Eaf Steel Slag Application Posibilities In Croatian Asphalt Mixture Production

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This paper demonstrates the results of testing basic physical and chemical properties of steel slag generated in the steel mill of CMC Sisak d.o.o., Croatia, with the purpose of its characterization as the type of waste, i.e. by-product intended for recycling in other industries. Special attention has been directed at investigating the possibilities of it being used as substitute for natural mineral aggregates when producing asphalt mixtures.

The results which were obtained by testing geometric, physical-mechanical properties, as well as the properties of duration on the specimen of electric arc furnace steel slag, have satisfied the conditions for manufacturing mixtures of the tested steel slag and natural aggregate which can be used in asphalt production. In comparison to the natural carbonate and silicate aggregates which are used in asphalt mixtures on highways and roads with heavy traffic, the examined steel slag has equally good physical-mechanical properties.

Within the framework of this project, test fields have recently been constructed. The existing wearing course was replaced by an AC 11 type of asphalt, in one lane with conventional natural carbonate aggregate and in the other two lanes with slag aggregate from CMC Sisak (0/4, 4/8, 8/11). The results of measurements of skid resistance on the section constructed using natural aggregate, and the section made using steel slag aggregate, were comparable. By means of laboratory analyses and in situ monitoring it should be possible to prove that asphalt composites containing slag have sufficient durability, and can achieve and maintain the required surface characteristics for road traffic safety.

Keywords: Metallurgical waste; steel slag; road construction; asphalt

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1. Introduction

The history of the use of iron and steel slag dates back a long way. European Slag Association (2006) has reported about the earliest reports on the use of slag refer to Aristotle who used slag as a medicament as early as 350 B.C. Throughout history use of slag has ranged from the novel to the usual including: cast canon balls in Germany (1589), wharf buildings in England (1652), slag cement in Germany (1852), slag wool in Wales (1840) reinforced concrete in Germany (1892) slag bricks made from granulated slag and lime in Japan (1901) according to *Iron and Steel* (2007). In the past, the application of steel slag was not attractive because vast volumes of blast furnace slag were available. Through awareness of environmental considerations and more recently the concept of sustainable development, extensive research and development has transformed slag into modern industrial product which is effectively and profitably used.

The increase of steel slag was slow due to the high iron content as only iron (steel) was recycled from the slag and the rest of it was mainly disposed of to landfills. Today, due to the ever increasing share of steel production in electric arc furnaces in the world, the steel mill slag becomes more and more important and it replaces blast furnace slag in many fields of application. For example, portion of the separated slag, that does not have an increased content of metallic components, with regard to its properties, can be applied in the construction industry according to M. Frias Rojas et al. (2004), D. Venkateswaran et al. (2007) and P.E. Tsakiridis et al. (2008). Furthermore, A. Rastovčan-Mioč et al. (2001) was observed that electric arc furnace slag (EAFS) can be used as inexpensive absorbing agent in the treatment process for waste waters burdened with metallic ions.

EAFS, which is converted from the unalloyed carbon steel production, is the most interesting one from civil engineering point of view. With supervised manufacture and volume stability assurance its characteristics are comparable with natural mineral aggregate. For a long time past it has been world widely used in road construction for its first-class physical characteristics (resistance to fragmentation, resistance to polishing) and chemical inertness. Slag application in the wearing course of pavements would certainly be most sensible. This kind of domestic slag application has never been used in the wearing course of pavements in Croatia until this year.

2. Experimental

The testing has been conducted on steel slag created during the production of EAF low carbon steel in Steel Mill of CMC Sisak, Croatia. Liquid steel slag was, after being poured out of the electric furnace cooled with water, after which it was subjected to the following procedures: grinding, magnetic separation in order to remove leftover particles of the cooled steel melt, fragmentation and sieving. The initial material had a grain size of 0/32mm and was crushed. In this way an average specimen of steel slag was created, as well as specimens of granulometric fractions (0/4mm, 4/8mm, 8/11mm, 8/16mm i 16/32mm).

As the objective and purpose of this paper were to test the suitability of EAFS for its application in the manufacture of asphalt mixtures, analyses were conducted, which are common when testing physical and chemical properties of natural mineral aggregates intended for the same purpose. The granulometric composition, the shape of the particle, the flakiness index, the shape index, resistance to fragmentation, density and water absorption, polished stone value, resistance to freezing and thawing, magnesium sulfate test, volume stability as well as the determination of resistance to thermal shock was examined according to the European Standards (EN 196-2, EN 933-1, EN 933-4, EN 1097-2, EN 1097-6, EN 1097-8, EN 1367-1, EN 1367-2, EN 1744-1 and EN 1367-5).

In order to determine basic properties of EAFS asphalt mixtures analysis were conducted as follows: granulometric composition was determined according to the norm EN 12697-2, soluble binder content (EN 12697-1), bulk density (EN 12697-6), maximum density (EN 12697-5), void content (EN 12697-8), void in the mineral aggregate (EN 12697-8), void filled with binder (EN 12697-8), Marshall test (EN 12697-34), water sensitivity of bituminous specimens (EN 12697-12), Indirect tensile strength of bituminous specimens (EN 12697-23), stiffness modulus (EN 12697-26), Wheel tracking (EN 12697-22, procedure B in air), Properties of pavement and skid resistance.

3. Results And Discussion

3.1. Chemical and mineralogical composition of EAF slag

Chemical analyses of EAFS have determined that CaO ranges in slag is 33.22 %, Fe_2O_3 29.64 %, SiO_2 10.86 %, MgO 13.09 %, Al_2O_3 1.66 %, MnO 6.18 %, Na_2O 0.02 %, K_2O 0.06 %. The mineralogical analysis of EAFS showed a very high crystalline nature, detecting the presence of the following: wustite (FeO), dicalcium and tricalcium silicates ($2CaO{\cdot}SiO_2$, C_2S and $3CaO{\cdot}SiO_2$, C_3S), brownmillerite ($Ca_2(Al, Fe)_2O_5$, C_4AF) and mayenite ($12CaO{\cdot}7Al_2O_3$, $C_{12}A_7$). The analyzed slag specimens do not have the glass stage, therefore the presence of chromite, as well as free CaO or MgO has not being identified.

The procedure of testing volume stability of the observed slag specimens has determined that the slag has the expansion of up to 2.9 %, thus placing it into the highest class (3.5 % is allowed) according to EN 13043.

3. 2 Geometric, physical, and mechanical characteristics of EAFS

Geometric properties of EAFS in terms of shape index and flakiness index satisfy the highest criteria (***FI_{10}; SI_{15}***). Granulometric composition of fraction 0/4mm satisfy the class **G_A85** while fraction 4/8, 8/16 mm by its granulometric composition satisfy the highest class ***G_C 90/10***, and the fraction 16/32 mm is classified as ***G_C 90/15***.

Resistance of EAFS specimen to wear in the wet state satisfies the highest class ***M_{DE}10*** and resistance to fragmentation via the Los Angeles method satisfies the highest class (***LA_{15}***). The determined densities of EAFS specimen is high, which was expected considering aggregate origin. Water absorption is bigger than 1%, and the tested durability via magnesium sulfate method, as well as frosting and defrosting method, and the final results satisfy the lowest classes. Affinity of aggregate to bituminous binder was good.

Table 1: Comparison of physical properties of EAFS and natural aggregates

Properties	EAFS	Natural aggregates	
		Diabaz Croatia	Carbonate Croatia
Resistance to fragmentation (LA)	13	15	29
Resistance to abrasion (micro-Deval)	8	8	11
Frost resistance (Mg_2SO_4, % by weight)	1.0	0.0	1.7
Frost resistance, freezing and thawing (% by weight)	0.4	0.0	0.3
Polished stone value, PSV	70	NA	32
Fines (% by weight)	0.5	0.5	NA
Water absorption (% by weight)	>1	<1	<1
Bulk density (Mg/m^3)	3.4	2.8	2.6
Volume stability (% V/V)	2.9	NR	NR

NR – Not relevant; NA – Not available

3. 3 Characteristics of EAFS asphalt mixture

Within the framework of the CMC Sisak project (*Possibility of metallurgic waste utilization in CMC Sisak, Croatia*), test fields have recently been constructed, whose purpose is to validate the suitability of slag aggregate for use in wearing asphalt courses. By means of laboratory analyses and in situ monitoring it should be possible to prove that asphalt mixtures containing EAFS have sufficient durability, and can achieve and maintain the required surface characteristics for road traffic safety.

On the basis obtained preliminary results the test field was constructed on Aug 30th 2009 by the Ceste Sisak d.o.o. It is located on county road in Petrinja town, SMŽ County.

The annual average traffic across the test field is 2000 vehicles per day. The width of the test field is 6m, its length is 200 m, and the thickness of asphalt layer is 4 cm.

Table 2: Testing results of physical and mechanical properties of asphalt mixture

Physical and mechanical properties of asphalt mixture	Unit	Test field	
		EAFS AB 11	Carbonate AB 11
Soluble binder content (EN 12697-6; point 9.3)	% (m/m)	5,1	5,4
Bulk density (EN 12697-6; point 9.3)	kg/m^3	2724	2368
Maximum density (EN 12697-5)	kg/m^3	2927	2469
Void content (EN 12697-8)	% (v/v)	6,9	4,1
Void in the mineral aggregate (EN 12697-8)	% (v/v)	20,6	16,6
Void filled with binder (EN 12697-8)	% (v/v)	66,3	75,4
Stability (EN 12697-34)	kN	15,2	11,7
Tangential flow (EN 12697-34)	mm	1,1	0,9
Flow (EN 12697-34)	mm	2,5	1,9
Marshall quotient (EN 12697-34)	kN/mm	6,1	6,2
Mass of dry sample	g	1249,7	1243,5
Testing temperature	^oC	25,0	25,0
Water sensitivity of bituminous specimens (EN 12697-12)	kPa	1608 (25^{o}C)	1513 (25^{o}C)
Water sensitivity of bituminous specimens (EN 12697-12)	kPa	1287 (40^{o}C)	1215 (40^{o}C)
Indirect tensile strength ratio	%	80,0	80,3
Indirect tensile strength of bituminous specimens	kPa	3988 (5^{o}C)	3638 (5^{o}C)
Indirect tensile strength of bituminous specimens	kPa	1847 (25^{o}C)	1700 (25^{o}C)
Stiffness modulus (IT-CY) (EN 12697-26)	MPa	7128	5642

* Natural carbonates (Tounj, Croatia)

The existing wearing course was replaced by an AC 11 type of asphalt, in one lane with conventional natural aggregate (carbonate aggregate *Tounj* 0/4, 4/8 and 8/16) and in the other lane with mixture 70% EAFS aggregate from CMC Sisak d.o.o. (0/4, 4/8, 8/11) and 30% natural carbonate aggregate 0/4 mm and bitumen standard grade 50/70.

The results of the examined asphalt mixtures with EAFS showed good results of physical and mechanical properties of asphalt mixture in comparison with asphalt mixture with natural aggregate, table 2.

The results of measurements of wheel tracking, table 3, skid resistance, and other properties, as well, on the section constructed using natural carbonate aggregate, and the section made using EAFS aggregate, were comparable.

Table 3. Wheel tracking, small size device, procedure B in air (EN 12697-22)

Parameter	Unit	Test field	
		EAFS AB 11	Carbonate AB 11
Wheel – tracking slope	mm/1000cycles	0,09	0,53
Proportional rut depth	%	5,7	18,4
Rut depth	mm	2,7	7,9

Both, skid resistance and surface texture are comparable. The levels of skid resistance are similar on both lanes, i.e. on the lane where there was the EAFS in the asphalt mixture, and on the lane where there was the natural stone aggregate, table 4.

Table 4. Skid resistance and surface texture

Parameter	Unit	Test field	
		EAFS AB 11	Carbonate AB 11
Skid resistance	SRT	48	50
Surface texture (sand)	mm	0,40	0,39

4. Conclusions

The results of the examined geometric, physical, and mechanical and durability properties indicate that the tested EAFS satisfy the characteristics necessary for their use in asphalt mixtures. The good volume stability (2.9%) of EAFS in relation to natural aggregates used in asphalt mixtures on highways and other top-class traffic load roads showed that examined slag has equally good properties, and can be used in the production of asphalt mixtures on test field.

After construction of the test field using EAFS aggregate it was found that no problems had been encountered in the designing of the mixture or in the placing of the asphalt in the test field. From the previous discussion, it is possible to indicate the demonstrated applications for EAFS asphalt mixtures in order of relative merit; surface course mixtures that take advantage of the excellent wheel tracking and skid resistance and good wear resistance of EAFS asphalt. It is necessary that the test field be subject to further monitoring, mainly with the aim of monitoring long-term changes in skid resistance.

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