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INVESTIGATING THE IMPACT OF USING SLAGS TO IMPROVE PAVEMENT STRENGTH PROPERTIES

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Resumen: Los agregados forman más de 75 wt o volumen de concreto y sus propiedades físicas y mecánicas tienen un efecto significativo en las propiedades del concreto. Los problemas medioambientales de las escorias de depósitos en el complejo de acero, por un lado, y la falta de fuentes adecuadas de agregados para diversas aplicaciones en el sector de carreteras, por otro, resultan en el uso de estas escorias para reemplazar los agregados naturales. Debido a las características de la escoria y también a la importancia y efecto de los agregados en las propiedades físicas de la resistencia del hormigón, en este estudio, las escorias se sustituyen por agregados naturales en el hormigón. El objetivo de este estudio es investigar la posibilidad de sustitución de la escoria como agregado en superficie de concreto e investigar su efecto sobre parámetros mecánicos de hormigón y pavimento. En el primer paso, para detectar la escoria consumida y sus propiedades mecánicas, se realizaron pruebas para considerar la posibilidad de utilizar los medidores de flujo de Zob Ahan Company en pavimento de hormigón como agregado. Después de esto, se hicieron muestras de cubo de hormigón con diferentes porcentajes de escoria de varios tipos diferentes de grado de cemento y después de 28 días de curado, se ensayó la resistencia a la compresión de los mismos. Mediante el uso de resultados de ensayos de resistencia a la compresión para diversos grados de cemento, se puede obtener una cantidad óptima y máxima de escoria para la construcción de pavimentos de hormigón. Dado que los parámetros más importantes en el diseño del pavimento de hormigón son su resistencia a la flexión y el diseño del pavimento se realiza en consecuencia, para cada grado de cemento y su escoria óptima, se hicieron vigas de hormigón 45 × 10 × 10 en laboratorio y se ensayaron resistencia a la flexión a alcanzar el módulo de rotura o resistencia a la flexión del hormigón. Finalmente, para evaluar el rendimiento del hormigón de los diseños de mezcla mencionados, se realizó una prueba de hormigón fresco. De acuerdo con los resultados de la investigación, el uso de escoria en hormigón como agregado causará una mejora en su resistencia a la flexión que el hormigón convencional.

Palabras clave: escoria, mejoras, pavimento, mejora de la calidad

Abstract: Aggregates form more than 75 wt or volume of concrete and their physical and mechanical properties have a significant effect on concrete properties. Environmental problems of depot slags in steel complex on the one hand and lack of suitable aggregates sources for various applications in the road industry on the other hand, result in the use of these slags to replace natural aggregates. Due to the characteristics of the slag and also the importance and effect of aggregates in physical properties of strength of concrete, in this study, slags are replaced with natural aggregates in concrete. The aim of this study first is to investigate the possibility of replacement of the slag as aggregate in concrete surface and investigating its effect on mechanical parameters of concrete and pavement work. In the first step, to detect consumed slag and their mechanical properties required tests were performed to consider the possibility of using Zob Ahan Company flow meters in concrete pavement as aggregate. After that, concrete cube samples with different percentages of slag several different types of cement grade was made and after 28 days of curing, compressive strength of them were tested. By using compressive strength test results for various grades of cement, optimum and maximum amount of slag may be obtained for the construction of concrete pavements. Since the most important parameters in the design of concrete pavement is its flexural strength and pavement design is done accordingly, for each grade of cement and its optimal slag, concrete beams 45 × 10 × 10 were made in laboratory and were tested on flexural strength to achieve modulus of rupture or flexural strength of concrete. Finally, to evaluate the performance of concrete from mentioned mix designs, fresh concrete test was performed on them. According to the results of the research, the use of slag in concrete as aggregate will cause an improvement in its flexural strength than conventional concrete.

Keywords: slag, upgrades, pavement, quality improvement

1. INTRODUCTION

The use of waste resulting from various industrial processes to obtain different products are important from different aspects (5). Help preserve irreplaceable resources, reduce environmental pollution and recover energy spent in process of producing these wastes are among the objectives of these materials usage. Slags are the byproduct of the production of iron and steel factories that are often stack as big depots (million tons) around the factories (12). Over the years, extensive researches have been done throughout the world to use this material and multiple fields for this purpose have been proposed. Some of the advantages of slag are high pressure and abrasion resistance, high internal friction angles, having corners and rough surface materials which can be used in different layers of road pavement. Slags have always been one of the major problems of steel factories because of considering large space for its depot. Allocation of this space can have heavy financial costs for these factories. In such circumstances where the presence of slag in these factories is harmful, the absence of aggregate in many other regions or countries creates problems for construction projects and increase the costs of building in these areas (2). If slags can be used as aggregate in construction projects, it is possible to solve problems of steel factories and lack of stone materials for these regions at the same time and also preserve the stone natural resources that are non-renewable that is very important from an environmental standpoint. The use of slags that have high strength and durability, result in increased bearing capacity of the road pavement. In many road projects carried out in developed countries to prevent many failures, they use slags as natural aggregates in different layers of pavement. In Iran steel factories produce 2 million tons of slag in which these slags can be used in road construction projects. The experience of using molten metal furnace slag in the construction of slag cement is more than a hundred years. Molten metals slag compared to steel slags have less active silica. Thus, the molten metal slag is used as pozzolanic materials in cement (7). In America and many European countries, they use slags in road pavement for a long time. The first use of slag in pavement dates back to 1960 in America and Canada Between 1970 and 1980 in Baltimore, many road pavement projects were conducted using slag. The use of slag were common in Europe and in European countries for many projects, the slag was used as an alternative for aggregate in the construction of pavement layers (basis, substantive and surface) (3). In the past two decades, according to conducted research, the scope of slag application is expanded and its use has grown dramatically in recent years. For example, the use of slag only in New York City was between more than 250 thousand tons 1990 and 1995 (4). Table 1 shows the advantages and disadvantages of slag.

Table 1.The advantages and disadvantages of slag

disadvantages	Advantages
Increase of bitumen in the slag asphalt than conventional asphalt	Use waste raw material at very low cost
Using the range of certain slag material gradation in asphalt	Reduced harvest of natural and mineral resources
Increase the density of asphalt and asphalt transportation costs	Improve at least 20 percent of the properties and life span of asphalt
	Relatively easy and functional technology
	Has a very long history of use in different countries

2. RESEARCH METHODOLOGY

In standards ASTM C33 the slag is mentioned as aggregate that can be used in the construction of concrete. For this reason in the first step, general tests for identification of consumed materials were made and using the slag as aggregate in concrete construction were carried out. After that, with respect to standard ACI 325.9R-99 and limitations of compressive strength in it, cubic samples with three cement grade 200, 300 and 350 kilograms per cubic meter and aggregate replacement percentages of 0, 25, 50, 75 and 100% of the slag were made and 28 days of curing they were tested for compressive strength. Then mix designs that in addition to the compressive strength limitations, have the highest percentage of slag were determined. In the next step, because of important role of modulus of rupture in design, beams were made out of mentioned mix designs and they were tested for flexural test and by doing fresh concrete tests slump, air content and determine the density of fresh concrete, performance of aforementioned mix designs and the possibility of using them in operating conditions were determined.

Conducted experiments on materials

In this study, two types of aggregates were used: natural aggregate and oxygen furnace slag (convertor).

Chemical analysis test

This test was done by wet method and the results are presented in table 4.

Table 2. Chemical analysis of converter slag (a) and converter sludge (b)

Amount (%)	Mixture
7.87	FeO
4.46	MnO
8.92	Si_2O
52.85	CaO
2.22	MgO
4.76	P_2O_5
0.78	AI2O3
0.057	ZnO
0.032	K_2O

Los Angeles abrasion test

To determine the slag resistance to abrasion, according to Standard ASTM C131, Los Angeles test was conducted on consumed material. In this test 250 grams of materials with size 19 mm and 2500 gr material with size 12 mm with 11 metal balls were put inside the device and results are presented in table 3.

Table 3. Results of Los Angeles abrasion test

Wear percentage	Construction materials remaining on sieve 12	Construction materials passed through sieve 12	Type of material
22/4	3880	1120	Natural
18/2	4090	910	Slag

Tests to determine the density and water absorption

Tests of density and water absorption for coarse and fine materials are separately done according to standards ASTM C127 and ASTM C128 and its result are used in mix design and with regard to this Water consumption and the materials needed can be obtained. The results of density tests and water absorption on natural aggregates and slag are presented in table 4.

Table 4. Results of density and water absorption test

Moisture percentage	density	Type of material	
1/1	2/53	Coarse grained	Natural aggregate of rock
4/9	2/56	Fine grained	
1/7	3/38	Coarse grained	Slag
6/8	2/93	Fine grained	

As can be seen the natural aggregates water absorption is generally between 1 and 4 percent and slags water absorption percentage is more than that of aggregates. This indicates the presence of more pores in the structure of slags to aggregates.

- **Aggregate health test**

To determine aggregate health we followed standard ASTM C88. Here the results are based on the use of sodium sulfate solution. Slag weight loss in health test is 0.4 that compared with natural aggregates (0 to 5%) shows a significant reduction. This indicates a good resistance of slags against corrosion compared to natural aggregates. With the help of these properties it is possible to use slag in construction sub-base layer on soils that use a high percentage of sulfate. In Management and Planning Organization Publication No. 101, the maximum weight loss of materials in sodium sulfate is limited to 12%. While the amount of weight loss obtained for the slag is much less than this amount. Also it should be noted that the aggregate resistance against magnesium sulfate is less than sodium sulfate and the allowable percentage weight loss of materials in sodium sulfate is limited to 18%.

- **Compressive strength tests**

After doing initial tests to detect consumed materials and examining the possibility of using slags rather than aggregate, in this step we should obtain mix designs that can meet the presented limitations in defining concrete pavement according to standard ACI 325.9R-99.

In this step of the test program, compressive strength test was performed on samples to obtain mix designs that meet the condition in standard ACI for compressive strength. From the 15 available designs the ones which have a resistance less than 6.27 MPa will be excluded.

- **Mix design**

In mix design three cement grade 200, 300 and 350 kg per cubic meter were used to investigate separately the impact of different percentages of replacement of natural aggregates with slag on the concretes with low cement, medium cement and high cement. Cement used for samples were the same and cement type 2 was used in the construction of all of them. Gradation used in the mix design was selected according to ASTM C33 with gradation lesser than 19 mm. in figure 1 the percentage used on each sieve is presented.

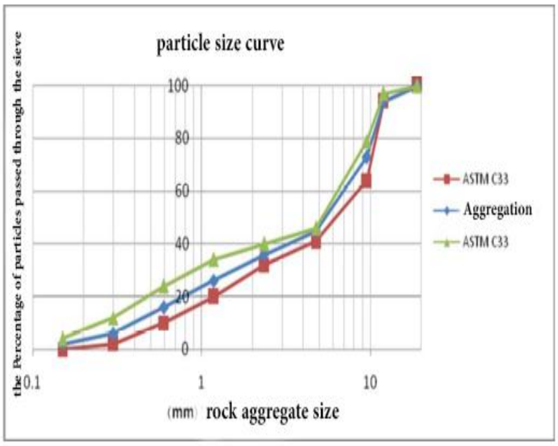

Figure 1. Gradation curves used in the mix design

Mix design properties for making one cubic meter of concrete are presented in the following table.

Table 5. Mix desi

200-100	200-75	200-50	200-25	200-0	Mixture design name	
200	200	200	200	200	Cement-kg	
156/4	150	143/5	137/1	130/6	Water-m3	
0	269	591	877	1169	Natural-kg	Coarse left on hairsievi 4
1552	1187	758	388	0	Slag-kg	Microlithic oasshng per 4
0	234	468	693	924	Natural-kg	Coarse left on hairsievi 4
1120	850	569	280	0	Slag-kg	Microlithic oasshng per 4

gns with grade 200 kg per cubic meter

Table 6. Mix designs with grade 300 kg per cubic meter

300-100	300-75	300-50	300-25	300-0	Mixture design name	
300	300	300	300	300	Cement-kg	
200/9	195/1	189/3	183/4	177/6	Water-m3	
0	264	527	791	1555	Natural-kg	Coarse left on hairsievi 4
1400	1050	700	350	0	Slag-kg	Microlithic oasshng per 4
0	208	417	625	834	Natural-kg	Coarse left on hairsievi 4
1011	758	506	253	0	Slag-kg	Microlithic oasshng per 4

Table 7. Mi

350-100	350-75	350-50	350-25	350-0	Mixture design name	
350	350	350	350	350	Cement-kg	
223/1	217/6	212/1	206/6	201/1	Water-m3	
0	249	499	748	998	Natural-kg	Coarse left on hairsievi 4
1325	993	662	331	0	Slag-kg	Microlithic oasshng per 4
0	197	394	592	789	Natural-kg	Coarse left on hairsievi 4
956	717	478	239	0	Slag-kg	Microlithic oasshng per 4

x designs with grade 350 kg per cubic meter

The following graphs are density – percentage graphs that were measured before breaking of samples.

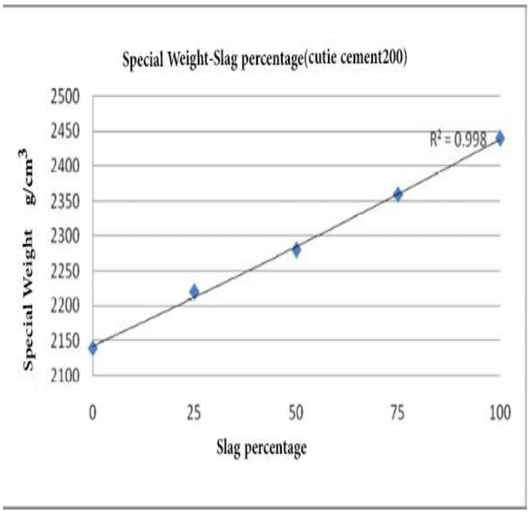

Figure 2. Density – percentage slag for samples with grade 200

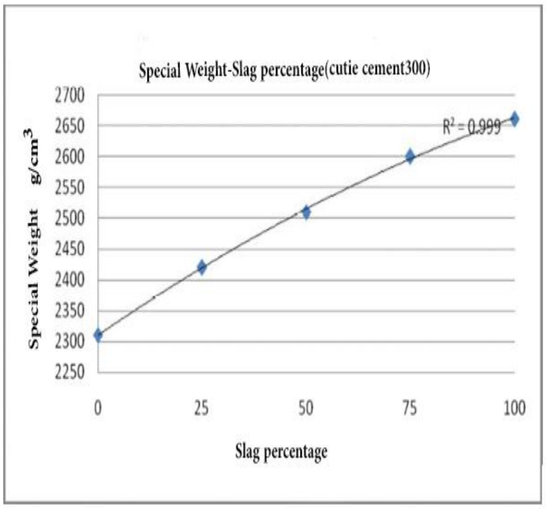

Figure 3. Density – percentage slag for samples with grade 200

Table 8: Physical Properties of concrete grade 200

Special weight-kg/m3	Dry weight-gr	Sample dimensions-cm			sample
	2419	10/24	10/04	10/07	350-0-1
2330	2414	10/14	10/1	10/04	350-0-2
	2439	10/34	10/07	10/1	350-0-3
	2535	10/26	10/04	10/02	350-25-1
2460	2557	10/3	10/08	10/01	350-25-2
	2551	10/24	10/02	10/06	350-25-3
	2647	10/25	10/08	10/02	350-50-1
2550	2660	10/22	10/04	10/09	350-50-2
	2641	10/29	10/1	10/04	350-50-3
	2706	10/15	10/1	10/13	350-75-1
2640	2718	10/18	10/07	10/07	350-75-2
	2764	10/27	10	10/09	350-75-3
	2843	10/3	10/04	10/04	350-100-1
2740	2827	10/21	10/08	10/06	350-100-2
	2844	10/18	10/09	10/07	350-100-3

Table 9: Physical Properties of concrete grade 350

Special weight-kg/m3	Dry weight-gr	Sample dimensions-cm			sample
	2371	10/22	10	9/98	300-0-1
2310	2279	10/04	10/03	10/06	300-0-2
	2435	10/22	10/06	10/06	300-0-3
	2505	10/33	10/03	10/03	300-25-1
2420	2478	10/14	10/02	10/05	300-25-2
	2503	10/22	10/06	10/05	300-25-3
	2538	10/12	10/01	10/04	300-50-1
2510	2576	10/21	10	10	300-50-2
	2557	10/12	10/05	10/06	300-50-3
	2676	10/16	10/01	10/14	300-75-1
2600	2640	10/12	9/98	9/96	300-75-2
	2647	10/19	10/04	10/02	300-75-3
	2830	10/27	10/07	10/13	300-100-1
2660	2722	10/22	10/05	10/08	300-100-2
	2763	10/19	10/08	10/04	300-100-3

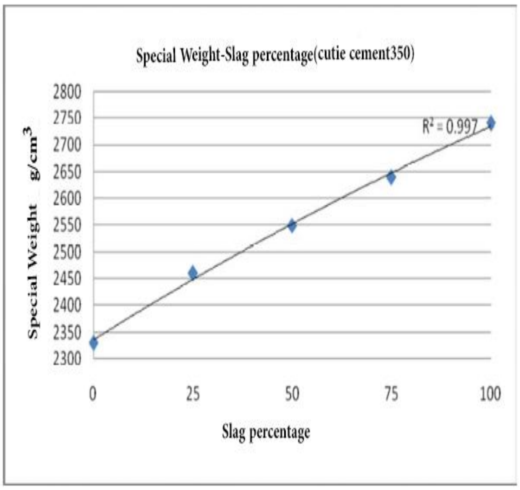

Figure 4. Density – percentage slag for samples with grade 350

3. FINDINGS

In this study after making three samples for each mix design and curing for 28 days, samples broke down under compressive strength test and the results are presented in the following table and graphs:

Table 10. Compressive strength test results for samples of cement grade 200

Sand ratio to total aggregate:0/6	Water to cement:0/5	Cement fineness:200 kg/m3
Pressed resistance	Special weight-kg/m3	design name
21/5	2140	200-0
22/2	2220	200-25
19/8	2280	200-50
16/4	2360	200-75
12/8	2440	200-100

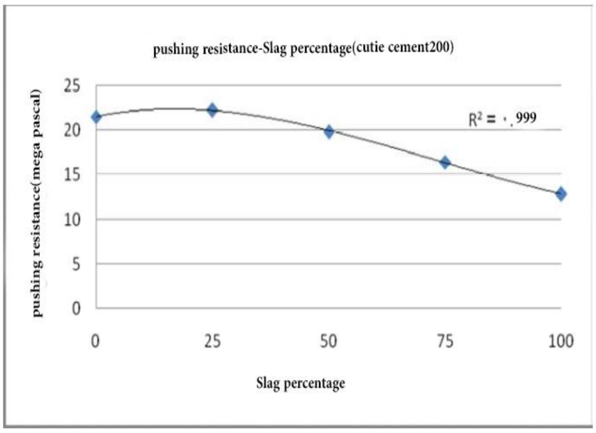

Figure 5. Slag density – percentage cure for samples with grade 200

Table 11. Compressive strength test results for samples of cement grade 300

Sand ratio to total aggregate:0/6	Water to cement:0/5	Cement fineness:300 kg/m3
Pressed resistance	Special weight-kg/m3	design name
25/6	2310	300-0
37/1	2420	300-25
34/3	2510	300-50
33/4	2600	300-75
25/7	2660	300-100

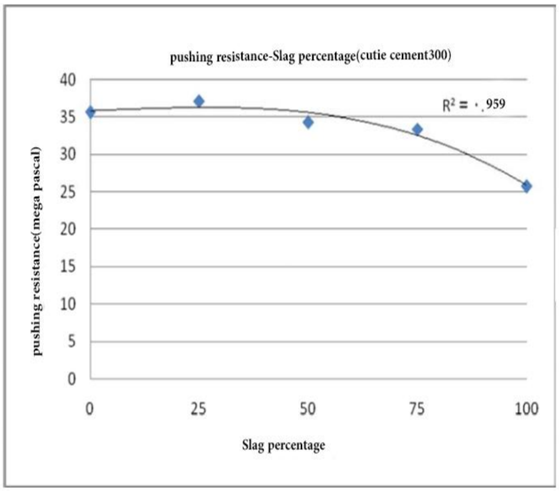

Figure 6. Slag density – percentage cure for samples with grade 300

Table 12. Compressive strength test results for samples of cement grade 300

Sand ratio to total aggregate:0/6	Water to cement:0/5	Cement fineness:350 kg/m3
Pressed resistance	Special weight-kg/m3	design name
46/1	2330	350-0
48/9	2460	350-25
44/2	2550	350-50
40/7	2640	350-75
34/4	2740	350-100

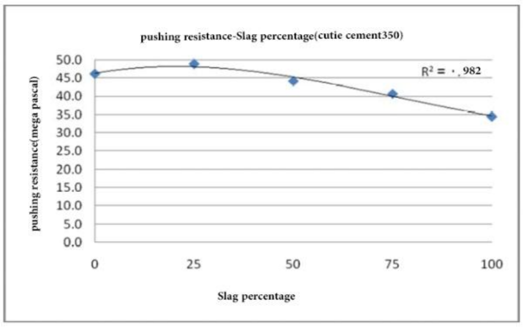

Figure 7. Slag density – percentage cure for samples with grade 350

With regard to the test results as it is clear from the graphs, with an increase in cement grade, the compressive strength of samples increases.

4. CONCLUSION

According to the obtained results of tests on slag it can be concluded that slag can be a suitable substitute for natural aggregates and it is possible to use it on constructing base, sub-base, concrete and asphalt pavement, traverse aggregate context etc. So the overall results of the tests are:

- Compressive strength test results show that 25 percent strength of iron slag increases the compressive strength of concrete.
- With the increasing substitution of slag to more than 25 percent, the graph takes downward trend. When the percentage of slag use becomes more 75 percent, downward sloping graph gets faster and concrete compressive strength 100% slag drops sharply.
- Due to minimum compressive strength stated at ACI 325.9R-99 for concrete pavement, it concrete with grade 350 kg per cubic meter we can replace all aggregates and concrete grade 300 kg per cubic meter up to 75% them with slag.

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