Proceedings of the 7th International Conference on Civil Structural and Transportation Engineering (ICCSTE'22)
Niagara Falls, Canada – June 05-07, 2022
Paper No. 101
DOI: 10.11159/iccste22.101

Assessing the Use of By-Product Foundry Sand in Asphalt Mixtures

Dina Kuttah
Swedish National Road and Transport Research Institute, VTI, SE-58195 Linköping, Sweden.
dina.kuttah@vti.se

Abstract **-** It is well known that recycling of by-product materials saves natural resources, reduce by-product volumes, and reduce the need to virgin materials. The steel industry produces a myriad of metal components for industrial chains, which in turn generates mineral discarded sand molds. Although these sands are clean before their use, after casting they may contain contaminants. Therefore, huge quantities of excess by-product foundry sand (BFS) end up occupying large volumes in landfills. In Sweden, approximately 200000 tonnes of excess BFS end up in landfills. The transportation and construction industries have the greatest potential for reuse by-products because they use vast quantities of earthen materials annually. Accordingly, an experimental work has been undertaken to evaluate the possible use of two chosen BFS from two Swedish foundries in a conventional Swedish asphalt mixture. The experimental procedure of this research has focused on the dosage, environmental and technical properties of the same mixture type ABT 11 and the same bitumen (160/220) but at different replacement proportions of the conventional fine sand with the two BFS. The environmental requirements in addition to the technical requirements, namely, void ratio, static indirect tensile strength ratio, and resilient modulus before and after moisture induced sensitivity tests of the asphalt mixtures have been investigated in the current study. The test results demonstrated that the BFS from both foundries can be incorporated in the selected asphalt mixture at specified replacement proportions of the conventional fine sand fraction 0-2 mm as discussed in the paper.

Keywords**:** Asphalt, by-product foundry sand, indirect tensile strength, moisture induced sensitivity tests, resilient modulus.

1. Introduction

The steel industry produces a myriad of metal components for industrial chains such as the automobile industry, which in turn generates mineral discarded sand moulds (by-product foundry sand, BFS) that end up occupying large volumes in landfills. The physical, chemical and technical characteristics of virgin foundry sand make it a popular material for sand molds, but after several reuses in molds and cores, it becomes a by-product foundry sand "BFS" [1]. This means that the foundries generating large amounts of excess sand annually. In Sweden today, approximately 200,000 tonnes of by-product foundry sand are produced and approximately 3 million tonnes circulate in the foundries' internal cycle [2].

Since replacement of natural soils and aggregates with solid industrial by-products is highly desirable, many researchers have been focused on recycling and reusing solids industrial by-products in new manufacturing of building materials including asphalt. Accordingly, an experimental work has been undertaken to demonstrate the possible use of BFS in asphalt mixtures and to evaluate the performance of a chosen asphalt mixture incorporating different percentages of Swedish BFS produced by two foundries namely Federal- Mogul Göteborg foundry AB and Storebro foundry AB.

2. Effect of by-product foundry sand in asphalt mixtures properties

Concerning physical characteristics, it was found that for asphalt mixtures incorporating BFS, the percentage of air voids of the asphalt mixtures increase with increasing the BFS contents in the mixtures [3].

The densities of the asphalt mixtures were found to decrease as the percentage of BFS increase [1, 4, 5].
Regarding the optimum binder content, it was found that for HMA mixtures containing various amounts of BFS, the optimum binder content increased with increasing the BFS percentage [5,6].

With respect to the technical characteristics of the asphalt mixtures incorporating BFS, it was found that the Marshall stability of the asphalt samples decreased as the quantity of BFS increased [1, 3, 7] and Marshall flow decreased with increasing BFS in the asphalt mixtures [1,5].

As for the indirect tensile strengths (ITS) of the asphalt mixtures, it was found that the ITS decreased as the percentage of BFS increased [1, 3, 5, 7]. In relation to moisture susceptibility, it has been found that the BFS has a little effect on the moisture susceptibility of the mixtures. Some researchers contend that when BFS replacement is higher than 15%, asphalt mix may become more sensitive to moisture damage (i.e., stripping) due to the presence of silica [8]. Generally, the BFS, may decrease the unconditioned (dry) tensile strength and thus reduce the durability of asphalt mixtures; on the other hand, BFS do not necessarily increase or decrease a mixture's rutting potential but do improve fatigue performance [4]. Nevertheless, studies have shown that by-product foundry sand can be used to replace between 8 and 25 percent of the fine aggregate content in asphalt mixes [9].

It is important to highlight that although by-product foundry sand can be successfully incorporated into asphalt mix designs, large variability can exist between sands. Therefore, each sand should be treated as a unique source of aggregate [4]

3. Testing Plan

The laboratory investigation on the effect of the chosen by-product foundry sand on the performance of a common Swedish asphalt mixture have been started by characterizing the physical, chemical and environmental properties of the aggregate used to manufacture the asphalt samples. Then series of technical and environmental analysis have been carried out on various asphalt samples prepared with and without BFS ant different replacement percentages.

4. Materials Used

In this study, the adopted Swedish asphalt mixture is ABT 11 (160/220). This mixture type it is one of the most common asphalt mixtures used in Sweden, therefore, it has been adopted to evaluate the influence of BFS from the two foundries involved in this study, namely, Federal- Mogul Göteborg foundry AB and Storebro foundry AB. Stone. These types of BFS have been used as fine aggregate in the asphalt mixtures by substituting partially the 0-2 mm fraction of the natural fine aggregate at different percentages. The annual production of excess BFS by Federal- Mogul Göteborg foundry is about 400 tons. The binder used is water glass (Sodium silicate) which is cured with (Veloset 1 and 3), see Figure 1 A. The annual production of excess BFS by Storebro foundry is about 1200 -1400 tons. This foundry uses castings by hand molding with furan resin sand, in which furan resin plays a role as a bonding agent, see Figure 1 B.

For this study, the particle size distribution and gradation properties of the chosen BFS and the natural sand have been declared according to SS-EN 933-1 [10], see Figure 1 C. According to this figure, the BFS from Federal- Mogul Göteborg foundry AB has about 3% of its particle sizes smaller than 0.062 mm and about 97% falling between 0.062 and 1 mm. The BFS from Storebro foundry has 100% of its particle sizes passing 2 mm sieve and retained on 0.062 mm sieve. This gradation makes the BFS suitable also to partially substitute the conventional fine aggregate fraction 0-2 mm. The other fractions used to manufacture the asphalt mixtures were in accordance with TDOK 2013:0529 [11] requirements for ABT 11 and brought from the same natural crushed stone source "Skärlunda" as the one for fraction 0-2 mm given in Figure 1, as will be discussed later.

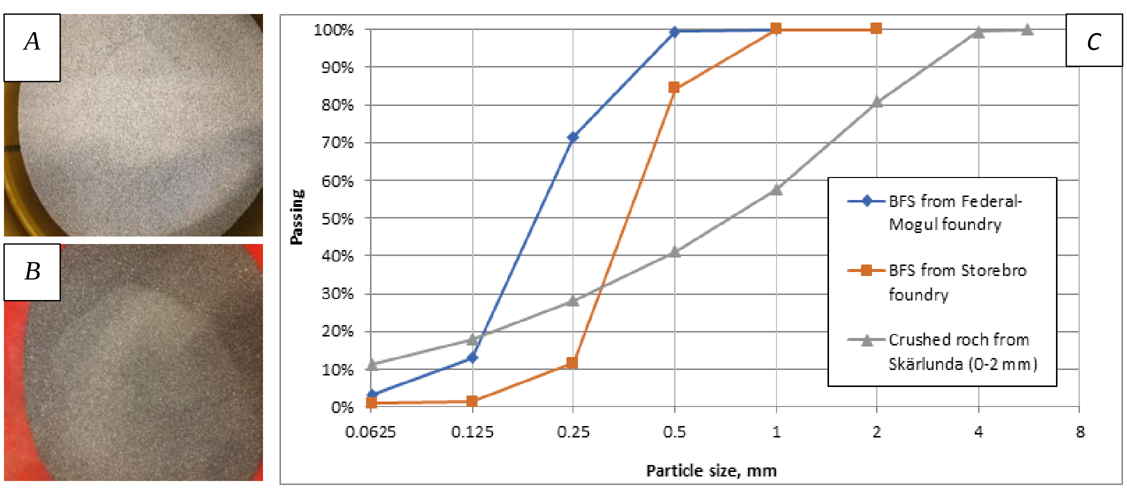


Fig. 1: A- (A) BFS from Federal- Mogul Göteborg foundry AB, (B) BFS from Storebro foundry AB, (C) The particle size distributions of the used aggregates fraction 0-2 mm.

Regarding the physical properties of the used aggregate, the specific gravity of the BFS from Federal- Mogul Göteborg and Storebro foundries are found to be 2.63 and 2.58 respectively. These specific gravity values of the used BFS are closed to the specific gravity of 2.66 for the conventional fine sand from Skärlunda. The water absorbability of the BFS from Federal- Mogul Göteborg is 0.1% which is lower than the water absorbability of the BFS from Storebro foundry which has found to be 0.4%. The water absorbability of Skärlinda sand is zero according to SS-EN 1097-6 [12]. The result of XRF (X-ray fluorescence) and XRD (X-Ray Diffraction) analyses carried out by Sibelco Technical Center Dessel on BFS from Federal- Mogul Göteborg foundry and Storebro foundry indicates that the BFS from Federal- Mogul Göteborg foundry and Storebro foundry are essentially formed by quartz mineral with 76.6% and 87.5% respectively. The high percentage of silica (SiO_2) of 89.9% in the BFS from Federal- Mogul Göteborg foundry and 88.35 in the BFS from Storebro foundry, as obtained by XRF analysis, goes well with the XRD analysis since quartz is the most common form of crystalline silica.

Bitumen of type 160/220 grading has been used in this study. The characteristics analysis of the selected binder has showed that the binder has a penetration value of 192 (0.1mm) at a temperature of 25 °C and a softening point of 40 °C when tested in accordance with SS-EN 1426 [13] and SS-EN 1427 [14] respectively.

5. Preparation of the Asphalt Mixtures for Laboratory Tests

The experimental tests carried out in this study contemplates testing the same mixture type ABT 11 and the same bitumen type 160/220 at 6% but at different replacement proportions of the conventional fine sand fraction 0-2 mm.

The tested asphalt mixtures include one reference (control) series without any BFS replacement, three series at 1%, 4% and 8% replacement proportions of the conventional fine sand by BFS from Federal-Mogul Götebory foundry and three series at 4%, 8% and 12% replacement proportions of the conventional fine sand by BFS from Storebro foundry. Accordingly, it has been necessary to adjust and optimize the mixing fractions of each series to give the best fitting to the ideal particle size distribution of standard ABT 11 mixture. Table 1 shows the resulting granulometric composition of the mineral aggregates with and without the addition of BFS from the two foundries.

Table 1: Granulometric composition of mineral aggregate asphalt mixtures with and without BFS.

Aggregate	Mixture designation						
	REF	FM 1%	FM 4%	FM 8%	S 4%	S 8%	S 12%
Filler	2.7	2.7	2.	3.1	3.8	5.1	6.7
0-2 mm	48.8	48.3	46.3	42.7	45	40.6	35.4
2-4 mm	0.3	1.1	4	8.5	4.2	8.5	13.5
4-8 mm	26	25.7	24.6	22.9	24.6	23.0	21.2
8-12 mm	12.6	12.7	13	13.5	13	13.4	14
12-16 mm	8.8	8.8	8.7	8.6	8.7	8.6	8.5
16-25 mm	0.7	0.7	0.7	0.7	0.7	0.7	0.7
% Total	100	100	100	100	100	100	100
% Replacement of BFS by weight of the conventional sand fraction 0-2mm	0	2.06	8.7	18.80	9	19.75	33.7
% Replacement of BFS by total weight of the total asphalt mixture	0	1	4.03	8.03	4.05	8.02	11.94

In Table 1, "REF" refers to the reference mixture without BFS, "FM" refers to mixtures with BFS from Federal-Mogul Götebory foundry and "S" refers to mixtures with BFS from Storebro foundry.

For each series given in Table 1, fourteen asphalt samples of 100 mm diameter were prepared and compacted by Marshall compaction using 50 blows/ layers for each side of a Marshall specimen according to SS-EN 12697-30 [15].

6. Results and Discussions

6.1. Environmental analysis results

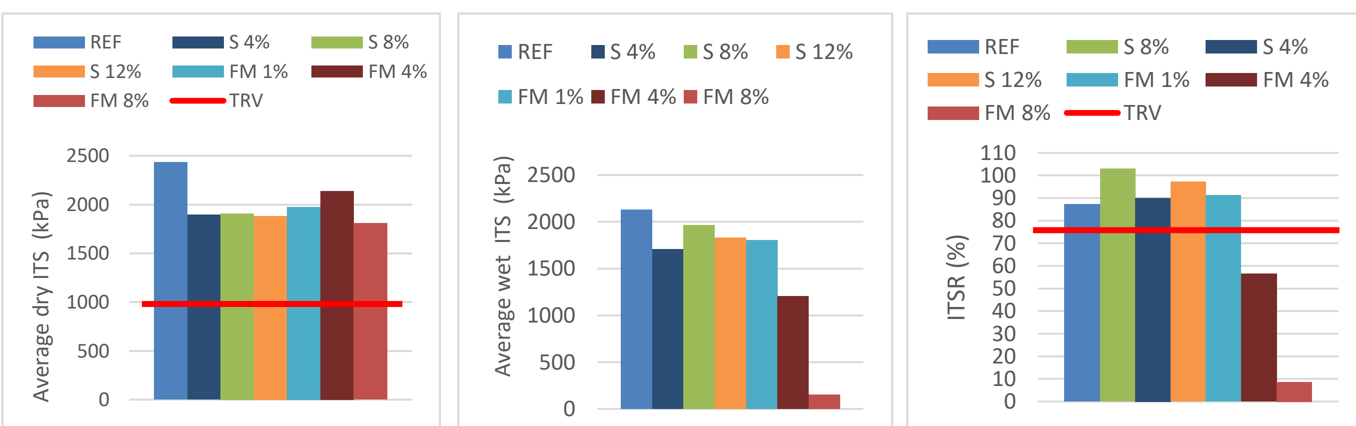
Leaching test ICP according to ASTM D3987 ICP-Quantitative [16] have been carried out on the reference asphalt mixture, asphalt mixture with 8% BFS from Federal-Mogul Göteborg foundry and asphalt mixtures with 12% BFS from Storebro foundry. These tests include the leaching tests and pH tests as carried out by Sibelco Technical Center Dessel.

The tests results showed that the elements analyzed in the leachate for FM 8% and S 12% were within the same limits as for the reference mixture measured in mg/kg TS units, namely (Arsenic<0.2, Barium <0.08, Cadmium <0.08, Cobalt<0.08, Chromium<0.08, Copper<0.08, Molybdenum<0.08, Nickel<0.08, Lead <0.2, Zinc<0.08 and Selenium <0.4). The groundwater will thus not become contaminated with metallic compounds. Also, the pH scale of the three mixtures showed that all the tested mixtures are basic with pH>7.

6.2. Technical characteristics tests results

This paragraph discusses the main technical characteristics of the chosen asphalt mixtures (with and without BFS) determined through various laboratory tests, namely, static water susceptibility via indirect tensile strength test, void ratio, Marshall stability and flow, resilient modulus at dry conditions and the resilient modulus at wet conditions before and after moisture Induced Sensitivity Test (MIST).

In order to check the potential stripping problems with the use of the two chosen types of by-product foundry sand, Marshall specimens were prepared, and the stripping resistance (water sensitivity) of the samples was evaluated based on the loss of the indirect tensile strength (ITS) up on wetting according to TDOK 2017:0650 [17]. The ITS test has been caried out according to SS-EN 12697-23 [18]. Figure 2 A shows the average static indirect tensile strength for each series. It is evident from Figure 2 that all the asphalt mixtures with 1%, 4% and 8% BFS from Federal-Mogul Göteborg foundry and mixtures with 4%, 8% and 12% BFS from Storebro foundry, in addition to the reference mixture, showed relatively high indirect tensile strengths.



(A) *(B)*

(C)

Fig. 2: (A) The average static indirect tensile strength for each series at dry conditions, (B) The average static indirect tensile strength for each series at wet conditions, (C) Static indirect tensile strength ratios of different asphalt mixtures.

It can be seen from Figure 2 A that all the tested asphalt mixtures showed ITS at dry conditions higher than the minimum allowable value of 1000 kPa according to TDOK 2013:0529 [11] requirement. Upon conditioning (wetting), high amounts of BFS from Federal-Mogul foundry affected negatively the ITS values of the asphalt mixtures, given the soft characteristic of asphalt as shown in Figure 2 B. It can be seen from Figure 2 C that the indirect tensile strength ratios (ITSR) for asphalt mixtures with 4% and 8% BFS from Federal-Mogul Göteborg foundry were lower than the minimum ratio of 75% required by TDOK 2013:0529 [11]. Due to the very low ITSR (of less than 10%) recorded for FM 8%, this mixture has been excluded from further laboratory investigations in this study. As shown in Figure 2 E, among the asphalt mixtures containing BFS, mixture S 8% was the one with the highest ITSR, followed by series S 12%, FM 1%, S 4% and REF respectively. In summary, all these mixtures, namely, S 12%, S 8% S4%, FM 1%, and REF fulfilled the Swedish Transport Administration (TRV) requirements in terms of both dry ITS and ITSR.

The air voids content of an asphalt specimen is calculated according to SS-EN 12697-8 [19] using the maximum density of the mixture, according to SS-EN 12697-5 [20] and the bulk density of the specimen, according to SS-EN 12697-6 [21]. This method has been adopted to test the void ratio of the Marshall asphalt specimens prepared in this study.

It was observed that all the seven mixtures tested in this study meet the Swedish standards regarding the minimum and maximum void ratio requirements according to TDOK 2013:0529 [11] (between 1.5% to 3.5% by volume for ABT 11, 160/220 binder) as discussed previously.

It can be noticed from Table 3 that the bulk densities of the asphalt samples have increased with increasing the BFS from both foundries. Regarding the void ratios, mixture S 12% has the lowest void ratio as compared to all other mixtures. The mixtures of series S with BFS from Storebro foundry maintained a decrease in void ratio when the proportion of BFS in the mixture was increased while no such a trend observed for BFS from Federal-Mogul Göteborg foundry.

Table 3: Void ratio tests results

Serie	REF	FM 1%	FM 4%	FM 8%	S4%	S8%	S12%
BFS (%)	0	1	4	8	4	8	12
Void ratio (%)	2.92	2.25	2.74	2.07	2.59	2.32	1.61
Bulk density (Mg/m^3)	2.335	2.343	2.344	2.347	2.347	2.358	2.370

The observation of decreasing the void ratio with increasing the BFS contents differ from those reported by Javed [3] who noticed an increase in the percentage of air voids of the asphalt mixtures with increasing the BFS contents in the mixtures. This difference in the observations can be attributed to the differences in the gradations of the used BFS and the corresponding adopted asphalt mixture. According to Table 3, the reference mixture had the highest void ratio among all mixtures.

Since asphalt mixtures with 12% BFS from Storebro foundry showed the lowest void ratio of 1.61% among the tested mixtures which is very close to the minimum allowable value of 1.5% according to TDOK 2013:0529 [11] requirement for ABT 11, 160/220 binder, and to be in the safe side, asphalt mixtures of up to 8% BFS from Storebro foundry seems to be promising and hence are recommended for further laboratory investigation in this study.

Table 4: Marshall Stability and Flow Tests Results

Series	Foundry sand	Stability	Flow	Marshall quotient
	%	kN	mm	kN/mm
REF	0	12.34	2.57	4.8
S 4%	4	8.28	2.88	2.9
S 8%	8	7.72	3.08	2.5
F 1%	1	10.25	3.19	3.2
F 4%	4	9.80	3.23	3

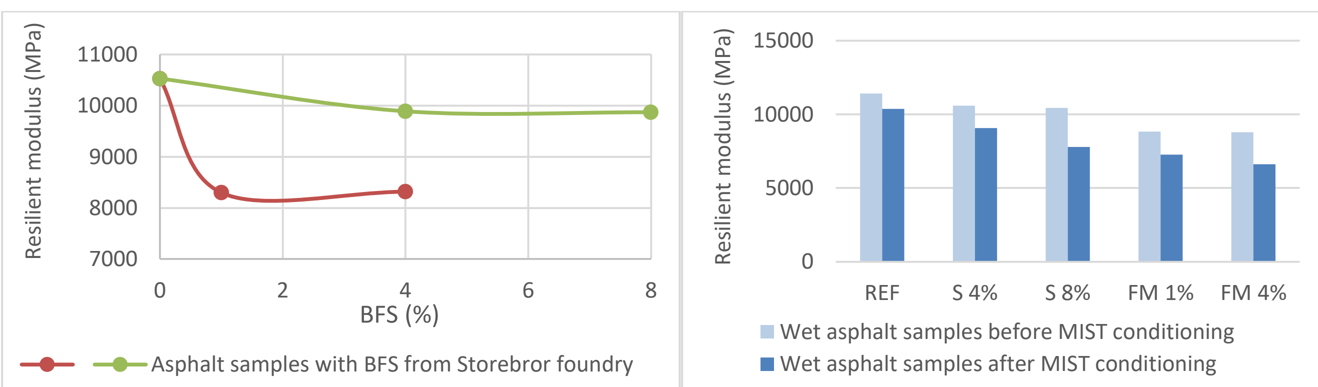
The method given SS-EN 12697-34 [22] part E, has been adopted in this study to determining Marshall stability, flow and Marshall quotient of specimens of asphalt mixtures prepared in this study. In terms of Marshall stability and flow tests results, it can be seen from Table 4 that the reference mixture has showed the best performance with the highest stability and lowest flow values. Regarding the mixtures with BFS, it can be noticed from Table 4 that the mixtures with 4% BFS from Federal-Mogul Göteborg foundry recorded higher stability than the corresponding mixture with 4% BFS from Storebro foundry, but it had the highest flow value too. This observation is probably due to the higher absorption characteristics of BFS from Storebro foundry as compared to the BFS from Federal-Mogul Göteborg foundry. Also, this observation could even be due to the grain size, since BFS from Storebro has smaller particle size and therefore larger surface area and thus it consumed more binder which resulted in lower stability, at the same proportion of BFS.

In terms of Marshall quotient (stability/flow ratio), the mixtures with 4% BFS from Federal-Mogul Göteborg foundry and Storebro foundry have recorded very close values of 3 kN/mm and 2.9 kN/mm respectively. Note that, a higher Marshall quotient means higher stiffness and a better resistance to permanent deformation [23]. In summary, the use of BFS decreased the stability of the asphalt mixtures while increased their fluency.

The resilient modulus tests were carried out in accordance with FAS 454 [24]. In this test a cylindrical sample is subjected to a vertical, periodical load on the lateral surface (normal frequency = 0.3 Hz with a pulse length of 0.1 s). The horizontal resilient deformation during unloading is measured and the stiffness modulus is then calculated according to a formula from the theory of elastic cylinders. The test is performed at different temperatures, usually -5, 10 and 25 ° C.

Regarding the resilient modulus test, the use of BFS from both foundries decreased the resilient modulus (MR) of asphalt samples tested under dry conditions. Adding 1% BFS from Federal-Mogul Göteborg foundry to the asphalt mixture caused a sharp decrease of 21% in MR as compared to the MR value of the reference mixture. Further increase in BFS from Federal-Mogul Göteborg foundry (e.g. to 4%) did not record further decrease in MR values.

On the other hand, asphalt mixtures with 4% BFS from Storebro, showed only 6.5% decrease in MR as compared to the MR of the reference mixture. Similarly, further increase in BFS from Federal-Mogul Göteborg foundry (e.g. to 8%) did not record further decrease in MR values as compared to the MR value of the reference asphalt mixture, see Figure 3 A.



(A) *(B)*

Fig. 3: (A) The resilient moduli for different dry asphalt samples with different BFS contents, (B) Effect of MIST conditioning on the resilient moduli of the wet asphalt samples with different BFS contents.

Since moisture damage is one of the major problems encountered in asphalt pavements, the dynamic water susceptibility of asphalt mixtures should be determined in addition to the static water susceptibility tests described in previously. Therefore, the effect of moisture damage on the resilient modulus (MR) property of the asphalt samples using Moisture Induced Sensitivity Test (MIST) has been evaluated in this study in accordance with ASTM D7870/D7870M-20 [25].

MIST is an accelerated conditioning method designed to simulate the stripping mechanisms under cyclic (dynamic) loading. It can simulate moisture damage due to water, repeated traffic loading and elevated in place temperatures. It can be conducted on compacted laboratory and field samples at adjustable temperature, pressure and number of cycles.

The test involves placing a sample inside a cylindrical sample chamber (3 levels for up to 3 samples), filling the chamber with water, closing the sample chamber lid, and starting the test.

After determining the resilient moduli at dry conditions for the series REF, FM 1%, FM 4%, S4% and S 8%, the samples were soaked in water and then the resilient modulus tests have been carried out on these wet samples before MIST conditioning. Later, the same wet samples were conditioned by MIST for 7000 cycles under 4 hours and tested again for their resilient moduli. This action was important to get a fair comparison in resilient moduli of the tested samples under wet conditions before and after MIST conditioning for all the tested series.

It can be seen from Figure 3 B that conditioning the wet asphalt samples by MIST, caused a reduction in the initial wet resilient moduli for all the tested samples even the REF mixture but at different rates. The wet resilient moduli decreased by 9.1%, 14.5%, 25.5%, 17.7% and 24.7% for the REF, S 4%, S 8%, FM 1% and FM 4% mixtures respectively after 7000 conditioning cycles with MIST. This means that the asphalt mixture with 4% BFS from Storebro foundry recorded the lowest decrease in wet resilient moduli, after the reference mixture, due to MIST conditioning.

2. Conclusions and Recommendations

This study deals with carrying out laboratory investigations to evaluate the use of two types of Swedish by-product foundry sand (BFS) in asphalt mixture, namely, ABT 11.

From this study it can be concluded that BFS can be used as an alternative for sand fraction 0-2 mm at different replacement percentages for the asphalt mixture ABT 11 depending on the type of the BFS. Based on the laboratory tests carried out in this study, BFS from Storebro foundry appears to be suitable to substitute up to 12% of the total weight of the asphalt mixture. However, since asphalt mixtures with 12% BFS from Storebro foundry showed the lowest void ratio of 1.6% among the tested mixtures which is very close to the minimum allowable value of 1.5% according to the Swedish Transport Administration (TRV) requirement, and to be in the safe side, asphalt mixtures of up to 8% BFS from Storebro foundry seems to be promising and hence are recommended for further investigation under long-term traffic loading and climate conditions. On the other hand, asphalt mixtures with up to 1% BFS from Federal-Mogul Göteborg foundry is recommended for further investigations under long-term traffic loading and climate conditions due to the high-water sensitivity of this BFS.

In summary, the use of 8% BFS from Storebro foundry and 1% BFS from Federal-Mogul Göteborg foundry (by the total weight of the asphalt mixtures ABT 11 (160/220) at 6% binder content) proved to be adequate according to the laboratory investigations carried out in this study and meets the physical and technical criteria of TRV as per TDOK 2013:0529 [11].

Acknowledgements

This study has been 50% financed by the Swedish Energy Agency within the framework of the Strategic Innovation Program RE: Source. Also, the project has been co-funded (50%) by partners from the Swedish foundry industry, namely, Sibelco Nordic AB, Federal- Mogul Göteborg foundry AB and Storebro foundry AB. The author would like to thank all the partners for their interest and support to the project.

References

[1] R. Bakis, H. Koyuncu, A. Demirbas “An investigation of waste foundry sand in asphalt concrete mixtures”. Waste Management and Research, 24:269-274, 2006.
[2] Nils Lindskog, and Henric Lassesson “Reduction of the benzene content in excess sand from foundries ”, IVL Swedish Environmental Institute , Report B2304, Stockholm, Sweden, 2018.
[3] S. Javed “Use of Waste Foundry Sand in Highway Construction (Final Report)”. School of Civil Engineering, Purdue University, West Lafayette, Ind., Project No. C-36-50N, Report JHRP-94/2, 1994.

[4] P. J. Tikalsky, H. U. Bahia, A. Deng, and T. Snyder "Excess foundry sand characterization and experimental investigation in controlled low-strength material and hot-mixing asphalt", Final Report. The Pennsylvania State University, Transportation Research Building, University Park, PA, U.S.A., U.S. Department of Energy, Contract No. DE-FC36-01ID13974, 2004. TOCLOFLOTfnl.doc (osti.gov).
[5] P. Dyer, L. M.G. Klinsky, S. Silva, R. A. Silva and M. G. Lima "Macro and microstructural characterisation of waste foundry sand reused as aggregate. Road Materials and Pavement Design 22 (2): 464-477, 2021.
[6] D. Kuttah, I. Indacoechea, I. Rodríguez, P. Lastra González, E. Blas, R. Casado, R. Boysen, J. Planche, L. Trussardi "ALTERPAVE Methodology", Deliverable 5.2, Alterpave European project, 2018.
[7] A. Gedik, A. Lav, and M. A. Lav "Investigation of alternative ways for recycling waste foundry sand: An extensive review to present benefits", Canadian Journal of Civil Engineering 45(6),1-36, 2018.
[8] E. Winkler, and A. A. Bol'shakov "Characterization of foundry sand waste. Center for Energy Efficiency and Renewable Energy", University of Massachusetts at Amherst, Chelsea Center for Recycling and Economic Development, Technical Research Program; Technical report no. 31, 2000.
[9] FIRST "Foundry sand facts for civil engineers", Federal Highway Administration, Report nr FHWA-IF-04-004, https://www.fhwa.dot.gov/pavement/pubs/013791.pdf, 2004.
[10] SS-EN 933-1 "Tests for geometrical properties of aggregates – Part 1: Determination of particle size distribution – Sieving method", Swedish Standards Institute (SIS), Stockholm, 2012. Standard - Ballast - Geometriska egenskaper - Del 1: Bestämning av kornstorleksfördelning - Siktning SS-EN 933-1:2012 (sis.se)
[11] TDOK 2013:0529 "KRAV- Bitumenbundna lager" Trafikverket, Version 2.0, 2015. https://tekniskhandbok.goteborg.se/wp-content/uploads/1E_77_TDOK-2013-0529-Bitumenbundna-lager_2016-10.pdf
[12] SS-EN 1097-6 "Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption", Swedish Standards Institute (SIS), Stockholm, 2013.
[13] SS-EN 1426 "Bitumen and bituminous binders- Determination of needle penetration", Swedish Standards Institute (SIS), Stockholm, 2015.
[14] SS-EN 1427 "Bitumen and bituminous binders - Determination of the softening point - Ring and Ball method", Swedish Standards Institute (SIS), Stockholm, 2015.
[15] SS-EN 12697-30 "Bituminous mixtures- Test methods- Part 30: Specimen preparation by impact compactor). Swedish Standards Institute (SIS), 2019.
[16] ASTM D3987-12 "Standard Practice for Shake Extraction of Solid Waste with Water Standard Test Method for Shake Extraction of Solid Waste with Water", ASTM International, PA, USA, 2020.
[17] TDOK 2017:0650 "Bitminous pavement and mixture. Determination of water sensitivity of bituminous specimens using indirect tensile test" Swedish Transport Administration requirement, version 10, 2017.
[18] SS-EN 12697-23 "Bituminous mixtures - Test methods for hot mix asphalt - Part 23: Determination of the indirect tensile strength of bituminous specimens", Swedish Standards Institute (SIS), Stockholm, 2017.
[19] SS-EN 12697-8 "Bituminous mixtures - Test methods - Part 8: Determination of void characteristics of bituminous specimens". Swedish Standards Institute (SIS), 2019. https://www.sis.se/api/document/get/80009156
[20] SS-EN 12697-5 "Bituminous mixtures – Test methods – Part 5: Determination of the maximum density". Swedish Standards Institute (SIS), 2019. https://www.sis.se/api/document/get/80009155
[21] SS-EN 12697-6 "Bituminous mixtures – Test methods – Part 6: Determination of bulk density of bituminous specimens". Swedish Standards Institute (SIS), 2020. https://www.sis.se/api/document/get/80020499
[22] SS-EN 12697-34 "Bituminous mixtures – Test methods –Part 34: Marshall test". Swedish Standards Institute (SIS), 2020. https://www.sis.se/produkter/anlaggningsarbete/vagbyggnad/korbana/ss-en-12697-342020/
[23] D. Kuttah, I. Rodríguez, and I. Indacoechea "New Asphalt Mixtures Performance Validation at Lab. Scale", Deliverable 3.2, Alterpave European project, 2017.
[24] FAS Metod 454 "Bituminous pavement and mixture. Determination of resilient modulus of asphalt concrete by indirect tension test", FAS Service AB, 1998.
[25] ASTM D7870 / D7870M – 20 "Standard Practice for Moisture Conditioning Compacted Asphalt Mixture Specimens by Using Hydrostatic Pore Pressure", ASTM International, PA, USA, 2020.