INCORPORATION OF INDUSTRIAL WASTE AS AGGREGATES IN HOT MIX ASPHALT

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Abstract - With the growing need to save natural resources and value waste that was previously worthless, waste recycling becomes imperative. Thus, with the techno-scientific growth and in the perspective of sustainability, it is observed that waste has the potential to replace significant percentages of materials considered "virgin". An example is the replacement of crushed aggregates with foundry sand. In this work, a mix design study of two asphalt mixes, a base mix (AC 20) and a surface mix (AC14) was carried out to evaluate the maximum amount of foundry sand residue that could be used. Water sensitivity tests were performed to evaluate the mechanical behavior of these mixtures. For the superficial mixture with foundry sand (AC14FS) the maximum of sand used was 5%, with satisfactory results of sensitivity to water. In the base mixture with sand (AC20FS) the maximum of sand used was 12%, which had less satisfactory results. However, from an environmental point of view, the re-incorporation of this residue in the pavement is beneficial, because it prevents it from being deposited in landfills.

Keyword - Foundry sand, Hot mix asphalt, waste valorization, industrial waste, sustainability

I. INTRODUCTION

Waste is considered a global problem that affects all of society. Human activities have always produced waste in large volumes, which contain characteristics that are more harmful to nature than to humans themselves [1], [2].
According to studies carried out by Algarvio (2009), the civil construction industry causes several impacts due to the extraction of natural resources, such as wood, water, ores and natural aggregates, as well as the high consumption of energy [3].
According to Torgal and Jalali (2010) the construction industry is responsible for 30% of carbon emissions. Worldwide, the construction industry consumes more raw materials (approximately 3000 Mt/year) than any other economic activity [4].
To minimize environmental impacts in road design, recycled materials are commonly used, with the aim of reducing the extraction of new materials and the environmental impacts resulting from this industrial activity. Thus, industrial waste such as foundry sand is one of the solutions to make pavements more sustainable [5].

The foundry industry generates a significant amount of waste, including foundry sands. The waste management produced by the sector has become an environmental, economic, and social imperative. One way of mitigating the environmental impact of this waste is its recovery, following the European Union's policy, to reduce landfills [6].
According to Nascimento et al., (2017), the estimated annual production of this waste in Portugal is around 50,000 tons per year. Furthermore, this waste can replace a part of the smaller conventional aggregates in bituminous pavements, according to their granulometry [7].

Several authors have studied the mechanical properties of foundry sand incorporation into asphalt pavements. Dyer et al., (2018) investigated the incorporation of foundry sands in hot bituminous mixtures and observed that the mixture with sand requires a greater amount of bitumen compared to the conventional mixture. However, other results of this test demonstrated a mechanical performance similar to the conventional mixture [8].

Abdulsattar and Mohammed (2018), studied the partial incorporation of foundry sands into hot bituminous mixtures in four percentages, namely: 5%, 15%, 20% and 25%, in addition to a control mixture. These authors verified that the mixtures with 15 and 20% of sand had mechanical properties equivalent to those of the control mixture [9].
Brandshaw et al., (2010), used foundry sand as fine aggregates in hot bituminous mixtures, having analysed the replacement of various portions of the conventional aggregate by foundry sand of ferrous materials. The results showed that the 15% replacement rate of natural aggregate has a satisfactory performance for the mixture. When the incorporation rate is higher than 15%, the asphalt mixture becomes more sensitive to aggregate loss and deformation, thus resulting in early pavement degradation [5].

Nascimento et al., (2017), evaluated the incorporation of 5% of foundry sand in asphalt pavements for the asphalt base layer, the results show that superior compressive strength compared to the control mix. [7].

II. MATERIALS AND METHODS

A. Materials

To produce the hot mixt asphalt pavement (HMA), granite aggregates (14/20, 6/14,4/6 and 0/4) and limestone filler were used. A 35/50 penetration grade bitumen was used as the binder. A foundry sand obtained from a foundry company locate in the north of Portugal, was used as an alternative material to replace the fine aggregates (0/4).

B. Methods

One of the objectives of this work is to maximize the incorporation of wastes in two types of HMA, for wear layer (AC14 Surf) and for bond/base layer (AC20 bin/base): one AC 14 and AC 20 with the incorporation of foundry sand and another with 100% conventional material (control mixture). Thus, the design of the bituminous mixtures in the laboratory was carried out following the EN 12697-35 standard. This standard establishes the temperature of the mixture that must be considered, depending on the classification of the bitumen used, which is based on its penetration at 25 °C. The temperature used to produce the various mixtures in this work was 165 °C, since a 35/50 bitumen was used.

After the mixtures were produced, cylindrical specimens were compacted (Marshall specimens) to determine their volumetric characteristics and the water sensitivity of the mixtures. Compaction was carried out taking as a reference that each specimen should have a height close to 63.4 mm and a diameter of 101.6 mm. The compaction of the specimens was carried out with a hammer or impact compactor standardized in accordance with standard EN 12697-30, applying 75 strokes on each face of the specimen (based on the national annex of standard EN 13108-1).

Water sensitivity

The Indirect Tensile Strength Ratio (ITSR) test allows the determination of water sensitivity of asphalt mixture, based on the ratio between the average indirect tensile strength value of three water-conditioned test specimens and the average value of three dry specimens. The indirect tensile strength (ITS), test method was performed using a uniaxial test equipment to diametrically apply a load to a specimen until failure, according to EN 12697-12 standard.

III. RESULTS AND DISCUSSION

To start the production of asphalt mixtures, it was necessary to carry out a granulometric distribution specified by the NP EN 933-1 standard. Thus, a granulometric curve adjustment of the aggregates was made, to determine the amounts of foundry sand to be incorporated in two mixtures, a superficial one (AC14 Surf) and a base one (AC20 Base), as shown in Fig. 1 and Fig. 2.

The granulometric analysis is an important physical property for providing information on particle sizes, which will influence the study of the voids amount, which ends up affecting the mechanical behaviour of the mixtures and, consequently, of the pavement.

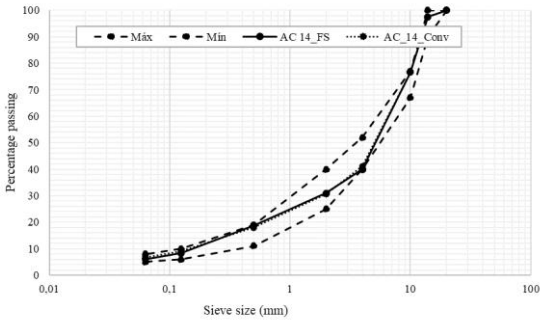


Fig. 1 - Grading curves of AC14 mixture

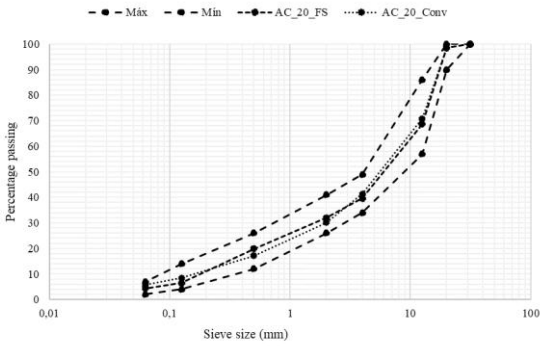


Fig. 2 - Grading curves of AC20 mixture

Through this granulometric study, it was possible to establish the quantities of each material, and thus, for this work, the granulometric grade was modelled to incorporate the largest possible amount of foundry sand, to save the natural aggregates and respecting the specified granulometric grade in the specifications of the Portuguese Infrastructure Specifications for roads [10]. Thus, for the AC 14 mixture it was possible to incorporate 5% of foundry sand, while in the AC 20 mixture the incorporation rate was 12%.

Water sensitivity test result

The water sensitivity test was used as a performance control test of the bituminous mixtures under study, since it is a test that allows evaluating the mechanical behavior and durability of the mixtures when exposed to more severe climatic actions.

The results obtained in the indirect tensile strength test are shown in Fig. 3. The conserved strength index (ITSR) is obtained by dividing the average value of the indirect tensile strength of the wet group by the equivalent strength of the dry group.

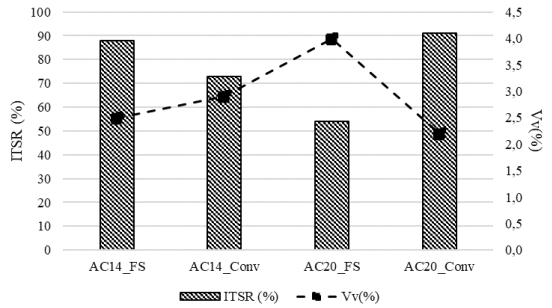


Fig. 3 – ITSR results of the studied mixture

The results presented in fig 3, in general, showed that the ITSR results of the mixtures studied were satisfactory, except for the AC20FS mixture, whose result was significantly lower.

IV.CONCLUSION

The results of water sensitivity of the mixtures showed that the incorporation of a high percentage of foundry sand affects an adequate compaction (resulting in a volume of voids higher than expected, compared to an equivalent mixture without foundry sand) and, consequently, in a less interesting performance. Thus, it can be said that the preliminary results obtained in this work are encouraging, being possible to obtain mixtures with the incorporation of foundry sands whose behavior can be compared to equivalent mixtures produced only with virgin materials. However, to validate these results, it is suggested to carry out a more in-depth study, with the inclusion of Marshall tests (for a more rigorous formulation of the mixtures, optimizing the percentage of binder of each mixture), as well as fatigue tests (for an adequate evaluation of the resistance to the appearance of cracking in layers built with mixtures that incorporate this type of materials).

REFERENCES

[1] P. K. Gautam, P. Kalla, A. S. Jethoo, R. Agrawal, and H. Singh, “Sustainable use of waste in flexible pavement: A review,” Constr. Build. Mater., vol. 180, pp. 239–253, 2018.

[2] S. Kaza, L. Yao, P. Bhada-Tata, and F. Van Woerden, What a waste 2.0: a global snapshot of solid waste management to 2050. World Bank Publications, 2018.

[3] A. N. Algarvio, “Reciclagem de resíduos de construção e demolição: Contribuição para controlo do processo.” FCT-UNL, 2009.

[4] F. Pacheco-Torgal and S. Jalali, “A sustentabilidade dos materiais de construção.” Universidade do Minho. TecMinho, 2010.

[5] S. L. Bradshaw, C. H. Benson, E. H. Olenbush, and J. S. Melton, “Using foundry sand in green infrastructure construction,” in Green Streets and Highways 2010: An Interactive Conference on the State of the Art and How to Achieve Sustainable Outcomes, 2010, pp. 280–298.

[6] O. Yazoghli-Marzouk, N. Vulcano-Greullet, L. Cantegrit, L. Friteyre, and A. Jullien, “Recycling foundry sand in road construction–field assessment,” Constr. Build. Mater., vol. 61, pp. 69–78, 2014.

[7] L. P. Nascimento, J. R. M. Oliveira, and C. Vilarinho, “Analysis of foundry sand for incorporation in asphalt mixtures,” in WASTES–Solutions, Treatments and Opportunities II, CRC Press, 2017, pp. 443–449.

[8] P. P. O. L. Dyer, M. G. de Lima, L. M. G. Klinsky, S. A. Silva, and G. J. L. Coppio, “Environmental characterization of Foundry Waste Sand (WFS) in hot mix asphalt (HMA) mixtures,” Constr. Build. Mater., vol. 171, pp. 474–484, 2018.

[9] Z. A. Abdulsattar and E. A. Mohammed, “EFFECT OF WASTE FOUNDRY SAND ON INDIRCT TENSIL STRENGTH OF ASPHALT MIXTURE,” J. Eng. Sustain. Dev., vol. 22, no. 4, pp. 116–123, 2018.

[10] S. A. Estradas de Portugal, “Caderno de Encargos Tipo Obra: 14.03–Pavimentação Características dos materiais. vol.” V, 2014.

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