Viability for the use of foundry sand to reduce use of cement in cement concrete

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ABSTRACT: Foundry sand is among one of the most produced industrial solid residues in the world. Currently, there are numerous researches around the world about the possible uses for discarded foundry sand, including its use as a substitute for part of the natural sand used in construction. However, the volume of this residue used in different sectors of industry is still small. In this context, understanding that the construction industry presents a great potential for the solution of problems related to the discarded residues generated by other processes by incorporating these materials as building material, this paper seeks to promote the use of FS by reducing the use of Portland cement in the manufacture of cement concrete. To this effect, our experimental program replaced sand for FS and reduced a percentage of the use of Portland cement to determine the characteristics of the materials used and the properties of the cement concrete. Natural sand was partially replaced by foundry sand at the percentages of 5%, 10% and 15%, and the use of Portland cement was reduced by 5%, 10% and 15%. The results showed that de use of FS for Portland cement concrete manufacture is viable. It was concluded that de sample with the reduction of 5% in cement and the substitution of 15% of natural sand for FS presented the best technical, economical and environmental viability.

Keywords *Foundry sand; cement concrete; construction.*

1. INTRODUCTION

Among the manufacturing processes, the foundry occupies a prominent place in the market, depending on their ability to produce elements with a variety of shapes and sizes, being responsible for creating parts of the utmost responsibility, which are aeronautics, mechanical and automotive industry (Soares, 2000). His process uses sand to create male molds that shape metal parts. These sands called sandy base, virgin sand or even conventional sand, have the ability to absorb and transmit heat, they allow the gases evolved during the molding process to go through its grains (Alves, 2012).

Usually, the sands are used for several cycles in the casting process; however, there is a limited number of times that can be effectively reinserted because their grains lose angular shape required for the formation of molds (Alves, 2012). So they are discarded and intended to trench landfills, receiving the name of discarded foundry sand (UFS) or simply foundry sand (FS). If the FS are deposited in improper or unmonitored sites may change the chemical, physical and biological soil and water, causing damage to the environment.

The amount of sand consumed depends on the type and the part produced ranges from 0,8 to 1 ton per ton of molten; after the demolding step, about 90% of the sand can be easily reinserted into the process, but about 10%, contaminated, to be discarded (Casotti *et al*, 2011). The FS represent one of the largest volumes of industrial waste produced in the world and its reuse contributes to the reduction of gaseous emissions, consumption of virgin material and results in economic gains.

Brazil occupies the seventh position in world production of castings, which are made about three thousand tons of metal parts per year. More than half is destined for the automotive components market, because of the sector to be strong in the country. For 2018 it is projected a production of almost four thousand due to indirect exports as engines, automotive components and capital goods (Brazilian Foundry Association, 2014).

Currently, there are numerous national and international researches, discussing possibilities for the use of foundry sand disposal, including the partial replacement of fine aggregate (natural sand). However, the volume of waste used in different industrial sectors is still small. In this context, given that the construction industry has great potential for solving problems related to the disposal of industrial waste generated in other processes, through its incorporation into building materials, this paper seeks to promote the attractiveness of using FS by reducing the use of Portland cement in the manufacture of concrete.

Thus, the experimental program proposed aimed to determinate the characteristics of the materials used and the Portland cement concrete properties, obtained with replacements of fine aggregate by FS and also with percentage reduction Portland cement consumption. It carried out the partial replacement of natural sand for foundry sand disposal under 5%, 10% and 15% content and Portland cement reductions of 5%, 10% and 15%.

This research was motivated by the positive results obtained in previous research (Lima, 2014) which replaced part of the natural sand (5%, 10%, 15%, 20%, 25%, 30% and 50%) by casting dispose sand (channel break) from the same source. In that investigation, it was found that all mixtures molded from foundry sand, from the earliest age of the Portland

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cement concrete, showed axial compression strength higher to the ones molded only with natural sand.

In this sense, internationally, the recent research conducted by Prabhu *et al* (2015) concluded that a replacement rate up to 30% natural sand by FS is favorable for the production of concrete without adversely affecting the strength and durability. Siddique *et al* (2015) also have positive results for the partial replacement of fine aggregate for foundry sands.

2. EXPERIMENTAL PROGRAM

The experimental program was developed in three parts. Initially the materials were characterized, by performing the recommended laboratory tests in the Brazilian Technical Standards. Then there was the dosage of Portland cement concrete and finally were carried out tests on the produced concrete.

2.1 Materials

The materials used were Portland cement type CP IV-32, coarse aggregate (crushed stone 1), natural sand, foundry sand (FS). It was used Portland cement type CP-32 IV of Votoran brand because that has as main characteristic their environments resistance to chemical attack as sulfate, sewage and seawater.

For the physical characterization of cement, fineness modulus tests were carried out, density and determining setting time. Results in Table 1.

Table 1. Portland cement characterization

Features	Results
Fineness # 0,075 (%)	0,28
Specific Gravity (g/cm^3)	2,84
Loose Bulk Density (kg/dm^3)	0,97
Setting Time (h)	03:40

The natural sand needed for the research came from the city of Santa Maria (RS), 180 km from Ijuí (RS) - the research site. In it the following tests were performed: granulometric composition, specific weight of fine aggregate and loose bulk density (Table 2).

The FS was courtesy casting company located in distant municipality 45 km from Ijuí (RS). For this research, we used the sand generated in the channel break process.

The FS characterization tests were the same as natural sand due to the similarity of materials. But as it is a residue, it was necessary to carry out specific laboratory tests (leaching and solubilization). In these, the FS performed within the limits allowed by the Brazilian Technical Standards for the solubilization and, for leaching, the residue was classified as non-toxic class IIB - inert. Table 2 also shows the characteristics of FS. It is noticed that the FS has specific and unitary mass loose less than the natural sand.

Table 2. Characterization of natural sand and ADF

Features	Results of natural sand	Results of ADF
Max. Diameter (mm)	1,20	0,60
Fineness Modulus	1,90	1,16
Specific Gravity (g/cm^3)	2,60	2,43
Loose Bulk Density (kg/dm^3)	1,53	1,33

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The coarse aggregate #1 crushed basaltic from the Ijuí region (RS), was characterized as its particle size distribution, density and absorption of coarse aggregate and loose bulk density (Table 3).

Table 3. Characterization do coarse aggregate

Features	Resultados
Max. Diameter (mm)	19
Fineness Modulus	6,75
Specific Gravity (g/cm^3)	2,93
Loose Bulk Density (kg/dm^3)	1,69

The water required for the hydration of cement, came from the Civil Engineering Laboratory of UNIJUÍ's well. The standard unit used was kilogram; it has lower probability of error in dosage tests compared to the liter.

2.2 Experimental mix proportion of Portland cement concrete

After the outcome of the physical characterization of materials was calculated dosage of the constituents of Portland cement concrete by the method of Portland Cement Brazilian Association (ABCP), because this is the most used method in the country.

Table 4 identifies the 16 mixtures, according to the replace of natural sand for foundry sand and cement reduction. For each mix, 10 specimens were molded and 8 were used for the tests for the axial compression strength tests and 2 to determinate the tensile strength.

Table 4. FS Replacement percentage and Portland cement reduction

Reduction\Replacement	0%	5%	10%	15%
0%	R0S0	R0S5	R0S10	R0S15
5%	R5S0	R5S5	R5S10	R5S15
10%	R10S0	R10S5	R10S10	R10S15
15%	R15S0	R15S5	R15S10	R15S15

The factor of water/cement (w/c) was calculated to achieve the strength of 25MPa. Set the w/c ratio of 0.59 were calculated substitutions 5%, 10% and 15% conventional sand for FS and 5% cement reduction, 10% and 15%, all changes were made in mass (Table 5).

Table 5. Material consumption

Mixture	Consumption (kg)				
	Cement	Natural sand	FS	Crushed stone #1	Water
R0S0	8,69	14,95	0,00	32,50	5,13
R0S5	8,69	14,20	0,75	32,50	5,13
R0S10	8,69	13,45	1,50	32,50	5,13
R0S15	8,69	12,71	2,24	32,50	5,13
R5S0	8,26	14,95	0,00	32,50	5,13
R5S5	8,26	14,20	0,75	32,50	5,13
R5S10	8,26	13,45	1,50	32,50	5,13
R5S15	8,26	12,71	2,24	32,50	5,13
R10S0	7,82	14,95	0,00	32,50	5,13
R10S5	7,82	14,20	0,75	32,50	5,13
R10S10	7,82	13,45	1,50	32,50	5,13
R10S15	7,82	12,71	2,24	32,50	5,13
R15S0	7,39	14,95	0,00	32,50	5,13
R15S5	7,39	14,20	0,75	32,50	5,13
R15S10	7,39	13,45	1,50	32,50	5,13
R15S15	7,39	12,71	2,24	32,50	5,13

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After separate the materials, began the molding of the test specimens (10x20cm). Before receiving the material, the mixer was dampened to control the amount of water used in the molding, thus avoiding that part of the mixing water were adhered by the equipment. The launch sequence of materials was, gravel, cement, FS and natural sand. Gradually put up water until the concrete was visually with good workability, and the Slump Test was performed according to the Brazilian Standard.

Upon reaching the desired workability (90 ± 10mm) the amount of water left was measured and the factor w/ c was recalculated. Sequentially began the molding of the test specimens in cylindrical molds that contained a layer of mineral oil. After molded, the specimens were taken to the humid chamber, where they remained under hydration until the test.

2.3 Axial compression strength test and tensile strength by diametrical compression

The axial compression strength tests were performed at 7, 14, 21 and 28 days. The tensile strength by diametrical compression analysis were performed only after 28 days of each mix. Such tests were performed in the Civil Engineering Laboratory of UNIJUÍ under standardized press (Figure 1), were evaluated by body-of-proof cylindrical with dimensions of 10cm in diameter and 20cm in height.

Figure 1. Axial compression strength test. Source: Authors, 2016

For the determination of the compressive strength test, specimens were placed in the center of the press, so that the resultant of the forces pass through the axis of the sample under compression. The advance of the machine was set in 0,05MPa per second. Determination of axial compressive strength is extremely simple, obtained only by the division of the rupture force by the specimen area.

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To determine the tensile strength by diametrical compression first were placed two small battens on the extreme points of the test piece, so the contact with the universal test machine dishes were only along two diametrically opposed generatrices. The progress has also been set up in 0,05MPa per second up to rupture of the specimen. The result was obtained from the ratio of twice the strength at the time of rupture and the result of π multiplied by the diameter and the height of the specimen.

3. RESULTS E DISCUSSION

In order to display the results, it was decided to remove the mixtures molded with 15% cement reduction and without FS in the mix. Were there was a reduction of 15%, the concrete workability lost, making it difficult to produce the specimen.

3.1 Axial compression strength

The Figure 2 illustrates the results of the compressive strength test for age of 7 days. The results obtained without cement reduction showed best results, as it reduces 5% and 10%, the strength decreases. This behavior was expected, since the cement is responsible for generating resistance of concrete.

The R0S10 and R0S15 mixtures resulted 18,5 and 19MPa while R10S10 and R10S5 resulted in 12,2MPa and 10,8MPa respectively. It is perceived gain in strength in mixtures molded with higher FS contents.

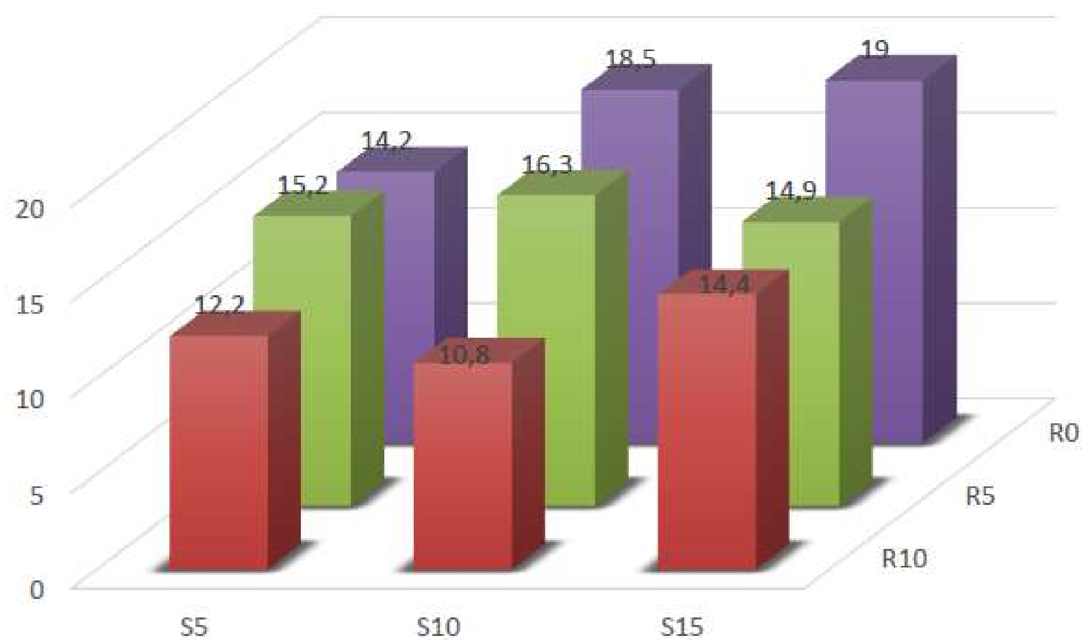

Figure 2. Axial compression strength - 7 days. Source: Authors, 2016

At 14 days (Figure 3) show up the same previous findings, especially on the low strength gain obtained in the features molded with 10% reductions. The reduction of 5% brought average drop 2MPa of strength, while 10% reduction brought downward 7MPa. It is noticed that the loss of the strength does not behave linearly with cement reduction.

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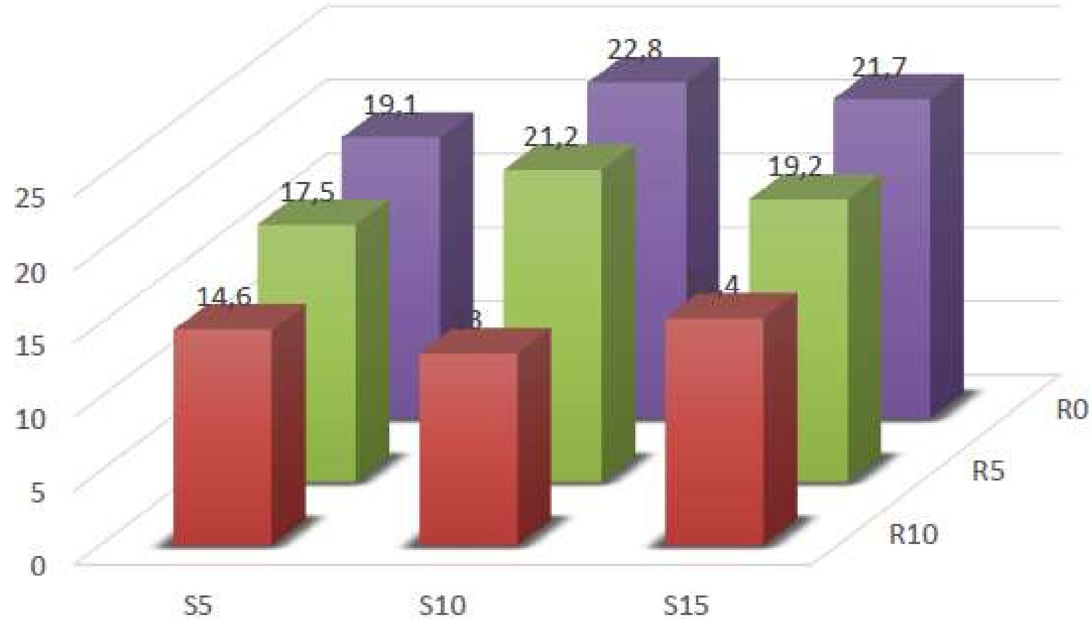

Figure 3. Axial compression strength - 14 days. Source: Authors, 2016

The Figure 4 illustrates the results obtained for 21 days. The mixtures without reducing cement and replacement of 10 and 15% natural sand by FS reached 25,8MPa while the traces with 10% reduction of cement had little evolution between 7 and 21 days.

The specimens made with a reduction of 5% cement maintained similar strength with those specimens molded without any reduction, with only a small decrease. It can be seen that 10% or more cement reductions considerably impair the compressive strength of the concrete.

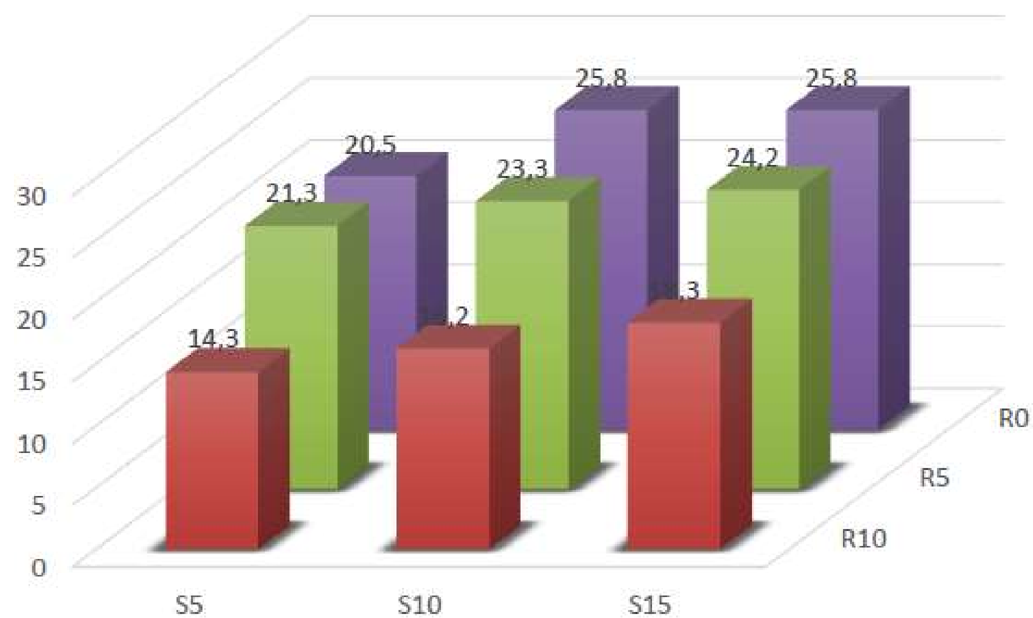

Figure 4. Axial compression strength - 21 days. Source: Authors, 2016

At 28 days (Figure 5), it was clear that a gain in strength was obtained with higher FS contents. The best results were obtained with 15% replacement of conventional sand by FS.

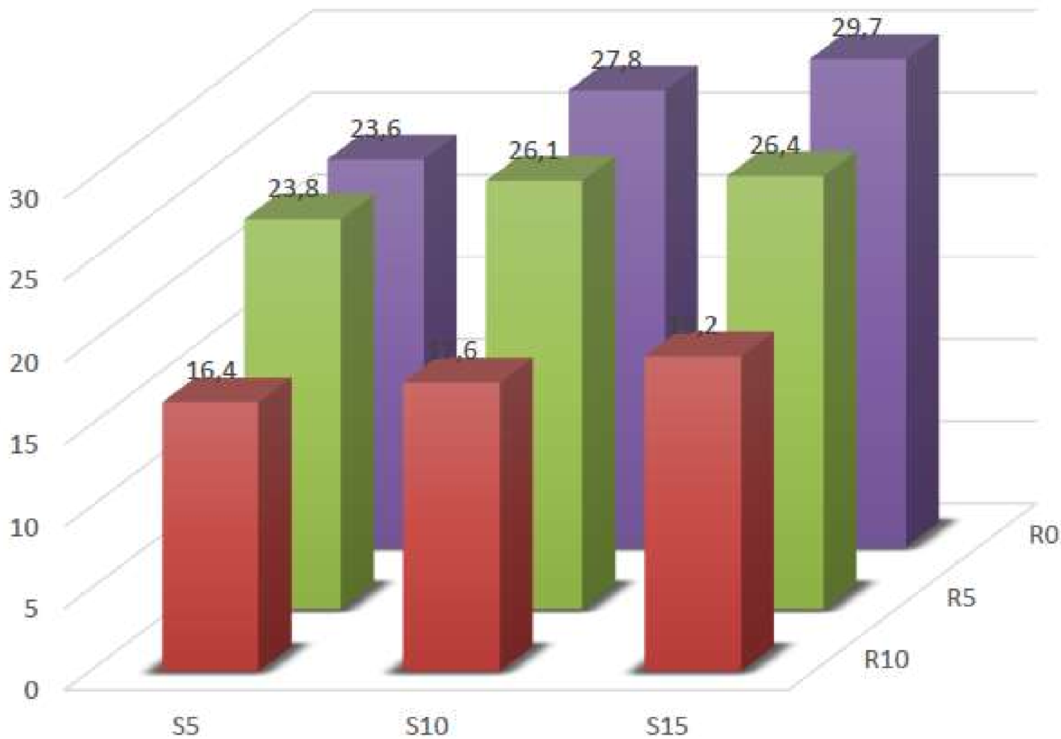

Figure 5. Axial compression strength - 28 days. Source: Authors, 2016

The mixtures R0S15, R5S10 and R10S15 reached, respectively, 29,7; 26,4 and 19,2MPa. Mehta and Aïtcin (1990) cited Furquim (2006) studied partial Portland cement replacement for mineral additions and explained that the increased strength is caused by physical effects: Very small particles fill the voids and improve the effects in the transition zone, bringing up the strength of concrete. This explanation can be confirmed in this study, because the fineness modulus of FS was 1,16 and the natural sand, 1,9.

The Table 6 presents concrete properties at early age. The Slump Test was set between 8 and 10 cm, ranging from 8.5 to 10cm. Little variation in actual density was observed (γ), getting around 2500 kg/m^3.

Table 6. Property of concrete at early age

Mixture	R0S5	R0S10	R0S15	R5S5	R5S10	R5S15	R10S5	R10S10	R10S15
Slump (cm)	9,5	8,5	9	10	9,5	9,5	9,8	9,5	10
γ real (kg/m^3)	Not obtained	2556,6	2516,9	2544,5	2526,8	2546,7	2524,6	2537,9	2509,1
Water consumption (kg)	4,59	4,5	4,64	4,49	4,48	4,48	4,47	4,43	4,45
w/c revised	0,53	0,52	0,53	0,54	0,54	0,54	0,57	0,57	0,57

Water consumption was greater in mixtures without cement reduction. As less cement is reduced a greater amount of water was needed to achieve the required reduction. However the ratio between water and cement has increased due to reduced amount of cement. One possible cause for the slump test stipulated value has reached a lower amount of water is the fact that when the cement is removed, the concrete loses some of its cohesiveness, being more unstable and acquiring therefore a high reduction.

3.2 Tensile strength by diametrical compression

The test was performed after 28 days. Figure 6 presents the results, were little variation was noted, between 2,8MPa (R10S15) and 3,4MPa (R0S10).

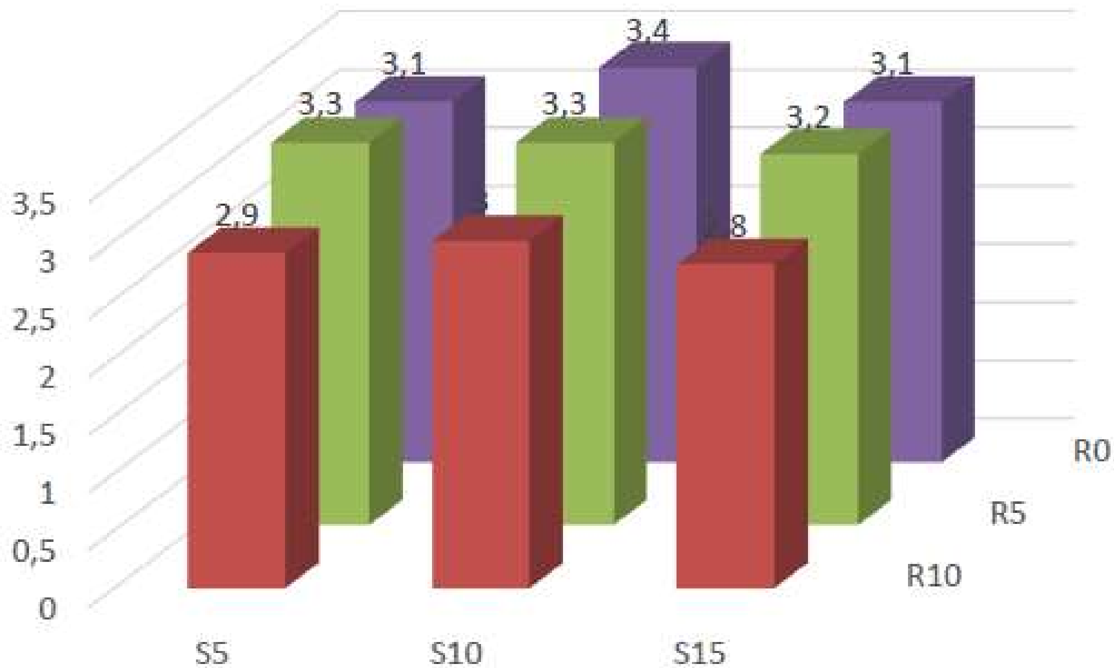

Figure 6. Tensile strength by diametrical compression - 28 days. Source: Authors, 2016

In the same manner as in the compressive strength tests, the results without reduction in cement and 5% cut were close, while 10% reduction resulted in a greater loss of strength. This data confirms the idea that 10% cement reduction would be very harmful to concrete.

4. CONCLUSIONS

The results show that the use of FS Portland cement concrete is technically feasible. Whereas the objective of this research was to promote the attractiveness of using FS by reducing cement consumption Portland in the manufacture of concrete, it can be concluded that the trace to 5% reduction of cement and replacing 15% of conventional sand for FS, presented the best technical, economic and environmental scenarios.

In terms of technical feasibility, this mixture was chosen because it got higher then 25MPa of Axial Compression Strength, value stipulated during the mix proportioning by the ABCP method. Moreover, presented tensile strength by diametrical compression 3,2MPa, at the rupture; was similar to the maximum found in the samples.

About the economic viability, this mixture can reuse 15% of FS, which correspond to approximately 9kg use of FS for each cubic meter of concrete. It infers that it is a cost-effective solution for the construction industry, which tends to pay less for raw materials, since the generating companies discards lots of this waste and has high cost for the maintenance of industrial landfills.

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Finally, in respect to environmental sustainability, it should be mentioned that the reduction in cement consumption reduces the release of pollutant gases into the atmosphere, and also reduces the exploration of natural deposits.

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