EXPERIMENTAL STUDY ON STRENGTH OF CONCRETE BY PARTIAL REPLACEMENT OF FINE AGGREGATE WITH COPPER SLAG

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ABSTRACT

Copper slag is a waste material obtained during the manufacturing of copper. Approximately 2.2-3 million tons of copper slag are produced. The disposal of this waste becomes a concern for environmental protection agencies and governments; thus possible alternatives to the disposal of this material are needed. Copper slag is a potential suitable candidate for the partial or full replacement of aggregate in concrete. To date a limited research has been performed on this topic in particular as types of copper slag vary according to the cooling process used.

The copper slag is used as a partial to full replacement of fine concrete aggregate. A series of tests were then performed at two different water to cement ratios to investigate the influence of copper slag content on salient concrete properties including workability, cube compressive strength, tensile splitting strength, and static modulus of elasticity in compression, flexural strength and surface water absorption.

Copper slag was produce variable effects on the resulting concrete properties, depending on the sand replacement level and water to cement ratio; in most mixes with copper slag gave concrete with adequate properties, with the optimal sand replacements by copper slag overall being in the region of 30-60%. Based on the results copper slag can be considered to be a suitable candidate for the partial replacement of fine aggregate in concrete.

Keywords: Industrial solid waste management, Copper slag aggregate, concrete properties.

I. Introduction

Copper slag is a waste material widely obtained from the industrial sector in the manufacturing of copper during the matte smelting process. When copper liquid settles down in the smelter due to its higher density, the smears of copper slag remaining on the surface are removed and cooled. Slow air-cooling creates a hard and crystalline product while fast cooling in water produces amorphous, glassy granulates. It is estimated that 14.98 million tons of copper are produced every year and that to obtain 1 ton of clear copper 2.2-3 million tons of copper slag are produced. Thus utilization and disposal of this waste material becomes a concern for environmental protection agencies and governments. Due to the increasing problem, studies on this material showed many possibilities of how it could be reused or recycled. At present copper slag is predominantly used for the recovery of metal or employed as an abrasive material and for abrasive and cutting tools, railway ballast, tiles, and glass and roofing granules. Some researchers also considered copper slag is used for replacement of aggregates in concrete and probably also as cement replacement due to its physical and chemical properties. In addition copper slag has been excluded from the listed hazardous waste category of the United States Environmental Protection Agency.

Further studies confirmed that the heavy metals present in the slag are stable and are not likely to dissolve significantly even through repetitive leaching under acid rain in a natural environment. Thus there would be no serious concerns regarding the leaching of toxic elements if copper slag was used in large-scale construction. This is promising, as concrete is the most widely used material in construction after water, thus providing an ideal opportunity for the recycling of waste materials in large quantities. Some limited studies were performed but these are not sufficient to give confidence in the industrial scale use of this material. In addition either air cooled or water-cooled copper slag were studied by researchers as concrete aggregates (either fine or coarse) further reducing the amount of the available experimental evidence for each type of slag and aggregate respectively.

In general aggregate properties influence the freshly mixed and hardened concrete properties. Concrete aggregate must be clean and free of objectionable materials, which can affect the bonding of the cement paste to the aggregate or be corrosive to metal reinforcement. It must be strong, hard and durable, uniformly graded and falling within certain upper and lower bounds of grading. For a material to be considered as aggregate for concrete production, the minimum requirements of workability, strength and durability of the resulting concrete should also be met. Further studies are thus required to assess whether concrete with copper slag would satisfy these requirements the experimental procedures and main results are described in this paper.

II. Experimental procedure, material and mixes

According to the supplier's description it isan inert synthetic mineral manufactured by granulation in water of the slag arising from unique fumed copper smelting processes. It is an iron silicate with trace metals bound in an amorphous glass in the form of complex silicates and oxides and contains no free silica. Its detailed chemical composition according to the supplier is presented in Table1.Other physic-chemical characteristics as determined in the supplier's datasheet are shown in Table 2. A main observation from Table 1 is that the copper slag has a much higher specific gravity than the natural mineral aggregate whose specific gravity tested during this research by thepycnometer method. This could cause some segregation in the concrete mixes containing both types of aggregate. The particle size distribution of the copper slag compared to the river sand aggregate used in the mixes.

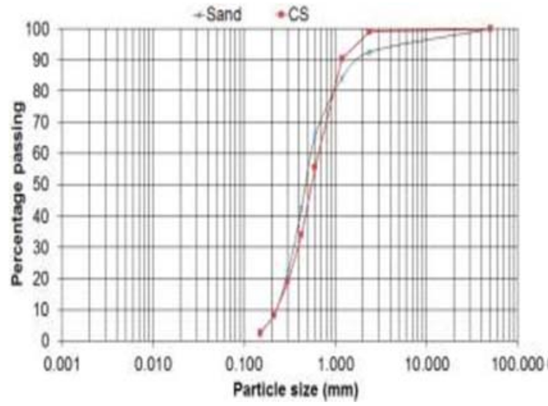

Figure 1: Particle size distribution of copper slag compared to the sand used in the tests

Determined using the dry sieving test. This confirms the suitability of the slag for use as fine concrete aggregate from the point of view of gradation. Concrete was made with a mix design of 1:1.5:3. The cement used was Portland cement strength class 52,5N obtained from the mix design was according to BS 5328: Part 1 guidelines for RC40 (BSI, 1997). The dry materials comprising cement, sand (or) copper slag and coarse aggregate were well mixed before the water was gradually included. Two different sets of mixes were made with water/cement (w/c) ratio of 0.55 and 0.45 respectively. The w/c ratio was kept constant when the sand was partly or fully replaced by copper slag (i.e. w/c of 0.55 and 0.45 respectively for the two sets of mixes).

Table 1: Chemical composition of the copper slag used in this study

Chemical	Composition %
SiO2	33.0 - 38.0
FeO	43.0 - 55.0
Al2O3	3.0 - 7.0
CaO	1.0 - 4.0
MgO	1.0 - 2.0
Na2O	0.1 - 0.5
K2O	0.1 - 0.5
Cu	0.5 - 0.7
Mn	0.2 - 0.4
TiO2	0.1 - 0.25
Pb	0.01 - 0.20
Zn	1.0 - 2.0
S	0.5 - 1.0
Cr (III)	0.1 - 0.24
Cr (VI)	nil
Free Silica	< 1.0

Table 2: Physic-chemical characteristics of the copper slag used in this study

Physical state	Solid, angular
Colour	Black, glassy
Odour	None
Specific gravity	3.3 kg/dm³
Bulk density	1.7 kg/dm³
Hardness	7 – 8 Mohs
Conductivity of aqueous extract	<15 ms m⁻¹
Chloride content	<15 ppm

III. Experimental Results

A. Slump test

As mentioned above, a possible anticipated difficulty when using aggregate other than that recommended for concrete could be the effect on the workability of the fresh concrete. Slump tests were performed according to BS EN 12350-2:2000 (BSI, 2000a) to assess concrete workability. Figure 2&3 presents results of the slump tests for each copper slag percentage for the two different w/c ratios used. These showed that all 0:55 w/c mixes had very high slump and hence workability. Due to the copper slag mixes showed lower slumps than the control mix, however without a particular pattern concerning the decreasing or increasing sand replacement. Namely the 30% and then 100% showed the same, lower slumps compared to the control mix, whereas all other mixes with sand replacements between 30 and 100% showed lower or higher values of slump without any particular trend.Interestingly these two copper slag percentages of 30% and 100% showed consistently the same and comparatively much lower slumps in both the 0.55 and 0.45 w/c ratios but it is difficult to explain why this happened consistently for these two particular copper slag percentages. It is possible that slumps were affected to some extent by some segregation and bleeding of the mixes which were variable according tothe w/c and copper slag content.

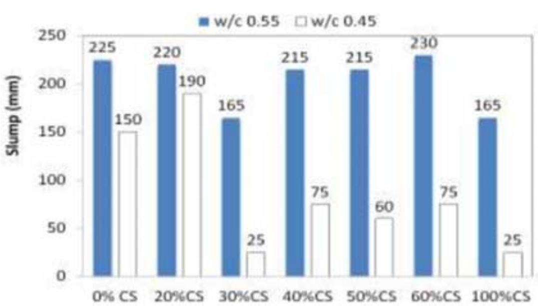

Figure 2: Slump test

Figure 3: Slump test

B. Cube compressive strength tests

These were performed in a 2000kN compression test plant according to BS EN 12390-3:2002 (BSI, 2002). Figures 4show the average cube compressive strengths for 7 and 28 days of curing for mixes with w/c=0.55 and w/c 0.45 respectively.

Figures show that compressive strengths of the mixes withcopper slag are generally lower than the control mix with one exception for eachw/c ratio. Although of lowerstrength than the control mix, thestrengths of the mixes with the lower w/cratio are generally closer to those of controlmix for all copper slag percentages. Thesmaller differences in strengths with respectto the control mixes of 0.45 w/c ratio,especially at 28 days curing, could be due toa usual variability in the concrete batchesaround a mean value, rather than showingany significant trends.

Figure 4: Compressive strength test

C. Tensile strength tests

The tensile strength of mixes was determined based on two indirect testingmethods: (a) the tensile splitting strength of 150 mm diameter and 300 mm height cylinders tested according to BS EN 12390- 6:2009 (BSI, 2009b). (b) The flexural strength, also known as Modulus of Rupture (MoR), determined from two point flexural strength tests on selected mix beams of 500mm length and a section of 100mm x100mm according to BS EN 12390-5:2009 (BSI, 2009c). It is therefore relevant for structures such as highway and airfield pavements loaded in bending and hence designed on the basis of the flexural strength of concrete.From figure 5 the splitting tensile strength results are consistent with the compressive strength results (i.e. generally lower or in one case equal strength values are noted) except that in this case the 30% copper slag mixes also showed a lower strength than the control mix, as opposed to compressive strength results. The values of the splitting tensile strength were about 7% of the value of the respective compressive strengths as was the case in the control mix. Conversely, a clear increase in the modulus of rupture (MoR), was observed in all copper slag mixes in comparison to the control mix.

Figure 5: Tensile strength test

IV. Conclusions

From the results it was shown that overall, mixes with the tested copper slag percentages had workability, strengths and modulus of elasticity comparable to those of normal concrete. Based on these findings it can therefore be concluded that this type of aggregate can be used as a substitute for natural sand, as none of the recorded properties appeared to present any significant changes with respect to the control mixes with natural concrete sand. An area that would need further investigation is possible effects linked to corrosion of metal reinforcement due to the iron oxide content of this aggregate. Other long-term durability data of concrete with this aggregate would also be necessary to produce this material at an industrial scale with confidence. Eventually, as for any other cases where unconventional materials are suggested for use in concrete, the viability of using this aggregate in concrete will depend on local economics, i.e. cost, availability of the material in sufficiently large quantities and availability and costs of similar natural aggregates in the respective regions where concrete production plants operate. Nonetheless with the depletion of the natural aggregates the use of suitable alternative aggregates based on waste materials should be encouraged as a potentially more sustainable option overall.

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