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Laboratory investigations on bituminous concrete mixtures utilizing foundry sand.

Investigaciones de laboratorio sobre mezclas de hormigón bituminoso utilizando arena de fundición.

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ABSTRACT

This research work reports the effect of foundry sand (FS) mineral filler (MF) aggregate on characteristics of bituminous concrete grading-2 (BC-2) mixtures and compares the test results with the conventional BC-2 mixtures. The Marshall mixture design method is adopted to assess the optimal bitumen content at 4% air voids for bituminous concrete grading-2 specimens prepared using 0, 25, 50, 75, and 100 percent FSMF content. Split tensile strength test and water resistivity test were conducted to study the performance characteristics of bituminous concrete mixtures. EDXA (Energy Dispersive X-ray Analyzer) and SEM (Scanning Electron Microscope) were also performed to investigate the element content (mineralogical composition) and texture (morphology) of foundry sand (FSMF). The test results show that utilizing foundry sand as a mineral filler in bituminous concrete enhanced the stability, split tensile strength, and split tensile strength ratio when compared to mixtures containing conventional mineral filler material. Hence use of foundry sand mineral filler aggregate in the production of BC-2 mixture is recommended.

Keywords— Foundry sand, Split Tensile Strength, Split tensile strength ratio, SEM, EDXA

RESUMEN

Este trabajo de investigación reporta el efecto del agregado de relleno mineral (MF) de arena de fundición (FS) sobre las características de las mezclas de hormigón bituminoso grado-2 (BC-2) y compara los resultados de la prueba con las mezclas convencionales BC-

2. El método de diseño de mezcla de Marshall se adopta para evaluar el contenido óptimo de betún al 4% de vacíos de aire para muestras de concreto bituminoso de clasificación 2 preparadas con 0, 25, 50, 75 y 100 por ciento de contenido de FSMF. La prueba de resistencia a la tracción dividida y la prueba de resistividad del agua se llevaron a cabo para estudiar las características de desempeño de las mezclas de concreto bituminoso. También se realizaron EDXA (Analizador de rayos X de dispersión de energía) y SEM (Microscopio electrónico de barrido) para investigar el contenido de elementos (composición mineralógica) y la textura (morfología) de la arena de fundición (FSMF). Los resultados de la prueba muestran que la utilización de arena de fundición como relleno mineral en hormigón bituminoso mejoró la estabilidad, la resistencia a la tracción dividida y la relación de resistencia a la tracción dividida en comparación con las mezclas que contienen material de relleno mineral convencional. Por lo tanto, se recomienda el uso de agregado de relleno mineral de arena de fundición en la producción de la mezcla BC-2.

Palabras clave: arena de fundición, resistencia a la tracción dividida, relación de resistencia a la tracción dividida, SEM, EDXA

INTRODUCTION

Foundry sand is a metal casting industrial by-product produced during the molding & core-making production processes. The mold creates the outside shape of the castings, while the core creates the internal. If the component to be manufactured has deep holes or hollow portions, sand cores should be incorporated into the mold. The physicochemical properties of foundry sand are significantly affected by the production process and the metallurgical sector from which it was produced. Because of the enormous amount of by-products produced and the few applications available, the use of these by-products is now much more critical and concerning in India. It is one of the industrial by-products generated by the country's foundry sectors. In India, several foundry companies produce around 3 million tonnes per year. The total amount of stock piled foundry by-product that has not been used in about 25 million tonnes. In recent years, extensive experiments have been undertaken to utilize foundry sand (FS) in construction work. Highway foundations and retaining walls [1; 2; 3], landfills liner [4; 5], bituminous concrete [6], and road bases [7] were among the applications. Due to its similar characteristics to sand bentonite mixes, existing studies showed that foundry sand (FS) can be efficiently utilized in geotechnical work [7]. Bakis et al. studied the behavior of bituminous mixtures with zero, four, seven, ten, fourteen, seventeen, and twenty percent foundry sand. The Marshall test analysis indicated that substituting 10percent of the total of the aggregates with foundry sand (FS) had a higher stability value when compared to mixtures with conventional materials [8].

Because of the above-mentioned literature and issues related to foundry sand disposal, research was initiated on the use of by-products of the molding industry in road construction. However, there is limited data available about the utilization of foundry sand (FS) as a pavement material in the surface course mixtures, base course, and sub-base course layers of pavements. This study provides the details of experiments conducted on Bituminous Concrete Grading-2 (FSMF) using foundry sand as mineral filler.

The current research consists in evaluating the Physico-chemical characteristics of foundry sand and the marshal mix design properties of BC-2 with 0, 25, 50, 75, and 100% FSMF. The temperature effect on split tensile strength and split tensile strength ratio has also been investigated.

The objectives of the research work is to evaluate the potentiality of the by-products of the molding industry in the BC2 (Bituminous concrete middle-limit grading II mixtures) as mineral fillers (FSMF) through laboratory investigation. SEM (Scanning Electron Microscope) and EDXA (Energy Dispersing X-ray Analyzers) are used to examine the morphology and chemical characteristics of the foundry sand mineral filler. Split tensile strength and split tensile strength ratio of BC-2 mixtures containing 0, 25, 50, 75, and 100 percent FSMF were also measured using STS (Static tensile strength) equipment.

MATERIALS AND METHODS

In the study, viscosity grade bitumen VG-30 was used for the preparation of BC-2 mixtures. Foundry sand from MPM Steel Industries (Bhadravati taluk, Shimoga district, Karnataka, India) was utilised as mineral filler. SEM and EDX techniques are used to assess the morphological and chemical parameters of the foundry sand and the results of GSD (Grain size distribution) are presented in Figure 1. The aggregate gradations [9] relating to the bituminous concrete mix are used in accordance with MoRT&H (Ministry of Road Transport and Highways) Section 500, Table No. 500-18, 4th Revision Specification, and are shown in Table 1 and Figure 2. The Marshall bituminous mixture design methodology (ASTM: D-1559 and Asphalt Institute Manual Series No. 2, Sixth Edition, 1993) is utilized to prepare BC-2 (Bituminous concrete mid-limit grading-II mixtures with 0, 25, 50, 75, and 100 percent FSMF. Laboratory tests are conducted on VG-30 bitumen and aggregates as per IS (Indian Standard) testing procedures and IRC (Indian Road Congress) specifications, and their suitability in the bituminous concrete grading-2 mix is also assessed. Initially, the Marshall mixture design was adopted to determine the optimal binder percentage (OBC). After determining the optimal binder percentages for 0, 25, 50, 75, and 100% FSMF in BC-2 mixtures, laboratory performance studies such as static indirect tensile strength and moisture sensitivity tests are performed.

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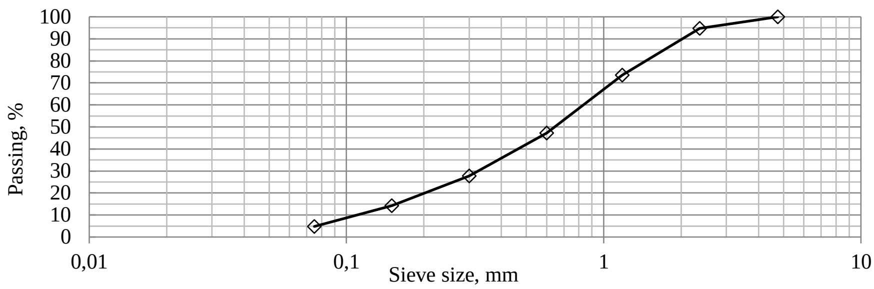

Fig. 1 Grain size distribution for Foundry sand

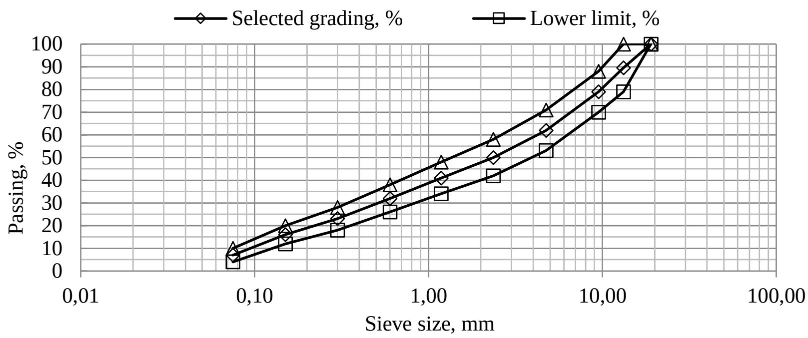

Fig. 2 Gradation of BC2 mixtures

Table 1 Gradation table for BC2 mixtures

IS Sieve size, mm	Range of aggregate grading	Retained percent (Mid limit)	FSMF content, %
19.0	100	10.5	0, 25, 50, 75
13.2	79 - 100	10.5	& 100
9.5	70 - 88	17	
4.75	53 - 71	12	
2.36	42 - 58	9	
1.18	34 - 48	9	
0.6	26 - 38	9	
0.3	18 - 28	7	
0.15	12 - 20	9	
0.075	4 - 10	7	

Basic properties of conventional and foundry sand materials were carried out using standard testing procedures. The traditional aggregates used in this study were found to meet the MoRT&H specification, section 500, Table number 500–17 [9]. The test results are shown in Table 2.

Table 2 Properties of Quarry stone Aggregates (QSA) and Foundry sand (FS)

Description of Tests	Test Results
Combine Index of QSA, %	30.10
Loss Angeles Abrasion Value of QSA, %	26.00
Aggregate Impact Value of QSA, %	22.05
Water Absorption of QSA, %	0.30
Stripping of QSA, %	98.00
Sp.gr of Quarry stone CA	2.67
Sp.gr of Quarry stone FA	2.76
Sp.gr of Quarry stone MF	2.84
Sp.gr of FSMF	2.23
Specific surface area of Cement, cm^2/gm	3181
Specific surface area of FSMF, cm^2/gm	2775
Specific surface area of stone MF, cm^2/gm	2838

The VG30 viscosity grade bitumen [10] is used to prepare the BC-II mixture, and the results of the experiments are summarized in the table. 3.

Table. 3. Properties of VG30 binder

Description of tests	Results
Penetration value @ 25°C, 0.1mm	68.33
Softening point in °C	51.75
Ductility value @ 27 °C in cm	82.5
Specific gravity(Sp.gr) @ 27 °C	1.00
Flash Point in °C	260.0
Viscosity test @ 135°C in cst	390.0

DESIGN OF BC-2 MIXTURE: Using ASTM D-1559–1979 [11], Marshall tests is performed to assess the stability, the Marshall flow, and optimum binder percentage (OBC) of the BC-2 mixture. Marshall samples prepared and tested for Marshall testing for BC-2 mixtures with 0, 25, 50, 75, and 100 percent FSMF @ OBC, and are presented in Table 4.

Table. 4 Marshall properties of BC-2 mixtures with FSMF

FSMF content	Stability, KN	Flow, mm	Total air voids (Vv), %	Bulk Density (Gb), g/cc	VMA, %	VFB, %	OBC, %
FSMF0%	23.16	3.63	4.17	2.37	17.18	75.75	5.48
FSMF25%	23.07	3.60	4.21	2.37	17.07	75.32	5.42
FSMF50%	23.25	3.57	3.98	2.37	16.79	76.29	5.40
FSMF75%	23.72	3.53	3.86	2.37	16.64	76.80	5.40
FSMF100%	23.89	3.47	3.88	2.35	16.46	76.41	5.36

STS TEST: Split Tensile Strength (STS) tests are performed as per ASTM D 6931-12 [12] on cylindrical specimens compacted @ 4% air voids for 0, 25, 50, 75, and 100 percent FSMF at 25 °C, 45 °C, and 65 °C respectively. The split tensile strength is obtained using Eqn. 1, and the results are given in Fig. 3.

$$\mathrm{STS} = \frac{2\mathrm{P}}{\pi \mathrm{dt}} \quad (1)$$

Where: STS = Split tensile strength in MPa, P = Failure load in Newton,
t = Thickness of specimen in mm, d = Diameter of specimen in mm.

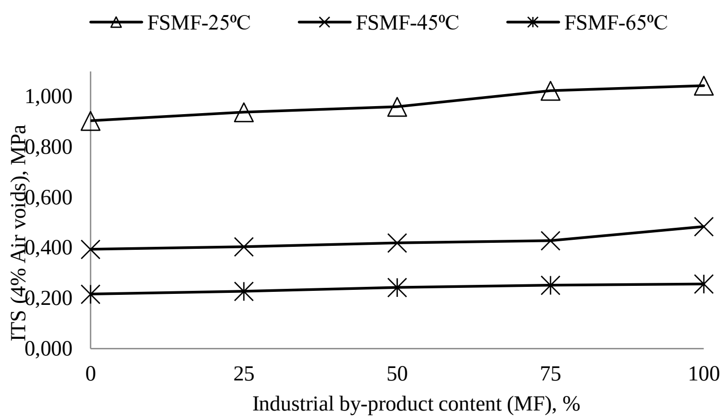

Fig. 3 Split tensile strength values of BC-2 mixtures at 4 percent air voids

WATER RESISTIVITY TEST: At OBC, two sets of Marshall samples are prepared according to AASHTO T-283 [13]. The ratio of the STS (Split Tensile Strength) of the conditioned specimen to the unconditioned specimen gives the STSR (Split Tensile Strength Ratio) and results of STSR (Split Tensile Strength Ratio) for 0, 25, 50, 75, and 100 percent FSMF at 25°C, 45°C, and 65°C are presented in Table 5 and 6 respectively.

Table 5 STSR of BC2 mixtures containing FSMF and traditional mixtures

Temperature, °C	FSMF0%	FSMF25%	FSMF50%	FSMF75%	FSMF100%
25	0.857	0.854	0.860	0.857	0.856
45	0.861	0.862	0.865	0.854	0.864
65	0.852	0.859	0.854	0.871	0.882

SEM AND EXDA: The surface texture and shape of the traditional MF and FSMF were investigated using the SEM technique and are presented in Figure 4 and 5 respectively. The X-ray chemistry equipment EDXA (Energy Dispersive X-ray Analyzer) is utilized to study the quantitative elemental composition of FSMF, and the findings are shown in Table 7 and 8 respectively.

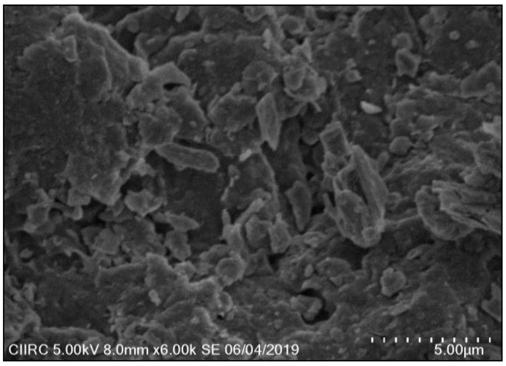

Fig. 4. SEM micrographs of FS-MF

Table 7 Quantitative elemental composition of FS material

Element Line	Weight, %	Atom, %
C K	9.60	15.83
O K	36.24	44.88
F K	2.23	2.33
Al K	11.35	8.33
Si K	40.58	28.63
Si L	----	----
Total	100	100

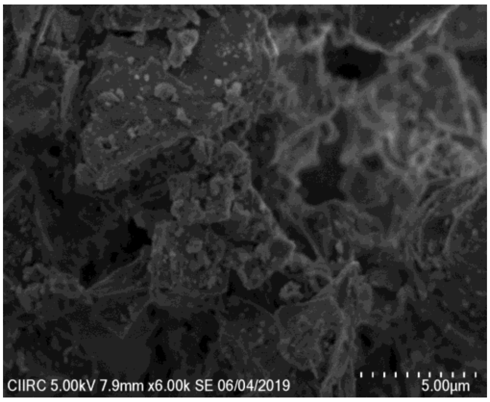

Fig. 5. SEM micrographs of Quarry stone-MF

Table 8 Quantitative elemental composition of traditional MF

Element Line	Weight, %	Atom, %
C K	11.23	20.57
O K	30.70	42.23
Si K	39.20	30.72
Si L	---	---
K K	4.46	2.51
K L	---	---
Br L	14.42	3.97
Total	100	100

RESULTS AND DISCUSSION

It is observed from the Table 4 that the BC-2 mixtures using FSMF showed high stability value as the FSMF content in the BC-2 mixture increases. It is also found that the stability value higher for BC-2 mixtures with 25, 50, 75 and 100 per cent FSMF compared to BC-2 mixtures with traditional mixtures (0 percent FSMF). Table No. 4 showing the variation of flow value with 0, 25, 50, 75 and 100 percent of FSMF. It is found that the Flow value of mixture decrease as the FSMF increases in the BC-2 mixture. This is because of lower specific surface area, irregular shape and rough textured FSMF particle replacing sub rounded shape particle of traditional material in the mixture. It is also identified that the OBC referring to 4 per cent air void is marginally lower for BC-2 mixtures with 25, 50, 75 and 100 per cent FSMF compared to BC-2 mixtures with 0 per cent FSMF. This may be due to lower specific surface area of FSMF particle in mixture reduced the OBC when compared to traditional material. Figure 3 illustrate the variations of split tensile strength values with 0, 25, 50, 75, and 100 percent FSMF content at temperatures of 25ºC, 45ºC, and 65ºC, respectively. It is observed that, when the FSMF increases in bituminous grading-2 mixtures, the split tensile strength value increases. Compared to conventional materials (FSMF-0), the shape, rough texture, and good interlocking characteristics of Foundry sand mineral filler (Figure 4 and Figure 5) are ideal for bituminous concrete grading-2 mixtures; hence, the split tensile strength (STS) value of the mixture prepared with FSMF has been increased. From Table 5 and 6, obtained results of water resistivity tests on BC-2 mixtures with FSMF 0, 25, 50, 75 and 100 percent replacement satisfy the section 500 Table 517 and 519 of MoRT&H 4th revision specifications. Quantitative elemental composition of FSMF (Table 7 and Table 8) shows that high percentage of weight (40.58 percent) and atom of Silica (28.63 percent) compare to traditional filler (39.20 percent). Also, foundry sand has a high percentage of silica and atom percent (Table 7 and Table 8), which contributes to its significant resistance to moisture-induced damage, which can be seen in static split tensile strength ratio (STSR) test results.

As conclusion, the broad objective of this research study is to investigate Marshall parameters, strength parameters, and resistance to water of bituminous concrete grading-2 mixtures replacing traditional material with 0, 25, 50, 75 and 100 percent of FSMF. The bituminous concrete mixture containing FS-MF has significantly lowered the optimal bitumen content, which reduces the cost of production compare to bituminous concrete mixture of traditional material. Split tensile strength of the mixtures has increased with foundry sand MF contents. However, the poor interlocking property of traditional material reduces its strength. Water resistance testing of bituminous concrete mixtures measured at 25, 45 and 65 degrees Celsius, the split tensile strength ratio of all mixtures meets the prerequisite minimum requirement. The incorporation of Foundry sand to the grade-2 mixture of bituminous concrete significantly improved water resistance compare to traditional mixtures.

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