ELECTRIC-ARC FURNACE SLAG UTILIZATION IN HOT MIX ASPHALT

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ABSTRACT

This study deals with investigation of electric-arc furnace slag utilization as filler material in hot mix asphalt. In the meantime, as natural supplies of high quality granular materials used in highways have become less abundant, the highway engineer is faced with the challenge of finding alternative materials to meet the requirements for these materials. Some of these alternative materials are; hydrated lime, Portland cement, marble dust, fly ash, coal dust, pumice dust, sewage sludge ash, steel slag etc. Both environmental and economic factors also contribute to the growing need for the use of reclaimed materials in asphalt pavements. One of these reclaimed materials, ferrochromium (FeCr) slag, has not been used extensively in pavements even though it has got promising features. In this study, FeCr slag has been obtained from an electrometallurgy establishment in Turkey. Various percentages of binder, limestone filler and slag filler were used to prepare Marshall specimens; then stability and flow tests and creep test were carried out on the specimens. In addition, particle size analysis, specific gravity, SEM observation, chemical analysis was performed on the materials prior to performance tests. Consequently, laboratory test results showed that asphalt mixtures containing FeCr slag filler are as good as or better than those of limestone filler. FeCr slag has potential to be used as a filler material in applications where crushed limestone filler is traditionally used.

Keywords: Mineral filler, slag, mixture design, permanent deformation

1. INTRODUCTION

The main flexible pavement material is use in today is asphalt concrete. This is a high-quality pavement surface composed of asphalt cement and aggregates, hot-mixed in an asphalt plant and then hot-lied. Asphalt concrete must provide a stable, safe and durable road surface. The properties of asphalt concrete depend on the quality of its components, binder, aggregates and filler, and the mix design proportions. Relative amounts of aggregate, binder and air void are very important [1].

In the meantime, as natural supplies of high quality granular materials used in highways have become less abundant, the highway engineer is faced with the challenge of finding alternative materials to meet the requirements for these materials. Some of these alternative materials are hydrated lime, Portland cement, marble dust[3], fly ash [4], coal dust [5], pumice dust [6], sewage sludge ash [7], steel slag [8] etc. Both environmental and economic factors also contribute to the growing need for the use of reclaimed materials in asphalt pavements. One of these reclaimed materials, ferrochromium slag, has not been used extensively in pavements even though it has got promising features.

A certain amount of filler is necessary in bituminous mixtures to obtain the required density and strength. The filler particles fill a portion of the space between sand and gravel particles, and thus contribute to increase density. The filler also influence the optimum binder content in bituminous mixtures by increasing the surface area of mineral particles. Several studies; Puzinauskas [2], Anderson et al. [9], Kandhal et al. [10], Shahrour and Saloukeh [11], Ishai et al. [12], Ishai and Craus [13], Tayebali et al. [14], Hussain Bahia [15] conclude that fillers largely influence the asphalt mixture performance. Different filler materials may have different mechanical properties in the asphalt mixture. Dukatz and Anderson [16] have investigated eight different filler materials to investigate the mechanical properties of asphalt and they found that different filler materials have different effects on stiffness and had almost no effect Marshall stability and void ratio.

In this study, various percentages of asphalt cement, limestone filler and FeCr slag filler were used to prepare the Marshall specimens and then stability and flow tests and creep test were carried out on the specimens. After getting design parameters, utilization of slag filler in asphalt mixtures was investigated in comparison with limestone filler.

2. MATERIALS

The basic materials used in this study are, mineral filler and aggregate, asphalt cement and FeCr slag.

2.1. Properties of Mineral Filler

Mineral filler is usually defined as a material which passes No.30 (0,600 mm) standard sieve. Moreover; at least 70 percent of this material passes No.200 (0,075 mm) standard sieve [18]. Mineral filler plays an important role in arranging the properties of the mixture; however, it covers a very little part of all aggregate. Filler is generally used at low rates such as 3% – 9%. This component change the aggregate gradation by filling air voids until a certain amount and this provides more touch points between aggregate particles and this contributing to obtain denser mixtures [19]. This situation is particularly important for surface layers, because increased composite and increased density gets good impermeability.

The function of mineral filler is more than filling voids. In addition, filler shows binder and slippery effects in the bituminous mixtures and helps to get mortar, this dual role differs mineral filler from other aggregates.

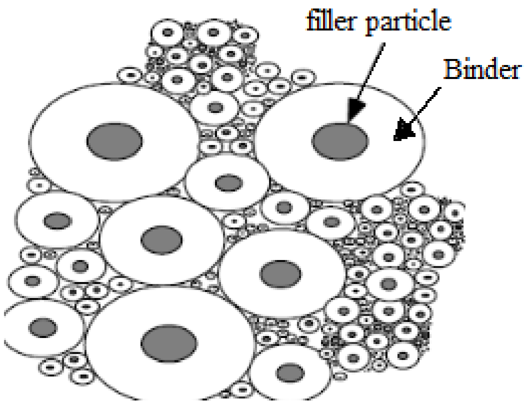


Figure 1 : Fillers' interaction with bitumen

2.2. Properties of Slag Filler (FeCr slag)

Ferrochromium slag dust is used as artificial filler in this study. Slag was obtained from ETİ Electrometallurgy Establishment (ETİ E.E.) which is founded in Antalya-Turkey. Every day, approximately 70-80 tons of Ferrochromium slag (FeCr slag) are produced in ETİ E.E. and disposal of the waste slag constitutes a problem. Chemical analysis of FeCr Slag is shown in Table 1.

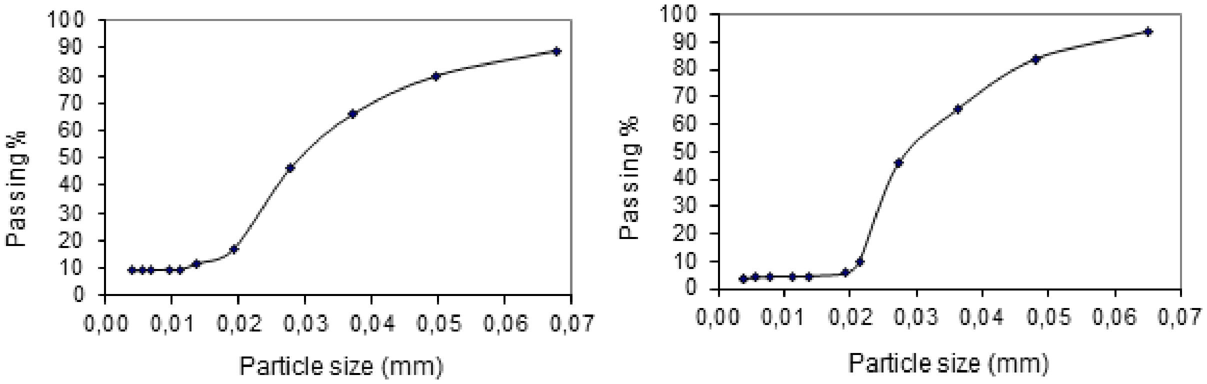
Table 1 : Chemical Properties of Electric-arc Furnace Slag (Ferrochromium slag)

Element	Cr_2O_3	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	S	C
Percentage	0.52	31.18	1.02	8.66	45.58	12.78	0.08	0.11

During the Ferrochromium and Silico-ferrochromium production process in the electric-arc furnaces, unreduced oxides and some SiO_2 form a liquid slag layer on the pots. Slag is poured into the slag molds and let to cool in open air. Air cooled FeCr slag is gradually transformed into powder form and it gains a crystal structure because of slow cooling process.

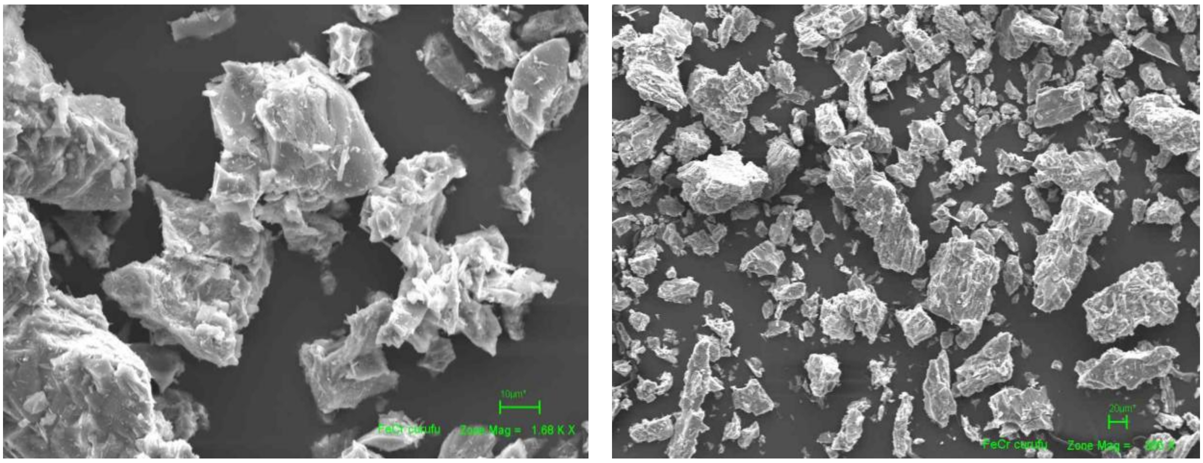
Only the minus No.200 sieve (0,075 mm) fraction of FeCr slag was evaluated in this study. The grading of slag filler and limestone filler were measured with a hydrometer analysis test. In this test, the filler is allowed to settle in solution and the rate of settling is related to particle size. Gradation curves for two fillers are shown on graphs given in Figure 2.a and 2.b).

Scanning electron microscopy (SEM) was used to observe the microstructure of slag filler particles (Figure 3). The SEM micrographs were obtained from Akdeniz University, Antalya/Turkey. The micrograph shows that the slag filler particles have rough and sharp surface with crystal structure. This phenomenon may cause the higher friction inside the samples.



a.) b.)

Figure 2 : Particle size distributions of filler (a- Slag filler, b- Mineral filler)



a.) b.)

Figure 3 : SEM images of FeCr slag (a- 1680x , b- 365x magnified)

2.3. Mineral Aggregate

Crushed aggregate of Antalya region was used in this study, aggregate gradation shown in Figure 4.
Physical properties of aggregate and filler are shown in Table 2.

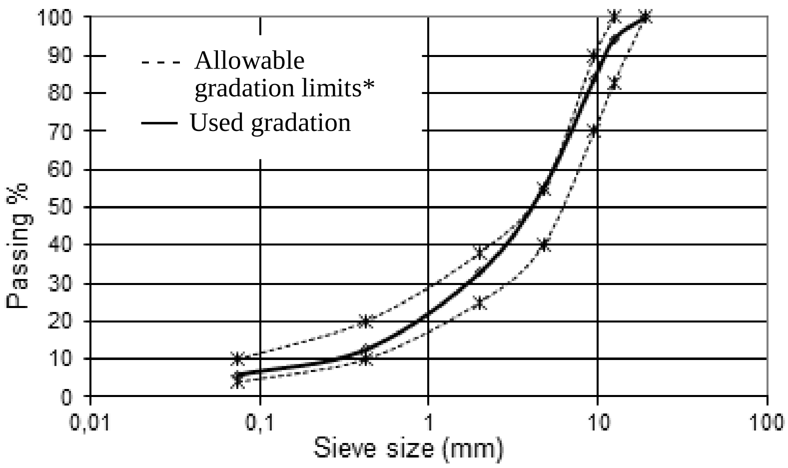


Figure 4 : Aggregate gradations

(* Turkish Highway Administration's suggested gradation limits for hot climate regions)

Table 2 : Physical Properties of Aggregate and Filler

Properties	Value	Limits	Standard
Specific gravity of course aggregate	2,70 gr/cm^3	-	TS-EN 1097-6
Course aggregate, water absorption	0,37 %	Max 2,0	TS-EN 1097-6
Specific gravity of fine aggregate	2,65 gr/cm^3	-	TS-EN 1097-6
Los Angeles abrasion loss of aggregate	20,2 %	Max 30%	TS EN 1097-2
Freeze thaw test with Na_2SO_4	4,3 %	Max 12%	TS-EN 1367-2
Aggregate stripping resistance	72 %	Min 50%	ASTM D 1664
Limestone filler bulk specific gravity	2,69 gr/cm^3	-	ASTM D 854
FeCr slag filler bulk specific gravity	3,16 gr/cm^3	-	ASTM D 854

2.4. Asphalt Cement

50-70 penetration grade asphalt cement is selected. Determined properties of asphalt cement are shown in Table.3.

Table 3 : Properties of Asphalt Cement [21]

Properties	Unit	Value	Related Standard
Penetration, 25°C, 100 g, 5 sec	1/10 mm	62	TS EN 1426
Ductility, 25 °C, 5 cm/min.	cm	100+	TS EN 13398
Softening point (ring and ball method)	°C	50,1	TS EN 1427
Flash point (Cleveland open pot)	°C	339	TS EN ISO 2592
Specific gravity	gr/cm^3	1,023	TS 1087

*****TS: Turkish Standards

3. PERFORMANCE OF ASPHALT MIXTURE

Diameter of 101.7 mm and a height of 63.5 mm Marshall specimens were prepared with various asphalt contents to determine the optimum bitumen content for each filler type. 7 different asphalt content at 0,5% increments (3,5% - 4,0% - 4,5% - 5% - 5,5% - 6% - 6,5%) and two filler materials (slag filler and limestone filler) were used for specimens. The initial filler content was 7%. Marshall mixture design method, described in ASTM D.1559 was applied in the study. Stability and flow test were carried out on these specimens. The specimens were also tested for density and voids analysis. According to Marshall design method optimum bitumen contents were determined for each filler type. Average of the two optimum bitumen contents determined as optimum bitumen content (5,1%).

Marshall specimens were prepared with 75 standard compaction blow for each side, considering heavy traffic level. This is better simulates the required density for pavement construction. Mixing and compaction temperatures were controlled to produce viscosities of 170±20 cst and 280±30 cst, respectively [22]. Three specimens were manufactured for each combination.

In further tests, defined optimum bitumen content (5,1%) and various filler contents (2,5% - 5% - 7% - 10%) were used to prepare specimens. Aggregate gradations used for new specimens are shown in Table 5. When the filler content was increased from 0 to 10 percent, in order to accommodate the increased quantity of filler, an equal volume of fine aggregate (minus No.10) was removed and replaced by an equal volume of filler. Specimens were than tested for stability and flow, permanent deformation, air void content, density, voids filled with bitumen, voids in mineral aggregate. Test results are shown in Figures 5 to 10.

Table 4 : Hot Mix Asphalt Design Specifications (KGM* 2006)

Specification	Binder Course		Friction Course	
	Min	Max	Min	Max
Std. Impact Number	75		75	
Stability, KN	7.5	-	9.0	-
Air voids in mixture, VTM %	4	6	3	5
Voids in Aggregate, VMA %	13	-	14	-
Flow, 1/100 in (mm)	8 (2)	16 (4)	8 (2)	16 (4)
Bitumen %	3.5	6.5	4	7
HMA Density*	2.30 – 2.50			

*Turkish Highway Administration Office

Minimum stability criteria suggested by Asphalt Institute for heavy traffic condition is 8006 N [23].

Table 5 : Gradations for Mixtures Containing Various Filler Percentages

Filler content (%)	**0**	**2,5**	**5.0**	**7.0**	**10**
Sieve Grade	Total Percentage Passing				
¾"	100	100	100	100	100
½"	91,5	91,5	91,5	91,5	91,5
3/8"	80	80	80	80	80
No.4	47,5	47,5	47,5	47,5	47,5
No.10	30	30,5	31	31,5	32
No.40	12	13	14	15	16
No.200	0	2,5	5	7	10

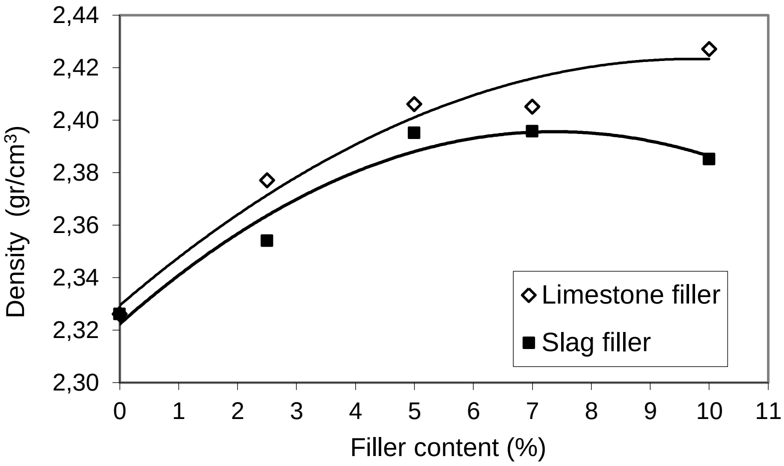


Figure 5 : Filler content versus specimen density

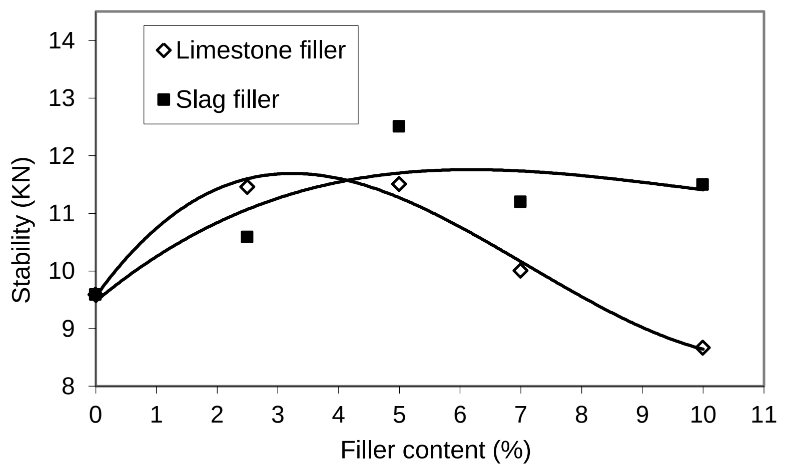


Figure 6 : Filler content versus Stability

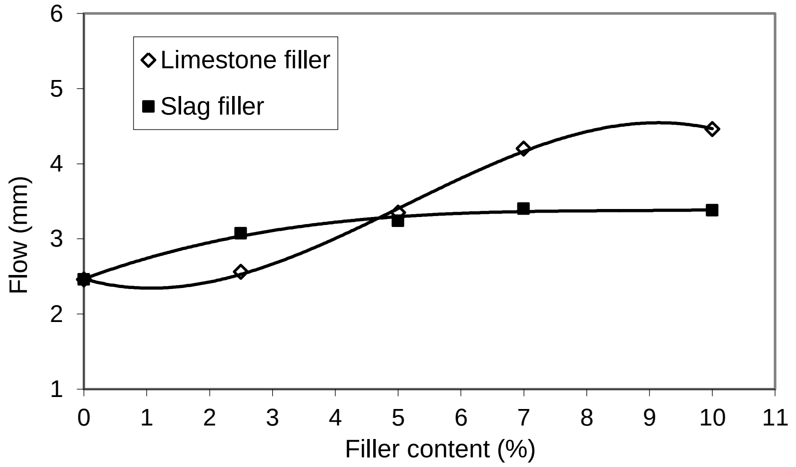


Figure 7 : Filler content versus Marshall flow

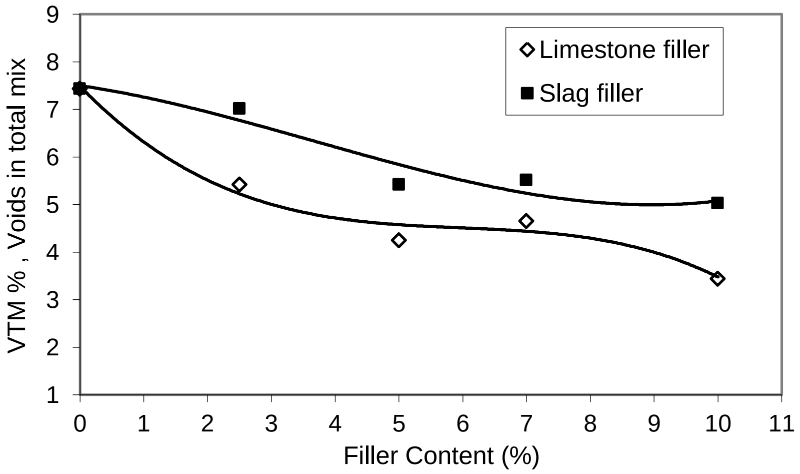


Figure 8 : Filler content versus Voids in total mixture

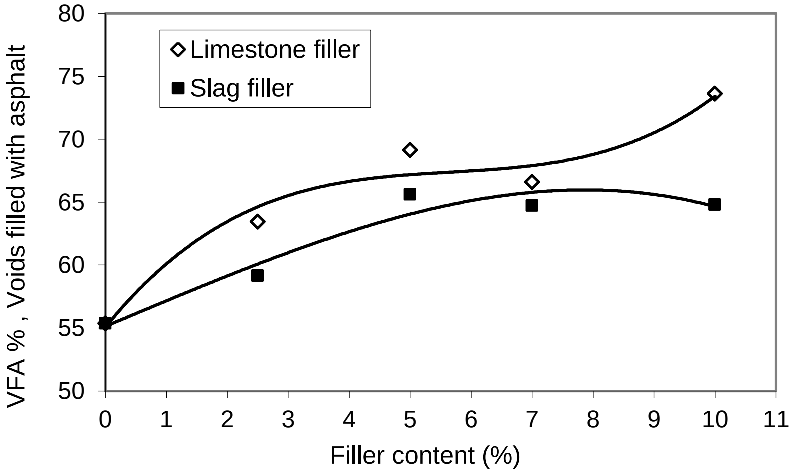


Figure 9 : Filler content versus Voids filled with asphalt
(Suggested VFA criteria by KGM, min: %65 – max: %75)

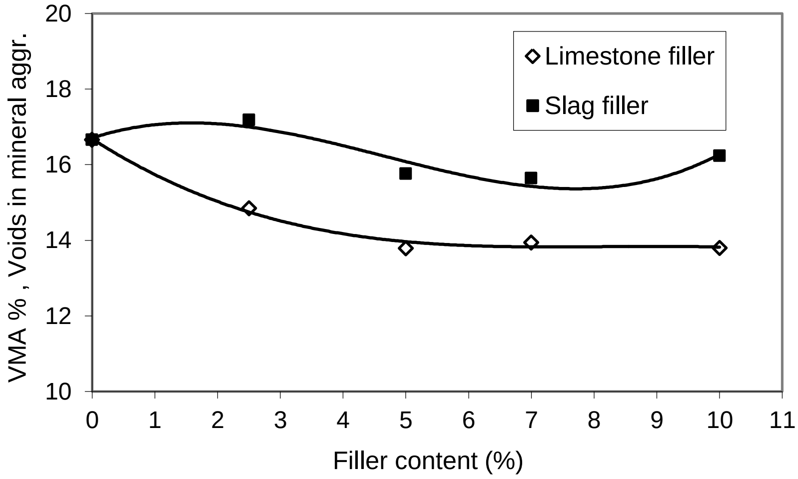


Figure 10 : Filler content versus Voids in mineral aggregate

Test results analyzed according to design parameters of hot mix asphalt and filler materials evaluated comparatively for use in asphalt pavements. With increasing of filler percentages, the densities of specimens were increased as expected (Figure 5). Densities of samples made with FeCr slag showed similarity to limestone filler.

Stability and flow results of the specimens produced with FeCr slag filler showed better performance than limestone filler. Especially at the higher filler percentages (7%, 10%), the significant improvement was observed with FeCr slag filler. Specimens made with slag filler showed 15% improved stability in comparison with control specimens.

According to flow results, specimens with FeCr slag showed quite satisfactory values which doesn't go over criteria limits of 4 mm, also at 10% filler (the highest flow result was only 2,4 mm). On the other hand, flow result of the limestone filler were went up to max limit of flow at 7% and 10%percent. This situation can be explained by microstructure and surface properties of filler materials. The filler particles were observed by SEM as shown in Figure 3. The micrograph shows that the slag filler particles have rough and sharp surface with crystal structure. This phenomenon can be the possible reason of FeCr slag's lower flow and higher stability results. Mainly flow value of specimens could be assessing as a major indicator of inner friction. Hence, the increment of inner friction due to crystal structure and sharp surfaces of specimens are expected.

Specimens with slag filler showed higher VTM (voids in total mix) values compared to limestone filler (see Figure 8). However this is cannot asses as a preferred situation, until a certain amount of air void increment, it plays a preventive role to bleeding of asphalt pavements, particularly in hot climate regions bleeding is a key factor of proper pavement design.

McLeod [24] developed the volumetric criteria for the specimens compacted with a Marshall hammer with 75 blows on each side of the specimen. Since, McLeod recommended that the VMA, which is the volume of voids between the aggregate particles, should be restricted to a minimum value of 15%; also KGM recommends the minimum VMA value of 14%. Mainly, VMA value varies with air voids and aggregate size. Specimens with slag filler show higher VMA values than limestone filler specimens (see fig.10). Test results range between 15.6 – 17.2 for slag filler and 13.8 – 16.6 for limestone filler.

3.1. Dynamic Creep Test

The Dynamic creep test is a test that applies a repeated pulsed uniaxial stress on an asphalt specimen and measures the deformations in the same direction using Linear Variable Differential Transducers (LVDT's) [25]. The samples were prepared for dynamic creep test with different FeCr filler ratios and optimum bitumen content (5.1%). Three samples (101 mm diameter and 63.5 mm height) from each mix were tested and the average values of the accumulated (permanent) deformations were recorded [26].

After sample preparation, the samples have been kept overnight in room conditions then those have been put into the cabinet in which temperature is controlled and conditioned to the test temperature. The permanent deformation tests have been carried out at 40 ˚C. The samples are preconditioned to the testing temperature overnight. The samples were mounted into the testing frame for dynamic creep test. 5000 cycles of 100 kPa axial stresses was applied on each sample. At the beginning, 100 cycles of 100 kPa axial stress was applied on each sample for conditioning. Five different types of samples which contain FeCr slag filler were prepared.

Fig.11 shows the relationship between the number of cycles and the axial accumulated permanent deformation for the tested groups.

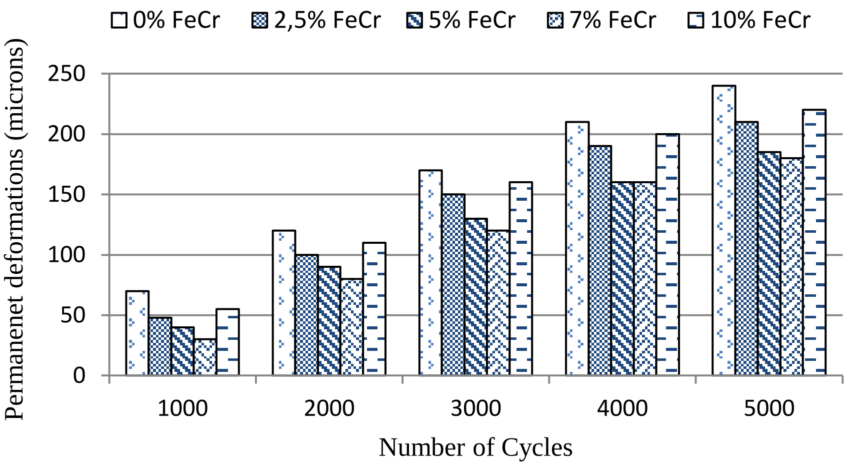


Figure 11 : Relationship between axial accumulated permanent deformation and loading cycles

Control mixture (0% FeCr filler) has maximum permanent deformation about 240 microns at the end of test. For the mixes containing FeCr slag at different filler ratio, the plastic deformations decrease until 7% FeCr content, after that plastic deformation increase (Fig.11). Therefore it can be concluded that up to a certain value of the FeCr filler content in the sample plastic deformations decrease, after that it is increases. The reason behind is that certain amount of filler, fills the void inside the samples and increases the stability, but after a certain value, the filler material avoids the bounding between the grains and the asphalt.

4. CONCLUSIONS

This investigation was mainly undertaken to evaluate the FeCr slag performance of asphalt concrete mixes having different percentages of slag filler and find the optimum replacement percentage of the limestone filler by the slag. To fulfill this objective, laboratory evaluation of asphalt concrete mixes with different combinations of FeCr slag filler and limestone filler were conducted. Stability and flow properties, density and voids analysis of Marshall specimens were studied, including different types and various percentages of fillers. Marshall mix design procedures and suggested criterions of Asphalt Institute and KGM were taken into account.

The test results showed that the use of FeCr slag as filler material in asphalt mixtures instead of limestone filler may be promising to obtain a material suitable for engineering purposes. It's recommended to use slag filler in current hot mix asphalt up to 7% where they are abundant. After 7% slag content, HMA density slightly decrease and plastic deformation of samples increases. Therefore it can be concluded that up to a certain value of the FeCr filler in the sample, fills the voids inside the sample and increases the stability, but after a certain value, the filler material avoids the bounding between the grains and the asphalt.

Consequently, electrometallurgy establishments generally don't expect an income from the slag. They are looking for the utilization of slags which occupy large areas in factories. In fact, with the assistance of elements mentioned above, using FeCr slag as filler material in road pavements would provide economic and environmental benefits compared to conventional filler materials.

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