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Foundry Sand for Manufacturing Paving Units

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1. Summary

Foundry is the process where metal is shaped using molds made by metal or sand, being the second one the most commonly used in Brazil. The foundry sand consists in sand and binders, normally clay. Over the last 20 years more than 30.000.000 cubic meters of waste were discarded in sanitary landfills, and currently the reuse of it is being encouraged. This paper investigates the availability to use foundry sand to produce paving units as a substitute for the fine sand. Tests were conducted at a local manufacturer, close to the foundry industry, using a vibrocompresser machine and the local materials along with the spent foundry sand. The paving units were analyzed in accordance with the Brazilian Standard ABNT NBR 9781 for requirements on paving units for interlocking concrete pavement. Further tests on durability were applied as water absorption and abrasion tests, in accordance with the European Standard EN 1338. The units produced using spent foundry sand show, initially, a darker color due to the presence of seacoal, but tend to lose the color along with use. Although one of the samples were in compliance with the requirements, the use of foundry sand reduces the mechanical strength when compared with a reference without it, thus it´s necessary further research in order to analyze the reason for that reduction.

2. Introduction

The spent foundry sands represent one of industrial solid wastes with higher production volume. Only in Brazil are generated about three million tonnes per annum (ABIFA, 2009). The extraction of sand used for construction coupled with the accumulation of sand casting discarded in landfills cause significant environmental impacts. Therefore, the recycling of discarded foundry sand should be encouraged to reduce the quantity of sand extracted from nature.

Some preliminary studies on the use of spent foundry sand as aggregate for foundry applications in building construction has been made in Brazil (CARNIN, 2008; COUTINHO, 2004; STEFENON, 2003; BONET, 2002, BONIN, 1995; BINA et al, 2000; CAMARGO et al,2006) with satisfactory results.

The report developed by the Environmental Protection Agency of the United States - EPA, 2006 shows that the largest volumes of spent foundry sand being used in geotechnical applications as bases for roads and landfill cover. The report highlights that, depending on the quality of the spent foundry sand, this may be an excellent aggregate for the production of Portland cement concrete and asphalt concrete products. In more rare cases, spent foundry sand is being used in agriculture and other applications such as composting.

In Europe, the reuse of foundry waste is recent, but rapidly developing, seen as a priority within the European industry for its benefits of environmental preservation and economic development.

In Brazil, both in the state of Santa Catarina and in the State of São Paulo, the spent foundry sand can be used in asphalt mixtures and concrete precast products without structural function in accordance with the laws of each state (Santa Catarina Resolution CONSEMA 011/2008 and Decisão da diretoria No 152/2007/C/E.

This study shows the use of spent foundry sand as aggregate to manufacture paving units for interlocked concrete pavement and provides mechanical and environmental aspects of this use, explored in depth in this investigation.

3. Materials and methods

3.1. Foundry Sand

The foundry sand is a mixture of several elements that combine features of giving perfect workability of the mixture that comprises the molding box. Flexibility, compatibility, refractoriness, cohesion, mechanical strength to both compression and traction volumetric expansion, permeability and perfect demolding are some characteristics that sand gets due mixture (BONIN, 1995).

The foundry sand consists essentially of: sand, seacoal dust, bentonite and water. The foundry sand mixture can vary depending on the manufactures, and the one used in this study has the following materials and proportions: 88% of washed sand, 8% of bentonite, 2% of seacoal dust and 2% of water.

The main component of the foundry sand used is a fine aggregate, mineralogically pure called "sand base." The sand base consists essentially of silica (silicon dioxide - SiO_2).

The bentonite is a hydrous silicate of alumina (in its composition contains silicon, aluminum, iron, calcium, magnesium, potassium and sodium). It is formed by lamellae, being classified by their thickness.

In general, the seacoal dust consists of volatile material, fixed carbon, ash, sulfur and water.

The water comes to the mixture to increase the cohesion by increasing its humidity.

In summary, the mold shape the outer faces while the males conform the inner faces of the metal piece.

In order to approve the use of the foundry sand it is necessary to verify the requirements set out by Resolução CONSEMA 011/08 carrying out the following characterizations:

• Characterization and Classification of spent foundry sand, according to ABNT NBR 10004;

• Chemical analysis of the extract leachate - using the methodology presented in the ABNT NBR 10005;

• Chemical analysis of aqueous extract;

• Analysis of toxicity tests, according to the methodology established by Ordinance No. FATMA. 17, April 18, 2002.

The characterization and classification of spent foundry sand were performed in the Laboratory of Chemistry Acquaplant Brazil Ltda, located in Joinville - SC. The results are shown in Table 1.

The classification was done by comparing the results obtained in the analysis with the standards that are in ABNT NBR 10004 - Solid Waste: Appendix F - Concentration - Maximum Value in the extract obtained by leaching test; Annex G - Standards for testing solubilization.

According to the comparison between the leaching and solubilized shown in Table 1 spent foundry sand residue is classified as Class IIA - not inert in relation to elements aluminum and iron with values above the standard in analysis in solubilized. According to the study by CARNIN, 2008 Joinville soils haven aluminum, iron and manganese in the solubilized extract, above the maximum allowed by the NBR 10.004. If they were industrial waste would be classified as Class II Waste A - Not Inert. It should be noted that the foundry sand is not a hazardous waste.

Following the procedures set forth in Resolution CONSEMA 011/08 for spent foundry sand use on precast concrete products without structural function is to present concentrations of pollutants in the leachate extract obtained according to ABNT NBR 10.005, below or equal to the allowed concentrations (Table 2). Must also present concentrations of pollutants in aqueous extract smaller or equal to the maximum permissible concentrations and also must have pH in the range between 5.5 and 10.0. The results of these can be seen in Table 3.

It was also conducted the study on acute toxicity of the extract solubilized spent foundry sand as FATMA Ordinance n. 17/02. The acute toxicity tests were performed in the Laboratory of Environmental Toxicology, Federal University of Santa Catarina.

The methodology for testing of acute toxicity with Daphnia magna microorganisms followed NBR 12 713 2003. The results of toxicity tests can be seen in Table 4.

Table 1- Chemical parameters in the spent foundry sand leachate, solubilized according NBR 10.004

Parameters	Leachate (mg/L)		Solubilized o (mg/L)	
	NBR 10005		NBR 10006	
	Results	MVA [(1)]	Results	MVA [(1)]
Aluminum			**44,26**	0,2
Arsenic	< 1,000 x 10^{-4}	1,0	3, 990 x 10^{-3}	0,01
Barium	< 0,20	70	< 0,20	0,7
Cadmium	< 0,001	0,5	< 0,001	0,005
Lead	< 0,01	1,0	< 0,01	0,01
Cyanides			< 0, 005	0,07
Chlorides			49,67	250
Copper			< 0, 005	2,0
Total chromium	< 0,030	5	< 0, 030	0,05
Total phenols			0, 125	0,01
Iron			**25, 988**	0,3
Fluoride	< 1,000	150	< 1, 000	1,5
Manganese			< 0, 005	0,1
Mercury	< 1,000 x 10^{-4}	0,1	< 1, 000 x 10^{-4}	0,001
Nitrate (expressed as N)			8,00	10,0
Silver	< 0,02	5,0	< 0,02	0,05
Selenium	< 1,000 x 10^{-4}	1,0	< 1,00 x 10^{-4}	0,01
Sodium			127, 530	200
Sulfate (expressed as SO_4)			50,48	250
Zinc			0, 019	5,0

(1) MVA – Maximum Values Allowed – ABNT NBR 10.004 / 2004.

Table 2 - Chemical parameters of the spent foundry sand extract leached according to Resolução CONSEMA 011/08

Parameters	Results	Mva [1]
Arsenic (mg/L)	< $1,000 \times 10^{-4}$	0,50
Barium (mg/L)	0,03	10,0
Cadmium (mg/L)	< 0,001	0,10
Lead (mg/L)	< 0,01	0,50
Total chromium (mg/L)	< 0,030	0,50
Leached mass (g)	50,025	-
Mercury (mg/L)	$1,700 \times 10^{-3}$	0,02
Selenium (mg/L)	$1,90 \times 10^{-3}$	0,10

[1] MVA – Maximum Values Allowed – Resolução CONSEMA 011 de 2008.

Table 3 - Physio-chemical parameters of spent foundry sand aqueous extract according Resolução CONSEMA 011/08.

Parameters	Results	MVA [1]
Cyanides (mg/L)	< 0,005	2,0
Chlorides (mg/L)	12,53	2.500,0
Copper (mg/L)	0,015	2,5
Total phenols (mg/L C_6H_5OH)	< 0,050	3,0
Total iron (mg/L)	6,239	15,0
Fluoride (mg/L)	< 1,000	14,0
Manganese (mg/L)	< 0,005	0,50
Mass leached (g)	50,060	-
Nickel (mg/L)	< 0,020	2,0
Final ph of the aqueous extract (-)	6,88	5,5 – 10,0
Initial ph of aqueous extract (-)	7,95	-

Sodium (mg/L)	97,58	2500,0
Total Dissolved Solids (mg/L)	612,0	5.000,0
Sulfate (mg/L)	123,68	2.500,0
Sulfide (mg/L)	< 0,050	5,0

(1) MVA – Maximum Values Allowed – Resolução CONSEMA 011 de 2008.

Table 4 - Results of acute toxicity tests with Daphnia magna.

Sample	Ph	Dilution Factor - FD	Maximum Limit - FD	Results
Spent Foundry sand – 1ª réplica	7,62	1	4	Nontoxic
Spent Foundry sand – 2ª réplica	7,48	1	4	Nontoxic
Spent Foundry sand – 3ª réplica	7,44	1	4	Nontoxic
Spent Foundry sand – 4ª réplica	7,66	1	4	Nontoxic
Spent Foundry sand – 5ª réplica	6,90	1	4	Nontoxic

According to the results we found that the spent foundry sand meets all requirements of Resolution 011/08, and thus can be used in the manufacture of concrete with no structural function.

3.2. Paving blocks materials

The following materials were used to manufacture the paving units:

• Cement CP V ARI (high initial resistance cement, according NBR – 5733)

• Water,

• Aggregates,

• Spent foundry sand from Topy SA of Joinville.

The particle size characterization on both the aggregates and the spent foundry sand was conducted according to ABNT NBR7211 and are shown in Figure 1.

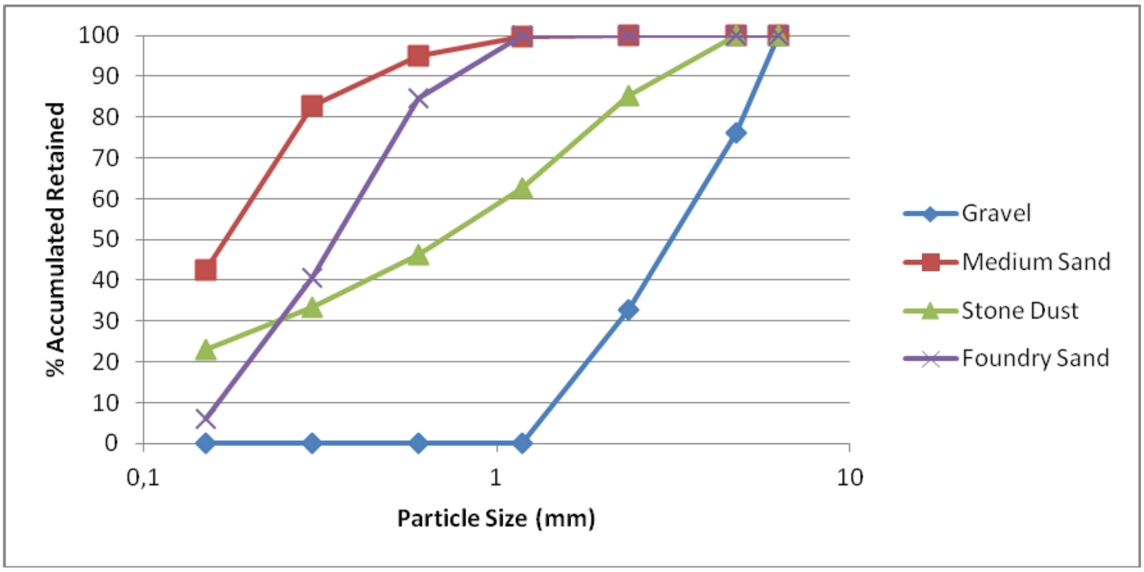

Figure 1 - Aggregates and spent foundry sand grain Size Distribution

3.3. Mix design

Four samples were tested with different mix designs where the spent foundry sand content ranged from 18% to 40%, as shown in Figure 2.

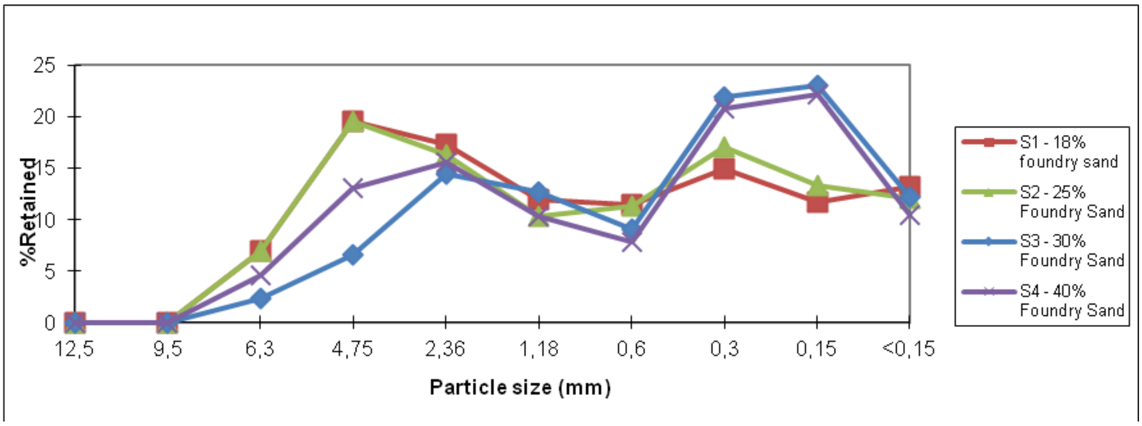

Figure 2 - Mix designs with spent foundry sand content ranging from 18% until 40%

For each sample it was produced 1 cubic meter of paving units using a hydraulic vibrocompresser machine. On Figure 3 it is shown paving units produced using spent foundry sand. After molding the paving units were kept in a humidity chamber for 24 hours and then were palletized.

Figure 3 - Paving units containing spent foundry sand right after moulding.

After the curing process it was determined the compressive strength, abrasion strength and water absorption, both on the samples containing spent foundry sand and on the mix design normally used by the manufacturer, as reference. The compression strength was determined according to the ABNT NBR 9780 which consists in compression strength using two cylinders of 90mm, as shown in Figure 3. The abrasion strength and the water absorption were conducted according to CEN EN 1338.

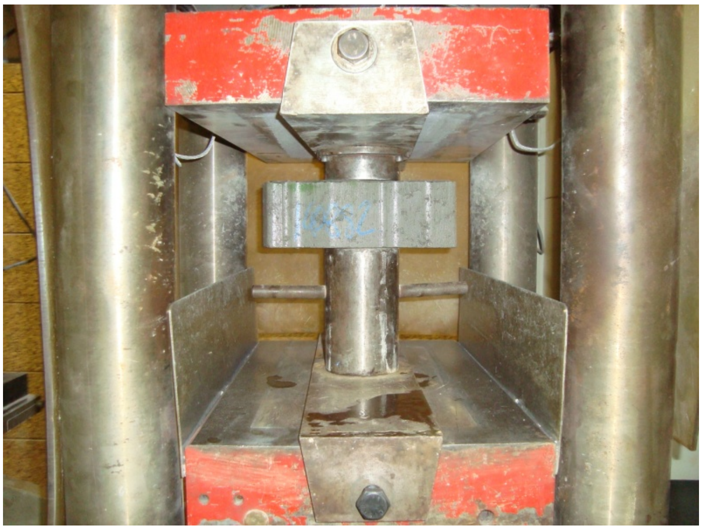

Figure 4 - Compressive strengh testing method according to ABNT NBR 9780

4. Results

The results on the hardened state are shown on Table 7. Only S1 (highlighted) achieved the minimum requirement on compression strength according the ABNT NBR 9781, of 35MPa. This mix design has the least spent foundry sand content, and it's possible to observe that the more spent foundry sand incorporate in the mix the more the compression resistance decreases.

Table 5 - Results on the hardened state

Sample	Spent Foundry Sand Content	fpk	Abrasion Cavity	Water Absorption	Specific Weight (g/cm^3)
	(%)	(MPa)	(mm)	(%)	
Reference	-	43,80	18,25	3,40	2,34
S1	**18**	**35,70**	**18,35**	**3,00**	**2,24**
S2	25	30,10	18,70	3,30	2,23
S3	30	19,80	18,00	5,00	2,34
S4	40	14,80	19,63	4,40	2,35

On Oliveira (2011) study using spent foundry sand on mortar, the specimens presented expansion which lead to decrease on mechanical strength. However, in this case it wasn´t observe any expansion and the water absorption content were lower than the maximum content of 6% required on EN CEN 1338, thereby that cannot be the motive for the low compressive strength.

On another study, from Camargo (2006), it was analyzed the bentonite and seacoal dust influence on a cement paste through DRX and MEV characterization and they observe influence on the cement hydration. The presence of those two wastes favours the ettringite formation and increased the crystallinity of the C-S-H phase due to a higher Si/Ca relation on hydrous calcium silicate. Although they affirm that this influence is not substantial to lead to an alteration on the mechanical properties of the concrete, it might explains the lower compressive strength observed on the paving units using spent foundry sand. Since the bentonite and seacoal dust content vary in each foundry sand, it would be necessary further study the material used in order to confirm if that's the reason for the lower strength.

However, since one of the samples achieve the requirements demand by Brazilian Standard ABNT NBR 9781 they are approved to be used on interlocking concrete pavement.

The paving units shows a darker coloration due to the seacoal dust, as can be observe on Figure 5, that tends to fade along the life cycle of the paving. That doesn´t have influence on its used and have only to be informed to final costumer, especially due to the expected variation of the color.

Figure 5 - Paving unit using foundry sand.

5. Conclusions

The incorporation of spent foundry sand on paving units can be a viable option on reusing that waste in Brazil. After its use being approved according the laws on foundry sand disposal, four samples with different mix design and different ranges of spent foundry sands were tested, and the sample containing 15% of spent foundry sand (S3) presented itself in accordance with the Brazilian standards and thus could be normally used. However this mix design uses the least amount of spent foundry sand among all the tests and in order to use more material is necessary to conduct tests on the influence of the seaseacoal and bentonite on the cement hydration. Also can be tested different mixing designs with improving particle packing to compose the mix, although that would go against the idea of maintaining the normal production and materials of the manufacturer.

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