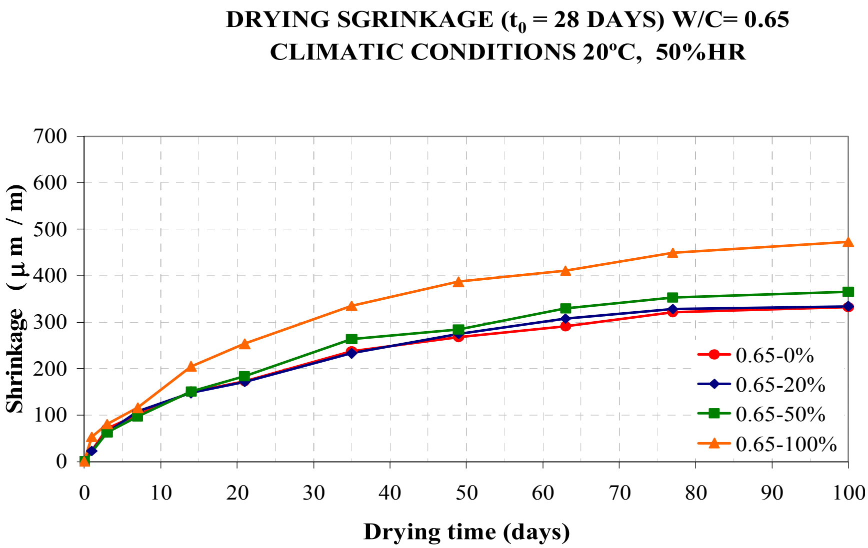

Figure 3. Drying shrinkage recycled concrete aggregate w/c ratio 0.65.

The Fig. 2 show a similar drying rate for the w/c 0.5 RAC independent of recycled aggregates of concrete content.

The Fig. 3 shows a lower influence of recycled aggregates in shrinkage strain in w/c ratio 0.65 concrete for RCA replacement level 20% and 50% besides the total replacement of coarse fraction by RCA increases considerable the deformation. The drying rate decreases as RCA content in concrete increases. For w/c ratio 0.65 concrete the extent of the drying rate is more appreciated (Fig. 4).

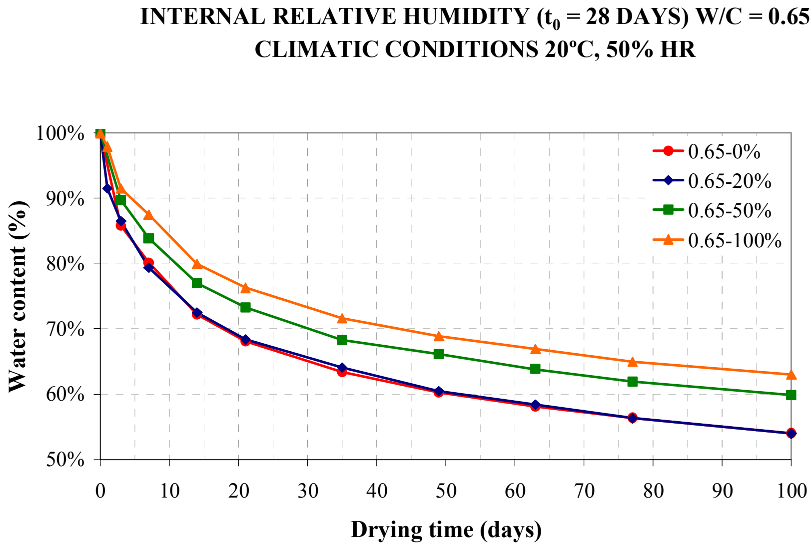

Figure 4. Lose water recycled concrete aggregate w/c ratio 0.65.

3.2. Creep

Fig. 5 and fig. 6, shows the creep tests results, in terms of the ratio of the creep strain at time t to stress applied. Creep curves start in the t-t′=0 which corresponds to the moment of loading, show that the increase of specific creep is influenced by RCA content.

TIME (100 days)	**W/C = 0.5**				**W/C = 0.65**			
Replacement RCA level	0	20%	50%	100%	0%	20%	50%	100%
Shrinkage$_{(100, 28)}$ (μm/m)	349	402	472	576	332	334	365	472
Relative Shrinkage	1	1.15	1.35	1.65	1	1.01	1.09	1.43
Internal RH$_{(100, 28)}$	64%	65%	63%	67%	54%	54%	60%	63%
Relative Internal RH	1	0.99	1.01	1.05	1	1.00	1.11	1.17
Specific Creep (μm/m)/Mpa	23.0	25.7	29.7	37.1	37.2	32.7	33.9	45.5
Relative Specific Creep	1	1.12	1.29	1.61	1	1.06	1.04	1.39

Table 4. Time-dependent deformations RCA, $t-t_0$ = 100 days, and t-t′ = 100 days

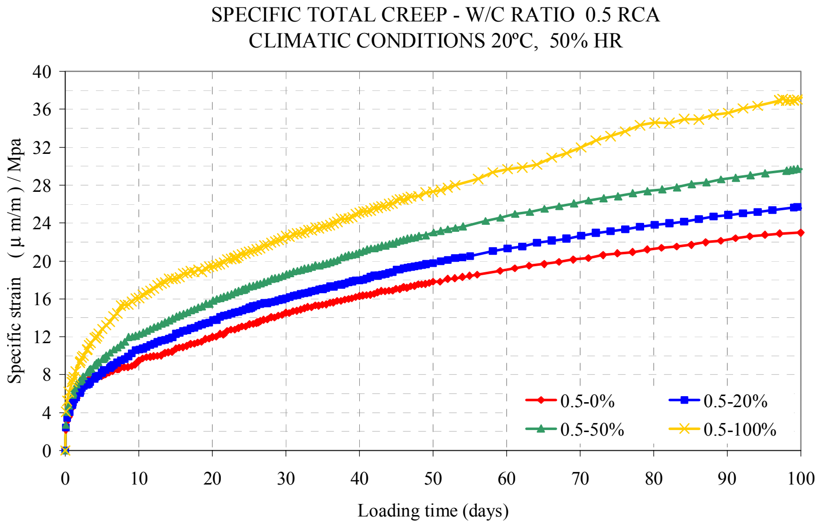

Figure 5. Specific Creep, recycled concrete aggregate w/c ratio 0.5

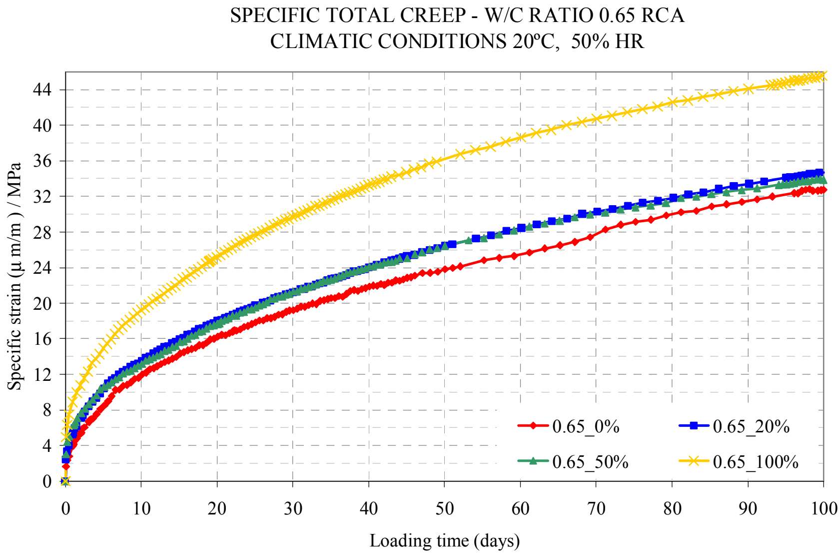

Figure 6. Specific Creep, recycled concrete aggregate w/c ratio 0.65

Creep concrete curves show evidence of a proportional development and that creep curves of recycled concretes specimens increase their deformation as RCA content increases. For

20% and 50% replacement levels of RCA for w/c 0.65 concrete, there is not a significant difference with the control concrete, the same that happens in the drying shrinkage.

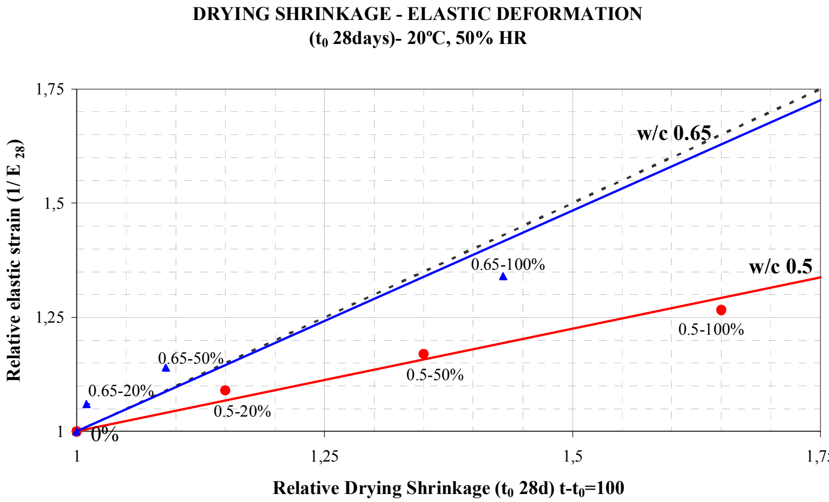

Figure 7. Relation shrinkage deformation – elastic deformation of recycled concrete aggregate

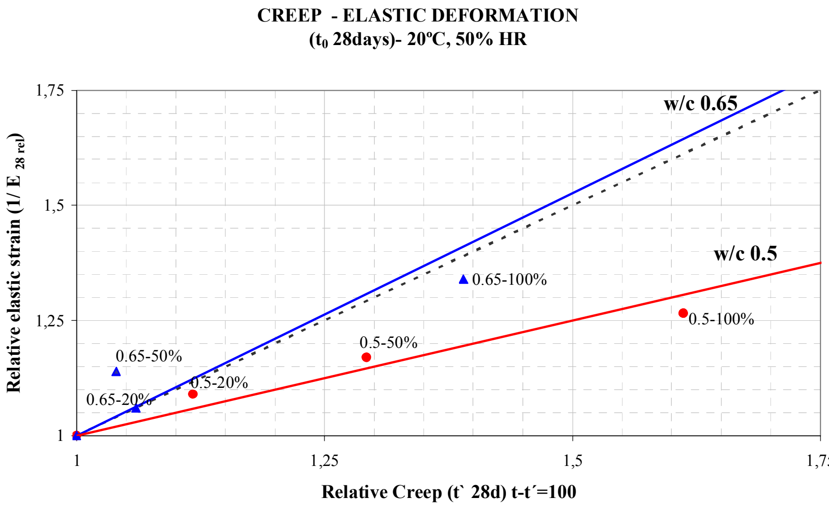

Figure 8. Relation creep deformation – elastic deformation of recycled concrete aggregate

3.3. Elastic deformation and time-dependant deformation

The elastic modulus in compression was tested on cylindrical concrete specimens 150 mm x 300 mm with 28 days of age. The fig. 7 and fig. 8, shows the relation of the elastic modulus with drying shrinkage and total creep at 100 days of age. For recycled concrete the decrease of elastic modulus is related with the increases of time-dependent deformations. This relation is modified when the cement paste content increase as is the case of w/c ratio 0.5 concrete used in this study.

4. Conclusions

Based on the test results of the creep and shrinkage experiments carried out at constant ambient conditions, the following conclusions are drawn:

1. The effect of concrete mixtures on the time-dependent deformations is remarkable.

2. The drying is accelerated for the w/c 0.65 ratio concrete normally by its greater porosity, although this rate is decrease as RCA content is increased, by the effect of retention of free water.

3. As showed the results, the influence of RCA content on time-dependant deformations is more important for w/c ratio 0.5 concrete, probably to higher cement content.

4. From the test results in the present study no general valid conclusions may be drawn concerning the effect of including RCA in concrete mixtures on the long-time behaviour of concrete, however is valid to estimate the time-dependent deformations through the decrease of elastic deformations for moderate strength concretes (< 35 MPa). For medium and high strength concrete (>35 MPa) with greater cement paste contents the time-dependent deformations are increased considerably and especial studies are needed.

5. Considering the multiple factors that affect the shrinkage and creep. Much more experimental test are needed to be able to quantify the relations of observed phenomena.

References

[1] ASTM C-512; Standard test method for creep of concrete in compression, technical committee C09, (2002).

[2] Domingo-Cabo A, et Al. Creep and shrinkage of recycled aggregate concrete, *Construction and Building Materials*, 2009, V 23, (7), 2545-2553.

[3] Gomez J M V. Deferred Behavioral Verification of Concrete with Aggregate from Recycled Concrete, Part II) Experimental Study of Creep, *Proceedings of the Fifth International Conference on the Environmental and Technical Implications of Construction with Alternative Materials*, 2003, 115-125.

[4] Hansen T C, Boeegh E,. Elasticity and Drying Shrinkage of Recycled- Aggregate Concrete, *ACI Journal, 1985,* Vol 82 N°5, 648- 652.

[5] Hansen T C, Torben C,. Recycled Aggregates and Recycled Aggregate Concrete, Second State-Of-The-Art Report, Developments 1945-1985, (1996) *Materials and Structures*.

[6] Limbachiya M C, Leelawat T, Dhir R K,. RCA Concrete: A Study of Properties in the fresh State, Strength Development and Durability, *Proceedings of the International Conference on the Use of Recycled Concrete Aggregates*, 1998, 227-238.

[7] Nishbayashi S, Yamura K,. Mechanical Properties and Durability of Concrete from Recycled Coarse Aggregate Prepared by Crushing Concrete, Demolition and Reuse of Concrete and Masonry, Vol. 2, Reuse of Demolition Waste, *Proceedings of the Second International RILEM Symposium on Demolition and Reuse of Concrete and Masonry*, 1998 Japan 652-659.

[8] Ravindrarajah R S, Tam C T,. Methods of Improving the Quality of Recycled Aggregate Concrete, Demolition and Reuse of Concrete and Masonry, Vol. 2 Reuse of Demolition Waste, *Proceedings of the Second International RILEM Symposium*, Ed Y. Kasai, 1998 575-584.

[9] Sánchez de Juan M., (2005) Estudio sobre la Utilización de Árido Reciclado para la Fabricación de Hormigón Estructural. *Tesis Doctoral, Universidad Politécnica de Madrid.*

[10] UNE 83-318, Ensayos de hormigón. Determinación de los cambios de longitud, AENOR (1994).