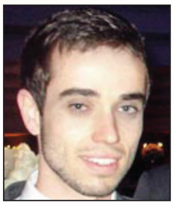
Volume 4, Number 4 (October, 2011) p. 642-662 • ISSN 1983-4195

REVISTA IBRACON DE ESTRUTURAS E MATERIAIS

IBRACON STRUCTURES AND MATERIALS JOURNAL

Influence of foundry sand residues on the fresh and hardened properties of mortars produced with portland cement

Influência do emprego de areia de fundição residual nas propriedades no estado fresco e endurecido de misturas cimentícias

W. R. L DA SILVA [a]
wilsonecv@gmail.com

E. TOCHETTO [b]
eduardo_tochetto@hotmail.com

L. R. PRUDÊNCIO JR. [c]
prudenciouk@hotmail.com

A. L. OLIVEIRA [d]
alexandre@ifsc.edu.br

Abstract

The foundry sand waste (FSW) derives from moulds used in the metallurgical industries. The present experimental study was developed to evaluate the influence of the use of FSW on concrete properties. The mixtures were produced with cement CPV-ARI-RS, water reducing admixture, FSW, natural and crushed aggregates. The properties on the fresh state were evaluated by means of flow table test and the determination of the incorporated air content. On the hardened state, compressive strength tests were performed. The initial results have shown that the use of FSW leads to an increase in the air content and cracking, caused by expansive reactions. As a result of that, a reduction in the compressive strength has been noticed. In order to define the origin of the presented trends, a complementary study was developed using FSW with different compositions. However, regardless the composition of the FSW, the obtained results presented trends which were similar to the ones previously observed. Finally, considering the materials herein used, the addition of FSW in concrete is considered inadequate since this leads to a decrease not only in the compressive strength, but also in the durability of the material.

Keywords: residues, foundry sand waste, expansive reactions

Resumo

A areia de fundição residual (AFR) consiste em um resíduo arenoso proveniente dos moldes utilizados no processo de fundição de metais. O presente trabalho foi desenvolvido com o objetivo de avaliar a influência do uso da AFR nas propriedades concreto. Para tanto, utilizou-se cimento CPV-ARI RS, aditivo plastificante, AFR e areias fina, média natural e de britagem. As propriedades no estado fresco foram avaliadas através da determinação da consistência e teor de ar incorporado. No estado endurecido avaliou-se a resistência à compressão axial. Os resultados indicaram que o uso da AFR resulta no aumento do teor de ar incorporado, fissuração por reações expansivas e conseqüente redução de resistência. Visando investigar a origem das tendências observadas, realizou-se um estudo complementar empregando AFR de diferentes composições. Todavia, independente da composição utilizada, os resultados indicaram tendência semelhante à observada anteriormente. Por fim, considerando os materiais empregados nesta pesquisa, conclui-se que a utilização da AFR em concreto é inadequada, pois prejudica não apenas a resistência mecânica, mas também a durabilidade do material.

Palavras-chave: areia de fundição residual, resíduos, reações expansivas.

[a] *MSc. Civil Engineer, Czech Technical University in Prague – CTU, Faculty of Civil Engineering, wilsonecv@gmail.com, Thakurova 7, 166 29 Prague 6 Czech Republic.*

[b] *Civil Engineer, Justiça Federal do Paraná – JFPR, eduardo_tochetto@hotmail.com, Av. Anita Garibaldi 888, 80540-180 Curitiba/PR Brazil.*

[c] *Professor, Universidade Federal de Santa Catarina – UFSC, Departamento de Engenharia Civil, prudenciouk@hotmail.com, Campus Universitário, s/n – Engenharia. Civil, Bloco B, r.114, 88040-970 Florianópolis/SC Brazil.*

[d] *Professor, Instituto Federal de Educação – IFSC, Departamento Acadêmico de Construção Civil, alexandre@ifsc.edu.br, Rua Mauro Ramos 950, 88020-300 Florianópolis/SC Brazil.*

Received: 22 Sep 2010 • Accepted: 31 May 2011 • Available Online: 07 Oct 2011

1. Introduction

The foundry consists of a manufacturing process where a metal or metal alloy, at a liquid state, is poured into a mold containing a cavity shaped and measures corresponding to the part which is to be produced. The sand molding method is the most widely used in metal casting. It is estimated that 85% to 90% of the metal casting industries uses bounded sand molds, which composition is given by a refractory granular material (sand based), water and organic additives and/or bentonite as binders. If bentonite clays are used as bounding materials then the process is known as clay bounded molding system (green sand), otherwise the process is defined as chemically bounded molding system. The chemically bounded molding represents approximately 10% to 15% of the processes used in metal casting. In this process the sand mold components are firstly mixed, and then dried in temperatures which range from 150 to 250 °C.

One of the problems inherent in the sand molding method is the fact that after a certain number of uses, the sand loses the properties necessary for the manufacturing of other molds, thus creating a significant amount of waste.

The production of one ton of cast metal generates approximately one ton of waste [1]. Data from the Brazilian Foundry Association [2] indicates that the production of castings in Brazil exceeded three million tons in 2007. Therefore, it appears that only in 2007, the Brazilian foundry industry generated approximately three million tons of foundry sand waste.

The Brazilian environmental law requires that the foundry sand waste must be disposed of in landfills or incinerated. This requirement creates a serious environmental problem, not only due to the high volume of waste produced, but also because the toxic substances found in them, since the sand is contaminated by chemical elements and compounds such as: arsenic, cadmium, lead, phenols, mercury, sodium, amongst others [3]. In addition to the environmental problem, the metal casting industry entrepreneurs are also concerned about the high cost of management and allocation of the large waste volumes. According to the Brazilian standards [4] the foundry waste sand is generally identified by the code A016 and classified as a non-hazardous waste – Class II. However, this classification may change according to the results obtained from solubility and toxicity analysis of the foundry sand waste.

In this context, companies in the sector have sought alternatives for reusing the waste foundry sand, which would decrease the cost of disposal of waste and also reduce the environmental impact. A potential alternative for the reuse of foundry sand waste is to use it in concrete production, given that the aggregates occupy over three-quarters of its volume. The use of foundry waste sand has been studied by various authors, e.g., Khatib & Ellis [5], Naik et al. [6, 7], Siddique et al [8], Tikalsky et al [9], e Kraus et al [10]. Also, Fiore & Zanetti [11] have investigated the use of foundry sand waste in the production of recycled concrete. In other researches, e.g., Klinsky [3], Bakis et al. [12] e Javed et al. [13], the use of foundry sand waste in the production of asphalt concrete has been investigated.

Based on the aforementioned, it is noteworthy that in addition to eliminating the need for disposal in landfills, the use of waste foundry sand in

Table 1 – Aggregates used in the proposed study

Nomenclature	Description
AM	Medium river bed sand
AF	Fine dune sand
AB	Crushed aggregate
FSW	Foundry sand waste

Table 2 – Foundry sand waste – toxicity (leaching) analysis according to (16)

Parameters		FSW results	Reference limits defined by (4)	Detection limit
Arsenic	(mg/L)	<0.001	1.0	0.001
Barium	(mg/L)	0.061	70.0	0.008
Cadmium	(mg/L)	<0.0001	0.5	0.0001
Lead	(mg/L)	0.003	1.0	0.001
Chrome	(mg/L)	0.027	5.0	0.001
Fluoride	(mg/L)	0.150	150.0	0.05
Mercury	(mg/L)	<0.0001	0.1	0.001
Silver	(mg/L)	<0.0001	5.0	0.0001
Selenium	(mg/L)	<0.001	1.0	0.001
Initial pH	-	4.6	-	0.01

concrete would bring an additional benefit for the environment because it would prevent millions of cubic meters of sand to be taken from caves and rivers. Therefore, this study aims to evaluate the influence of the use of foundry sand waste on concrete the fresh and hardened.

2. Materials and experimental program

2.1 Materials used in the production of mixtures

Previously to the presentation of the materials used in the present study, it is important to mention that all the experimental tests was carried out in mortar mixtures due to the good correlation that has been obtained in previous studies [14].
In the production of mortar mixtures used throughout this study were used cement CPV ARI RS [15], density of 3.00 kg/dm³, and water reducing admixture (polyfunctional), density of 1.08 kg/dm³. Besides, three different types of aggregates were used. The description of each aggregate type and their nomenclature are presented in Table 1.
Regarding the foundry sand waste (FSW), this corresponds to fine dune sand (AF) collected immediately after the grinding of molds used in metal casting process. In this case, the AF has been mixed with crushed coal (coal-powder), sodium silicate ($NaSiO_2$) and CO_2 to obtain the sand molds. After the metal parts production, the sand mold was then milled resulting thus in the FSW.
The results obtained in the used FSW toxicity [16] and solubility analysis [17] are listed in Table 2 and 3, respectively. The toxicity analysis results (see Table 2) have shown that none of the analyzed parameters has crossed the limit specified in [4], therefore the used FSW was classified as an non-toxic residue. The solubility analysis results (see Table 3) have shown that the following parameters have

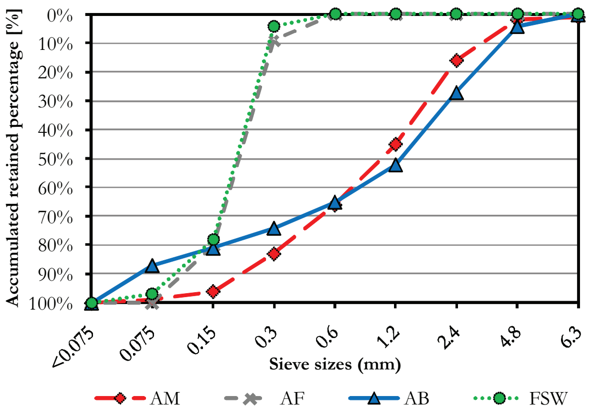
Table 3 – Foundry sand waste – solubility analysis according to (17)

Parameters		FSW results	Reference limits defined by (4)	Detection limit
Aluminum	(mg/L)	0.540	0.200	0.001
Arsenic	(mg/L)	<0.001	0.010	0.001
Barium	(mg/L)	0.019	0.700	0.008
Cadmium	(mg/L)	<0.0001	0.005	0.0001
Lead	(mg/L)	0.001	0.010	0.001
Cyanide	(mg/L)	<0.004	0.070	0.004
Chloride	(mg/kg)	16.3	250.0	0.500
Copper	(mg/L)	0.042	2.000	0.001
Chrome	(mg/L)	0.006	0.050	0.001
Phenol	(mg/L)	<0.01	0.010	0.010
Iron	(mg/L)	2.830	0.300	0.005
Fluoride	(mg/L)	<0.05	1.500	0.200
Manganese	(mg/L)	0.070	0.100	0.003
Mercury	(mg/L)	<0.0001	0.001	0.001
Nitrate	(mg/L)	<0.20	10.0	0.200
Silve	(mg/L)	<0.0001	0.050	0.000
Selenium	(mg/L)	<0.001	0.010	0.001
Sodium	(mg/L)	506.0	200.0	0.005
Sulfate	(mg/L)	15.7	250.0	2.000
Surfactants	(mg/L)	<0.05	0.500	0.050
Zinc	(mg/L)	0.154	5.000	0.001
Humidity	(%)	0.10	-	-
Final pH	-	11	-	-

Table 4 – Physical properties of different types of aggregates

# (mm)	Retained percentage (%) Aggregates			
	AM	AF	AB	FSW
6.30	1.0	0.0	0.0	0.0
4.80	2.0	0.0	4.0	0.0
2.40	16.0	0.0	27.0	0.0
1.20	45.0	0.0	52.0	0.0
0.60	66.0	0.0	65.0	0.0
0.30	83.0	9.0	74.0	4.0
0.15	96.0	80.0	81.0	78.0
0.075	99.0	100.0	87.0	97.0
<0.075	100.0	100.0	100.0	100.0
Fineness modulus	3.08	0.90	3.04	0.82
Dusty material content (%)	1.18	0.12	13.3	2.83
Density (Kg/dm³)	2.619	2.646	2.970	2.606

Grain size distribution curve



exceeded the limits specified in [4]: Aluminum, Iron and Sodium. Thus, the residue was classified as Class II A – non-inert.

The physical properties of each of the aggregates were determined according to test procedures specified in [18, 19, 20 and 21] and are presented in Table 4.

2.2 Experimental program

The experimental program applied to evaluate the use of FSW in mortar mixtures was divided in two stages. The first stage consists of the analysis of mortars produced with compositions between the aggregates AM, AF and FSW. The second stage consists of the analysis of mortars produced with compositions between the aggregates AB, AF and FSW. The details about each one of the mentioned stages are discussed in items 2.2.1 and 2.2.2.

2.2.1 Stage 1

The first stage aims to evaluate the potential use of foundry sand waste in concrete production. At this stage mortar mixtures with cement CP V ARI RS, polyfunctional water reducing admixtures, and compositions between the aggregates AM, AF and FSW were investigated.

The mortar made with the composition between AM and AF was considered as the reference mixture. It is noteworthy that this has unitary mass ratio of 1:3.22:0.66 (cement : aggregate : water). In the other mixtures, AM and AF fractions were volumetrically replaced by FSW in the proportions indicated in Table 5, the mortars nomenclatures are also presented in this table. The mortars materials content used in the study proposed in stage 1 are listed in Table 6.

Table 5 – Mortars nomenclature and volumetric percentages of aggregates used to produce the mortars – stage 1

Nomenclature	Aggregates		
	AM	AF	FSW
Ref	50%	50%	-
A1-1	50%	-	50%
A1-2	35%	-	65%
A1-3	20%	-	80%

Table 6 – Mortar materials content – stage 1

Materials (Kg/m³)	Ref	A1-1	A1-2	A1-3
Cement (1)	451	451	451	451
AM	722	722	505	289
AF	729	-	-	-
FSW	-	718	934	1149
Water	298	298	298	298
Admixure (2)	3.2	3.2	3.2	3.2
w/c	0.66			

(1) CP V ARI RS; (2) Water reducing admixture – 0.7% in relation to the cement mass.

Table 7 – Mortars nomenclature and volumetric percentages of aggregates used to produce the mortars – stage 2

Nomenclature	Aggregates		
	AF	AB	FSW
A2-1	50%	50%	-
A2-2	40%	60%	-
A2-3	30%	70%	-
A2-4	-	50%	50%
A2-5	-	60%	40%
A2-6	-	70%	30%

The mortars properties on fresh state were determined based on the evaluation of the incorporated air content and consistency. The incorporated air content was determined based on the gravimetric method. The consistency was assessed by means of flow table tests. In this case the mortar spreading diameter was measured immediately after the mold removal ($Flow_0$) and after applying 10 strokes ($Flow_{10}$). The testing procedures for determining the incorporated air content and consistency can be found, respectively, in the standards [22, 23].
After performing the abovementioned tests, three specimens with dimension of 5.0 x 10.0 cm (diameter x height) were molded for each mixture in order to evaluate the compressive strength at 7 days. The used molds are made of PVC.

2.2.2 Stage 2

The stage 2 was developed aiming to evaluate the use of FSW in a composition with fine crushed aggregate for further production of structural concrete with higher compressive strengths.
Aiming to meet the objectives of this stage, mortar mixtures were produced with cement CP V ARI RS, polyfunctional water reducing admixtures, and aggregates AF, AB and FSW. Table 7 shows the nomenclature used for the different aggregate compositions used at this stage.
The unitary mass ratio used for the production of mortars in stage 2 was based on the composition used in stage 1, i.e., 1:3.22:0.66. The volumetric replacement of AM by AB was then performed, thus obtaining the unitary mass ratio 1:3.43:0.66 (cement : aggregate : water). The mortars materials content used in the study proposed in stage 2 are presented in Table 8.
The tests used to evaluate the mortars properties on fresh and hardened state were identical to those described in stage 1 (see item 2.2.1).

3. Results and discussions

3.1 Results of stage 1

The fresh state tests results obtained for the mortar mixtures produced in stage 1 are presented in Table 9 and Figure 1a.

Table 8 – Mortar materials content – stage 2

Materials (Kg/m³)	A2-1	A2-2	A2-3	A2-4	A2-5	A2-6
Cement	451	451	451	451	451	451
AB	819	983	1147	819	983	1147
AF	730	584	438	-	-	-
FSW	-	-	-	719	575	431
Water	298	298	298	298	298	298
Admixture (2)	3.2	3.2	3.2	3.2	3. 2	3.2
w/c	0.66					

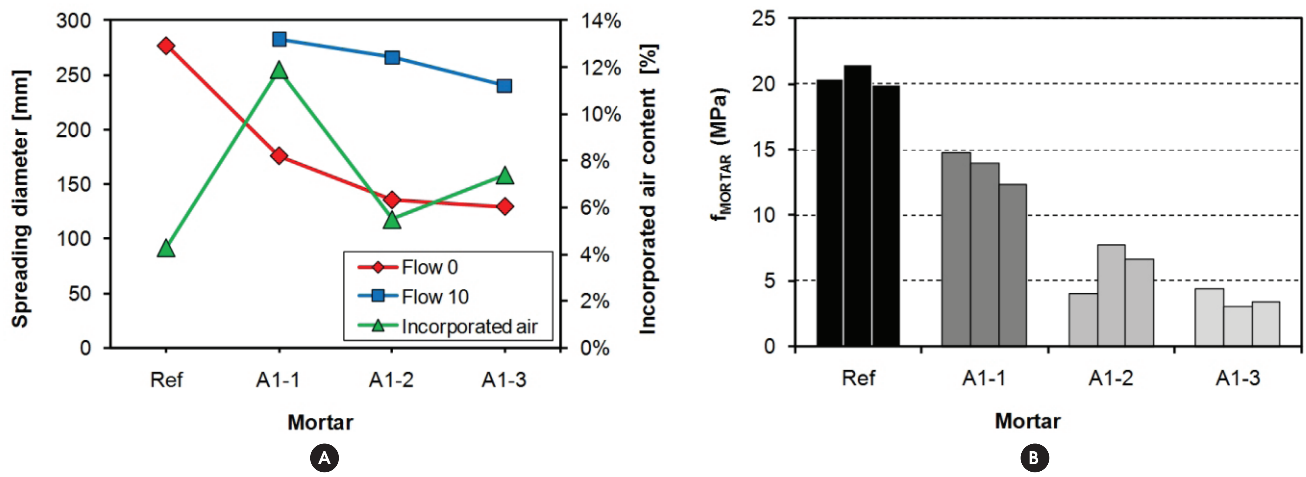
(2) Water reducing admixture – 0.7% in relation to the cement mass.

Table 9 – Fresh and hardened state tests results – stage 1

Nomenclature	$Flow_0$ (mm)	$Flow_{10}$ (mm)	Density (kg/m³)	Incorporated air content (%)	Compressive strength (MPa)(3)
Ref	277.0	-	2106.0	4.3%	21.4
A1-1	176.0	282.5	1930.0	11.9%	14.8
A1-2	135.5	266.0	2068.0	5.5%	7.7
A1-3	129.5	240.0	2027.0	7.4%	4.4

(3) Potential compressive strength, i.e., highest value out of three specimens.

Figure 1 – Stage 1 – mortar tests results: (a) fresh and (b) hardened state



The results shown in Table 9 and Figure 1a indicate that the addition of FSW resulted in increased levels of incorporated air when compared to the mortar Ref. However, it was not observed a clear trend with regard to the relationship between the incorporated air content and the percentage of FSW. Regarding the fluidity of the mixtures, it was observed that increasing the replacement level of AF by FSW contributed to the significant reduction in the fluidity of the mortar. In other words, it can be stated that the use of similar concrete mixtures may require a greater amount of water to achieve a given workability. This need leads to an increase of the water/cement ratio and consequently a compressive strength decrease.

The hardened state tests results obtained for the mortar mixtures produced on stage 1 are presented in Table 9 and Figure 1b.
The results presented in Table 9 and Figure 1b show that the use of FSW has significantly influenced the mortars compressive strength. The comparison between Ref. and A1-1, which differs only by replacing the AF by FSW, indicates a compressive strength reduction of 31%. This reduction was even greater with increasing FSW content in the mixtures.
Moreover, visual observation of the mortar specimens produced with FSW indicated the presence of expansive reactions which, in turn, led to material structure cracking as shown in Figure 2.

Figure 2 – Visual observation of the expansive reactions that have occurred in the mortars produced with FSW, e.g., A1-3: (a) mortar mixture expansion; (b) crack opening of ≈1,0mm

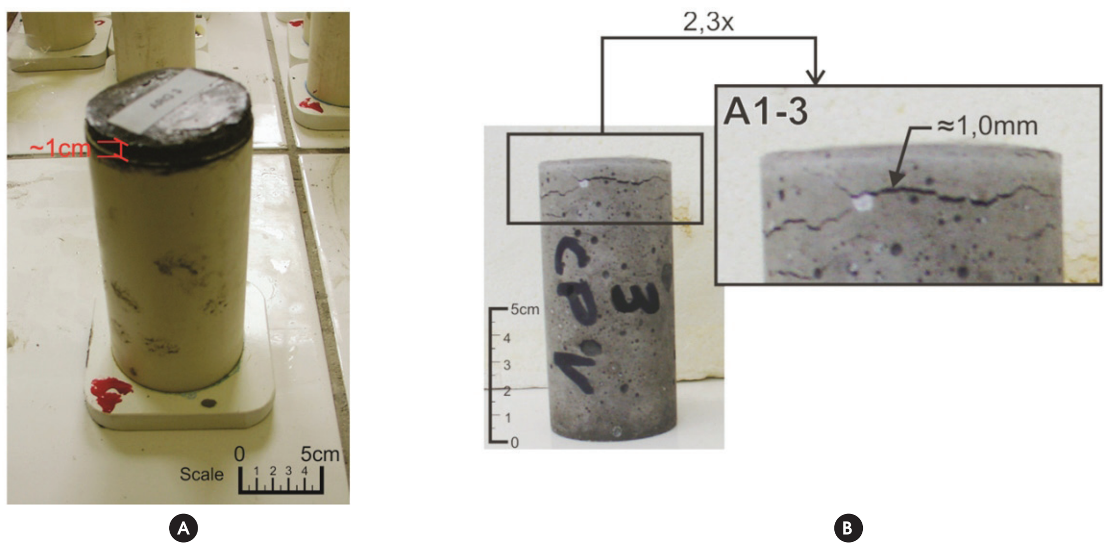


Table 10 – Fresh and hardened state tests results – stage 2

Nomenclature	$Flow_0$ (mm)	$Flow_{10}$ (mm)	Density (kg/m^3)	Incorporated air content (%)	Compressive strength (MPa)(3)
A2-1	202.0	300.5	2203.0	4.1%	24.3
A2-2	198.5	299.5	2196.0	5.2%	23.9
A2-3	190.5	288.0	2233.0	4.3%	24.2
A2-4	162.5	280.5	2087.0	8.8%	14.8
A2-5	149.0	265.5	2094.0	9.2%	15.3
A2-6	168.5	280.0	2167.0	6.9%	20.9

Note that the expansions were determined as higher when levels of FSW in the mixture were increased.
The results presented in Table 9 and Figure 1 indicate that despite the mixtures A1-2 and A1-3 have shown low levels of incorporated air content, their compressive strength is lower than those obtained for A1-1, which has a higher incorporated air content. Thus, it is likely that the expansion caused by the use of FSW contributed in a higher degree than the incorporation of air to reduce the compressive strength. To a first approximation, it is assumed that the effect of excessive expansion may have been caused by the presence of crushed coal (coal-powder), sodium silicate jointly with CO_2, or some metallic residue included in the FSW during the casting process.

3.2 Results of stage 2

The fresh state tests results obtained for the mortar mixtures produced in stage 2 are shown in Table 10 and Figure 3a.
The results presented in Table 10 Figure 3a indicate that the use of FSW has contributed to reduce the fluidity of the mixtures and increase the amount of incorporated air. Nonetheless, likewise in stage 1, it was not possible to establish a clear trend between the level of FSW addition and the incorporated air content.
The hardened state tests results obtained for the mortar mixtures produced in stage 2 are presented in Table 10 and Figure 3b.
Regarding the compressive strength at 7 days (see Table 10), once more it was observed a loss in strength due to the use of FSW. As observed in stage 1, it appears that increasing the content of FSW in the mixture results in a greater compressive strength reduction. In this case, the mortar produced with the highest level of FSW (A2-4) has shown a decrease of 39% when compared to the mix A2-1, followed by a reduction of 36% for A2-5 in relation to A2-2 and 14% for A2-6 relative to the A2-3.
The results obtained in stages 1 and 2 do not match with those presented by [8] and [9], which evaluated the use of FSW in concrete production and have found that this use does not result in compressive strength decrease. Similarly, the results presented by [13] indicate that the use of FSW to partially replace the fine aggregate is suitable for asphalt concrete. However, when comparing the results herein obtained with those published by [15], a similar trend is observed, i.e., increasing the content of FSW resulted in increased levels of incorporated air and a significant compressive strength reduction. The existence of differences between the results obtained in this work to other published results [8, 9, 13] is

Figure 3 – Stage 2 – mortar tests results: (a) fresh and (b) hardened state

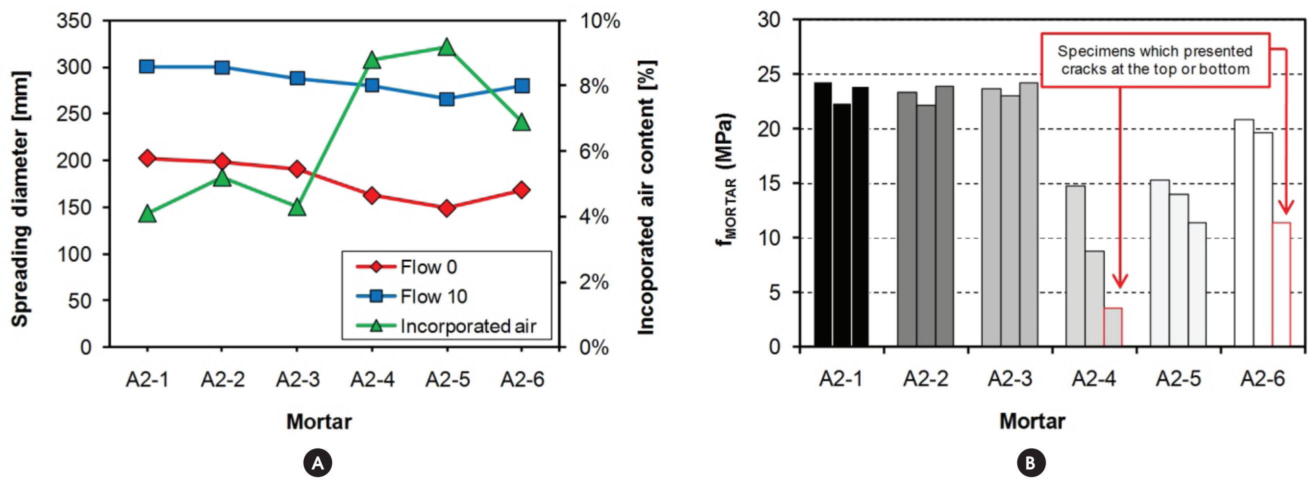


Table 11 – Mortars nomenclature, FSW composition and volumetric percentages of aggregates used to produce the mortars – complementary stage

Nomenclature	AM	AF	FSW	FSW components
Ref-2	50%	50%	-	-
A3-1	50%	-	50%	Silicate + Coal-powder + CO_2
A3-2	50%	-	50%	Silicate + CO_2
A3-3	50%	-	50%	Foumann + Coal-powder + CO_2

likely due to the different FSW chemical composition used in each study. In this case, it is emphasized that the content of the coal-powder in the FSW used by [8] was 5.15%, while the FSW used by [10] was 22%.
As for the expansive reactions, it is noteworthy that the expansion level achieved by the mixtures with crushed aggregates (AB) was not so pronounced as to verify the volume increase in the specimens, as noted in stage 1 (Figure 2). Nonetheless, despite the less expressive expansion, it is assumed that the loss in compressive strength observed have occurred due to the same reasons discussed in stage 1.
Based on the results obtained in stages 1 and 2, it has been decided to carry out further studies whose goals, methods and results are presented as follows.

4. Additional stage

The complementary study stage aims to identify the possible origin of the expansive reactions, and consequent compressive strength reduction, previously observed in the mortars mixtures produced with FSW.
To a first approximation, the expansive reactions and consequently compressive strength reduction observed in stages 1 and 2 are likely to be connected to the presence of the following elements in the FSW: coal-powder, $NaSiO_2$, CO_2 or small metal inclusions from the smelting process. Therefore, in this stage, mortars were produced with FSW composed by the following materials: a) AF + $NaSiO_2$ + coal-powder + CO_2 – d_1=2.652 kg/dm³; b) AF + $NaSiO_2$ + CO_2 – d_2=2.660 kg/dm³; c) AF + Foumann + coal-powder + CO_2 – d_3=2.654 kg/dm³.
The abovementioned density values were determined based on the recommendations described in [8]. The component called Foumann corresponds to a new binder product that has been tested to substitute $NaSiO_2$.
Note that all FSW types in this study stage were not subjected to metal casting, i.e., the molds for the casting process were produced, but were not used in the casting of metal parts, which excludes the presence of metallic residues in the FSW composition.
The ratio between the aggregates used in the mortars production, the mortars nomenclatures, and composition of the used FSW are listed in Table 11. The mortars materials content produced in the complimentary study are presented in Table 12.
The tests applied to evaluate the mortars properties on fresh and hardened state were identical to those described in stage 1 and 2 (see item 2.2.1).

4.1 Analysis of results of the additional stage

The fresh state tests results obtained for the mortar mixtures produced in the complementary stage are presented in Table 13 and Figure 4a.
The results presented in Table 13 and Figure 4a indicate that the performance of the mortar A3-3 was the worst between the tested mortars, both in the flow table test and incorporated air content. In regard to the mortar A3-1, although it has shown similar flow table test results when compared to the mortar Ref 3, A3-1 presented a higher percentage of incorporated air. The mortar A3-2 had the best result among the mortars produced with FSW (Table 13 and Figure 4a). A3-2 results point to a level of incorporated air which is similar to the one obtained by Ref 3 and also higher fluidity. Moreover, although the expansive reaction has occurred in A3-2, it was observed that this mortar has presented the less expressive expansion when compared to the others which were produced with

Tabela 12 – Mortar materials content – complementary stage

Materiais (Kg/m³)	Ref-2	A3-1	A3-2	A3-3
Cement(1)	466	466	466	466
AM	746	746	746	746
AF	754	-	-	-
FSW	-	755	757	756
Water	275	275	275	275
Admixture(2)	3.3	3.3	3.3	3.3
w/c		0.59		

Table 13 – Fresh and hardened state tests results – complementary stage

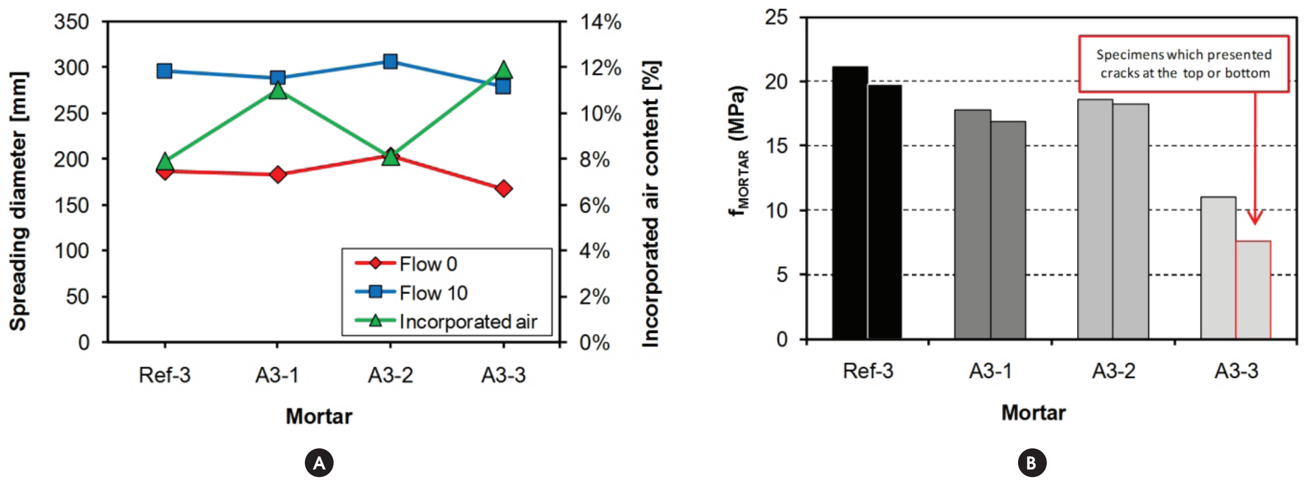
Nomenclature	$Flow_0$ (mm)	$Flow_{10}$ (mm)	Density (kg/m^3)	Incorporated air content (%)	Compressive strength (MPa)(3)
Ref-3	186.5	295.5	2064.0	7.9%	21.1
A3-1	183.0	288.5	1995.0	11.0%	17.8
A3-2	203.5	306.0	2062.0	8.1%	18.6
A3-3	167.5	278.5	1976.0	11.9%	11.0

FSW. This indicates a considerable contribution of the coal-powder in the occurrence of expansive reactions. Nevertheless, since the mixture A3-2 has also shown signs of expansion, it is assumed that the CO_2 present in the FSW has also contributed, in a lesser extent, for the occurrence of the expansive reactions.
The hardened state tests results obtained for the mortar mixtures produced on stage 2 are presented in Table 14 and Figure 4b. These results indicate that A3-3 has presented the worst performance among the tested mortars (48% reduction in compressive strength when compared to Ref 3). The mortars A3-1 and A3-2 had similar results with respect to compressive strength, in this case, a decrease of approximately 15% relative to Ref 3 was noted.
Comparing the results of this stage (Table 13 and Figure 4b) with those obtained in stage 1 (Table 9 and Figure 1b), it appears that the compressive strength decrease for mortar produced with FSW in stage 1 is more pronounced than the decrease observed in this stage. Therefore, it is proven that the presence of small metal inclusions in the FSW is a contributing factor to the occurrence of expansive reactions and consequent compressive strength reduction.

5. Conclusions

The conclusions reached in this work, are presented in the following paragraphs. Note that these conclusions are limited to the herein mentioned materials.
Initially, the results have indicated that the use of FSW has a significant influence on the fresh and hardened properties of mortars produced with Portland cement. Moreover, it has been found that this influence is a function of the FSW composition.
The results have also shown that the presence coal-powder in the FSW has a significantly higher effect in the expansive reaction and consequently compressive strength reduction than the presence of $NaSiO_2$ and CO_2. If the FSW has metal material traces in its composition then this effect is even greater.
The tests for the new foundry sand binder, named Foumann, to replace the $NaSiO_2$ has not presented good results. Though its use has resulted in reduced expansive reactions, the final compressive strength decrease was considerable.
Based on the presented results, it has been noted that the use of FSW to produce concrete leads to the occurrence of expansive reactions. Such reactions cause cracking in the material structure thus contributing to a substantial compressive strength reduction.
Therefore, if adding the expansive effects to the occurrence of cracking and loss of material strength, it can be concluded that the application of mixtures made with FSW becomes risky as to the structural and durability requirements.
However, the findings obtained in this work may not be general-

Figure 4 – Complementary stage - mortar tests results: (a) fresh and (b) hardened state



ized, because other studies have obtained satisfactory results that prove the possibility of using FSW as a partial replacement to aggregates in concrete production. Thus, since the FSW composition varies according to the manufacturing process, in all cases it is advisable to carry out preliminary tests in order to verify the effects caused by the use of FSW in the concrete production.

6. Acknowledgements

Thanks to CNPq for Prof. Dr. Prudêncio's research productivity scholarship. Concrete chemical admixtures company Rheoset for providing the water reducing admixture and Steel Company Colina for providing the foundry sand waste used in this research.

7. References

[01] MCINTYRE, S. W. et al. Beneficiation and reuse of foundry sand residuals: a preliminary report. Transactions of the American Foundry men´s Society, Volume 100, p. 201-208.

[02] ASSOCIAÇÃO BRASILEIRA DE FUNDIÇÃO. Apresenta informações sobre o mercado de fundidos no Brasil. Disponível em:<http://www.abifa.org.br>. Acesso em: 25 Jan. 2010.

[03] KLINSKY, L. M. G.. Proposta de reaproveitamento de areia de fundição em sub-bases e bases de pavimentos flexíveis, através de sua incorporação a solos argilosos. Dissertação. Escola de Engenharia de São Carlos da Universidade de São Paulo, São Paulo, 2008. 215 p..

[04] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR10004 – Residuos Sólidos - Classificação. Rio de Janeiro (2004).

[05] KHATIB, J. M., ELLIS, D. J.. Mechanical properties of concrete containing foundry sand. ACI special publication SP-200. American Concrete Institute; 2001. p. 733–48.

[06] NAIK, T. R., KRAUS, R. N., CHUN, Y. M., RAMME, W. B., SINGH, S. S.. Properties of field manufactured cast-concrete products utilizing recycled materials. Journal of Materials in Civil Engineering, Volume 15, Issue 4, 2003, p. 400-407

[07] NAIK, T. R., KRAUS, R. N., CHUN, Y. M., RAMME, W. B., SIDDIQUE, R.. Precast concrete products using industrial by-products. ACI Materials Journal, Volume 101, Issue 3, 2004, p. 199–206.

[08] SIDDIQUE, R., SCHUTTER, G., NOUMOWE, A.. Effect of used-foundry sand on the mechanical properties of concrete. Construction and Building Materials. Volume 23, Issue 2, 2009, p. 976-980.

[09] TIKALSKY P, GAFFNEY M, REGAN R. Properties of controlled low-strength material containing foundry sand. ACI Materials Journal. Volume 97., Issue 6, 2000, p.698-702.

[10] KRAUS, R. N., NAIK, T. R., RAMME, B. W., KUMAR, R.. Use of foundry silica-dust in manufacturing economical self-consolidating concrete. Construction and Building Materials. Volume 23, Issue 11, 2009, p. 3439-3442.

[11] FIORE, S., ZANETTI, M.C.. Foundry wastes reuse and recycling in concrete production. American Journal of Environmental Science, Volume 3, Issue 3, 2007, p. 135–142.

[12] BAKIS, R., KOYUNCU, H., DEMIRBAS, A.. An investigation of waste foundry sand in asphalt concrete mixtures. Waste Management Research, Volume 24, Issue 3, 2006, p. 269–274.

[13] JAVED, S., LOVELL, C.W.. Use of waste foundry sand in civil engineering. Transport research record 1486. In: Washington, DC: Transportation Research Board; 1994. p. 109-13.

[14] WEIDMANN, D. F., OLIVEIRA, A. L., SANTOS, J. PRUDÊNCIO JR., L. R.. Comparação da eficiência dos aditivos plastificantes e polifuncionais, In: 48º Congresso Brasileiro de Concreto, Rio de Janeiro, 2006.

[15] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR5737 – Cimentos Portland resistentes a sulfatos. Rio de Janeiro (1992).

[16] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR10005 – Procedimento para obtenção de extrato lixiviado de resíduos sólidos. Rio de Janeiro (2004).

[17] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR10006 – Procedimento para obtenção de extrato solubilizado de resíduos sólidos. Rio de Janeiro (2004).

[18] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 7211 – Agregados para concreto – Especificação. Rio de Janeiro (2009).

[19] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR-NM 248 – Agregados – Determinação da composição granulométrica. Rio de Janeiro (2003).

[20] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR-NM 46 - Agregados - Determinação do material fino que passa através da peneira 75 micrometro, por lavagem. Rio de Janeiro (2003).

[21] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR-NM 52 - Agregado miúdo - Determinação de massa específica e massa específica aparente. Rio de Janeiro (2003).

[22] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 13278 – Argamassa de assentamento de paredes e revestimento de paredes e tetos – Determinação da densidade de massa e do teor de ar incorporado. Rio de Janeiro (2003).

[23] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 13276 – Argamassa para assentamento e revestimento de paredes e tetos – Preparo da mistura e determinação do índice de consistência. Rio de Janeiro (2003).