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Mechanical characterization of concretes produced with construction and demolition waste

Caracterização mecânica de concretos produzidos com resíduos de construção e demolição

Caracterización mecánica del hormigón producido con residuos de construcción y demolición

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Abstract

The construction industry is responsible for the generation of large volumes of waste, known as construction and demolition waste (CDW). Around the world, millions of tons of these wastes are generated annually, which often become important environmental liabilities. The situation gets worse as the sector develops. In Europe, only 15 of the 27 countries in the European Union annually produce around 180 million tonnes of CDW, in Brazil, the data about this indicates that in 2014 the municipalities collected about 45 million tons of CDW, quantity 4.1% higher than in 2013. In this scenario, the present study aims to evaluate the partial replacement of natural aggregates by CDW (aggregates of concrete waste) in the production of concretes. In this sense, the effects of this substitution on the workability and mechanical characteristics of the concretes produced, as well as the influence of the mixing method and the percentage of superplasticizer additive on the same characteristics were evaluated. The methodology basically consists in the production of seven different traits, which are references and different combinations of mixing method, aggregate substitutions and superplasticizer percentages. Specimens of these traces were molded for mechanical characterization. Workability parameters were also evaluated. It is concluded that the workability is strongly affected by the addition of CDW, but a good workability can be obtained with the use of superplasticizer additives. The mixing method did not change the results obtained for this property. The results also indicate that the compressive and tensile strengths are not negatively affected by the substitution of aggregates, as well as being not significantly affected by the presence of the percentages of superplasticizer used, nor by the mixing methods.

Keywords: Concrete; CDW; Workability; Mechanical Characterization.

Resumo

O setor da construção civil é responsável pela geração de grande volume de resíduos, conhecidos como resíduos de construção e demolição (RCD). Em todo o mundo são geradas anualmente milhões de toneladas desses resíduos, que muitas vezes se tornam passivos ambientais importantes. A situação se agrava à medida que o setor se desenvolve, na Europa apenas 15 dos 27 países da União Europeia produzem anualmente cerca de 180 milhões de toneladas de RCD, já no Brasil, dados indicam que, em 2014, os municípios coletaram cerca de 45 milhões de toneladas de RCD, número 4,1% maior que em 2013. Diante desse cenário, o presente estudo tem como objetivo avaliar a substituição parcial de agregados naturais por RCD (agregados de resíduo de concreto) na produção de concretos. Nesse sentido buscou se

avaliar os efeitos dessa substituição na trabalhabilidade e nas características mecânicas dos concretos produzidos, bem como a influência do método de mistura e do percentual de aditivo superplastificante sobre as mesmas características. A metodologia consiste basicamente na produção de sete traços diferentes, que são referências e diferentes combinações de método de mistura, substituições de agregados e percentuais de superplastificante. Foram moldados corpos de prova dos referidos traços para caracterização mecânica. Também foram avaliados parâmetos de trabalhabilidade. Conclui-se que a trabalhabilidade é fortemente afetada pela adição de resíduos de construção e demolição, contudo uma boa trabalhabilidade pode ser obtida com o uso de aditivos superplastificantes. O método de mistura não alterou os resultados obtidos quanto a essa propriedade. Os resultados obtidos indicam também que as resistências à compressão e tração não são afetadas negativamente pela substituição de agregados, assim como não sofrem efeito significativo pela presença dos percentuais utilizados de superplastificante, nem pelos métodos de mistura.
Palavras-chave: Concreto; RCD; Trabalhabilidade; Caracterização mecânica.

Resumen

El sector de la construcción es responsable de la generación de grandes volúmenes de residuos, conocidos como residuos de construcción y demolición (RCD). Millones de toneladas de estos desechos se generan anualmente en todo el mundo, lo que a menudo se convierte en importantes pasivos ambientales. La situación empeora a medida que el sector se desarrolla, en Europa solo 15 de los 27 países de la Unión Europea producen anualmente alrededor de 180 millones de toneladas de RCD, mientras que en Brasil, los datos indican que en 2014, los municipios recolectaron alrededor de 45 millones de toneladas de RCD, 4.1% más que en 2013. Dado este escenario, el presente estudio tiene como objetivo evaluar el reemplazo parcial de agregados naturales por RCD (agregados de residuos de concreto) en la producción de concreto. En este sentido, se evaluaron los efectos de esta sustitución sobre la trabajabilidad y las características mecánicas de los hormigones producidos, así como la influencia del método de mezcla y el porcentaje de aditivo superplastificante en las mismas características. La metodología consiste básicamente en la producción de siete rasgos diferentes, que son referencias y diferentes combinaciones de métodos de mezcla, sustituciones de agregados y porcentajes de superplastificantes. Las muestras de estos rastros fueron moldeadas para caracterización mecánica. Los parámetros de viabilidad también fueron evaluados. Se concluye que la trabajabilidad se ve fuertemente afectada por la adición de residuos de construcción y demolición, sin embargo, se puede obtener una buena

trabajabilidad con el uso de aditivos superplastificantes. El método de mezcla no cambió los resultados obtenidos para esta propiedad. Los resultados obtenidos también indican que las resistencias a la compresión y a la tracción no se ven afectadas negativamente por la sustitución de agregados, así como tampoco sufren un efecto significativo por la presencia de los porcentajes de superplastificantes utilizados, ni por los métodos de mezcla.
Palabras clave: Hormigón; RCD; Trabajabilidad; Caracterización mecánica.

1. Introduction

The growth of waste generation is a global concern, one of the main waste generating activities is construction and demolition (Limbachiya, 2004). Data from Eurostat report that from 2004 to 2014, the development of waste production in the European Union (EU) of the economic activity of construction was 57.2%, and the alarming volumes of waste production were also explained, only in 2014, the EU generated about 61.8 million tons of construction and demolition waste (CDW). In Holland, in 2007, production of CDW revolves around 14 million tons, with this type of waste being the third largest source of waste in the country (Hendriks, Nijkerk, & Van Koppen, 2007). More recent European data indicate that only 15 of the 27 EU countries annually produce about 180 million tonnes of CDW (Gomes & De Brito, 2009). In Brazil, in 2014, the municipalities collected about 45 million tons of CDW, 4.1% higher than in 2013 (ABRELPE, 2014).

Due to the high porosity and water absorption, characteristics of the CDW, it is very common that they promote changes in the characteristics of the concrete in a fresh state, especially in relation to workability. The recycled aggregate tends to retain a greater amount of water from the mixture, thus decreasing the workability (Angulo, 2005; Geng & Sun, 2013; Ryou & Lee, 2014; Zhang & Zong, 2013).

Studies evaluating the tensile strength and compression of concretes manufactured with CDW indicate different results. While some studies present loss of mechanical performance (Bhutta et al., 2013; A. Richardson, Coventry, & Bacon, 2011; A. E. Richardson, Coventry, & Graham, 2009; Zhang & Zong, 2013), there are those in which there is no substantial loss of resistance (Etxeberria, Vázquez, Marí, & Barra, 2007; Evangelista & de Brito, 2010; A. Richardson et al., 2011). This divergence can reside in the different research methodologies and materials involved in the studies, since when it comes to CDW, there is a diversity of ways to conduct research with regard to the obtaining, composition, selection and method of use of the material. While some researchers opt for the use of material untreated

(Zhang & Zong, 2013), there are researches that develop treatment prior to substitution [10] or even select the most indicated residues for the maintenance of resistance, such as concrete residues (Etxeberria et al., 2007; Evangelista & de Brito, 2010). It should also be emphasized that the researches have several percentages of substitutions, with different constitutions, as predominantly ceramic or cementitious materials, which directly affects the resistance variation.

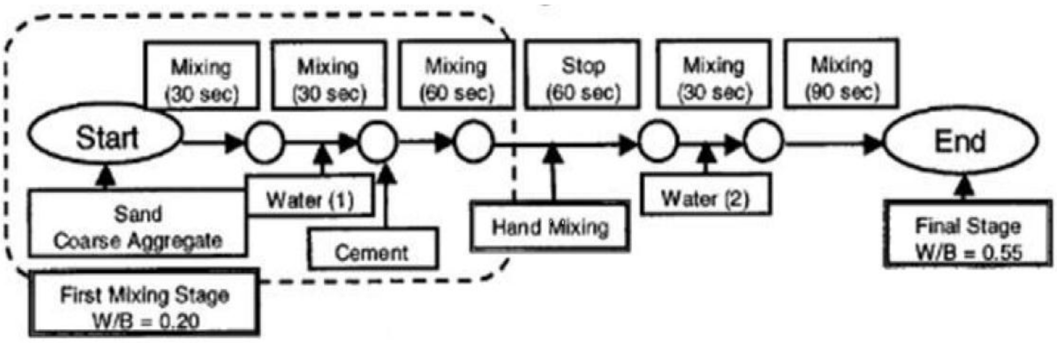
In view of this panorama, this article aims to enrich the discussion on the use of construction and demolition wastes as used as coarse aggregates in the production of structural concrete. In this sense, the effect of this use on the workability and the mechanical characteristics of these new concretes is evaluated.

2. Materials and methods

In order to investigate the characteristics of concrete with partial substitution of natural aggregates (NA) by recycled concrete aggregate (RCA), seven mixtures were elaborated for subsequent characterization tests. Of these mixtures, four have substitutions of 50% of the NA by RCA, and the others are related to the reference concrete (manufactured only with natural aggregates) for comparison. The substitution to the percentage of 50% occurs because the literature indicates that the substitution of 100% is difficult due to the significant problems in relation to workability (Limbachiya, 2004). In the search to work with a high percentage, given its potential to reduce the impact of construction with its possible use, we opted for 50%, a value already used by other correlated researches (Etxeberria et al., 2007; Gomes & De Brito, 2009; Limbachiya, 2004; Zhang & Zong, 2013).

In addition to the substitution of the aggregates, the mixing method was varied (single or double). In the double mixing method (Otsuki, Miyazato, & Yodsudjai, 2003; Tam, Gao, & Tam, 2005), the aggregates are added to the concrete mixer first. After 30 seconds of mixing add part of the water. At the beginning of the first minute of the mixture add the cement. After two minutes of operation, the concrete mixer is switched off for one minute and manual mixing is performed. In the relinking of the equipment adds the remainder of the water and the mixture proceeds for another two minutes. The present study adds the SP-II along with the second water. Figure 1 exposes the steps of the double blending method.

Figure 1: Double mixing method



Source: Otsuki, Miyazato e Yodsudjai (2003) adapted.

First, a comparison was made between concretes with 50% substitution produced with each of the methods. Once it was found that the double mixing method presented better results (compressive strength about 5% higher) and considering that this result is supported in the literature (Otsuki et al., 2003; Tam et al., 2005), this method was adopted for the other traits developed, including for reference concrete. Two percentages of superplasticizer additive were also evaluated, with minimum values (0.6%) and maximum (1%) recommended by the manufacturer in order to observe its influence on the characteristics of interest of the present work. Table 1 shows the mixtures made.

Table 1: Description of concretes manufactured for analysis.

IDENTIFICATION	DESCRIPTION
DM-RC	Reference concrete manufactured by double mixing
DM-SP1%-RC	Reference concrete manufactured by double mixing and addition of 1% superplasticizer
DM-SP0,6%-RC	Reference concrete manufactured by double mixing and addition of 0.6% superplasticizer
SM-RCA	Concrete manufactured by simple mixing, replacing 50% of NA by RCA
DM-RCA	Concrete manufactured by double mixing, replacing 50% of NA by RCA
DM-SP0,6%-RCA	Concrete manufactured by double mixing, replacing 50% of the NA by RCA and addition of 0.6% superplasticizer
DM-SP1%-RCA	Concrete manufactured by double mixing, replacing 50% of the AN by ARC and addition of 1% superplasticizer

2.1. Materials

The cement used in the study was the "Portland cement of high initial resistance", denominated as CP V ARI (ABNT, 2018), produced by Lafarge-Holcim. This option was due to the fact that it presented the smallest possible content of additions in its chemical composition among the cements of the region where the study was carried out. Table 2 presents the main chemical components of the cement used and the density of it is 2.973 g/cm³.

Table 2: Chemical composition of cement.

Component	Percentage (%)
CaO	64.17
SiO_2	18.93
Al_2O_3	5.16
Fe_2O_3	2.96
CO_2	2.92
SO_3	2.87
K_2O	0.86
MgO	0.76

The natural coarse aggregate was made of gneiss crushed, being classified as “Brita 1” by the Brazilian Standard (ABNT, 2009a). The recycled concrete aggregate was made by crushing CDW in the same dimensions of the natural aggregate. Figure 2 shows the visual aspect of RCA and NA.

Figure 2: Recycled aggregate concrete (left) and Natural aggregate (right).

The following tests of characterization of the coarse aggregate were performed: Coarse aggregate - Determination of the bulk specific gravity, apparent specific gravity and water absorption (ABNT, 2009b); Aggregates - Determination of the unit weight and air-void contents (ABNT, 2006); Small-size coarse aggregate - Test method for resistance to degradation by “Los Angeles machine” (ABNT, 2001); Aggregates - Sieve analysis of fine and coarse aggregates (ABNT, 2003). Table 3 presents the results of these tests for the natural and recycled aggregates.

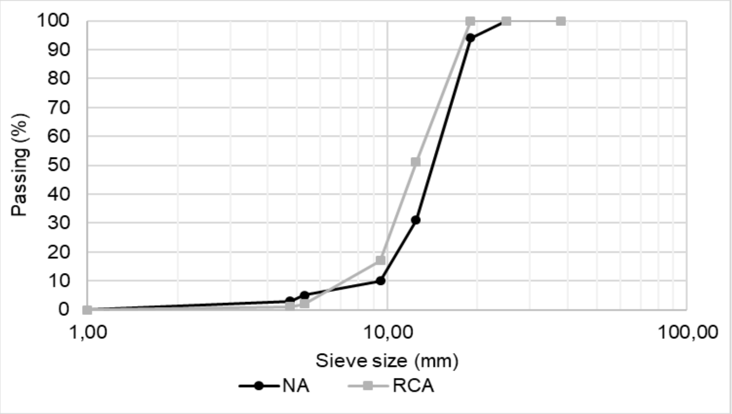
Table 3: Properties of the coarse aggregates.

Property	NA	RCA
Dry aggregate specific mass (g/cm³)	2.66	2.55
Specific mass of the saturated aggregate with dry surface (g/cm³)	2.64	2.29
Specific mass (g/cm³)	2.63	2.12
Absorption (%)	0.33	7.88
Unitary mass of the aggregate (kg/m³)	1440.00	1175.79

Volume index of voids in aggregates (%)	45.67	53.73
Loss by abrasion (%)	22.00	50.80

The granulometric curves obtained for the coarse aggregates can be observed in Figure 3.

Figure 3: Granulometry of coarse aggregates.



The fine aggregate used was river sand. The characterization tests followed the Brazilian Standard. The specific mass obtained was 2.58 g/cm³ (ABNT, 1987). The values calculated for unitary mass of the fine aggregate and the index of material voids were 1393.68 kg/m³ and 45.81%, respectively (ABNT, 2006). The fineness module found was 3.04 (ABNT, 2003).

2.2. Mix

Table 4 shows the proportions of concrete mixtures used in the research. All the mixtures produced followed the proportions presented in table 4 and maintained the consumption of cement and the constant factor w/c (0.55). The substitution of the natural aggregates by the recycled aggregates was carried out in volume since, because they had a smaller density, when they were replaced using the mass they would occupy a larger volume in the mixture (Pacheco-Torgal, Tam, Labrincha, Ding, & De brito, 2013).

Tabela 4: Traço - Proporções da mistura.

MATERIAL	CONSUMPTION (kg/m³)
Water	200
Cement	364
Natural coarse aggregates	994
Natural fine aggregates	785

In some of the mixtures there was the use of the superplasticizer additive based on polycarboxylate, in 0.6 and 1.0% of the weight of the cement. These values are the minimum and maximum percentages recommended by the manufacturer. Thus, the effects of the use of superplasticizer in its recommended range of use could be evaluated.

2.3. Study stages

The study was divided into three phases:

• Phase 1: SM-RCA and DM-RCA mixtures. At this stage the influence of the mixing method of the materials in the production of recycled concrete was measured. The mixtures were made using the conventional simple mixing method and double mixing.

• Phase 2: DM-SP0.6%-RCA and DM-SP1%-RCA mixtures. This stage aimed to evaluate the effects of the use of additives in concrete with recycled aggregates.

• Phase 3: DM-RC, DM-SP0.6%-RC and DM-SP1%-RC mixtures. In this stage, the concrete mixtures of reference were produced for the comparison with the concretes produced with partial substitution of the recycled aggregates.

2.4. Rheology

To evaluate the workability of concrete mixtures, the Slump Test was performed according to the Brazilian Standard (ABNT, 1998).

2.5. Mechanical Properties

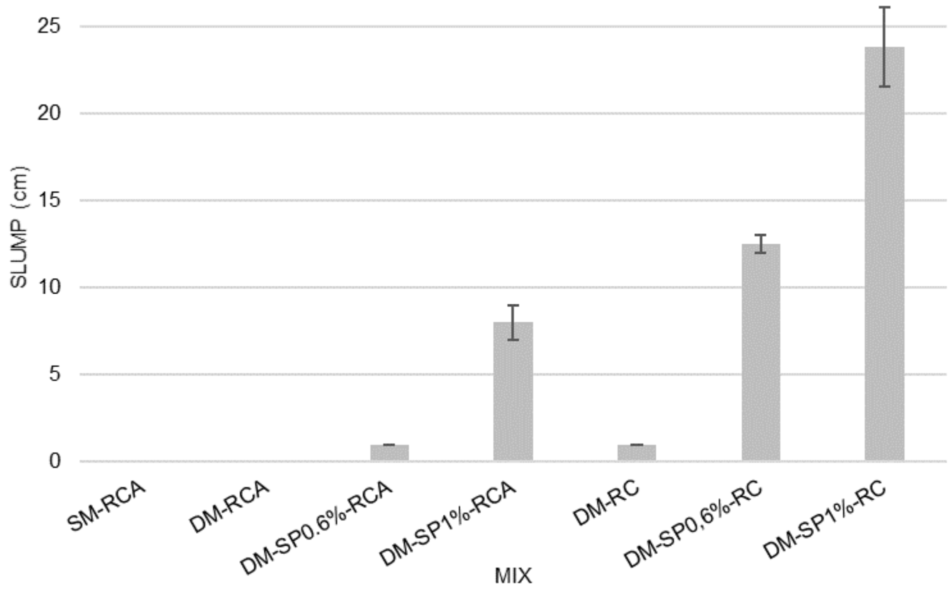
To evaluate the mechanical characteristics, a universal testing machine with a capacity of 2000 kN was used. The tests of axial compression and tensile strength were performed at 28 days, after a period of submerged curing, according to the recommendations of the Brazilian Standard (ABNT, 1996, 2011).

3. Results and discussion

3.1. Workability

The effects of the recycled aggregate and the Superplasticizer additive on the workability of the concretes were measured through the Slump Test and the results are shown in Figure 4.

Figure 4: Slump test results.



To analyze the results presented, it is observed that in relation to the mixing method there was no variation of workability, since both recycled concrete without additive SP II obtained zero reduction.

When comparing the concretes with the use of 50% of RCA with those produced without recycled aggregate, the workability is always lower in the mixtures containing RCA, regardless of the use of SP II or the mixing method. This fact is due to the high absorption of RCA that remove mixing water from the mixture. The results found are aligned with what is expected through the literature, since several authors report loss of workability with the use of recycled coarse aggregates (Geng & Sun, 2013; Limbachiya, 2004; Ryou & Lee, 2014; Zega & Di Maio, 2011).

The addition of superplasticizer proved to be effective, increasing the workability in all cases where it was used. The addition of 0.6% of SP II in the case of the use of 50% of ARC was not sufficient, since the abatement was 1 cm. In the case of concrete reference, the

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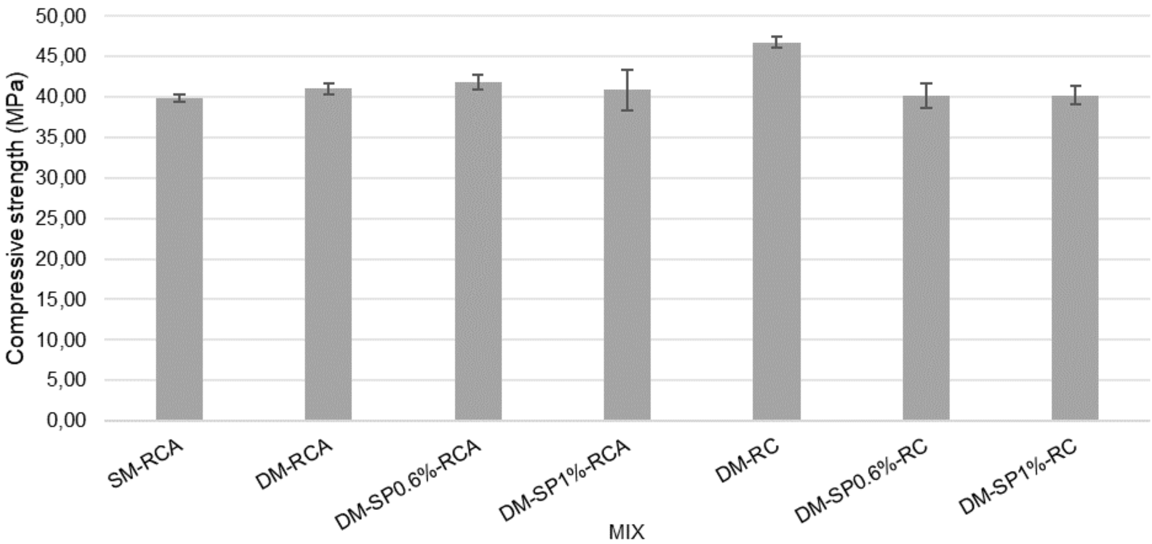
use of 1.0% of superplasticizer proved inadequate, because it raised the abatement to 24 cm, a considerably high value, with the material presented unwanted appearance, with easily noticeable segregation.

3.2. Compressive Strength

With regard to compressive strength, the resistances are similar when the standard deviation is considered - the only exception is the reference concrete without superplasticizer, which obtained resistance about 10% higher than the other mixtures. This fact can be observed in the results presented in Figure 5.

Figure 5: Compressive strength results - 28 days.



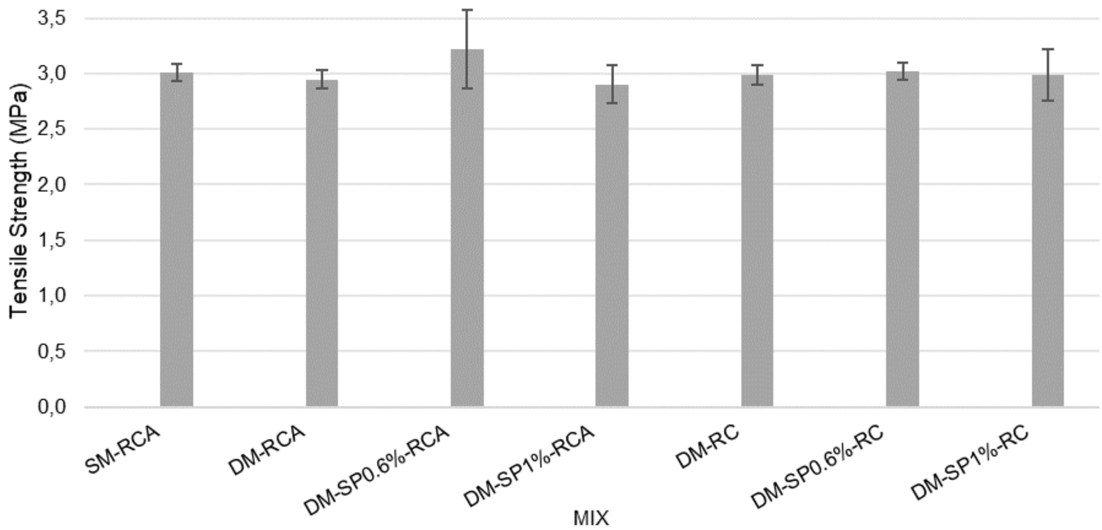
The reduction of the factor w/b occurring in the mixtures with RCA reduced the losses provided by the lower resistance of this aggregate in relation to the NA. Thus, the mixtures with RCA presented resistance similar to the reference.

Several authors report similar results, in which the addition of recycled aggregates does not affect the compressive strength of the new concrete mixtures (Amorim, De Brito, & Evangelista, 2012; Etxeberria et al., 2007; Evangelista & de Brito, 2010; A. Richardson et al., 2011; Sagoe-Crentsil, Brown, & Taylor, 2001). It is noteworthy that the present study used recycled concrete aggregates and thus, it keeps similarity with previous studies in which similar residues were used that indicate that its use provides the maintenance of resistance (Etxeberria et al., 2007; Evangelista & de Brito, 2010; Sagoe-Crentsil et al., 2001). Researches have also found good results by performing treatments on residues from different origins such as the pre-saturation of recycled aggregates (Amorim et al., 2012; A. Richardson et al., 2011).

3.3. Tensile strength

The analysis of Figure 6 shows that the tensile strength is similar in all mixtures, when the standard deviation is taken into consideration. This proves that the use of RCA in substitution of the NA does not affect this mechanical parameter. The use of superplasticizer and the mixing method also do not affect the tensile strength.

Figure 5: Tensile strength results - 28 days.



Etxeberria et al. (2007) reported an increase in tensile strength due to the effectiveness of the new Interfacial transition zone of recycled concrete. Already Kou et al. (2011) expose that recycled concrete obtains results similar to the reference concrete.

It is found that in the present study, the mixing method – simple or double – does not significantly affect the mechanical characteristics, as can be seen in figures 5 and 6. The double mixture was adopted as a standard since the bibliography indicates improvements in durability characteristics (Otsuki et al., 2003; Tam et al., 2005).

4. Conclusions

Based on the results of this research, some conclusions may be exposed. About the workability of concretes, it can be concluded that it is strongly affected by the addition of construction and demolition waste. As expected by the results presented by the literature, the addition of recycled aggregates impaired the workability of the mixtures. Although this effect has been observed, good workability can be achieved with the use of superplasticizers additives. Although the demand for superplasticizer is greater than that found in conventional concretes, it is possible to obtain adequate mixtures within the limits established by the manufacturers (in this case, up to 1%), it can even suggest future assessments using different percentages higher than the recommended minimum (0.6%, used in this study). The method of mixing (single or double), investigated for the production of concretes with substitution of aggregate, did not alter the results obtained for the workability, since both mixtures presented reduction of the cone trunk equal to zero;

The results of compressive strength show that the use of CDW in substitution to NA did not present harmful effects on new concretes. The same can be said about the mixing method and the addition of superplasticizer. Considering the due statistical deviations, the compressive strength was maintained even when replacing the NA with RCA, regardless of the percentage of superplasticizer and the mixing method. The only exception to this tendency is the result of the reference concrete without the use of additives, which showed values about 10% higher than the other mixtures. It is believed that the reduction of the factor w/c provided by the use of RCA maintains the resistance of concrete similar to the concrete with NA;

It was verified that the use of RCA (up to 50% replacement) in concretes does not cause loss of tensile strength. There was also no influence of the mixing method and additive in the results obtained.

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