DESIGNING OF HIGH DENSITY CONCRETE BY USING STEEL TREATMENT WASTE

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Abstract. High density concrete is widely used in railway, crane counterweight, radiation shielding in nuclear plants or other radiation related application in medical establishment. The aim of this study is to increase the density of concrete and accomplish it by using steel treatment waste as aggregates- iron dross (mainly iron oxides) and steel punchings which are locally available.

Two different mixes with the same w/c ratio and cement content were designed by using fine grinded iron dross and a mix of steel punchings with sizes less than 11.2 mm as aggregates. The traditional concrete aggregates were replaced by steel treatment waste in the amount of 50% and 100%. Physical and mechanical properties (density, compressive and tensile strength, freeze-thaw resistance and others) were determined for obtained concrete. The concrete with density up to 4640 kg/m3 was obtained in this study.

Keywords:.high density concrete, steel treatment waste, aggregates, steel punchings, iron dross, mechanical properties.

1. Introduction

Conventional concrete is used worldwide in building industry mainly produced from water, cement, traditional silico-calcareous aggregates (sand, gravel) and chemical admixtures (superplasticizers, air entrainers, set retarders etc.). There is a possibility reusing industrial solid waste as a partial replacement of aggregate in construction activities. It not only saves environment and landfill space but also reduces the demand for extraction of natural raw materials. Preserving natural aggregates is a matter of sustainable development to ensure sufficient resources for future generations (Rakshvir and Barai, 2006).

With increasing environmental pressure to reduce waste and pollution and to recycle these one as much as possible, the concrete industry has begun adopting a number of methods to achieve these goals (Sear, 2005). Sustainable construction requires a critical review of prevailing practices, techniques and sources of raw materials. In recent years, focus has been turning to natural and industrial wastes and byproducts that have previously received little attention (Bai et al., 2005). Recycling is a logical option for materials not suitable for composting. Plastics, metals and glass are the most common materials (Hawken, 1994).

Concrete with density higher than 2900 kg/m^3 is called high density concrete. The density of concrete can be increased by using high-weight aggregates, such as barite, hematite, iron ore and steel shot with densities over 4000 kg/m^3 (Topçu, 2003). Using steel treatment waste products- iron dross and steel punchings as high-weight aggregates can be beneficial and solve the waste and pollution problem. High density concretes are widely used as railway, crane counterweight, radiation shielding in nuclear plants or other radiation related application in medical establishment (Mehta and Monteiro, 2006).

Since approximately three-quarters of the volume of concrete are occupied by aggregate, it is not surprising that aggregate quality is of considerable importance. Not only can the aggregate limit the strength of concrete, but the aggregate properties also greatly affect the durability and structural performance of the concrete (Neville and Brooks, 1990).

Ismail and AL-Hashmi examined the potential for using waste iron in concrete mixes as a partial replacement for sand. The experimental study indicated that conversion of iron waste into aggregates could offer a feasible solution for waste management. The tests of those waste-iron concrete mixes revealed that this method performed efficiently to improve compressive, flexural strength, increase density, but decrease the slump value.

Topçu in his work used barite aggregate instead of traditional silico-calcareous aggregate to increase its weight. He prepared several concrete mixes at different w/c ratios to determine the most favorable w/c ratio of high density concrete produced with barite. It was concluded that the most favorable w/c ratio is 0.40 and the cement dosage should be greater than 350 kg/m^3.

Kilincarslan et al. have performed an experimental work to investigate the effect of barite rate in concrete mix on physical and mechanical properties of concrete. It was obvious that the density of concrete increased with the increase of barite rate in concrete. 3507 kg/m^3 was the maximum value of concrete density obtained in this work.

2. Experimental study

2.1 Materials

Ordinary Portland cement Type I CEM I 42.5 N was used in this study. The chemical composition and physical properties of the cement are presented in Tables 1 and 2, respectively. Superplasticizer Sikament 50/56 was used to provide mix fluid consistency and minimize water/cement ratio.

Table 1. Chemical composition of cement

Compounds	% (by weight)
CaO	60.720
SiO_2	18.680
Al_2O_3	4.990
MgO	4.560
Lime	4.400
Fe_2O_3	3.020
SO_3	2.860
Loss of ignition	2.450
K_2O	1.680
Na_2Oekv	1.220
Insouluble residue	0.690
Na_2O	0.110
Cl^-	0,004

Table 2. Mechanical and Physical properties of cement

Properties	Value
Compressive strength (Mpa):	
1 day	14
2 days	27
28 days	51
Setting time (min)	200
Fineness (m^2/kg)	330
Bulk density (kg/m^3)	1200

The natural aggregate was sand and gravel with maximum sizes of 4 mm and 12 mm, which were obtained from local dolomite mining and processing company. The physical properties and gradation of the sand and gravel were obtained according to LVS EN 1097 and LVS EN 933 and are shown in Table 3 and Fig. 1, respectively. Two different aggregates with high density (iron dross and steel punchings) were used as replacement material for natural aggregates previously named with the aim to produce concrete with extra high density.

Quantities of iron dross are produced annually in Latvian metallurgical JSC "Liepajas metalurgs". The iron dross is a steel treatment waste which is produced in steel rolling process, when the outer layer of heated steel oxidizes by the presence of air. A sample of the iron dross "as received" from the factory is shown in Fig. 2. The mineralogical content of iron dross was determined by X-ray analyze. Iron dross contains FeO, α-Fe_2O_3 and MgO·40CuO·10ZnO·50Fe2O4. The particle geometry of iron dross was basically placoid.

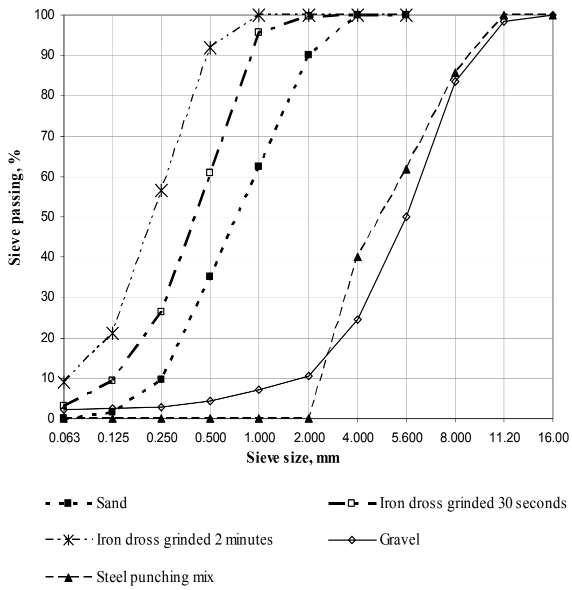

Fig. 1. Aggregate grading curves

Fig. 2. Sample of iron dross

The iron dross was pretreated before using it as aggregate for production of concrete. It was ground in planetary ball mills with nominal speed of 300 rpm in order to obtain aggregates suitable for replacement of natural sand. Two aggregates with different particle sizes were obtained by grinding the iron dross for 30 seconds and 2 minutes. The physical properties and gradation of the iron dross grinded 30 seconds and 2 minutes are shown in Table 3 and Fig. 1, respectively.

Table 3. Physical properties of aggregates

	Iron dross aggregate		Mix of steel punchings	Natural aggregate	
	30 seconds grinded	2 minutes grinded		Sand	Gravel
Density (g/cm^3)	5.20	5.20	7.80	2.60	2.65
Bulk density (g/cm^3)					
Freely settled	2.77	2.96	4.08	1.62	1.62
Tapped	3.33	3.95	4.52	1.73	1.75
Void ratio (%)					
Freely settled	47	43	48	38	39
Tapped	36	24	42	33	34
Fineness modulus	2.1	1.3	-	3.0	6.2

Steel punchings with cylindrical form and different diameters and heights were obtained as waste products from "Driving Chain Factory Ditton". The description of steel punchings parameters is given in Table 4. The mix of steel punchings was created in order to get high-weight concrete aggregates with an acceptable gradation for use of them as coarse-grained aggregate in concrete composition. The maximum steel aggregate size is 11.2 mm. The mix of steel punchings is shown in Fig. 3. The physical properties and gradation of the mix of steel punchings are shown in Table 3 and Fig. 1, respectively.

Table 4. Cylindrical form steel punchings sizes

Steel punchings	Diameter; mm	Height; mm
1	3.6	1.3
2	4.5	1.3
3	4.9	1.4
4	5.3	1.1
5	6.4	1.6
6	7.2	1.7
7	7.7	2.9
8	11.7	3.8

Fig. 3. Mix of steel punchings

2.2 Mix compositions

Multi-component aggregate mix was used with the aim to provide optimal particle packing and good mix workability (Shakhmenko, 2004). Two types of concrete mixes with the same w/c ratio 0.47 and cement content of 470 kg/m^3 were designed with high density waste aggregate (fine grinded iron dross and mix of steel punchings) and natural aggregate. Fine grinded iron dross and a mix of steel punchings were used (in 50% (S50) and 100% (S100)) for replacement of traditional concrete aggregate. The third generation superplasticizer was used for production of concrete mix in the amount of 1.5 % from cement mass. Details about aggregate proportions in concrete mixes are given in Table 5. In both mixes the iron dross and steel punchings proportion was 2:3.

Table 5. Details about aggregate proportions

Concrete mix	S50	S100
	% aggregate	
High-weight waste aggregate:	50	100
Iron dross:		
Grinded 30 seconds	5	20
Grinded 2 minutes	15	20
Mix of steel punchings	30	60
Natural aggregate:	50	-
Gravel	35	-
Sand	15	-

2.3 Casting, curing and testing

All ingredients were weighted on laboratory scales and mixed in drum mixer. To determine mechanical and physical properties 100 x 100 x 100 mm cubes were casted in plastic molds. The casting and curing was performed according to LVS EN 12390-2. Concrete casting was accomplished in two layers of 50 mm each. Instead of vibrating table, to avoid high density aggregate segregation, the concrete compaction was performed shaking it 10 times against solid surface with range 10…20 mm. After it was kept 24 h at room temperature and covered with plastic membrane to avoid water evaporation, the concrete was demolded, marked and submerged into clean water at 20±2 °C till the testing. The slump test was carried out according to LVS EN 12350-2.

Physical properties of concrete specimens were tested after 28 days of curing. Hardened concrete density was determined according to LVS EN 12390-7.

Compressive strength tests were carried out at the ages of 7 and 28 days. The cubes were tested according to LVS EN 12390-3. Tensile strength test was carried out at the age of 28 days according to LVS EN 12390-6. Tested cubes were in saturated surface dry condition.

Freeze-thaw resistance for obtained concrete was tested according to LVS CEN/TS 12390-9. The CDF (Capillary suction of De-icing solution and Freeze-thaw test) method has been chosen for freeze-thaw resistance. The test contains from 28 freeze-thaw cycles and the cube lateral surfaces are covered with a solvent-free epoxy resin. The specimen is tested only from one open surface in the presence of 3 mass% sodium chloride and 97 mass% demineralized water. One cycle lasts 12 hours and the temperature amplitude is from -20 °C to +20 °C. The result is expressed in the total amount of scaled material related to the test surface after *n*th cycle m_n:

$$m_n = \frac{\sum \mu_s}{A} \cdot 10^6; g/m^2 \qquad (1)$$

where μ_s is the mass of scaled material (g), A is the area of test surface (mm^2). The amount of scaling was determined after 14 and 28 freeze-thaw cycles. The mean value of scaling at 1500 g/m^2 after 28 freeze-thaw cycles proves to separate sufficiently well concrete with high resistance against freeze-thaw attack from less resistant concrete.

3. Results and discussion

3.1 Workability

The slump of S50 concrete mix was 19.2 cm, but slump of concrete mix S100 was 17.3 cm. The test results show that there is a decrease in slump with an increase in the steel treatment waste in concrete mixes. It might be due to the angular shapes of iron dross and steel punching particles.

3.2 Physical properties

The results of density, water absorption and open porosity are given in Table 6. Both mixes using steel treatment waste showed higher density than conventional concrete with density of 2400 kg/m^3. The densities of concrete specimens made with 50% and 100% steel treatment waste aggregate increased 1.47 and 1.93 times, respectively, compared with the density of conventional concrete. This tendency can be attributed to the fact that the bulk density of iron dross and steel punchings is 2 and 3 times higher than for the natural aggregates. No significant difference was established in open porosity and water absorption between concrete mixes.

3.3 Compressive and tensile strength

Results of the compressive and tensile strength tests for the concrete specimens are given in Table 7. There is possible to conclude that the compressive strength of high weight concrete decreases with increasing of steel treatment waste in the composition. The final compressive strength of concrete specimens with 50% and 100% steel treatment waste aggregate was 40.7 and 36.6 MPa. This trend might be due to the aggregate angular shape and smooth surface of steel punchings, creating a weak contact zone between the cement paste and aggregate. The tensile strength of concrete samples cured for 28 days was not significantly affect by increasing the steel treatment waste aggregate in the concrete composition.

3.4 Freeze-thaw resistance

Table 8 presents the total amount of scaled material related to the test surface after 14 and 28 freeze-thaw cycles. Concrete specimens made by using 50% steel treatment waste aggregate showed a scaling value 5605 g/m^2 after 14 freeze –thaw cycles. Since the result remarkably (3.74 times) exceeded 1500 g/m^2 (LVS CEN/TS 12390-9), the concrete mix was declared as poor resistant against freeze-thaw attacks and excluded from further test procedure. Scaling value of 1206.7 g/m^2 was obtained for concrete mix S100 after 28 cycles, proving to be well resistant against freeze-thaw attacks.

Table 6. Physical properties of concrete mixes

	S50	S100
Density (kg/m^3)	3520	4640
Open porosity (%)	4.9	5.1
Water absorption (%)	1.4	1.1

Table 7. Compressive and tensile strength

	S50	S100
Compressive strength (Mpa):		
7 days	35.4	32.0
28 days	40.7	36.6
Tensile strength (Mpa)	4.10	4.15

Table 8. Amount of scaled material

	S50	S100
Value of scaling (g/m^2):		
14 cycles	5605.0	886.7
28 cycles	-	1206.7

4. Conclusions

The experimental results show that steel treatment waste products – iron dross and steel punchings- can be used as aggregates for production of high density concrete.

It was feasible to design a concrete with density up to 4640 kg/m^3 by using steel treatment waste as aggregate.

The slump for S50 and S100 was 19.2 and 17.3 cm and compressive strength for S50 and S100 was 40.7 and 36.6 MPa. The slump and compressive strength values decreased with an increasing content of steel treatment waste in concrete composition, which might be due to the angular shape of waste aggregate.

Concrete specimens with 100% steel treatment waste aggregate (S100) showed to have high resistance against freeze-thaw attacks with a scaling value of 1206.7 g/m^2 after 28 freeze-thaw cycles.

Concrete specimens with 50% waste aggregate (S50) failed the test with a scaling value of 5605 g/m^2 after 14 freeze-thaw cycles and were declared as poor resistant concrete against freeze-thaw attacks.

This study demonstrates the potential use of steel treatment waste as high density aggregate and requires further research.

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