INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

PREDICTION OF THE BEHAVIOUR OF CONCRETE WITH RECYCLED AGGREGATES

THE INTERNATIONAL EXPERIMENTAL *"STATE-OF-THE-ART"*

SUMMARY

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Engenharia Civil

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1. Introduction

1.1 General information

The construction industry is one of the economic sectors with greater responsibility and contribution to natural resources depletion and production of solid waste. Within this sector, the activities related with the use of concrete, from the production till the demolition, have a preponderant role.

According to the organization Strategic Development Council (2002), each year around 6 billion tons of concrete are produced, equivalent to 1 ton per human being in the planet. The amount of natural, and finite, resources needed to maintain this level of production of concrete is a great problem to be solved in a short-term future.

On the other hand, the demolition of old structures also produces a great environmental impact. As referred by Masood et al (2001), concrete demolition waste in the European Union and United States of America is up to 100 million tons each year. The high prices for transportation of waste and the lack of authorized landfill places are some of the obstacles to this activity.

Therefore, these two aspects (the necessity of resources to produce new concrete and the high economic and environmental cost of demolition waste) lead to the need of developing technologies for using the recycled aggregates (RA) in the production of concrete.

So far, the major use of recycled aggregates has been as backfill and base course pavement construction. Although it may be considered as a re-use of this material, it is actually a "downcycling" process in terms of its properties, because the potentiality of this resource is not being fully used. The production of structural concrete with RA is the best way of inverting this tendency and contributing to an effective sustainability of the process.

This study is centred on the research for experimental campaigns on concrete with recycled aggregates (RA) done by investigators worldwide and the graphic analysis of those results in order to relate the properties of hardened concrete with the properties of the aggregates (natural and recycled) used. Along with this study, another is being developed, with the same subject, dedicated to the analysis of similar experimental campaigns done in Portugal in the last years, namely at Instituto Superior Técnico.

1.2 Scope and methodology of the investigation

The research for international experimental campaigns was the first step of this investigation. With the collected information, a database was created referring the most important properties of the aggregates and the experimental test procedures of each campaign.

A common conclusion to all the investigations done about this subject is a generalized reduction of the mechanical and durability properties of the concrete with RA, with the increase of the substitution rate of RA by natural aggregates (NA), when compared with concrete with NA only. The main objective of this study is the definition of procedures that allow the estimation of the properties of the concrete with recycled aggregates by knowing the density and the water absorption of the aggregates, natural and recycled, used in the production of the concrete. Another parameter for this estimation can also be the results of the compressive strength of the concrete at the age of 7 days. The influence of the aggregates properties in the behaviour of the concrete properties is commonly recognized by many authors. Limbachiya et al (2000), in their study about high-strength concrete with RA, refer, in the conclusion chapter, the relationship between the density and water absorption of the recycled and natural aggregates.

In order to establish the correlation between the properties of the concrete with RA and the three parameters mentioned, the following methodology was adopted:

- analysis and organization of the data available from each experimental campaign, including the information about the test results for the properties of the aggregates used in the production of the concrete;
- calculation of the exact value of the density and water absorption of the aggregates used in the mixture, through the mix proportions of the concretes (with NA only and with RA) and the individual density and water absorption of the aggregates (natural and recycled);
- graphical analysis of the relationship between the substitution rate of NA by RA and each property of concrete;
- graphical analysis of the variation of the ratio between the properties of concrete with RA and the one with NA only (reference conventional concrete) and the substitution rate of NA by RA;
- graphical analysis of the variation of the ratio between the properties of concrete with RA and the reference concrete and the ratio between the weighed value of density of aggregates in the mixture of concrete with RA and the reference concrete;
- graphical analysis of the variation of the ratio between the properties of concrete with RA and the reference concrete and the ratio between the weighed value of water absorption of aggregates in the mixture of concrete with RA and the reference concrete;
- graphical analysis of the variation of the ratio between the properties of concrete with RA and the reference concrete and the ratio between the compressive strength at the age of 7 days of concrete with RA and the reference concrete.

After obtaining the graphical results for each experimental campaign, and in order to establish a relationship between the properties of concrete with RA and those of reference concrete for the largest amount of tests possible, the results of each property in the different campaigns were plotted in the same graphic.

A statistical analysis is made of each graphic through a regression line and the correspondent correlation coefficient. In order to simulate the real physical behaviour of the properties analysed with the regression line, this line was forced to go through the correspondent value of the reference concrete. However, this "correction" on the positioning of the regression line contributes to the reduction of the correlation coefficient.

2. Database

Taking into account to the international perspective of this investigation, the research for the database was mainly done on the internet. The search for information was also done through articles in scientific magazines, compilations of conferences or seminars and degree, master and doctoral thesis. Due to the lack of information on some of the articles, direct contact with the authors was also tried through electronic mail, but in the majority of the cases no response was obtained. Between all the sources analysed it is fair to point out the internet site of the São Paulo University considering the amount and quality of information available (technical articles and master and doctoral theses) on this subject. Unfortunately, the majority of the investigation centres does not follow the same procedure by allowing other investigators to access the information. A significant number of scientific articles are only available on a commercially basis. The criteria adopted for the selection of information on the articles analysed was:

- availability of the experimental results on the properties of the recycled aggregates, particularly the water absorption and mass density;
- availability of the experimental results concerning the largest amount of hardened and fresh concrete properties (mechanical and durability), particularly the compressive strength at the age of 7 days;
- the largest number of substitution rates of NA by RA;

- the largest number of unchanged parameters (w/c ratio, aggregate dimension composition, workability, type of curing, and others) in the experimental procedure of concrete with RA production;
- data information about the concrete with natural aggregates only.

From all the campaigns analysed only a small number was considered useful for this investigation, since the majority of the campaigns did not fulfil the criteria mentioned above. Actually, a general tendency was noted concerning the experimental procedures. Most of the investigators choose to keep constant the compressive strength level in all the concrete with RA (with different substitution rates) and the NA concrete, by increasing the amount of cement in the mixture or adjusting the water / cement ratio. This kind of experimental procedure leads to unfeasible and incomparable results when the focus of the investigation is the influence of the RA properties. It becomes impossible to measure the real effect of each percentage of RA replacing NA. Another handicap detected on the research was the lack of information related to the tests specifications or the procedures adopted. In some of the documents observed the test results were only presented graphically which, in most of the cases, makes the analysis for this study impossible.

Most of the campaigns were centred on coarse recycled aggregates. Only Khatib (2004) approaches the exclusive influence of fine recycled aggregates on the properties of the concrete with RA. It was also noticed that the majority of the investigations were about recycled concrete aggregates or a mixture of recycled ceramic and concrete aggregates. The number of campaigns only oriented for the study of recycled ceramic aggregates is very reduced, and for this reason this subject should be more developed (specially because of the particular properties of the ceramic aggregates, such as the high water absorption).

The information presented in the database was organized in order to be used by other investigators in an easy and fast way. The objective is to clearly identify the main properties analysed in each campaign. The following criteria were adopted for the database presentation:

- the RA origin: concrete, ceramic, both or a mixture of debris;
- the size of the substituted aggregates: coarse, fine or both;
- the parameters kept constant (unchanged criteria for the production of all the concretes: w/c ratio, size distribution, compressive strength, mix proportions, amount of cement, and others);
- the variable parameters, that define the objective of the investigation (substitution rate of NA by RA, w/c ratio, amount of fly ashes or synthetic fibres added, age of the testing, and others);
- the tests to the aggregates (density, water absorption, size distribution, bulk density, compressive strength, and others);
- the tests on fresh concrete (workability, density, bleeding, air content);
- the tests on hardened concrete (compressive strength, chloride and carbonation penetration, shrinkage, creep, water absorption, density, porosity, permeability, flexural and splitting strength).

After the collection of all the information, six campaigns were considered within the criteria defined for proceeding this study. The reference of the campaigns are: Carrijo (2005), Kou et al (2004), Leite (2001), Soberón (2002), Cervantes et al (2007) and Katz (2003).

3. Graphical analysis

The graphical analysis started with the relationship between the concrete properties and the substitution rate of RA by NA. After this representation, and in order to proceed with the analysis of the concrete properties behaviour as a function of the density and water absorption of the aggregates and the 7-day compressive strength of the concrete, the calculation of the weighed value for the density and water absorption of all the aggregates in the mixture was done.

3.1 Calculation of the exact density and water absorption of the aggregates in the mixture

The weighed value for the density of the aggregates in the mixture depends on 2 factors: the density of the individual aggregates (depending on their origin) and the proportion of each type of aggregates used in the mixture to produce the concrete. To calculate the mentioned value equation 3.1 was used, where the percentage of each type of aggregates is multiplied by the correspondent density.

$$D_{mix} = \frac{FA}{100} \times \left[\frac{subst_{FRA} \times D_{FRA} + (100 - subst_{FRA}) \times D_{FNA}}{100} \right] +$$

$$\frac{(100 - FA)}{100} \times \left[\frac{subst_{CRA} \times D_{CRA} + (100 - subst_{CRA}) \times D_{CNA}}{100} \right]$$

D_{mix} - weighed density of the aggregates in the mixture of concrete;

FA - percentage of fine aggregates used in the mixture;

$subst_{FRA}$ - substitution rate of fine recycled aggregates by fine natural aggregates;

$subst_{CRA}$ - substitution rate of coarse recycled aggregates by coarse natural aggregates;

D_{FRA} - density of the fine recycled aggregates;

D_{FNA} - density of the fine natural aggregates;

D_{CRA} - density of the coarse recycled aggregates;

D_{CNA} - density of the coarse natural aggregates.

For the calculation of the water absorption of the aggregates used in the mixture, a similar equation was adopted where the density values were replaced by the water absorption values for each type of different aggregates used. For each substitution rate a different value of density and water absorption of the aggregates in the mixture was obtained.

3.1 Relationship between the properties of the concrete and the three parameters

The information collected on the search for international campaigns allowed to establish correlations between nine properties of hardened concrete with recycled aggregates (compressive strength, splitting and flexural strength, modulus of elasticity, chloride penetration, shrinkage, creep, carbonation penetration and water absorption) and the density and water absorption of the aggregates in the mixture and the compressive strength at the age of 7 days.

In order to compare the different campaigns, the absolute values were converted into relative values by dividing the results of the concrete with recycled aggregates (BR) by the results for the concrete with natural aggregates only, the reference conventional concrete (BC).

Table 1 shows the qualitative criteria adopted to evaluate the correlation coefficient obtained by the regression lines in each graphic.

Table 1 - Qualitative classification for the correlation coefficient

Classification	Correlation coefficient
very good	$R^2 \geq 0,95$
good	$0,80 \leq R^2 < 0,95$
acceptable	$0,65 \leq R^2 < 0,80$
not acceptable	$R^2 < 0,65$

3.1.1 Compressive strength

Compressive strength is the most common tested property of hardened concrete, and for this reason, it was possible to

obtain results in 4 campaigns: Carrijo (2005), Leite (2001), Kou et al (2004) and Soberón (2002). The general trend identified for this property indicates a reduction of strength with the increase of the substitution rate of RA by NA.

Figure 1 shows the variation of the ratio between the 28 day compressive strength of concrete (f_c) and the ratio between the density (D) of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón e Kou. The correlation coefficient is considered good and a linear relation between the parameters can be identified. The reduction of the density of RA comparing to NA, due to the higher percentage of attached mortar of RA, contributes to the reduction of the ratio between the compressive strength of concrete.

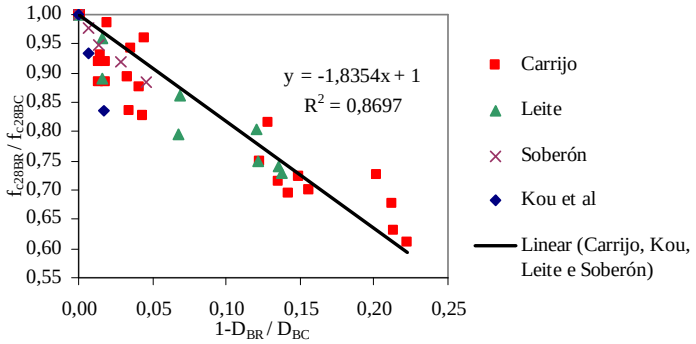

Fig. 1 - Variation of the ratio between the 28 day compressive strength of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón and Kou

The same analysis was performed with the variation of the ratio between the 28 day compressive strength of concrete and the ratio between the water absorption of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón and Kou and is presented in Figure 2. The correlation coefficient is considered acceptable, pointing towards a tendency for a linear behaviour between the ratios.

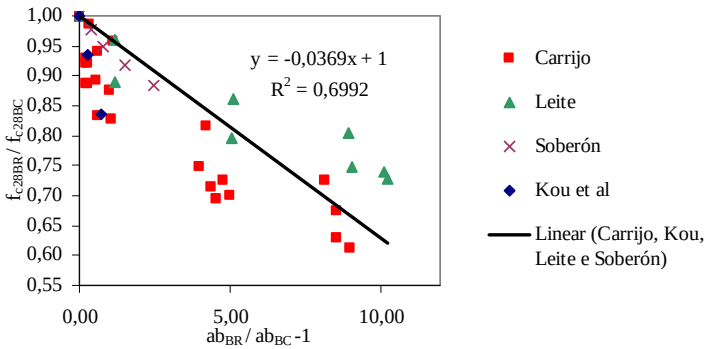

Fig. 2 - Variation of the ratio between the 28-day compressive strengths of concrete and the ratio between the water absorption of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón and Kou

Figure 3 shows the variation of the ratio between the 28 and 90-day compressive strength of concrete and the ratio between the 7-day compressive strength of concrete for the campaigns of Leite, Soberón e Kou. The inexistence of data about the 7-day compressive strength of the concrete in the campaign of Carrijo (2005) excluded the author in this particular analysis. The negative values in the abscissa axis mean that in the campaign of Soberón (2002), some of the results for the 7-day compressive strength of the concrete with RA were higher than the conventional concrete. This particular behaviour is not to be expected and contradicts the majority of the investigations; nevertheless, the values were included in the analysis contributing to the reduction of the correlation coefficient, considered as acceptable.

3.1.2 Modulus of elasticity

Modulus of elasticity results were obtained from the campaigns of Carrijo (2005), Leite (2001), Kou et al (2004) and Soberón (2002). In the majority of the investigations, the modulus of elasticity decreases when the substitution rate of RA for NA increases. This behaviour is mostly attributed to the lower stiffness of RA compared to NA. The higher

porosity of RA is responsible for the higher deformation of these aggregates when compared to NA, and this effect is also reflected in the concrete with RA when compared to conventional concrete.

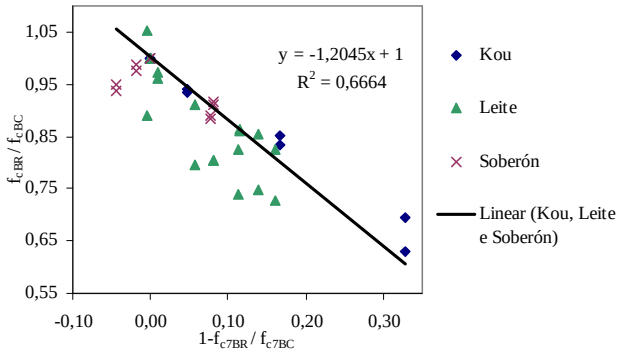

Fig. 3 - Variation of the ratio between the 28 and 90-day compressive strength of concrete and the ratio between the 7-day compressive strength of concrete for the campaigns of Leite, Soberón and Kou

Figure 4 shows the variation of the ratio between the 28 and 90-day modulus of elasticity of concrete and the ratio between the density of the aggregates in the mixture. On the right side of the figure the same ratio is presented but without the results of Kou et al (2004), because the ratio between the density of the aggregates in the mixture is very low, and for this reason, it has a negative contribution to the correlation coefficient. The correlation coefficients are considered acceptable in both cases.

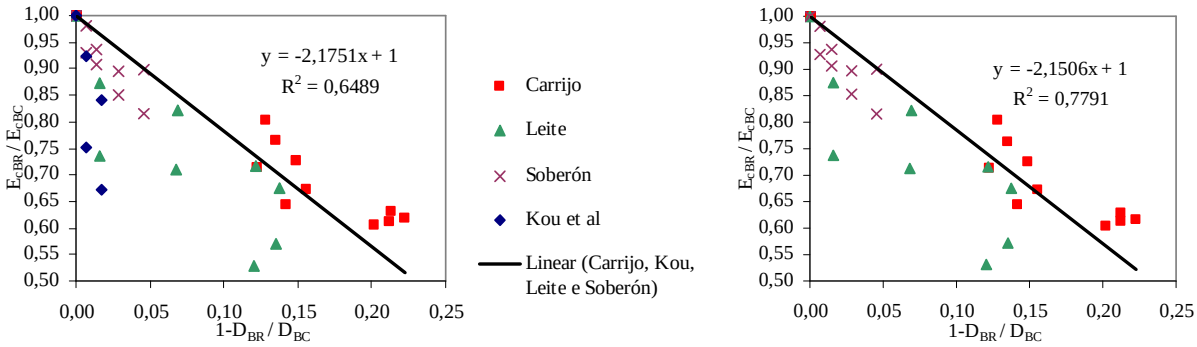

Fig. 4 - Variation of the ratio between the 28 and 90-day modulus of elasticity of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón and Kou (left) and without Kou (right)

The same variation for the ratio between the water absorption of the aggregates in the mixture is presented in Figure 5. The correlation coefficients are considered acceptable and, in the case of the analysis without the results of Kou et al (2004), good. It is possible to identify a linear tendency in the variation between the relations.

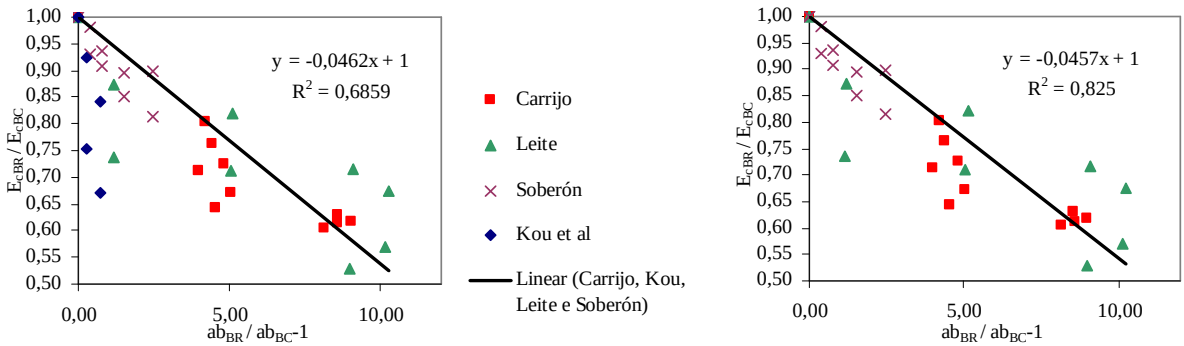

Fig. 5 - Variation of the ratio between the 28 and 90-day modulus of elasticity of concrete and the ratio between the water absorption of the aggregates in the mixture for the campaigns of Carrijo, Leite, Soberón and Kou (left) and without Kou (right)

Figure 6 shows the variation of the ratio between the 28 and 90-day modulus of elasticity of concrete and the ratio between the 7-day compressive strength of concrete for the campaigns of Kou and Soberón. The correlation coefficient is considered not acceptable and, for this reason, it is not possible to identify a linear relationship in the variation.

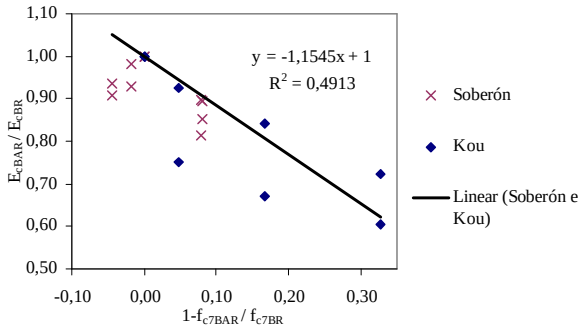

Fig. 6 - Variation of the ratio between the 28 and 90-day modulus of elasticity of concrete and the ratio between 7-day compressive strength of concrete for the campaigns of Soberón and Kou

3.1.3 Tensile strength

The campaigns of Kou et al (2004), Soberón (2002) and Leite (2001) tested concrete tensile strength at different ages (28 and 90 days). The results of Leite (2001) were only at the age of 28 days and very inconstant. Generally, the results of tensile strength graphics obtained confirm the scatter of test results for this property between different campaigns. Figure 7 shows the variation of the ratio between the 90-day tensile strength of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Soberón and Kou (left) and without Kou (right). The correlation coefficients are considered not acceptable for the two campaigns and good for the results of Soberón (2002) only.

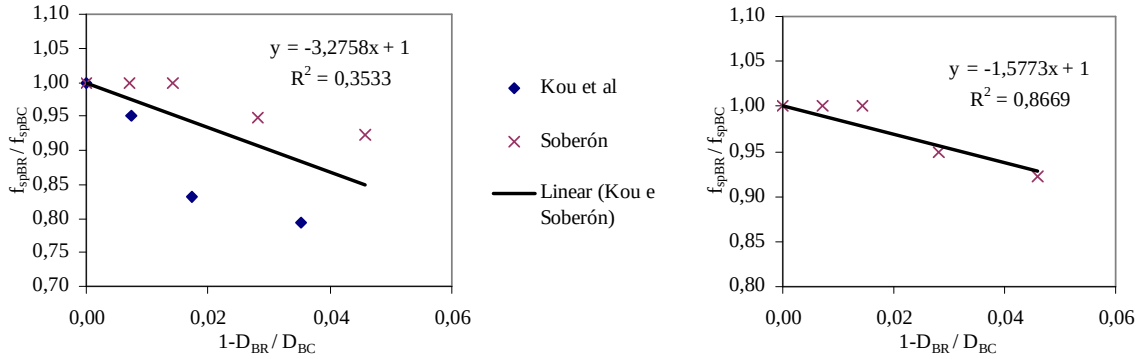

Fig. 7 - Variation of the ratio between the 90-day tensile strength of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Soberón and Kou (left) and without Kou (right)

Figure 8 shows the same correlation but for the water absorption of the aggregates in the mixture. The correlation coefficients obtained are also considered not acceptable and good.

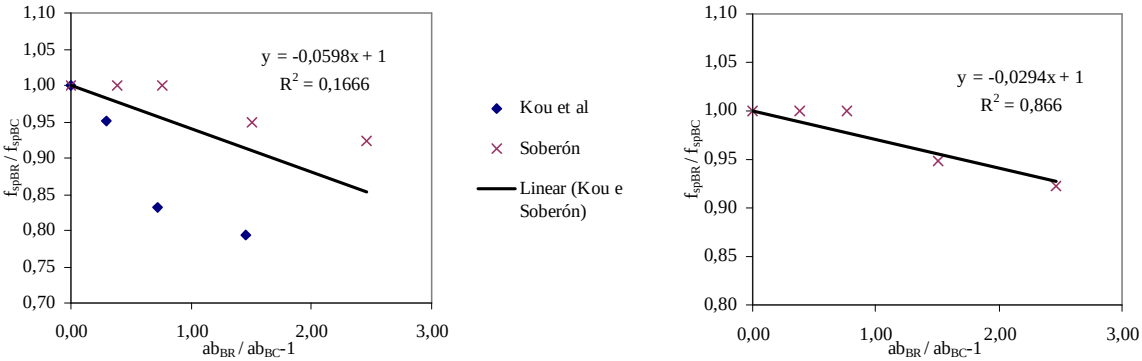

Fig. 8 - Variation of the ratio between the 90-day tensile strength of concrete and the ratio between the water absorption of the aggregates in the mixture for the campaigns of Soberón and Kou (left) and without Kou (right)

The variation of the ratio between the 90-day tensile strength of concrete and the ratio between the 7-day compressive strength for the campaigns of Soberón and Kou is shown in Figure 9. In this case the correlation factor is considered good.

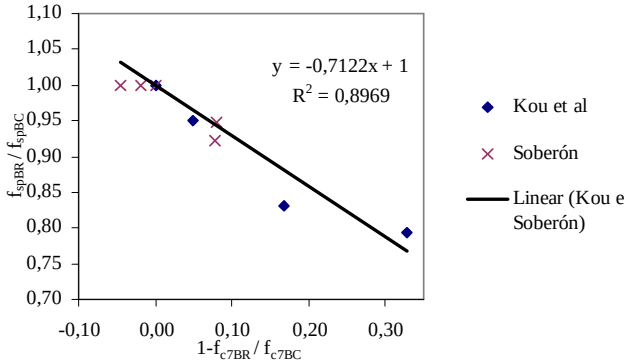

Fig. 9 - Variation of the ratio between the 90-day tensile strength of concrete and the ratio between the 7-day compressive strengths for the campaigns of Soberón and Kou

3.1.4 Flexural strength

For the flexural strength graphic analysis, the test results of Leite (2001) at the age of 28 and 90 days are used. From Figure 10, the variation of the ratio between the 28 and 90-day flexural strength of concrete and the ratio between the three parameters allow to conclude the existence of a linear relationship of the variation. In the three graphics the correlation coefficients are considered good.

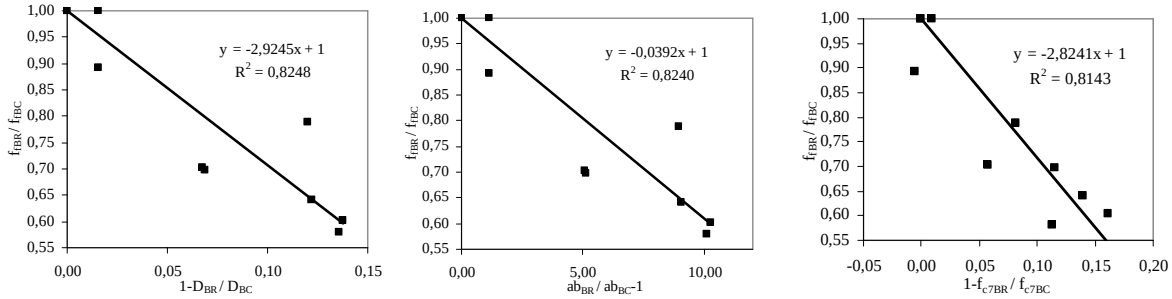

Fig. 10 - Variation summary of the ratio between the 28 and 90-day flexural strength of concrete and the ratio between the density (left), the water absorption (centre) of the aggregates in the mixture and the 7-day compressive strength of concrete (right) for the campaign of Leite

3.1.5 Chloride penetration

The chloride penetration results were obtained by Kou et al (2004) through the test defined in the ASTM C1202-94. This norm establishes the relationship between the electric charge across concrete during a certain period of time and the chloride penetration resistance of concrete. The higher values of electric charge correspond to a lower resistance against chloride penetration. It is expected that the chloride penetration resistance decreases with the increase of the substitution rate of RA by NA. Figure 11 summarises the variation of the ratio between the 28 and 90-day electric charge measured and the ratio between the density and water absorption of the aggregates used in the mixture and the 7-day compressive strength of concrete for the campaign of Kou et al (2004). The correlation coefficients obtained are all considered good, expressing the trend for a linear relationship of the variations.

3.1.6 Shrinkage

Shrinkage results were obtained from the campaigns of Cervantes et al (2007) and Soberón (2002) at the age of 28 and 90 days, respectively. Figure 11 shows the variation of the ratio between the 28 and 90-day shrinkage of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Cervantes et al (2007) and Soberón

(2002). The correlation coefficients obtained are considered not acceptable and acceptable for the 28 and 90-day results, respectively.

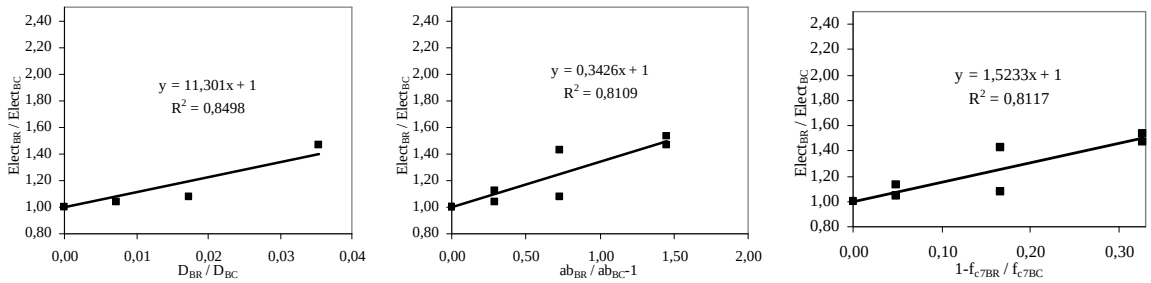

Fig. 10 - Variation summary of the ratio between the 28 and 90-day electric charge measured and the ratio of the density (left), water absorption (centre) of the aggregates in the mixture and the 7-day compressive strength of concrete (right) for the campaign of Kou

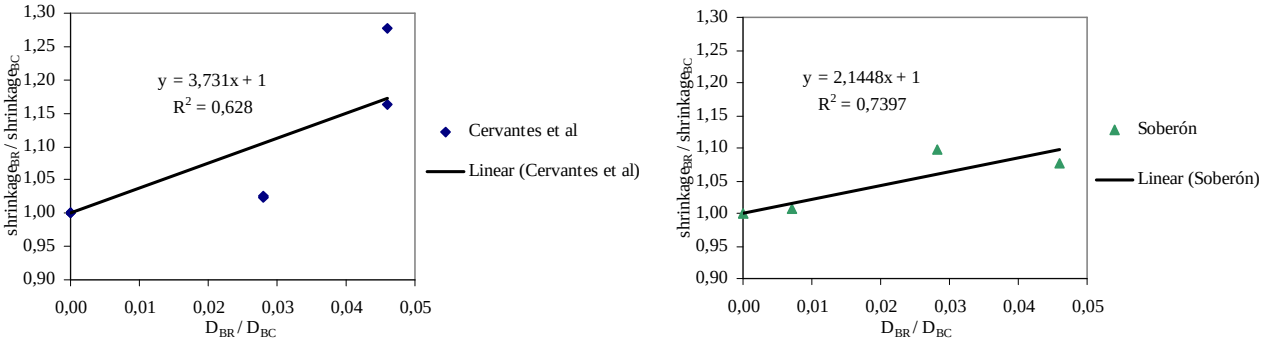

Fig. 11 - Variation of the ratio between the 28 (left) and 90-day (right) shrinkage of concrete and the ratio between the density of the aggregates in the mixture for the campaigns of Cervantes and Soberón

Figure 12 shows the same correlation but for the water absorption of the aggregates in the mixture. Coincidently, the correlation coefficients are equal and both considered acceptable.

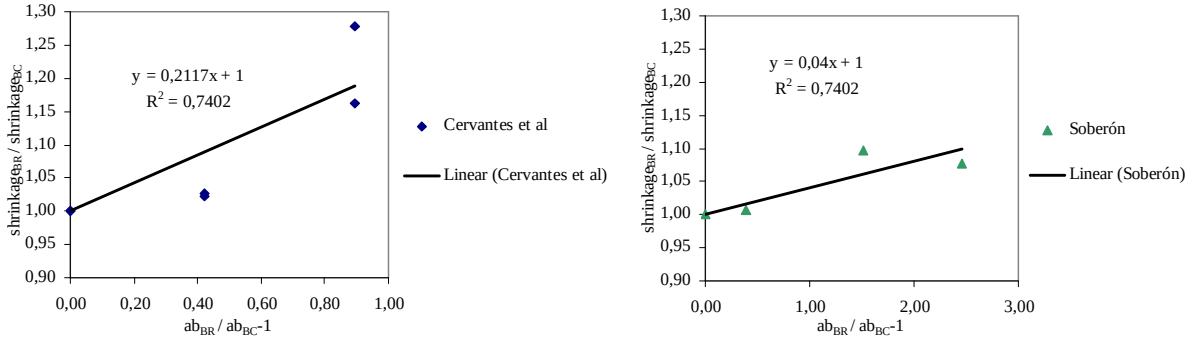

Fig. 12 - Variation of the ratio between the 28 (left) and 90-day (right) shrinkage of concrete and the ratio between the water absorptions of the aggregates in the mixture for the campaigns of Cervantes and Soberón

Since the 7-day compressive strength results for the campaign of Cervantes et al (2007) are considered not consistent, the analysis of the correlation with this parameter is not presented. Figure 13 shows the variation of the ratio between the 90-day shrinkage of concrete and the ratio between the compressive strength of concrete for the campaign of Soberón. The correlation coefficient obtained is considered good.

3.1.7 Water absorption

The water absorption of the concrete was tested by Soberón (2002) according to the UNE 83-310-90 norm. It is expected that an increase of the substitution rate of RA by NA increases the water absorption of concrete, mostly because of the higher water absorption of RA compared to NA (due to the mortar attached to the first ones). Figure 14 summa-

rises the variation of the ratio between the 28-day water absorption of concrete and the ratio of the density and water absorption of the aggregates in the mixture and the 7-day compressive strength of concrete for the campaign of Soberón (2002). The correlation coefficients are considered very good for the variation with the ratio between the properties of the aggregates in the mixture and not acceptable for the variation with the ratio between the 7-day compressive strength of concrete.

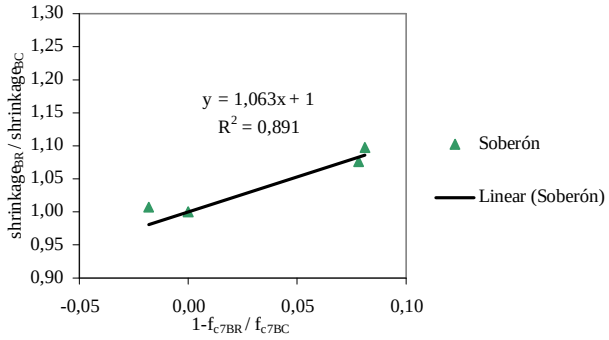

Fig. 13 - Variation of the ratio between the 90-day shrinkage of concrete and the ratio between the compressive strength of concrete for the campaign of Soberón

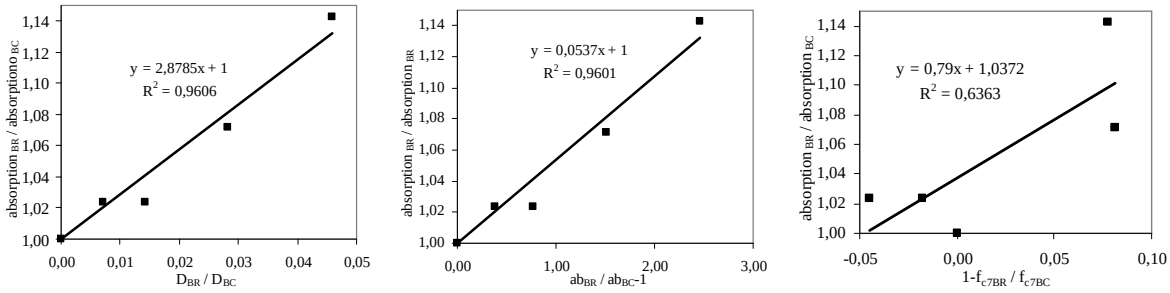

Fig. 14 - Variation summary of the ratio between the 28-day water absorption of concrete and the ratio of the density (left), water absorption (centre) of the aggregates in the mixture and the 7-day compressive strength of concrete (right) for the campaign of Soberón

3.1.8 Creep

Soberón (2002) tested the creep resistance of concrete at the age of 90 days. The reduction of the stiffness of RA compared with NA contributes to a higher creep with the increase of the substitution rate of the RA for the NA. Also, a hypothetical increment of the w/c ratio, to balance the higher water absorption of RA compared with NA, can contribute to higher values of creep in the concrete with RA. Figure 15 shows the variation summary of the ratio between the 90-day creep of concrete and the ratio of the density and water absorption of the aggregates used in the mixture and the 7-day compressive strength of concrete. The correlation coefficients obtained are considered very good for the variation with the ratio between the properties of the aggregates in the mixture and acceptable for the variation with the ratio between the 7-day compressive strength of concrete.

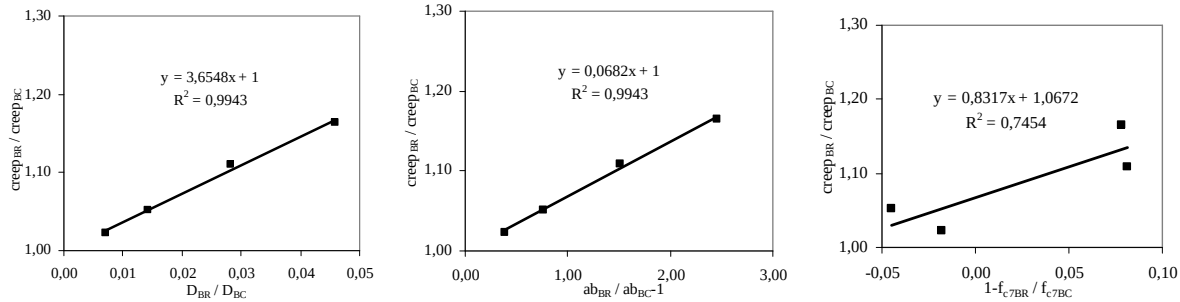

Fig. 15 - Variation summary of the ratio between the 90-day creep of concrete and the ratio of the density (left), water absorption (centre) of the aggregates in the mixture and the 7-day compressive strength of concrete (right) for the campaign of Soberón

3.1.9 Carbonation

The experimental campaign of Katz (2003) analyzed the carbonation effect in concrete for a conventional concrete and a concrete with recycled aggregates only. For this study, and in order to collect the largest amount of results, values obtained in the three areas of the concrete specimen tested (top, bottom and sides) were used. Like the resistance against chloride penetration, the carbonation penetration resistance is reduced with an increase of the substitution rate of RA for NA. This behaviour is mainly justified by the higher porosity of RA compared to NA.

Figure 16 shows the variation of the ratio between the 7-day carbonation penetration of concrete and the ratio of the density and water absorption of the aggregates used in the mixture and the 7-day compressive strength of concrete for the campaign of Katz (2003). The correlation coefficients are considered acceptable and good.

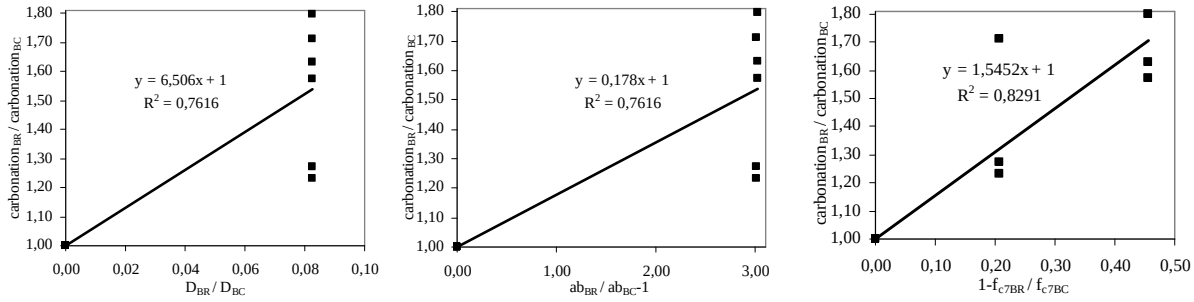

Fig. 16 - Variation summary of the ratio between the 7-day carbonation penetration of concrete and the ratio of the density (left), water absorption (centre) of the aggregates in the mixture and the 7-day compressive strength of concrete (right) for the campaign of Katz

4. Conclusions

The search for international experimental results for this study revealed great differences in the test procedures and organization of the published information. Most of the campaigns accepted the variation of more than one parameter, including the w/c ratio, making the analysis of the effect of the substitution rate impracticable. These obstacles excluded a great number of campaigns to be used in the graphical analysis developed.

Based on the selection of six campaigns, it was possible to analyse nine properties of the hardened concrete. The relationship between these properties and the density and water absorption of the aggregates used in the mixture and the 7-day compressive strength of concrete allowed the following conclusions:

- with very few exceptions, it is possible to establish a linear relationship for the variation of the ratio between the concrete properties and the ratio of the three parameters mentioned;
- generally, the density of the aggregates used in the mixture showed higher correlation coefficients in the graphical analysis with the hardened concrete properties;
- the 7-day compressive strength seems to be the most inadequate parameter to estimate the long-term concrete properties, since the lower correlation coefficients were, in general, obtained with this property; this behaviour can be justified by the influence of the variation of mixture procedures from one campaign to the other and by the higher scatter of results for young concrete;
- the lower results were obtained with the tensile strength and can be justified with the greater variability of this property compared with the compressive strength for example (a trend common to conventional concrete).

Notwithstanding the variability of factors introduced by each investigator in the experimental procedures, it is possible to validate a methodology of estimation of the properties of the concrete with recycled aggregates. The major advantage of this procedure is related with the low cost and short time needed to obtain the results to estimate the long-term properties of hardened concrete. This innovative methodology was registered as a Portuguese patent (n.º PT103756). The generalization of this procedure can, in the future, allow construction promoters to decide, in an economic and fast way, about the use of RA in the construction of new concrete structures.

Table 2 shows all the correlation obtained with this study (most were not mentioned in this summary). The correlation coefficient classification was identified by different colours.

Table 2 - Summary of the correlation between the different concrete properties and the density and water absorption of the aggregates in the mixture and the 7-day compressive strength of concrete

		Density		Water absorption		f_{c7d}*	
Property	Campaigns	R^2	declivity	R^2	declivity	R^2	declivity
f_{c28}	Carrijo/ Kou/ Leite /Soberón	0,8697	1,8354	0,6992	-0,0369	0,6339	1,3551
	Carrijo/ Leite /Soberón	0,8927	1,8284	0,7210	-0,0368	-	-
f_{c90}	Kou/ Leite/ Soberón	0,6514	1,4486	0,5778	-0,0192	0,7616	1,0539
	Leite/ Soberón	0,8152	1,4169	0,7716	-0,0190	-	-
f_c	Carrijo/ Kou/ Leite/ Soberón	0,8370	1,7693	0,5905	-0,0310	0,6664	1,2045
	Carrijo/ Leite/ Soberón	0,8734	1,7583	0,6250	-0,0308	-	-
E_{c28}	Carrijo/ Kou/ Leite/ Soberón	0,6636	2,1481	0,7003	-0,0456	0,3047	1,7111
	Carrijo/ Kou/ Soberón	0,7591	1,9224	0,7300	-0,0506	0,6356	1,3738
E_{c90}	Kou/ Soberón	0,6908	5,0790	0,5746	-0,0946	0,3026	0,9351
E_c	Carrijo/ Kou/ Leite/ Soberón	0,6489	2,1751	0,6859	-0,0462	0,2205	1,3997
	Carrijo/ Leite/ Soberón	0,7791	2,1506	0,8250	-0,0457	-	-
	Carrijo/ Kou/ Soberón	0,7147	1,9589	0,7044	-0,0515	0,4913	1,1545
f_{sp28}	Leite/ Soberón /Kou	0,3331	1,4282	0,2508	-0,0188	0,3019	0,7110
	Leite/ Soberón	0,4906	1,3441	0,4693	-0,0180	-	-
	Soberón /Kou	-	-	-	-	0,6356	0,6321
f_{sp90}	Soberón/ Kou	0,3533	3,2758	0,1666	-0,0598	0,8969	0,7122
	Soberón	0,8669	1,5773	0,8660	-0,0294	-	-
f_{sp}	Leite/ Soberón /Kou	0,2652	1,5305	0,1372	-0,0198	0,4904	0,7115
	Leite/ Soberón	0,5358	1,3530	0,5094	-0,0183	-	-
	Soberón /Kou	-	-	-	-	0,7858	0,6721
f_f	Leite	0,8248	2,9245	0,8240	-0,0392	0,8143	2,8241
$Chloride_{28}$	Kou	0,8821	-16,8710	0,8888	0,4108	0,8903	-1,8266
$Chloride_{90}$	Kou	0,8498	-11,3010	0,8455	0,2744	0,8460	-1,2199
Chloride	Kou	0,8101	-14,086	0,8109	0,3426	0,8117	-1,5233
$Shrinkage_{28}$	Cervantes	0,6280	-3,7310	0,7402	0,2117	-	-
$Shrinkage_{90}$	Soberón	0,7397	-2,1448	0,7402	0,0400	0,8910	-1,0630
Shrinkage	Soberón e Cervantes	0,5890	-3,1945	0,3626	0,0525	-	-
$Absorption_{28}$	Soberón	0,9606	-2,8785	0,9601	0,0537	0,6363	-0,7900
$Creep_{90}$	Soberón	0,9943	-3,6548	0,9943	0,0682	0,7454	-0,8317
$Carbonation_7$	Katz	0,7616	-6,506	0,7616	0,1780	0,8291	-1,5452

correlation coefficient acceptable ($0,65 \leq R^2 < 0,80$)
correlation coefficient good ($0,80 \leq R^2 < 0,95$)
correlation coefficient very good ($R^2 \geq 0,95$)

* excluded the campaign of Carrijo (2005) due to lack of data

- in the campaign of Kou et al (2004), only the results for the concrete with 0% of fly ash and with the cure by immersion were used.
- in the campaign of Carrijo (2005), the results for the concrete with RA classified as "ash" and "red" and with density under 2,2 g/cm^3 were used.
- in the campaign of Leite (2001), the test results and the values obtained by statistical method by the author were used.
- the regression lines were obtained automatically by the commercial software used and were conditioned to go through the point correspondent to the conventional concrete.