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Influence of the type of recycled aggregate from construction and demolition waste on the module of deformation of recycled aggregate concrete

Determinação da influência do tipo de agregado reciclado de resíduo de construção e demolição sobre o módulo de deformação de concretos produzidos com agregados reciclados




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Abstract

To contribute to the recycled aggregate concrete study, an experimental test was made by substituting the natural aggregates for recycled aggregates of concrete, of mortar and of red ceramic, which are the three main ingredients of Brazilian construction and demolition waste. Besides the aggregate types, the water/cement ratio (w/c) was also changed from 0.4 to 0.8, fixing the amount of pre soaking water of the recycled aggregates. The concrete's module of deformation was determined at 28-days age, using the Brazilian Standard ABNT NBR 8522/03, in cylindrical specimens. The results show that substituting the natural aggregates for the recycled aggregates reduces the module of deformation, and that the coarse red ceramic recycled aggregate and the fine concrete recycled aggregate were the ones that exerted the greatest and the smallest influence, respectively, on the concrete's module of deformation.

Keywords: recycling, construction and demolition waste, concrete, module of deformation.

Resumo

Com o intuito de contribuir no estudo de concretos produzidos com agregados reciclados, produziu-se um traço de referência (com agregados naturais) e outros 49 traços, substituindo-se os agregados naturais por agregados reciclados de concreto, de argamassa e de cerâmica vermelha, que são os 3 maiores constituintes dos resíduos de construção e demolição das cidades brasileiras. Além do tipo de agregado, também variou-se a relação água/cimento (a/c), entre os valores de 0,4 a 0,8, fixando-se o teor de água na pré-umidificação dos agregados reciclados. O módulo de deformação dos concretos foram determinados aos 28 dias, utilizando-se a norma brasileira ABNT NBR 8522/03, em corpos-de-prova cilíndricos. Os resultados apontam que a substituição do agregado natural pelo reciclado resulta em uma redução do módulo de deformação, sendo que o agregado graúdo de cerâmica vermelha e o agregado miúdo reciclado de concreto foram os que exerceram a maior e a menor influência, respectivamente, sobre o módulo de deformação dos concretos produzidos.

Palavras-chave: reciclagem, resíduo de construção e demolição, concreto, módulo de deformação.

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1. Introduction

The Civil Construction Industry is a productive sector that plays an important role in Brazil's economy. From 1980 to 1996, the sector was accountable for 65% of the national gross investments and in 2001 it was responsible for 15.6% of the GDP, with residential constructions representing a total of 6% and 9% of the national GDP [1].
In order to promote such impressive growth, currently, the civil construction industry is society's biggest end-user of natural resources, consuming from up to 20% to 50% of explored resources in the world [2]. Regarding wood, the Construction Industry uses up 2/3 of all of the wood extracted from the natural world [3].
Up to date construction projects and activities require a considerable amount of inert material, such as sand and gravel, customarily supplied by means of alluvial sediment extractions. Extracting such sediments modifies river courses as well as their natural balance, besides introducing environmental problems as modifications in their hydrologic and hydrogeological structure. Extracting inert rock formation material from uneven rocky terrain is an environmentally dangerous and problematic activity, seeing that it also causes instability in the environment [4].
As in all industrial processes, the products used in the civil construction industry generate extensive residues, needing to administrate such waste. According to John [2], the macrocomplex of the construction industry is accountable for 40% of the waste generated by the economy.
A solution gaining strength day-to-day among researchers is recycling construction and demolition (C&D) waste, and then using it in the very construction as alternative raw-material, since there is a serious shortage of natural aggregates to produce concrete in many urban areas, and when, at the same time, the increase of C&D waste generated in the same areas is also substantial. Thus, by means of recycling, another source of raw-material is used, besides conciliating a reduction in the disposal and the volume of waste [5].
Due to the important role of the civil construction industry in the commonwealth development, it is advisable to seek and adopt urgent measures to insert this sector's developed activities in the new model of development sought; sustainable development. According to John [2], "no society will be able to reach sustainable development without civil construction, which provides support, undergoing intense transformations".
The C&D wastes are characterized for having a variable composition with the locality and, when at the same locality, with time. However, wastes made up of concrete, mortar and red ceramic emerge as the main C&D wastes, representing more than 70% of the total aggregation [6], [3], [7], [8]. Such C&D waste heterogeneity directly influences the recycled aggregate's characteristics when produced with these wastes. Therefore, it is vital to understand the behavior characteristics of the concretes produced with such recycled aggregates when altering the proportion of its ingredients.

2. Objectives

Once the concrete's performance is modified, with the substitution of the natural aggregates for the recycled aggregates, it is necessary to understand the behavior of the concretes regarding some properties, mechanically as well as regarding its durability.
However, the present work limits to modelling the behavior of the concrete's modulus of deformation, and of the water/cement ratio between 0.4 and 0.8, produced by substituting the natural aggregates for the recycled aggregates, of concrete, of mortar and of red ceramic.

3. Methodology

3.1 Experimental project

Seven independent variables (factors) were identified, they are: the fine and coarse recycled aggregate of red ceramic, the fine and coarse recycled aggregate of mortar, the fine and coarse recycled aggregate of concrete and the water/cement ratio. The complete experimental project to study the whole effect of all seven factors on the response variable is the project of factorial experiments 2^k [9]. This project's execution consists of completing 2^7 concrete mixtures, that is 128 mixtures. Due to time and cost restrictions, the solution found to make viable the experimental part, with a high result rate of reliability, was using the second composed project.
The basis of the second composed project is a factorial project 2^k, fractioned or complete, where all of the 2k vertexes of a star and the central points of the star and the factorial project are added to this last one [9]. For this experiment, a fractioned factorial project and the central points were adopted.
The use of fractioned factors are quite functional when there is a great number of factors to be investigated over one or more response variables and the goal is time and cost optimization to obtain results, because fractioning means to divide the entire project in two or more blocks and then test only one of these blocks randomly [10]. This type of study using statistical tools has been previously performed by numerous Brazilian and international research [7], [8], [11]. For the featured complete project, it was divided into 4 blocks, testing only one block, meaning 32 mixtures, which are mixtures 1 to 32 in Table 1.
As the experiment has 7 factors, the star has 14 vertexes, which correspond to mixtures 33 to 46. Mixtures 47 and 48 correspond to the central points, which are equal, since the central point of the fractioned factorial project is the same as the seven-sided star. Mixtures 49 and 50 were inserted into the experimental project, since they represent the moment when all of the aggregates (recycled and natural) are in the concrete, attributing as values to the water/cement ratio the two averages of the inferior and superior thirds, in other words, 0.46 and 0.74. Table 1 shows all of the concrete mixtures defined in the experimental plan.
As the response variable, in other words, dependent variable, there is the module of deformation of the produced concretes, in agreement with the procedures described in NBR 8522/03 - Concrete - Determination of static modules of elasticity and deformation, and the tension curve deformation. There were other variables fixed, such as age-time of the tests (28 days) and pre-humidification of the recycled aggregates, so that they would not absorb the mix water, thus modifying the water/cement ratio (w/c).
Water absorption of the recycled fine aggregates and the natural fine aggregate was measured by the method proposed by NM 30/00 – Absorption of fine aggregate and the water absorption of recycled coarse aggregates, and the natural aggregate was measured by the method proposed by NM 53/02 –Coarse aggregate – Determination of specific gravity, apparent specific gravity and water absorption. For each aggregate, the absorption was defined twice, through two

samples. The mean results for the fine aggregates are in Table 2, and the mean results for the coarse aggregates are in Table 3.
The specific gravity for the recycled and natural aggregates were also determined by the method proposed by NBR 9776/87 – Fine aggregate – Determination of specific gravity by Chapman Flask for the fine aggregates, and by NM 53/02 – Coarse aggregate – Determination of apparent specific gravity and water absorption for the coarse aggregates. For each aggregate, the specific gravity was determined twice, through two samples. The mean results for fine aggregates are in Table 2, and the mean results for the coarse aggregates are in Table 3.
The bulk density of the recycled and natural aggregates was determined by the proposed method NM 45/00 – Aggregates – Determination of bulk density and empty voids. For each aggregate, the bulk density was determined twice using two samples. The objective of the bulk density determination was to discover which of the employed aggregates generated better casing, in other words, which one distributed best, leaving the least gaps in a determined volume. But since the recycled aggregates come from different raw-materials, with different specific gravities, the obtained test results cannot be compared, since for those, the influence of the specific gravity was not isolated. Then, the best way to compare them was to parametrize them from the specific gravity of the natural

Table 1 – Concrete mixtures defined by fractioning of the experiment

Mix	w/c Ratio	Coarse Aggregate				Fine Aggregate			
		Natural	Concrete	Red Ceramic	Mortar	Natural	Concrete	Red Ceramic	Mortar
01	0,46	100%	0%	0%	0%	100%	0%	0%	0%
02	0,74	100%	0%	0%	0%	0%	0%	100%	0%
03	0,74	100%	0%	0%	0%	0%	100%	0%	0%
04	0,46	100%	0%	0%	0%	0%	50%	50%	0%
05	0,74	0%	0%	0%	100%	0%	0%	0%	100%
06	0,46	0%	0%	0%	100%	0%	0%	50%	50%
07	0,46	0%	0%	0%	100%	0%	50%	0%	50%
08	0,74	0%	0%	0%	100%	0%	33%	33%	33%
09	0,46	0%	0%	100%	0%	0%	0%	0%	100%
10	0,74	0%	0%	100%	0%	0%	0%	50%	50%
11	0,74	0%	0%	100%	0%	0%	50%	0%	50%
12	0,46	0%	0%	100%	0%	0%	33%	33%	33%
13	0,74	0%	0%	50%	50%	100%	0%	0%	0%
14	0,46	0%	0%	50%	50%	0%	0%	100%	0%
15	0,46	0%	0%	50%	50%	0%	100%	0%	0%
16	0,74	0%	0%	50%	50%	0%	50%	50%	0%
17	0,46	0%	100%	0%	0%	0%	0%	0%	100%
18	0,74	0%	100%	0%	0%	0%	0%	50%	50%
19	0,74	0%	100%	0%	0%	0%	50%	0%	50%
20	0,46	0%	100%	0%	0%	0%	33%	33%	33%
21	0,74	0%	50%	0%	50%	100%	0%	0%	0%
22	0,46	0%	50%	0%	50%	0%	0%	100%	0%
23	0,46	0%	50%	0%	50%	0%	100%	0%	0%
24	0,74	0%	50%	0%	50%	0%	50%	50%	0%
25	0,46	0%	50%	50%	0%	100%	0%	0%	0%

aggregate in its group (coarse and fine) and thereby determining which was the refined bulk density of such materials. The mean bulk density for the fine aggregates is seen in Table 2, and for the coarse aggregates in Table 3.

3.2 Concrete production

An experimental dosage was performed with the natural aggregates using the method IPT/EPUSP [12], fixing the workability through the slump test method in 12±2cm, and therefore determining the dosage diagram (Figure 1). Table 4 shows the concrete composition of w/c ratio equal to 0.46, performed with natural aggregates. However, when substituting the natural aggregates for the recycled ones, some adjustments were necessary in the concrete dosage, such as volume compensation and adding water from the pre-soaking of the recycled aggregates.

Firstly, a volume compensation of the recycled aggregates to be employed in the pre-determined mixtures was done [13], [14], [7], [8], [15], seeing that simple mass substitution of the natural recycled aggregate would result in higher volumes of recycled aggregates, since the specific gravity of the recycled aggregates is lower than the specific gravity of natural aggregates. This requires more

Table 1 – Concrete mixtures defined by fractioning of the experiment (continuation)

Mix	w/c Ratio	Coarse Aggregate				Fine Aggregate			
		Natural	Concrete	Red Ceramic	Mortar	Natural	Concrete	Red Ceramic	Mortar
26	0,74	0%	50%	50%	0%	0%	0%	100%	0%
27	0,74	0%	50%	50%	0%	0%	100%	0%	0%
28	0,46	0%	50%	50%	0%	0%	50%	50%	0%
29	0,74	0%	33%	33%	33%	0%	0%	0%	100%
30	0,46	0%	33%	33%	33%	0%	0%	50%	50%
31	0,46	0%	33%	33%	33%	0%	50%	0%	50%
32	0,74	0%	33%	33%	33%	0%	33%	33%	33%
33	0,60	0%	50%	25%	25%	0%	33%	33%	33%
34	0,60	0%	0%	50%	50%	0%	33%	33%	33%
35	0,60	0%	25%	50%	25%	0%	33%	33%	33%
36	0,60	0%	50%	0%	50%	0%	33%	33%	33%
37	0,60	0%	25%	25%	50%	0%	33%	33%	33%
38	0,60	0%	50%	50%	0%	0%	33%	33%	33%
39	0,60	0%	33%	33%	33%	0%	50%	25%	25%
40	0,60	0%	33%	33%	33%	0%	0%	50%	50%
41	0,60	0%	33%	33%	33%	0%	25%	50%	25%
42	0,60	0%	33%	33%	33%	0%	50%	0%	50%
43	0,60	0%	33%	33%	33%	0%	25%	25%	50%
44	0,60	0%	33%	33%	33%	0%	50%	50%	0%
45	0,80	0%	33%	33%	33%	0%	33%	33%	33%
46	0,40	0%	33%	33%	33%	0%	33%	33%	33%
47	0,60	0%	33%	33%	33%	0%	33%	33%	33%
48	0,60	0%	33%	33%	33%	0%	33%	33%	33%
49	0,46	25%	25%	25%	25%	25%	25%	25%	25%
50	0,74	25%	25%	25%	25%	25%	25%	25%	25%

Table 2 – Characteristics of fine aggregates used

Aggregate	Testing method NM 30/00 Absorption(%)	Testing method NBR 9776/87 Specific gravity	Testing method NM 45/00 Bulk density (g/cm³)
Natural fine	0,42	2,64	1,56
Recycled fine of concrete	7,55	2,56	1,43
Recycled fine of mortar	4,13	2,60	1,39
Recycled fine of red ceramic	10,69	2,35	1,26

Table 3 – Characteristics of coarse aggregates used

Aggregate	Testing method NM 53/02 Absorption(%)	Testing method NM 53/02 Specific gravity	Testing method NM 45/00 Bulk density (g/cm³)
Natural fine	1,22	2,87	1,44
Recycled fine of concrete	5,65	2,27	1,54
Recycled fine of mortar	9,52	2,01	1,44
Recycled fine of red ceramic	15,62	1,86	1,46

water and cement in order to produce equivalent mixtures of the reference mixtures, that is, those with natural aggregates. The volume compensation of the recycled aggregates in the experimental project mixtures was done according to Equation 1, where:

$$M_{RA} = M_{NA} \cdot \frac{\gamma_{RA}}{\gamma_{NA}} \quad (1)$$

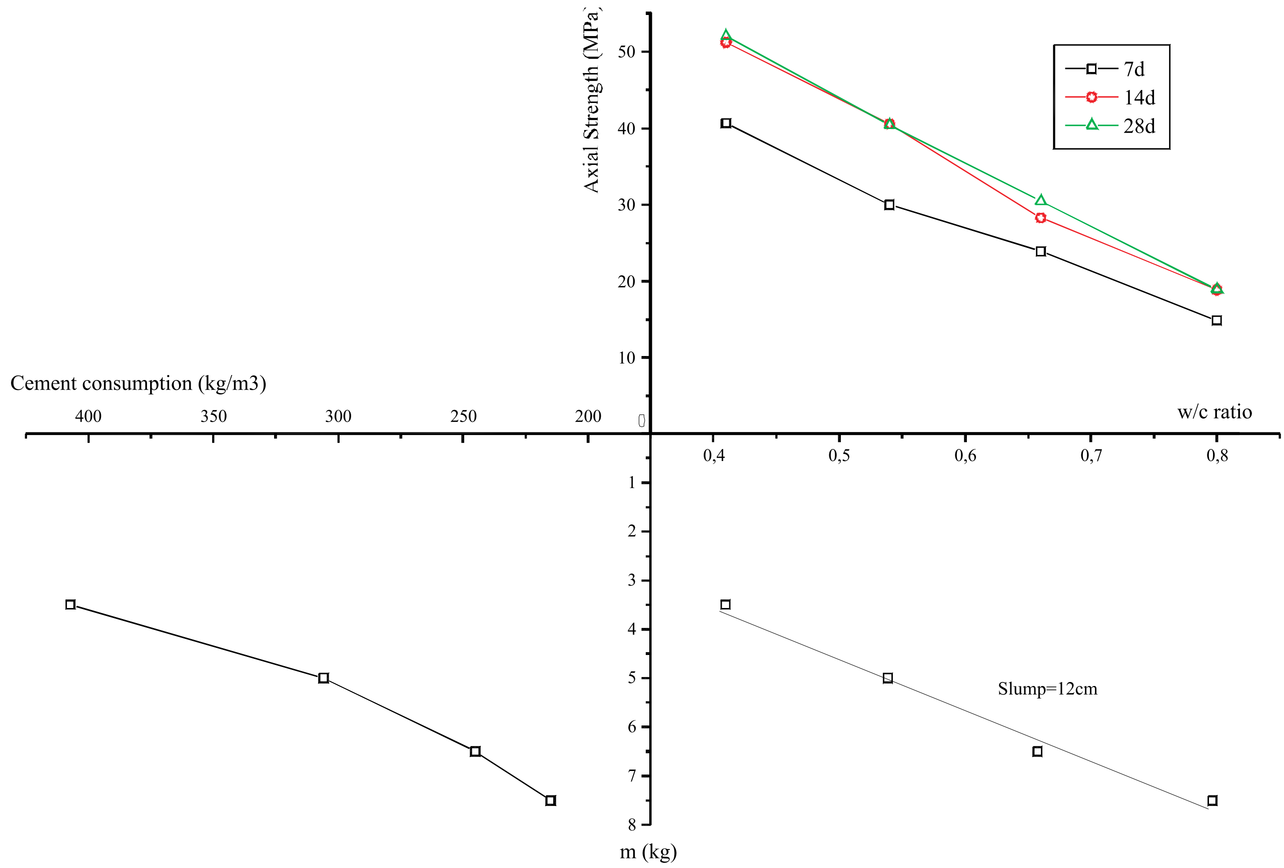
M_{RA}= recycled aggregate mass (kg)
M_{NA}= natural aggregate mass (kg)
γ_{RA}= specific gravity of recycled aggregate
γ_{NA}= specific gravity of natural aggregate

Afterwards, it was determined which water mass would be added to the recycled aggregates before make the concretes. So, the aggregates were put already soaked in the concrete mixer, therefore avoiding that part of the mixing water would be absorbed by the aggregates, which would hinder the hydrating process.

This pre-soaked water initially absorbed by the recycled aggregates will then be available within the mixture, hydrating the non-hydrated cement particles, besides helping in the curing process of the concrete. The water in the aggregate also propitiates forming a favorable transition zone between the new paste and the recycled aggregate, with some cases where it is impossible to define a distinct limit between the two phases, even by means of a microscope [16]. However, it is worth remembering that it is the aggregate's module that substantially governs the concrete's module [20]. In their research, some authors [7], [8] used proportions of about 40% to 50% of the total water absorbed in 24 hours. Others, [17], [18], [19] used greater proportions of water in the pre-soaking, reaching saturation. In this work, the recycled aggregates were moistened 10 minutes prior to mixing it, with 80% of the water that would be absorbed in 24 hours by the recycled aggregate mass corresponding to the mixture. This value was employed because it was seen that during the water absorption tests of the recycled aggregates these aggregates reach an average of 80% of total water absorption in the first 120 minutes after mixing. Since the hydrating reactions last a long time, surpassing the cement's grip time [20], which in the case of the cement used, was 245 minutes, it means that until this time, available water is assured for the hydrating reactions without being absorbed by the aggregates.

After this pre-soaking procedure, all of the coarse aggregates were added to the vertical axis pan-mixer, along with part of the mixing water. Afterwards, the cement and the rest of the mixing water were added, mixing it for some minutes. Then, the fine aggregate was added and it was mixed for some minutes. In some

Figure 1 – Diagram of concrete dosage



mixes it was also necessary to add some superplasticizer, until it reached the desired workability that was fixed at 12±2cm, as indicated by the slump test.

Once the intended workability was reached, four cylindrical specimens with 10cm (diameter) by 20cm (height) were molded for each produced mix, according to the procedures of NBR 5738/03 – Concrete – Procedure for molding and curing specimens, to perform module of deformation tests. After molding, the cylindrical specimens were exposed to room and humidity temperature for 24 hours, and then de-molded and placed in a humid chamber, where they remained up to 1 day before being tested. At this time, the specimens received a sulfur coat and were placed again in the chamber, where they remained until testing.

4. Results

4.1 Initial considerations

As already mentioned, the experimental project involves 7 independent variables and the experiment was fractioned so as to reduce the total number of specimens to be tested. The treatments were in accordance with the Second Composed Project, which enables to test linear and quadratic terms. The tests performed allowed testing linear and non-linear models, for a response variable. To better understand the models, a name abbreviation was done for the independent variables and response variables, seen

Table 4 – Composition of concrete with w/c ratio equal to 0.46, prepared with natural aggregates

Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (kg)
5.952	9.642	15	2.738

Table 5 – Symbology of variables used in the model

Símbolo	Variable – Name	Variable – Type
rcm	Percent of coarse aggreg. substituted for recycled mortar	independent
rfm	Percent of fine aggreg. substituted for recycled mortar	independent
rcc	Percent of coarse aggreg. substituted for recycled concrete	independent
rfc	Percent of fine aggreg. substituted for recycled concrete	independent
rcrc	Percent of coarse aggreg. substituted for recycled red ceramic	independent
rfrc	Percent of fine aggreg. substituted for recycled red ceramic	independent
w/c	water/cement ratio	independent
E_c	Module of deformation	Response

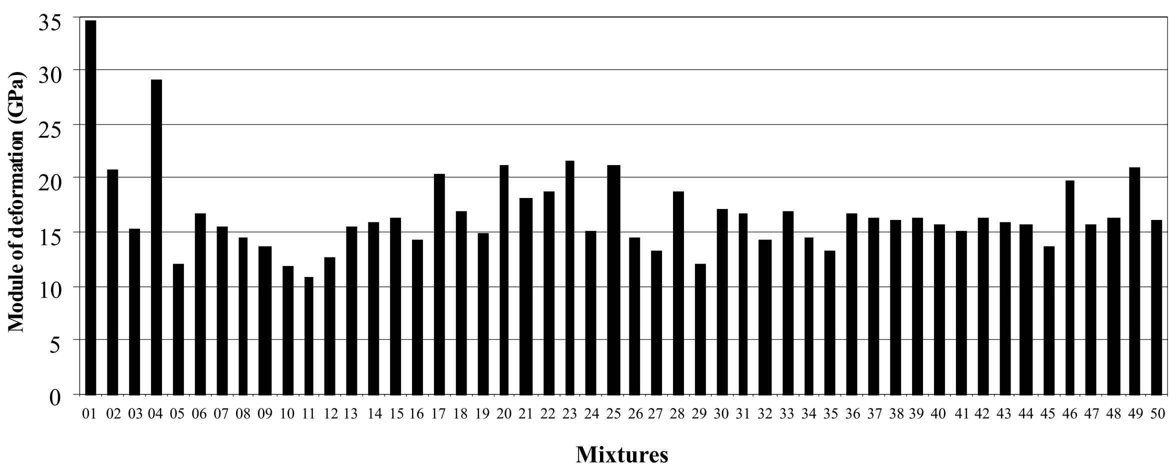
in Table 5. The collected data allow establishing models related to the response variables with the independent variables, therefore establishing simple models, as the multiple linear regression, or complex models, as the non-linear regression.
With the construction of the models, an analysis of the standardized residues was performed. The collected data that generated standardized residues with higher than 3 module were eliminated from the analysis, seeing that these were the values obtained for mixture 3.
The following analysis was developed and supported by a linear regression routine, even though it is relatively simple, it presented good results, since the determination coefficient was found to be 98%, with all of the factors considered significant. More complex models were tested, but the statistical gain was small, therefore, the simpler model was chosen.

4.2 Presentation, analysis and discussion of results

Twenty eight days after the specimens were molded, they were fractured. The mean results obtained for each mixture are in Figure 2. The model that best represents the deformation module of the concrete with recycled aggregates is the one in Equation 2.

$$E_c = \left(\frac{21{,}69}{w/c^{0{,}5}}\right).\left[1-\left(\%replaced\right)\right] \quad (2)$$

Figure 2 – Mean results of modules of deformations obtained for each concrete mixture



The first term in parenthesis refers to the module of deformation of the specimens without the substitution of the natural aggregate for the recycled one, a function of the water/cement ratio.
This term was previously defined from an analysis of the values obtained when the water/cement ratio is equal to 0.46, 0.60 and 0.74, defined to generate the best possible adjustment, in other words, to minimize the foreseen errors.
The second term, in brackets, defines a percentile to be applied over the original module, usually reducing it as a result of the substitution of the natural aggregate for the recycled one. Therefore, this module loss is a result of the natural aggregate ratio being replaced for the recycled aggregate, where:
Module loss = f (% replaced)
Then, a multiple regression was conducted, which identified the dependent variables that exert significant effect on the resistance loss of the concretes with recycled aggregates, which are all the dependent variables, except for the water/cement ratio (w/c). The model of resistance loss found has an excellent determination coefficient (98%), seen in Equation 3.

$$Module\ loss = 0{,}352.rcm + 0{,}158.rfm + 0{,}231.rcc + 0{,}110.rfc + 0{,}440.rcrc + 0{,}113.rfrc \quad (3)$$

Trying to insert the square terms (as for example rcm.rcm) or interactions (as rcm.rfm) did not improve the adjustment, therefore such complex terms were left out.
The final model that estimates the module of deformation from the substitution ratio of the natural aggregates for the recycled ones and the water/cement ratio is in Equation 4. In this model, the substitution ratios of the fine or coarse aggregates for the recycled ones should be understood in the scale 0 (0%) to 1 (100%), while the water/cement ratio is expressed in the general scale, varying from 0.4 to 0.8. It is worth noting that the sum of the substitution ratios of the natural aggregates for the recycled ones should be at most equal to 1 (100%) for each type of aggregate (coarse and fine).

$$E_c = \left(\frac{21{,}69}{w/c^{0{,}5}}\right)\left[1-(0{,}352.rcm + 0{,}158.rfm + 0{,}231.rcc + 0{,}110.rfc + 0{,}440.rcrc + 0{,}113.rfrc)\right] \quad (4)$$

In agreement with the presented model, substituting the natural aggregate for the recycled aggregate results in a reduction of the deformation module for all of the aggregate types, which is consistent with many papers by other authors [14], [21], [22], [19].
It is also observed that substituting the coarse aggregate produces a greater effect in the module loss than substituting the fine aggregate, as a result of the magnitude of the coefficients found for them. However, in Mehta and Monteiro's justification of such behavior [20], they report that the concrete's module of deformation is intrinsically associated to the volumetric fraction, the specific gravity, the module of deformation of the aggregate and the cement matrix and the characteristics of the transition zone. The authors point out that the aggregate's deformation is mainly associated to its porosity, and to a lesser degree, to the characteristically maximum dimension of the aggregate, to the form, texture, granulometry and to its mineralogical composition. According to them, it is the aggregate's module that controls the restriction capacity of the matrix deformation and this is determined by the porosity of the aggregate.
From the aforementioned statements and according to the characteristics of the recycled aggregates used in the experiments, in other words, that the specific gravity of the recycled fine aggregates is lower than the specific gravity of the recycled coarse aggregates [23], then it is consistent to state that the module of deformation of concretes produced with the former ones is lower than the module of deformation of concretes produced with the latter ones.
With the model described in Equation 4, graphs were created that illustrate the influence of each type of recycled aggregate, for substitution rates of 0%, 50% and 100%, for the intermediary water/cement ratios, in other words, 0.4, 0.6 and 0.74. From the values obtained to create the graphics, a table was set up with the reductions of the deformation module for each case. The graphics and the table are in Figures 3, 4 and 5 and in Table 6.
In the graphics and table one can be observed the water/cement ratio influence on the performance of the module of deformation of recycled aggregates concretes, since by increasing the w/c ratio from 0.46 to 0.60 and to 0.74, there is a reduction of 12% and 21% in the module, respectively, due to the w/c ratio. In accordance with these data, the least influence of the fine recycled aggregates on the behavior of the module of deformation can be also observed.
All of the recycled aggregates have a negative influence on the concrete's module of deformation produced with them, since the red ceramic coarse aggregate exerts the highest influence, reaching a 22% reduction in the module's value, for the substitution ratio of 50% and 44% for 100% substitution. Considering the recycled aggregate's characteristics one, such behavior can be explained seeing that the red ceramic coarse aggregate has the least specific gravity and the highest water absorption of all the aggregates used, therefore appearing to be the most porous.
Among the recycled aggregates, the concrete coarse aggregate exerts the least influence in the concrete's module value of deformation produced with it, thus, displaying a considerable reduction of 12%, for the substitution ratio of 50% and of 23% for 100% substitution. Some authors [13] claim that the highest deformation displayed by the concretes with recycled concrete aggregates is a result of the high mortar ratio (around 40% of its volume) which is found in it. This is also consistent with the results found by other authors [14], who also substituted the natural coarse aggregate for the recycled coarse aggregate of concrete, detecting a module of deformation about 19% less than the concrete with natural aggregates.
However, the recycled fine aggregate of concrete exerts the least influence, with a reduction of only 5% in the module of deformation for the substitution ratio of 50% and 10% for 100% substitution. This type of aggregate is known to have a high natural rock ratio in its composition, a grinding result of the concrete with natural aggregate that has a high specific gravity and the least water absorption, among the recycled aggregates used.
Confirming the results found, there are authors [24, 25] that state that the module of deformation of concretes with recycled ceramic aggregates only reach 50% to 66% of the concrete modules with natural aggregates of equal resistance. Some works [14, 19, 25] presented modules of deformation of concretes made of recycled concrete aggregates 15 to 45% less than the modules of conventional concretes.

Figure 3 – Results for module of deformation resulting from the substitution ratios of natural aggregates for recycled ones with water/cement ratio equal to 0.46

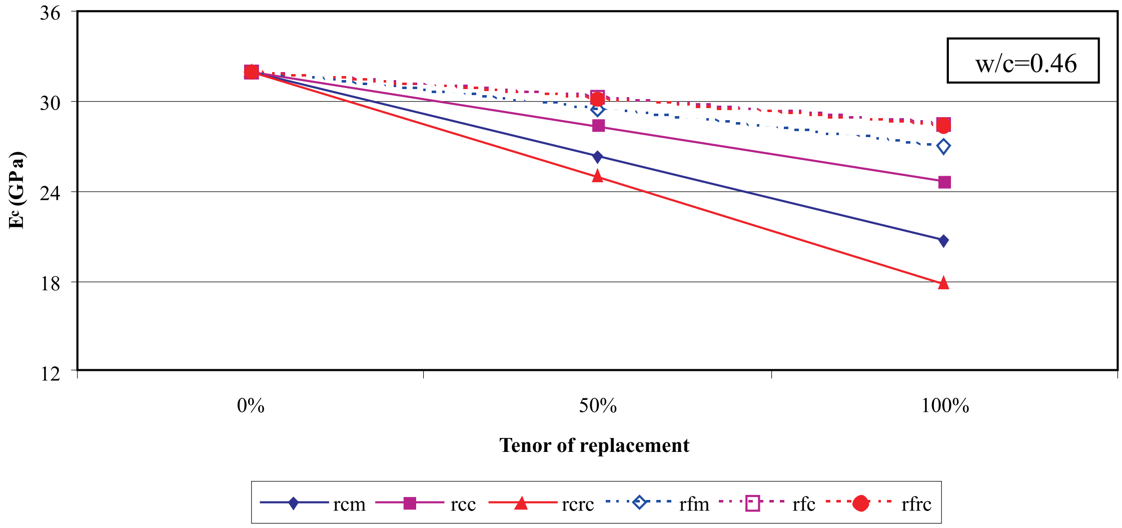


Figure 4 – Results for module of deformation resulting from the substitution ratios of natural aggregates for recycled ones with water/cement ratio equal to 0.60

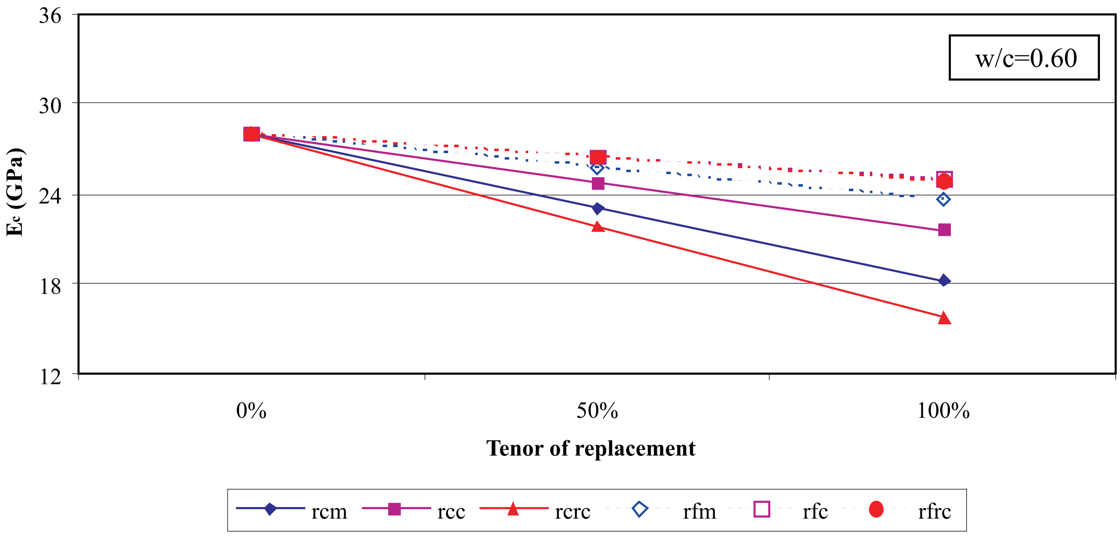


Figure 5 – Results for module of deformation resulting from the substitution ratios of natural aggregates for recycled ones with water/cement ratio equal to 0.74

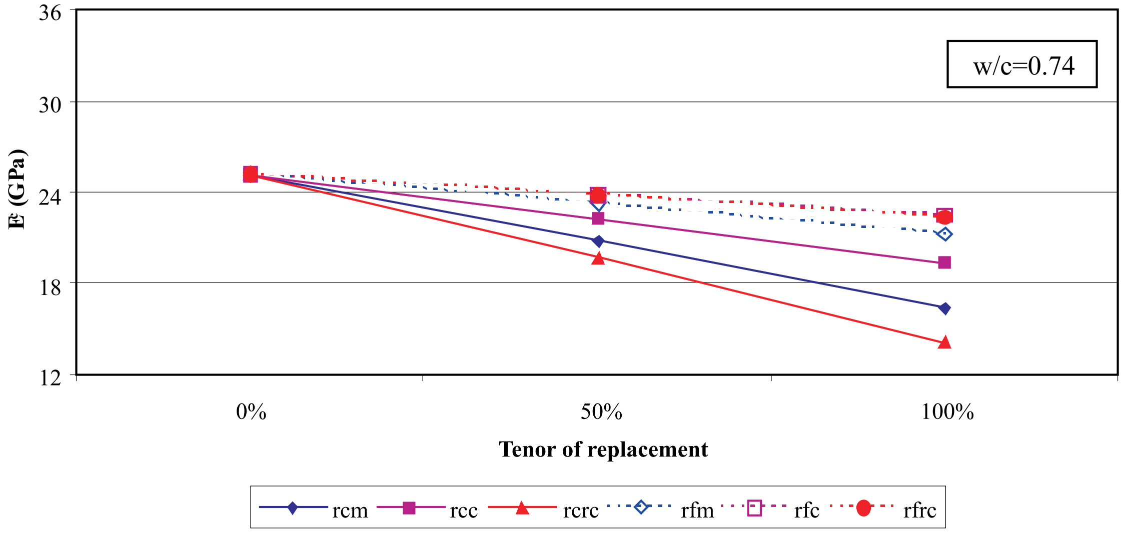


Table 6 – Module of deformation of concretes when substituting natural aggregate for recycled aggregate

Substitution ratio	Type of recycled aggregate: rcm	rcc	rcrc	rfm	rfc	rfrc
0%	1,00	1,00	1,00	1,00	1,00	1,00
50%	0,82	0,88	0,78	0,92	0,95	0,94
100%	0,65	0,77	0,56	0,84	0,90	0,88
Water/cement ratio						
	0,46		0,60		0,74	
	1,00		0,88		0,79	

5. Conclusions

The concretes produced with unanimous recycled aggregates exhibited inferior deformation modules than those produced with natural aggregates.
In agreement with the model, the recycled coarse aggregates exert greater influence on the module of deformation than the recycled fine aggregates.
Among all of the aggregates tested, the recycled coarse aggregate of red ceramic exerted the most influence on the concrete's module of deformation and the recycled fine aggregate of concrete exerted the least influence.

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