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Specific mass and water absorption from concrete manufactured with alternate aggregates

Massa específica e absorção de água de concretos manufaturados com agregados alternativos

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Abstract

Concrete is the second most used material on the planet. Due to strong growth in emerging economies, there is an expectation of greater consumption of material in the coming years. Due to this growth, we can observe that the environment is being greatly damaged by the generation of waste. There are several sectors that generate these wastes, among them stands out the steel, the water treatment and the extraction of gravel as raw material for concrete producers. Therefore, this paper presents a study on the use of alternative solid waste as aggregates for the manufacture of concrete. The residues used are: sludge Water Treatment Station (WTS), Manufactured Sand and Steel Slag. For both concrete mixtures were used to replace all or part of the fractions of coarse aggregate (crushed) and fine aggregate (sand). This substitution was made in mass. To benchmark adopted a trait that is standard with the use of 100% of the constituents of concrete by concrete adopted in the region. The admisture corresponds to a standard adopted characteristic compression strength of 25 MPa and a water/cement ratio of 0,61. The concrete were analyzed for physical properties according to ABNT normes. The results of concrete tests made with artificial sand and steel slag show as efficient material for structural applications. However, the concrete with the addition of WTS can be used for non-structural, such as filling element in projects that require low resistance to compression. These data were statistically analyzed by ANOVA and the results indicate that with judicious use, waste studied here, may be alternative to the traditional use of aggregates for concrete manufacture.

Keywords: concrete, sludge from water treatment plant, artificial sand, steel slag, aggregates.

Resumo

O concreto é o segundo material mais utilizado no planeta. Devido ao crescimento acentuado das economias emergentes, existe uma expectativa de consumo deste material ainda maior nos próximos anos. Em função deste crescimento, pode-se observar que o meio ambiente está sendo extremamente prejudicado com a geração de resíduos. Vários são os setores que geram estes resíduos, dentre estes, destacam-se os siderúrgicos, os de tratamento de água e o de extração de brita para matéria prima para as concreteiras. Sendo assim, este trabalho apresenta um estudo sobre a utilização de resíduos sólidos como agregados alternativos para a manufatura de concreto. Os resíduos utilizados são: Lodo de Estação de Tratamento de Água (LETA), Areia Artificial e Escória de Aciaria. Para tanto foram adotados traços de concreto com substituição total ou parcial das frações de agregados graúdos (brita) e miúdo (areia). Esta substituição foi feita em massa. Para parâmetro de comparação adotou-se um traço padrão com a utilização de 100% dos constituintes do concreto adotados pelas concreteiras da região. O traço padrão adotado corresponde a uma resistência característica a compressão de 25 MPa e uma relação água/cimento de 0,61. Os concretos foram caracterizados quanto às propriedades físicas segundo as normas da ABNT. Os resultados dos ensaios de concretos com os resíduos de areia artificial e escória de aciaria apresentaram-se como eficientes para aplicações estruturais. Porém, os concretos com adição de LETA podem ser utilizados para fins não estruturais, tal como, elemento de enchimento em projetos que exijam baixa resistência à compressão. Estes dados foram tratados estatisticamente, por meio da análise de variância ANOVA e os resultados indicam que, com a utilização criteriosa, os resíduos aqui estudados, podem ser alternativos à utilização dos agregados tradicionais para manufatura de concretos.

Palavras-chave: concreto, lodo de estação de tratamento de água, escoria de aciaria, areia artificial, agregados.

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1. Introduction

Most of what is produced and respectively consumed is still extracted from nature nowadays, from raw material to the garment industry, metallurgy, and consumption of goods, construction and other industries in various sectors.
Among the sectors that generate waste, there is the metal industry that generates a significant amount of waste, with the most varied features in all stages of its process. Some of this waste,known as melt shop waste, with the most diverse granulometric characteristics, from waste powder to waste of larger granulometry, in particle shapes.
Another sector, the Water Treatment Plant, generates a waste classified as sludge , which has the appearance of a clay material after it is dry.
The concrete producers use sand as a basic raw material , taken from rivers and streams, gravel from explosions of rock, among other constituents of concrete inputs such as cement, which also come from natural resources. In the extraction of gravel stone powder with various grain sizes is generated.
The solid waste from the mentioned sectors are generated in large quantities as shown below:
Manufactured Sand: The amount of material generated can reach 20% of the crushed material, Prudencio, Coelho, Gutstein, [1].
Water Treatment Station Sludge (WTSS): According to Hoppen [2], a conventional WTA that can treat 2400 l / s produces about 1.8 t / of sludge per day. In Brazil, the amount of sludge produced in water treatment is often not measured due to non-management of waste produced.
Melt shop Slag: in Brazil, according to the IAB-Brazil Steel Institute [3] steel production in 2008 reached 33.7 million tons, which is produced in average 120 kg of steel slag per ton of crude steel, a total of 4 million tons of slag was generated, which makes this product one of highest volumes of waste, among those generated in the steel industry.
Researches have been encouraged to use waste as by-products for different industrial sectors. This stimulation is mainly due to decrease the environmental impact caused by the withdrawal of non-renewable resources of nature.
Therefore, this paper presents the physical characterization of concrete manufactured with aggregate alternatives: water treatment station Sludge , artificial Sand and Melt shop Slag with respect to water absorption and density tests, comparing them to reference values obtained using aggregates of normal use as quartz sand and gneiss gravel for concrete characteristic resistance of 25 MPa.

1.1 Concrete

In the construction industry, the most commonly used material is concrete, a product that uses natural resources in its composition, such as sand and gravel, Isaia [4]. Researches have been undertaken with the objective of minimizing the removal of these natural resources. Thus, it seems that there is a great need to promote the treatment of these wastes, adding value to them, so they are transformed into raw materials for concrete production.

1.2 Agregates

According to Isaia [4], aggregates are materials that take place of about 70% to 80% of the volume in conventional concrete, so they all should be chosen with care and technical criteria, for they are the elements in greater quantity in the concrete..

2. Materials and experimental program

The methodology was developed in 03 steps, as described below.

2.1 Step 01: Selection of Materials

We used 03 types of waste from the region of the Steel Valley, besides the inputs normally used and marketed in the region. The wastes are: Water Treatment Station Sludge (WTSS), Manufactured Sand and Steel Slag.

Figure 1 – Water treatment station in Santana do Paraíso-MG

Figure 2 – Pedreira um valemix – crushing plant, located in the city of Timóteo-MG

Figure 3 – Melt shop Slag , deposited in the courtyard of Reciclos company in Timóteo-MG

We used Portland cement CP III E 40 and - Cauê / Camargo Correa. The option was due to the widespread use of the product in the local construction sites.

The natural sand source used is quartz, derived from Doce river. 0.5 m³ of the material was stored at Doce river storage yard, located at Rua A , No. 465, Parque do Rio Doce, Caratinga, MG. The sand went through natural drying process is then stored in a laboratory environment.

The gravel used during the research is of metamorphic origin and crushed from the gneiss rock. The material was from Pedreira Um Valemix, located in the city of Timoteo, MG. The material used in the study was collected from the storage yard of the crushing plant, in a quantity of 0.5 m³. All the material has gone through a natural drying process and then properly stored in a laboratory environment.

Waste used as alternative aggregates:

The aggregate produced with the WTSS has its origin in the stages of water purification, involving chemical reactions associated with the transport of organic material in settling ponds and disposal

Table 1 – measures for the concrete mix proposed for aggregates replacements

MassRange - 25 MPa - w / c ratio 0.61									
	Mixes	Agglomerates	Fine Aggregates (Kg)			Coarse aggregate (Kg)		Water (l)	Weight (Kg)
Discrimination	Reference	Cement (Kg)	Sand Artificial	Sand Natural	WTSS	Gneiss	Slag		Total
Mix 1	standard	6		12,7		15,37		3,7	34,07
Mix 2	LERE1	6	8,8	3,77	0,13	15,37		3,7	34,07
Mix 3	LERE2	6	8,45	3,62	0,64	15,37		3,7	34,07
Mix 4	LERE3	6	8	3,43	1,27	15,37		3,7	34,07
Mix 5	LERE4	6	8,89	3,77	0,13	7,69	7,69	3,7	34,07
Mix 6	LERE5	6	8,45	3,62	0,64	7,69	7,69	3,7	34,07
Mix 7	LERE6	6	8	3,43	1,27	7,69	7,69	3,7	34,07
Mix 8	LERE7	6	8,8	3,77	0,13		15,37	3,7	34,07
Mix 9	LERE8	6	8,45	3,62	0,64		15,37	3,7	34,07
Mix 10	LERE9	6	8	3,43	1,27		15,37	3,7	34,07
Sum		60	50,94	34,49	6,1	84,535	69,165		305,23

from water treatment stations. The material used in the study had its origin in the Water Treatment station (WTS) that supplies the city of Santana do Paraíso, MG, as shown in Figure [1].
We collected 1200 liters of WTSS, this material was dried in an oven for 72 hours at 100 ° C and stored in plastic containers in the laboratory.
The added artificial sand is a waste of metamorphic origin obtained from the processing of gneiss rock. It was collected from the crushing plant of Pedreira Um Valemix, located in the city of Timoteo-MG, as shown in Figure [2].
The reason for the use of this material was in terms of its physical and textural characteristics, but mainly because it helps reduce environmental impacts. It was subjected to natural drying processes, and soon after, properly stored in a laboratory environment.
The residue called melt shop slag was obtained after being processed by Reciclos company, located in the city of Timoteo, MG. The material was in the storage yard of the company, after being transported from the waste yard of ArcellorMittal company where it remained for 05 years after reactive stabilization . Figure [3].
The amount collected was 2 cubic meters of the material that had already been dried naturally.

2.2 Step 02: Dosage of materials and preparation of specimens

10 mixes were prepared as presented in table [1].
The procedures for preparing the concrete mix proportions followed the committee's report described in ACI 211 [5].
We adopted the mass dosage method, justified by the accessibility to information and the facilitated applications in the lab.
The adjustment in the mixtures presented below followed the recommendations of Mehta and Monteiro [6]. This step was taken so that the working control was assured for the conditions in which the concrete met the set standards. We adopted the procedure of rational dosage from a standard mix "conventional concrete" 1: 2.72: 3.19: 0.61 and characteristic resistance to compression (FCK) of 25 MPa. To perform the control of workability, we used the value of 100 ± 20 mm for the "Slump Test" according to ABNT NBR NM 67 [7].
The addition of WTSS followed a proportioning pattern in the 03 steps in the theoretical elaboration of the mixes. Steps 02 (mixes 5, 6 and 7) and 03 (mixes 8, 9 and 10) presented changes in the proportioning of coarse aggregate which is characterized by replacement of 50% of gneiss by 50% of slag and 100% of slag in step 02.
According to Souza [8] the addition of WTSS to replace the fine aggregate up to 4%, shows similar characteristics to conventional concrete. Therefore, we present a variation of replacement of sand for WTSS of 1%, 5% and 10%.
The proposed replacement of natural sand for artificial sand of 70% was based on experiments at Pedreira Um Valemix ,According to Sabino [9], it is recommended in the manufacturing of concrete.
According to Neville [10] the excellent proportion for coarse aggregate replacement by slag is of 50% without loss of resistance to compression.
We used an inclined axis mixer with capacity of 145 l, made by CSM, where prior priming with mortar was made. With the machine moving, the material was placed in the following order:
- 100% coarse aggregate plus 20% of the water,
- 100% cement plus 30% of the water,
- 100% fine aggregate plus 50% of the water

After placing all the material, it remained for about 05 minutes in the process of mixing and homogenization. Then the "Slump Test" was done to verify the projected value.
The molding and curing process was in accordance with NBR 5738 [11], and the testing of the specimens performed in the periods of 03, 07 and 28 days. Due to the amount of WTSS provided to use in the experimental mixes, we adopted the lower limit for the production of 10 specimens per mix. In carrying out the molding, we used cylindrical structures with dimensions of 10 cm x 20 cm, in which the manual densification was made. After molding procedures, the specimens were kept in a laboratory environment for approximately 24 hours, then unmolded and brought to a moist chamber, under conditions of relative humidity above 95% and temperature of 23 ° C ± 2 ° C.

2.3 Step 03: Tests for determining the specific mass and water absorption of concrete

Tests were conducted according to ABNT rules. The tests are:
• Determination of specific mass
The procedure for obtaining the specific mass of concrete was researched based on the proportioning of the materials determined by the mixes in the following steps, according to NBR 9833 [12].
a) A container of known volume was weighed;
b) The container was filled with the sample of concrete using the corresponding manual densification with rods, applying uniform strokes in 03 layers of 30 blows per layer, then the shallowing of the surface;
c) The container filled with concrete was subjected to reweigh;
d) The specific mass was calculated using equation 1.

$$\mu = m/V \tag{1}$$

in which: μ is the specific mass;
m is the concrete mass in kg;
V is the volume of the container.
• Determination of water absorption
The determination of water absorption followed the guidelines of ISO 9778 [13], in which samples of concrete molded into cylindrical shapes Ø 10 cm x 20 cm, were dried in an oven for 24 hours and then cooled and weighed and recorded their dry mass. Then the samples were subjected to complete immersion for a period of 24 hours, and the surface of the CP's slightly wiped with a dry cloth and re-weighed, therefore obtaining wet mass values of the tested series. The mathematical calculations to obtain the results were made by using equation 2.

$$\%_{humidity} = (m_{wet} - m_{dry})/\ m_{dry} \times 100 \tag{2}$$

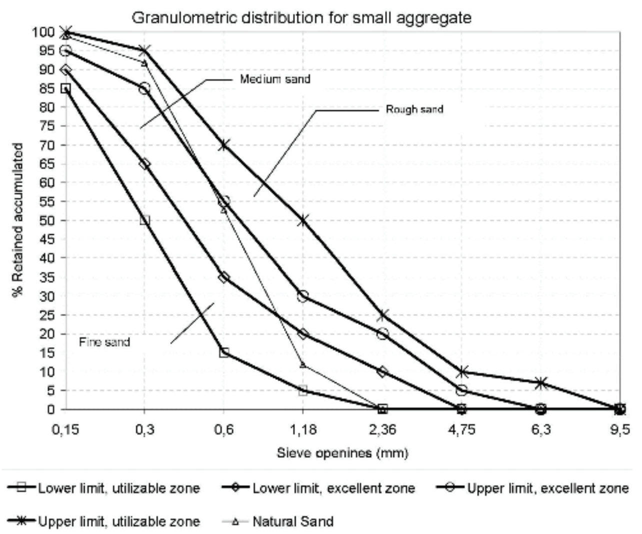
• Determination of resistance to axial compression
The resistance to axial compression of the concrete under study was determined following the method described by NBR 5739 [14].

Table 2 – Granulometric and physical Characterization of Natural sand

Sieve (mm)	Weight Retained (g)	Percentage	
		Retained	Accumulated
9,5			
6,3			
4,75		%	%
2,36		%	%
1,18	58,9	11,78 %	11,78 %
0,6	204,9	40,98 %	52,76 %
0,3	195,1	39,02 %	91,78 %
0,15	35,5	7,1 %	98,88 %
FUND	5,6	1,12 %	100 %
TOTAL	500	100 %	

Description		Results
Unit mass	(NBR 52)	1,444 Kg/dm³
Specific Mass	(NBR 52)	2,618 Kg/dm³
Materials In Powder Form	(NBR NM 46)	0,22%
Module of Fineness	(NBR 7211)	2,552
Maximum Diameter	(NBR 7211)	2,4mm
Coefficient of empties		44,84%

Figure 4 – Granulometric distribution for Natural sand



3. Results and discussions

Table [2] shows the granulometric and physical characterization of natural sand. It is observed that the sand is classified as medium, according to NBR 7211 [15], with fineness module MF = 2.552 and maximum diameter dm = 2.40 mm, in the excellent zone limits (2.20 to 2.90). It can be seen in figure [4] that the cumulative percentage retained exceeded the upper limit in the 0.15 and 0.3 mm sieves and was below the lower limit in the 1.18 mm sieve. The natural sand presents fineness module of MF = 2.552. It is worth to mention that this sand is used in Vale do Aço as medium sand.

Table [3] shows the granulometric and physical characterization of Artificial Sand. According to NBR 7211 [15] the artificial sand is classified as medium sand, with dm = 4.75 RS = 2.247 mm and, in the excellent zone limits (2.20 to 2.90). By observing figure [5] note that the percentage retained in the sieves 0.15, 0.3 and 2.36 mm does not fit the established range for medium sand, according to NBR 7211 [15]. However, the substantial percentage of material retained in these sieves has stimulated the use of all of the material in all granulometric range.

Table [4] shows the granulometric and physical characterization of the gravel. We can observe the values of dm = 12.5 mm and MF = 5.545 determined in accordance to NBR 7211 [15]. In the characteristic curve of the gravel which is shown in figure [6], the percentage in the sieves 2.36 to 6.3 mm do not match the established range according to NBR 7211 [15], but it was set as gravel

Table 3 – granulometric and physical Characterization of Artificial Sand

Sieve (mm)	Weight Retained (g)	Percentage Retained		Percentage Accumulated	
9,5					
6,3					
4,75			%		%
2,36	48,3	8,71	%	8,71	%
1,18	83,2	15	%	23,72	%
0,6	109,5	19,75	%	43,46	%
0,3	112,9	20,36	%	63,82	%
0,15	117,3	21,15	%	84,98	%
FUND	83,3	15,02	%	100	%
TOTAL	554,5	100	%		

Description		Results
Unit mass	(NBR 52)	1,444 Kg/dm³
Specific Mass	(NBR 52)	2,674 Kg/dm³
Materials In Powder Form	(NBR NM 46)	0,22%
Module of Fineness	(NBR 7211)	2,247
Maximum Diameter	(NBR 7211)	4,75mm
Coefficient of empties		46%

0 (zero) due to its vast use all over the region.
Table [5] shows the granulometric and physical characterization of the slag. According to NBR 7211 [15], we find dm = 19 and MF = 6.742 mm. The granulometric distribution of the slag is plotted in figure [7], the percentage retained in the sieves regard this residue as gravel 1, according to NBR 7211 [15].
The WTSS presented powdery characteristics after processing in hammer mill and was not possible to draw a granulometric curve. It has also presented similar clay characteristics due to color, texture and grain size.
Table [6] shows the values of physical properties (specific mass) for the fresh concrete.
The specific mass is intrinsic to the porosity of the material, NEVILLE [10]. The specific mass values for mix 2, 3 and 4 (with addition of WTSS) showed a decrease compared to the standard mix, due to the difficulty of mixing this product with powdery characteristics. As the slag was added, mix 5 had an increase of specific mass. Mix 6 and 7, showed a decrease in specific mass, due to the composition with the slag and WTSS. Mixes 8, 9 and 10 presented the highest values, as expected the specific weight of the slag.
Table [7] presents the results for the analysis of variance (ANOVA) for the specific mass variable response, due to the mix that was used. By analyzing the influence of the mixes in the specific mass, the P value was less than 0.05, with an adjustment of R-Sq = 82.16%. The P value was less than α of 0.05, so the results of specific mass are significantly different in the many evaluated mixes.

Figure 5 – Granulometric distribution for Artificial Sand

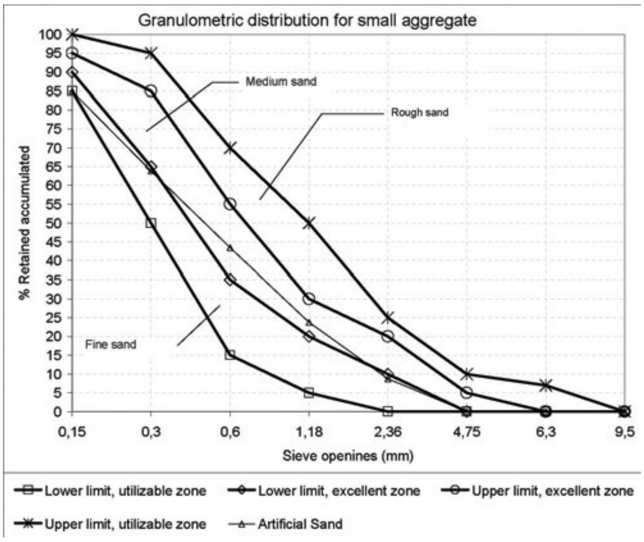


Table 4 – Granulometric and physical characterization of gravel

Sieve (mm)	Weight Retained (g)	Percentage Retained		Percentage Accumulated	
19			%		%
12,5			%		%
9,5	110,66	9,5	%	9,5	%
6,3	436,57	37,7	%	47,2	%
4,75	329,5	28,43	%	75,64	%
2,36	211,2	18,22	%	93,86	%
FUND	71,2	6,14	%	100	%
TOTAL	1159,21	100	%		

Description		Results
Unit mass	(NBR 52)	1,444 Kg/dm³
Specific Mass	(NBR 52)	2,632 Kg/dm³
Materials In Powder Form	(NBR NM 46)	0,42%
Module of Fineness	(NBR 7211)	5,545
Maximum Diameter	(NBR 7211)	12,5mm
Coefficient of empties		45,12%

Table 5 – Granulometric and physical characterization of slag

Sieve (mm)	Weight Retained (g)	Percentage Retained		Percentage Accumulated	
19	68	2,8	%	2,8	%
12,5	1643	68,3	%	71,1	%
9,5	469	19,5	%	90,6	%
6,3	140	5,8	%	96,4	%
4,75	3	0,12	%	96,55	%
2,36	7	0,29	%	96,84	%
FUND	76	3,16	%	100	%
TOTAL	2406	100	%		

Description		Results
Unit mass	(NBR 52)	1,41 Kg/dm³
Specific Mass	(NBR 52)	2,632 Kg/dm³
Materials In Powder Form	(NBR NM 46)	0,82%
Module of Fineness	(NBR 7211)	6,742
Maximum Diameter	(NBR 7211)	19mm
Coefficient of empties		46,43%

Figure 6 – Granulometric distribution for gravel

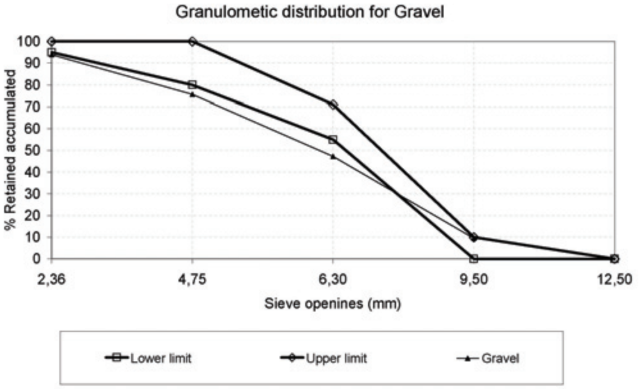


Figure 7 – Granulometric distribution for slag

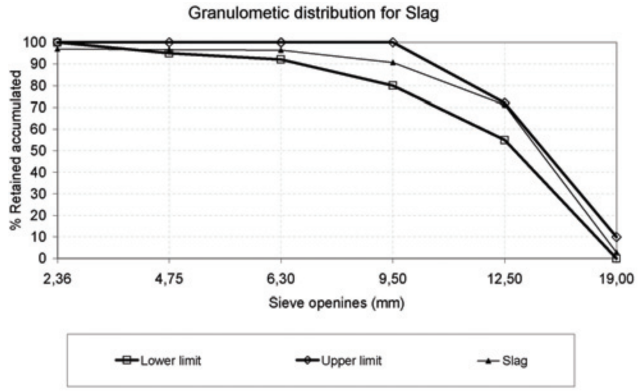


Table 6 – Specific mass values of fresh concrete

Discrimination	Reference	Specific mass (kg/m^3)
Mix 1	Standard	2230,37
Mix 2	LERE1	2178,12
Mix 3	LERE2	2213,69
Mix 4	LERE3	2168,9
Mix 5	LERE4	2213,41
Mix 6	LERE5	2069,53
Mix 7	LERE6	2081,22
Mix 8	LERE7	2246,84
Mix 9	LERE8	2235,01
Mix 10	LERE9	2234,65

Table [8] shows the values of water absorption for the concrete. The monitoring of water absorption determines the amount of permeable pores in the structure, knowledge of this pore structure allows one to predict the durability of a concrete, Wirquin [16].

It was observed that within the dosage sequences 1%, 5% and 10% for the WTSS, the absorption behavior followed a pattern of growth in the compositions that only coarse aggregate was used. The melt shop slag aggregate showed results of higher values in relation to the composition in which we used the natural aggregate gneiss rock “Gravel 0”. In this sequence, the mix LERE5 with replacement of 5%WTSS presented results of higher values of absorption in relation to the mixes in the comparison group and also in the other compositions, except for mix 10.

Table [9] presents the results for the analysis of variance (ANOVA) for the water absorption variable response.

Absorption showed significant value since its P-value is less than 0.05, with an adjustment of R-Sq = 71.90%, validating the analysis. The various mixes of the directly influence in the different results.

Table [10] shows the values of resistance to simple axial compression, for all the mixes of the concrete at 28 days. In the study of this issue, it was verified that in general, the values obtained show values directly proportional to the ages within the same substitution pattern.

As the WTSS replacement increases, the resistance to compression happens in a decreasing order when the proportion goes from 1% to 5%, decreasing even more with the compositions of 5% and 10%.

In cases where the compositions were fully dosed with coarse aggregate replaced 100% by melt shop slag, an increase of the resistance was found.

Table 7 – Analysis of variance for specific mass

Source	DF	SS	MS	F	P
Reference	9	218825	24314	29,66	0,000
Error	47	38531	820		
Total	56	257356			
	S = 28,63	**R-Sq = 85,03%**	**R-Sq (adj) = 82,16%**		

Table 8 – Table of water absorption of concrete

Discrimination	Reference	Absorption (%)
Mix 1	Standard	2,61
Mix 2	LERE1	2,57
Mix 3	LERE2	3,24
Mix 4	LERE3	3,92
Mix 5	LERE4	4,06
Mix 6	LERE5	4,75
Mix 7	LERE6	4,67
Mix 8	LERE7	4,23
Mix 9	LERE8	3,89
Mix 10	LERE9	5,05

4. Conclusions

Results for the concretes manufactured from waste: water treatment station sludge, artificial sand and steel slag allow us to conclude that:
The values of the specific mass of concrete compared with the standard mix: for mix 2, 3 and 4, with the addition of WTSS, showed a decrease. As the slag was added, mix 5, showed an increase in specific mass. Traces 6 and 7 showed a decrease in specific mass, due to the composition of the slag and WTSS. Mixes 8, 9 and 10 showed the highest values, since the slag is an aggregate of greater density.
For the water absorption in concrete manufactured with waste, only mix 2 showed lower value. It was observed that by increasing the percentage of WTSS, the capacity of water absorption increased. The concrete with the addition of melt shop slag as aggregate showed higher values of water absorption in relation to the composition, in which the natural gneiss rock "Gravel 0" was used. Mix 5 with replacement of 5% of WTSS showed higher values of water absorption in relation to all the other mixes, except mix 10.
For the compression resistance it was observed that the concrete with larger fractions of WTS S presented lower values in relation to the concrete adopted as a standard. This compression resistance happens in a decreasing order when the proportion goes from 1% to 5%, decreasing the even more with the compositions of 5% and 10% of WTSS
For the mixes that presented in their composition the substitution of coarse aggregate (gravel) by 100% for melt shop slag, there was an increase in resistance.

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Table 9 – Analysis of variance for water absorption

Source	DF	SS	MS	F	P
Reference	9	0,0038306	0,0004256	16,92	0,000
Error	47	0,0011821	0,0000252		
Total	56	0,0050127			
	S = 0,005015	**R-Sq = 76,42%**	**R-Sq (adj) = 71,90**		

Table 10 – Table of resistance to axial compression for the concrete at 28 days

Discrimination	Reference	Rupture Tension (MPa)
Mix 1	Standard	25,06
Mix 2	LERE1	20,43
Mix 3	LERE2	18,54
Mix 4	LERE3	17,90
Mix 5	LERE4	22,13
Mix 6	LERE5	21,60
Mix 7	LERE6	17,97
Mix 8	LERE7	26,34
Mix 9	LERE8	24,55
Mix 10	LERE9	21,52

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