A comparative analysis between the microstructure of foundry industry wastes and small aggregates for asphalt paving

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ABSTRACT

In this study, a representative sample of Discarded Sand from Casting (DSC) from foundry industry was analysed using a stereoscope at 10 and 40-fold increases and a SEM at 80 and 2,000-fold increments, obtaining high-definition images and quantitative elemental composition. Analogously, a sample of stone powder (a conventional aggregate used in asphalt paving) was also analysed for comparison. The petrographic analysis of DSC morphology revelated a most part of sub-angular grains with high sphericity formed from innocuous materials, similar the stone powder. Besides the difference in their harmfulness, there were also distinctions in their composition. From SEM/XSE, DSC presented 51,34% silica, 2,2% iron, 13,4% carbon, 3,9% aluminium and 0,4% magnesium, whereas the stone powder presented 60,42% silica, 14,93 % iron, 10,19% aluminium and 3,12% magnesium. The results confirm that the microstructure of residue will not prejudice the paving generating a reactive comportment in the asphalt matrix.

Keywords: Discarded sand casting, asphalt, SEM, casting.

1. INTRODUCTION

The residues of casting inside moulds are usually constituted of mineral sand. When discarded, this waste is called Discarded Sand from Casting (DSC) and goes to industrial landfills, occupying huge volumes. In paving projects, there is a great demand for mineral aggregates, since they comprise constituent layers of flexible pavements. These are increasingly scarce and costly materials, which foments the necessity of creating alternative less costly materials to replace them. Due to mineralogical similarities between DSC and small paving aggregates, it is plausible to employ DSC for reuse purposes in asphalt paving. To that end, it is necessary to know the chemical and morphological aspects of the residue and to verify if it could impair the performance of the asphalt mixture when composing a flexible pavement. Optical stereoscopy and X-ray scanning electron microscopy (SEM/XSE) are important tools to know the qualitative details of the morphology and elemental constitution of the aforementioned materials. Determining the feasibility of using DSC as an alternative aggregate in asphalt paving not only could engender financial advantages for projects, but could also increase the service life of landfills and reduce the extraction of exhaustible mineral resources.

1.1 The Generation of DSC and Its Consequences

The steelmaking industries are responsible for the production of metal parts used in casting processes, and these pieces are obtained by pouring the molten metal inside a negative mould consisting of fine mineral sand. Once the metal cools and becomes rigid, the mould is broken and the piece is obtained (Figure 1). Because of this industrial process, the fine mineral sand becomes so contaminated by metal that it can compromise the quality of other metal parts if used again. Consequently, that sand is generally disposed in landfills as an industrial waste and is called Discarded Sand from Casting (DSC), classified by CETESB, according to its Board Decision No. 152/2007 / C / E of August 08, 2007 [1], as an industrial solid waste class II -A or II-B. In agreement with classification II-A, this DSC fits as non-hazardous and not inert and, as to classification II-B, it fits as inert. The appropriate classification will depend upon the limits of substances that are present in this DSC [2].

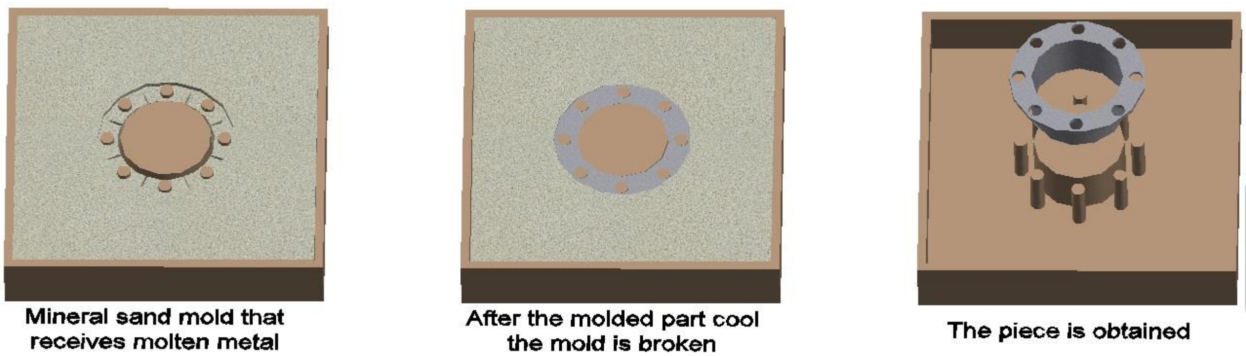


FIGURE 1 Illustration of industrial casting process [3]

DSC is periodically produced in large quantities in Brazil. According to a monthly report from the Brazilian Association of Foundry Industries - ABIFA [4], a daily average of 8,106.00 tons of castings were made in Brazil from January to May in 2016, generating an average of 0.8 to 1 ton of DSC for each ton of casting [5].

1.2 Asphalt pavements

Asphalt pavement can be defined as a surface that has received earthmoving services and has the function of offering drivers good conditions of comfort and safety, considering the best cost-benefit within an engineering project [6]. In terms of load capacity, they are classified into flexible, rigid and mixed (or semi-rigid), and are dimensioned according to where they will be applied and to the type and intensity of traffic (light or heavy). Flexible pavements are commonly applied in urban and interurban roads. A pavement comprises a set of several layers with decreasing load capacity from top to bottom, and the asphalt is assumed as a layer with finite thickness immersed in a semi-infinite space called a subgrade [7].

1.3 Use of DSC in asphalt concrete

In the face of a scenario where there is a high production of residues whose chemical and physical characteristics are similar to those found in fine aggregates used in asphalt paving, together with the need for alternative mineral resources in these projects, an opportunity to reuse DSC as aggregate in asphalt concrete arises.

One of the first studies regarding the use of DSC for asphalt concrete was developed in 1999 in the United States [8], where a manual was prepared for the management and reuse of DSC, along with recommendations and alternatives for its use in asphalt paving. That stimulated further investigations and many other subsequent works were developed in this area. In Brazil, savings generated in 2002 thanks to the incorporation of DSC in Hot Mix Asphalt (HMA) were highlighted [5]. Additional specific tests of asphalt concrete with DSC were included in the present work [9-10], aiming to show that they present results very close to those required by the standards of the Paving Manual [11]. Hence, the possibility of reusing DSC for asphalt paving purposes according to pavement standards is validated [12].

1.4 Study of aggregate and DSC microstructures

Within the Brazilian civil construction industry, the regulations established by competent organizations towards road projects are based on very old and purely empirical US standards, showing results in a macroscopic way and not considering the intrinsic mechanisms of the asphalt concrete/aggregate matrix. Thus, to provide a better understanding of the properties of this material, a physical and chemical study of DSC is necessary, verifying if the residue could affect the quality of this concrete negatively. This analysis is potentially innovative, since chemical investigations on the microstructure of DSC and aggregates for asphalt paving may provide a solid comprehension as to the interactions between the aggregate and the matrix of asphalt concrete. Consequently, similarities between the conventional aggregate and the residue, as well as pathologies that this residue could cause when incorporated into the HMA could be emphasized.

2 EXPERIMENTAL DATA

2.1 Materials Used

2*.1.1 Discarded Sand from Casting*

Material from an industrial waste landfill located in the city of São José dos Campos - SP, which receives this waste from the steel industry periodically.

2.1.2 Stone powder

Material from a quarry located in the city of Jambeiro - SP that has a granite deposit.

2.2 Development

Homogeneous small portions (3 ± 0.01 g) of each material were taken. In these portions, a double-sided carbon tape was pressed with one of the sticking parts and they were then positioned in the sampler of the scanning electron microscope. The assembly was submitted to SEM/XSE, as shown in Figure 3.

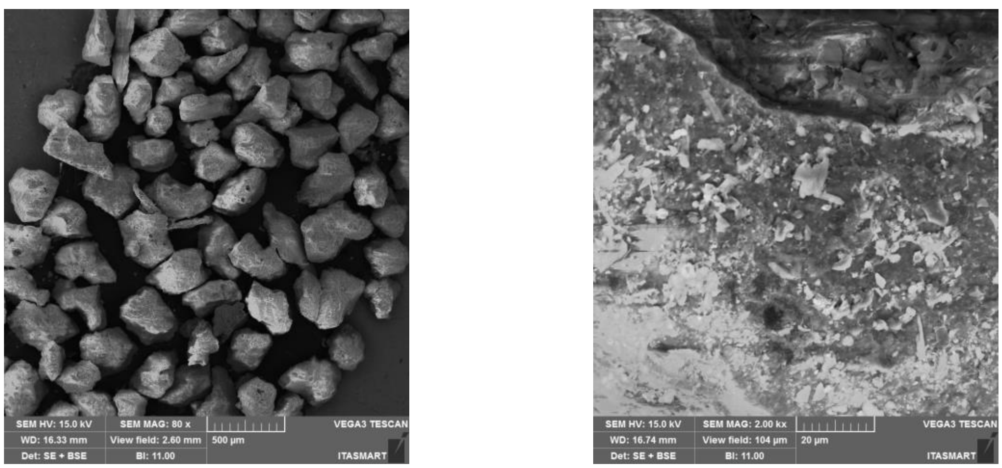
(a) (b)

FIGURE 3 Photographs of the samples placed in the SEM / XSE sampler (a) and of the equipment used (b)

From the previously mentioned portions, smaller portions (about 1 ± 0.01g each) were inserted into a stereoscope. In possession of the images obtained by the SEM and the stereoscope, a petrographic analysis of the grains [13] was carried out by means of the determination of the degree of roundness and the sphericity of the aggregates, performed in qualitative and quantitative ways.

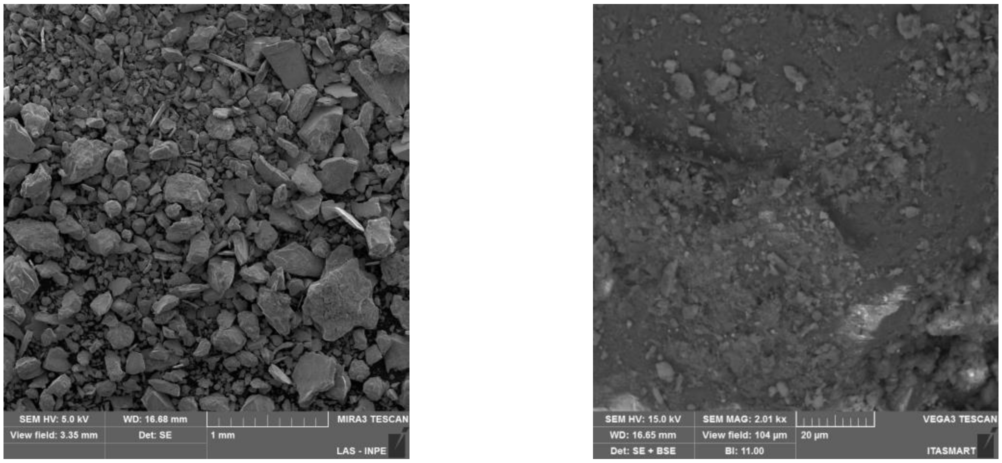
3 RESULTS

SEM images of the DSC and stone powder, obtained at magnifications of 80x and 2000x, are shown in Figures 4 and 5.



(a) (b)

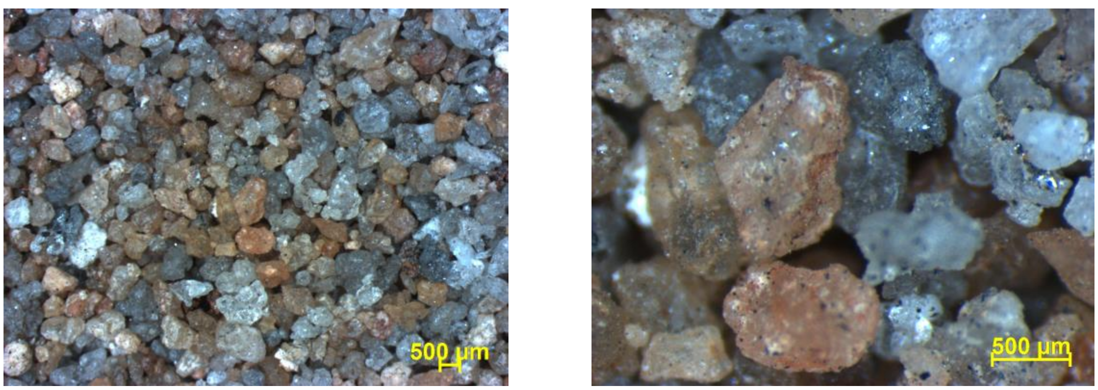
FIGURE 4 Amplified images of 80x (a) and 2000x (b) of the DSC obtained by SEM



(a) (b)

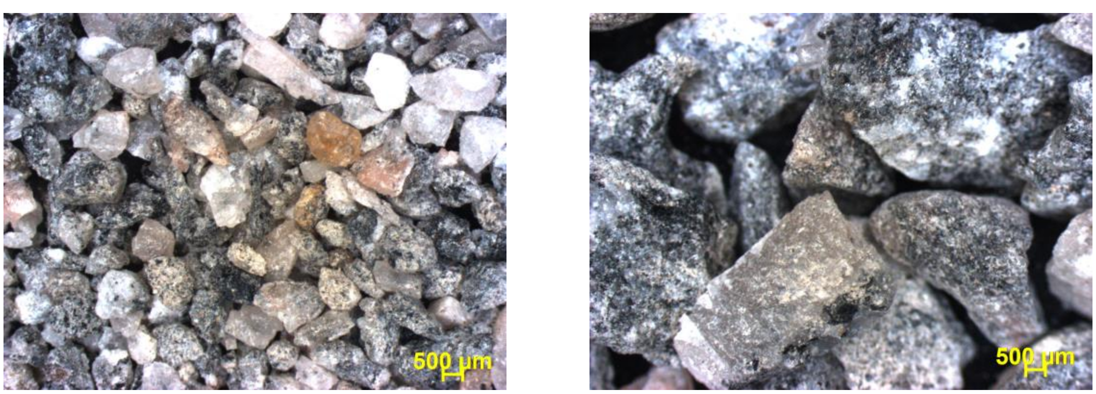
FIGURE 5 Amplified images of 80x (a) and 2000x (b) of the stone powder obtained by SEM

In the optical stereoscope, 10 and 40-fold magnified images of the DSC and stone powder were obtained, as shown in Figures 6 and 7.



(a) (b)

FIGURE 6 Extended images of 10 (a) and 40 times (b) of the DSC obtained by the Stereoscope



(a) (a)

FIGURE 7 Extended images of 10 (a) and 40 times (b) of the stone powder obtained by the Stereoscope

When obtaining the images, the SEM/XSE equipment also obtained the elemental composition of both DSC and stone powder, as depicted in Tables 1 and 2.

TABLE 1 Elemental compositions of the DSC and stone powder

Element	Material	
	DSC (Wt%)	Stone powder (Wt%)
C	13,4	-
N	2,7	-
O	48,8	42,23
Fe	2,2	14,93
Na	4,1	1,3
Mg	0,4	3,12
Al	3,9	10,19
Si	24	28,24
K	0,5	-

TABLE 2 Molecular compositions of the DSC and stone powder

Probable molecules (Wt%)	Material	
	DSC (Wt%)	Stone powder (Wt%)
Silica	51,34	60,42
Óxides	25,91	21,08
Organic molecules	13,40	-
Metals	11,10	29,54
Trace Elements	2,70	-

When performing the petrographic analysis of the materials, in other words, the classification according to their morphology, the results contemplated in the Table 3 were obtained.

TABLE 3 DSC morphoscopic analysis and stone powder

Petrographic classification [17]	Material	
	DSC	Stone powder
Petrographic analysis	Inoculant grains	Potentially deleterious grains
Degree of predominant sphericity	High	High
Prevailing rounding degree	Subangled	Subarrow
Predominant surface	Polished	Frosted
Classification for RAA	Inert	Potentially reactive
Recommendations	-	[13] Review

4 CONCLUSIONS

When comparing the microstructures of stone dust, which is a conventional aggregate in asphalt paving, and DSC, a residue of the steel industries, it is observed that despite small differences in their chemical compositions, the residue does not present any substance that could possibly generate some pathology to the asphalt mixture. Petrographically, the two materials forms are very similar. Although more research in this area is necessary, the results presented herein confirm the feasibility of using DSC as an aggregate in asphalt concrete.

REFERENCES

[1] CETESB, Decision of the Board of Directors, nº 152/2007 / C / E, 08/08/2007, disposes on procedures for sand casting management.

[2] Brazilian Association of Technical Standards. NBR 10004: 2004: solid waste: classification. Rio de Janeiro, 2004.

[3] Paulo Paiva Oliveira Leite Dyer. Schematic produced by the author based on conventional casting processes. São José dos Campos. 2017.

[4] Brazilian Foundry Association. Guide ABIFA of Foundry 2016. Foundry Magazine & Raw Materials, São Paulo, 2016.

[5] Paulo Bina. Methodology for the Use of Industrial Waste in Paving: Case Study of Sand Casting. Institute of Technological Research. São Paulo – SP, 2002.

[6] Humberto Santana. Manual of Pre-Mixed to Cold. IBP - Brazilian Institute of Petroleum. Rio de Janeiro:, 1993.

[7] Senco,Wlastermiler. Manual of Paving Techniques. Publisher PINI - São Paulo, 1997.

[8] The Casting Development Centre. Beneficial re use of foundry by products beneficial re-use for Managers Manual, USA. 1999.

[9] Ivan Iderado Bonet. Valorization of the sand casting residue (RAF), 142 f. Dissertation (Master in Production) - Production Engineering, Federal University of Santa Catarina, Florianópolis. 2002.

[10] Clauber Costa. Discarded Sand from Casting in Substitution to Fine Aggregate in Asphalt Mixtures for Paving. Military Engineering Institute. Rio de Janeiro, 2007.

[11] National Department of Roads and Roads. Manual of paving. 3 ed. Rio de Janeiro, 2006.

[12] National Department of Roads and Roads ME 043: 1995: hot bituminous mixtures: marshall test. Rio de Janeiro, 1995.

[13] Brazilian Association of Technical Standards. NBR 7389-1: 2009: aggregates: petrographic aggregate analises for concrete. Part 1: fine aggregate. Rio de Janeiro, 2009.