

POSSIBILITIES OF APPLICATION IRON CONTAINING WASTE MATERIALS IN MANUFACTURING OF HEAVY CONCRETE

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ABSTRACT

Rational use of highly dispersed metal waste is an important issue of material science and environment protection. The quantity of the powdered metallic materials used in industry is steadily increasing; they are especially widely used in the enterprises producing iron powders, in metal sheet production, as well as in abrasive machining. This paper presents an analysis of several kinds of metal waste such as iron and steel powders, mill scales, steel punching, metal shavings and other iron-containing waste from mechanical engineering and metallurgy industries, and the possibility of their use in the manufacturing of concrete products like fillers. This study investigates properties of the samples of the concrete manufactured using highly dispersed metallic fillers. The highest density obtained is in the range of 4000 - 4500 kg/m³. The common characteristics of the aforementioned materials are their low cost, availability and thus the potential for large production volumes, need for recycling, and tendency to further oxidation and corrosion.

Key words: metal fillers, heavy concrete, metal powders, metal dust, mill scale, steel punching

INTRODUCTION

A broad study of heavy concrete manufactured with iron inclusions commenced after the scientific publication "Strength and Fracture Toughness of Heavy Concrete with Various Iron Aggregate Inclusions" published in 2004 (Kan, Pie, Chang, 2004). The research in Latvia was launched in 2009 at the Riga Technical University and still is in progress. The result of the investigation at the Institute of Building Production is a patent of the Republic of Latvia LV 14019 B (V. Mironovs, Zemčenkovs, Korjakins, Šahmenko, 2010).

Heavy concrete materials are those with the density greater than 2600 kg/m³. In order to achieve higher density traditional fillers of concrete (sand, gravel, crushed rocks) are entirely or partially replaced with other materials with larger specific gravity - e.g., magnetite, hematite, barite, iron and steel powders, mill scales, steel punchings, metal shavings etc. For manufacturing heavy and extra heavy concrete the most commonly used material is either Portland cement or alumina cement (Chundelly, Geeno, 2001). Heavy concrete is used for the manufacturing of anchors, pontoons and contra weights, as well as in hydro technical structures and radiation shielding and storage.

In the production of metal powders and their manufactures the waste is generated in different

stages – dust particles on the filters, waste on sieves, powders from setting up equipment etc. (Дьячкова, Керженцева, Маркова, 2004).

Rational use of highly dispersed metal waste is an important issue of material science and environment protection. The quantity of the powdered metallic materials used in industry is steadily increasing; they are especially widely used in the enterprises producing powders, in metal sheet production, as well as in abrasive machining (Делюсто, 2002).

The common characteristics of the aforementioned materials are their low cost, availability and thus the potential for large production volumes, need for recycling, and tendency of further oxidation and corrosion. Considering the current economic situation in the construction industry in Latvia, economy of resources, reducing consumption of materials, and development of new materials with special properties such as high density and durability are the tasks of major importance.

1. PROPERTIES OF IRON CONTAINING CONCRETE FILLERS

1.1. Metal powders

This study analysed powders SC100.26 (Fig. 1), MH.80.23 and ASC.100.29 from the Swedish Company Höganäs AB.

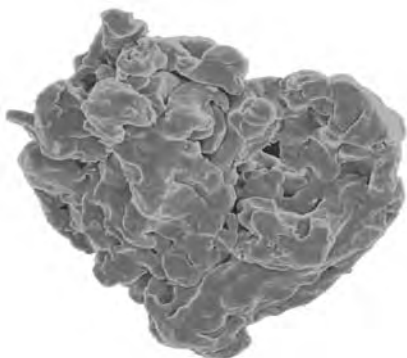


Figure 1. Powder SC100.26 microstructure (average particles size is 45 – 150 μm).

The metal powder SC100.26 has the best compressibility of all Höganäs sponge iron powder grades. The green strength is also high. It should be used particularly if high density after single pressing and sintering is desirable. MH80.23 is specially designed to match the requirements for self-lubricating bearings. Its range of the particle size is chosen to give an optimum pore structure for this application. The metal powder MH80.23 can also be added to powder mixes in small quantities to substantially improve green strength. The metal powder ASC100.29 is an atomised iron powder with a very high compressibility, which makes it possible to single press compacts with densities of up to 7.2 g/cm³. ASC100.29 is particularly suited for high density structural parts and as a base material for soft magnetic applications (Höganäs AB, 2010).

The iron content in powders is greater than 95%. The sieve analysis is shown in Fig. 2.

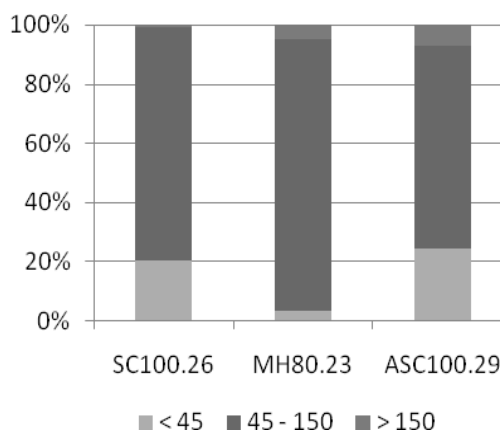


Figure 2. Sieve analysis, μm.

Table 1
Apparent density and flow of metal powders

Metal powder	AD, g/cm ³	Flow, s/50 g
SC100.26	2.68	29
MH80.23	2.30	34
ASC 100.29	2.98	24

The apparent density and flow of the aforementioned powders are shown in Table 1.

1.2. Metal dust

Air filters in manufacturing enterprises collect large amounts of dust. The Swedish company Höganäs AB delivers this waste material to consumers under the brand CMS (Fig. 3).

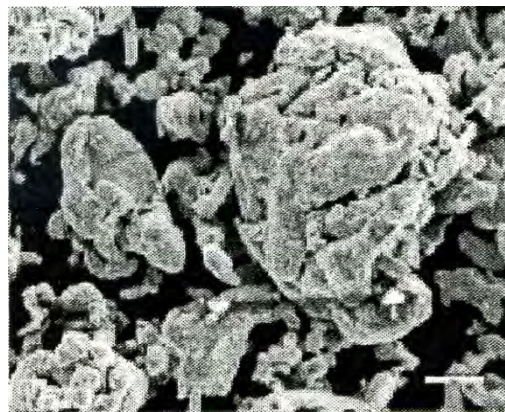


Figure 3. Microstructure of CMS.

Table 2
Sieve analysis of powder CMS 95

	<45, μm	45<212, μm	>212, μm
Test results	56.8%	43.2%	0.0%
Min	35.0%		
Max			1.5%

The product has high iron content (guaranteed over 90%), and its sieve analysis is shown in Table 2.

1.3. Mill scales

Mill scale is flaky dross obtained in rolling red hot steel or in steel mills. The thickness of the dross layer is approximately 10 – 15 microns.

The main components of iron dross are Fe₂O₃ (hematite), Fe₃O₄ (magnetite) and FeO. The properties of iron oxides are shown in Table 3.

Table 3
Properties of iron oxides

	FeO	Fe ₃ O ₄	Fe ₂ O ₃
Molar mass, g/mol	71.84	231.52	159.68
Specific gravity, g/cm ³	5.28	5.20	5.12
Hardness, HV	270 – 350	420 – 500	1030
Part of mass in mill scale	50%	40%	10%

The study used mill scale from the rolling of steel reinforcement supplied by “Liepajas Metalurģs” (Latvia). The particles of raw mill scale are shown in Fig. 4.

The iron content in the mill scale is greater than 70%, humidity from 1 to 5 % and specific gravity of the material is $5.2 \div 5.5 \text{ g/cm}^3$.



Figure 4. Raw mill scale from JSC “Liepajas Metalurgs”.

The mill scale had an apparent density of $1.9 \div 2.1 \text{ g/cm}^3$ and hardness from 200 to 500 HB. The sieve analysis of the mill scale is shown in Table 4.

Table 4
Sieve analysis of raw mill scale

<150, μm	150 – 300, μm	300 – 600, μm	> 600, μm
34.73%	25.25%	10.82%	29.20%

In order to decrease the size of the particles, it is possible to process the raw mill scale. One of the methods is grinding.

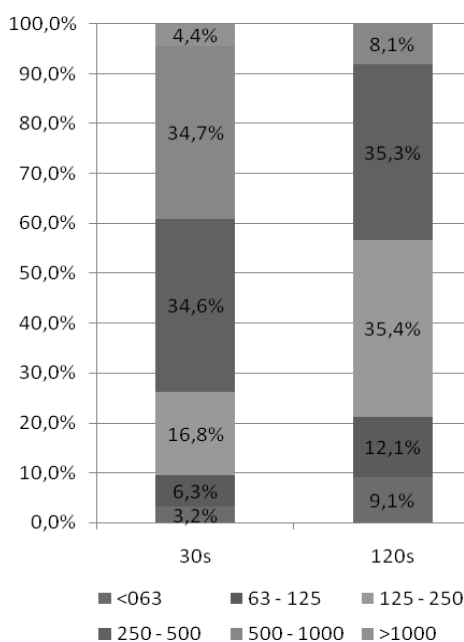


Figure 5. Sieve analysis of grinded mill scale, μm.

Table 5
Sieve analysis of grinded mill scale

Particle size, μm	Grinded mill scale	
	30 s	120 s
<063	3.2%	9.1%
63 – 125	6.3%	12.1%
125 – 250	16.8%	35.4%
250 – 500	34.6%	35.3%
500 – 1000	34.7%	8.1%
>1000	4.4%	0.0%

Fig. 5 and Table 5 present the sieve analysis of 30 s and 120 s grinded mill scales. It was ground in planetary ball mills with nominal speed of 300 rpm (Kazjonovs, Bajare and Korjakins, 2010).

1.4. Steel punching

One kind of steel scrap is steel punching, which is formed by cutting sheet materials (Fig. 6).



Figure 6. Steel punching from JSC “DITTON Driving Chain Factory” (Latvia). Diameter $3.0 \div 10.8 \text{ mm}$, height $0.5 \div 3.3 \text{ mm}$. The specific gravity of steel punching is 7800 kg/m^3 .

This research used punching formed by the stamping of circuit elements supplied by the enterprise JSC “DITTON Driving Chain Factory” (Latvia). The cuttings have a round shape and various geometric dimensions, the diameter and thickness of the samples are shown in Table 6. The specific gravity of steel punching is 7800 kg/m^3 .

Table 6
The size of steel punching

	Steel punching types							
	D, mm	3.0	3.9	4.6	5.8	6.4	7.1	10.8
H, mm	0.7	0.8	0.5	1.0	1.0	2.3	3.3	

The investigation of the properties reveals that hardness of the elements is up to 100 HB.

2. HEAVY CONCRETE COMPOSITIONS AND PROPERTIES

2.1. Mixture proportioning and preparation

This study analysed prepared types of heavy concrete S1 and S2 that are patented in Latvia (Mironovs, Zemčenkovs, Korjakins, Šahmenko, 2010). The components used in manufacturing heavy concrete and their part of mass are shown in Table 7.

Table 7
Heavy concrete compositions (by weight)

Component	Mix	
	S1	S2
Cement CEM I 42.5N	1.00	1.00
Mill scale	3.95	3.49
Sand	0.65	0.00
Steel punchings	0.00	2.69
Metal powder	0.00	1.62
Superplasticizer	0.015	0.016
W/C ratio	0.55	0.62

Several ingredients are prepared before application, e.g., the steel punching is cleaned of oil that is applied in the manufacturing process. The traditional concrete component sand is applied as fine filler in the mix S1. In the second mix S2 all traditional concrete components are replaced with iron containing waste materials.

In order to improve the workability of the mix and reduce W/C ratio, a superplasticizer is added in both mixtures. Optimisation of packing is applied to decrease W/C ratio of the concrete and enlarge its density. Vibration of the concrete is used briefly to avoid the segregation as a result may be issued of metal filler higher specific gravity. Three specimens have been prepared as for compression tests as well for tensile test using each concrete composition S1 and S2. To provide detailed properties of the concrete, this study also discusses two heavy concrete types S50 and S100 from the scientific publication "Designing of High Density Concrete by Using Steel Treatment Waste".

Table 8
Details about aggregate proportions

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

The heavy concrete S50 and S100 and their aggregate proportions are shown in Table 8, the mechanical and physical properties in Table 9 and Table 10 respectively (Kazjonovs, Bajare, Korjakins, 2010).

2.2. Properties of mix

The physical properties of the heavy concrete samples are shown in Table 9. As expected, the iron containing waste materials heighten the density of the product.

Table 9
Physical properties

Concrete type	Density, kg/m ³
S1	3200
S2	4300
S50	3500
S100	4600

The highest density obtained in this study is in the range 4000 – 4500 kg/m³. Also, approximate expenses were estimated for heavy concrete mixtures. The higher density sample had greater expenses mainly due to the metal powder used as fine filler. After 28 days the samples were tested in compression and tension. The results are shown in Table 10.

Table 10
Mechanical properties (after 28 days)

Concrete type	Compressive strength, MPa	Tensile strength, MPa
S1	50.7	7.15
S2	43.1	6.32
S50	40.7	4.10
S100	36.6	4.15

The results show that S2 mixture has lower strength in compression and tension than S1 mixture. The structure of a split S2 sample is shown in Fig. 7. Another potential drawback of steel punching is corrosion that should be tested in further researches.

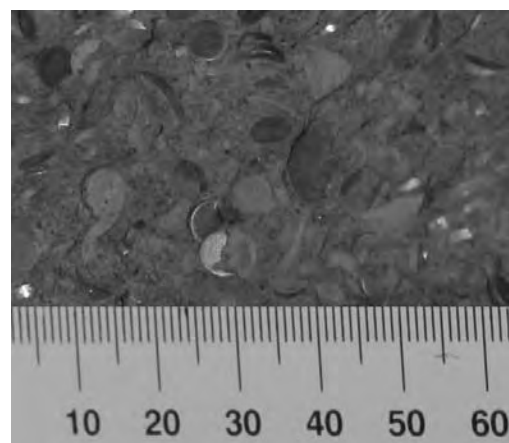


Figure 7. Structure of S2 mixture sample.

The research by Kan, Pie and Chang (2004) reveals that the elastic modulus of heavy concrete is higher than for the regular concrete mortar. Moreover, it is increasing with the increase of iron ore. As shown in Fig. 8, heavy aggregate inclusion of 48.8% in the volume makes the elastic modulus of concrete raise approximately 1.5 times that of regular mortar.

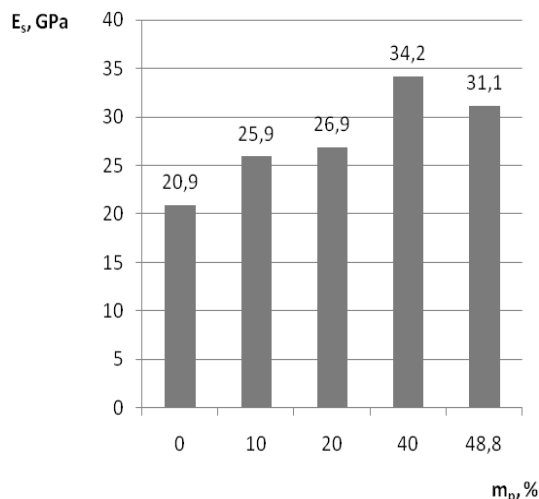


Figure 8. Modulus of elasticity for concrete with various metallic aggregates.

However, it does not make the compressive strengths too much difference as previously mentioned (Kan, Pie and Chang, 2004).

3. APPLICATION POSSIBILITIES OF HEAVY CONCRETE

Heavy concrete has high application possibilities in the field of contra weights. The main contra weight material properties are their high density, fine resistance to external environment impacts and low production cost.

Contra weights are used to ensure stability of enginery – e.g., machinery, lifts, bridges, floodgates, cranes etc. (Mehta and Monteiro, 2006)

It is also effective to use heavy concrete in underwater constructions due to its high density that is more notable because of the buoyant force (1), namely, the weight in the water depends on the material mass and density.

$$P = mg \left(1 - \frac{\rho_w}{\rho_m}\right) \quad (1)$$

where P – weight in water, N;
m – mass of manufacture, kg;
g – gravitational acceleration, m/s²;
 ρ_w – density of water, kg/m³;
 ρ_m – density of material, kg/m³.

Heavy concrete can be used to manufacture the substructure of breakwaters. Another perspective

product category includes anchors which would be suitable in fast currents or rocky seafloor. The Institute of Building Production has developed the construction scheme of such anchor that is shown in Fig. 9.

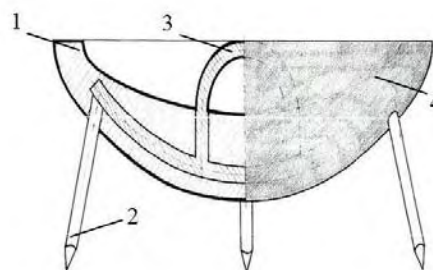


Figure 9. Construction scheme of anchor (1 - heavy concrete body, 2 – metal pine, 3 – metal ring, 4 – rubber cover).

The rubber cover is used to avoid unfavourable impacts of sea water and possible corrosion. In this study were produced anchor model made of heavy concrete with the density approximately 4300 kg/m³ (Fig. 10).



Figure 10. Anchor model.

Heavy concrete could also be used as a radiation shielding material in nuclear stations and buildings with heightened radiation level. There are two types of radiation:

1. X-rays and gamma rays. According to the Compton scattering effect, the attenuation efficiency is approximately proportional to the mass of the material used in the shield of radiation (Mehta and Monteiro, 2006). Also, researches confirm that the attenuation coefficient depends on the density of the concrete (Ismail and Al-Hashmi, 2008).
2. Neutrons. An efficient neutron-occluding material consists of heavy elements such as iron the atomic mass of which is 56 and light elements, preferably, hydrogen (Mehta and Monteiro, 2006).

The structure of heavy concrete conforms to both types of radiation attenuation requirements. In addition, heavy concrete has a decent compressive strength, and thus it is usable as a supporting structure. Bore could be used as filler in concrete in order to better attenuate the radiation.

CONCLUSIONS

1. As planned, the iron containing waste materials heighten the density of product. The highest density obtained in this study is in range 4000 – 4500 kg/m³, though higher density concrete also had greater expenses per mass unit.

2. Elastic modulus of heavy concrete is higher than regular concrete mortar and is increasing with the increase of metallic aggregates .
3. Optimization of packing was applied to decrease concrete W/C ratio and enlarge density.
4. Vibration of concrete was used briefly for avoiding of segregation as a result may be issued of metal filler higher specific gravity.
5. Potential drawback of steel punching is corrosion that should be tested in further researches.

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