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CIVIL INFRASTRUCTURE

Waste Foundry Sand (WFS) as Aggregate Replacement for Green Concrete

Globally, 113 million tonnes (Mt)/year of cast metal are produced, generating 10-20 Mt/year of waste foundry sand (WFS). In the UK alone, 200,000 tonnes of WFS are disposed via landfilling, challenging current efforts in tackling climate change and sustainable development (CO2 emissions due to transportation, extraction of natural resources, increase in landfill inputs). Concrete uses up to 90% of natural aggregate per tonne of concrete produced, including sand. The latter is the most extracted material in the world today. Approximately 40-50 billion tons of sands are mined around the globe for construction each year (UNEP2016).

This work examines the use of waste foundry sand (WFS) as a replacement for fine aggregate (sand) in concrete. Two types of WFS supplied by Weir UK were used: quartz and chromite sand. After initial chemical and physical characterization, both types of sand were deemed suitable for use in construction. We compared the physical and chemical properties of both WFS types to river sand used for concrete production. Quartz and chromite WFS were finer and contained less silicon than conventional sand but richer in metallic ions. Leaching tests showed that WFS released metals, but their chloride, fluoride and sulphate content was less than river sand. WFS was then used in concrete at different fine aggregate replacement levels (30%, 50% and 100%). We investigated the mechanical performance at 28 days of curing, water transport and durability properties. Whilst the overall compressive strength decreased with increasing the WFS content, samples subjected to freeze/thaw cycles exhibited outstanding durability performance with respect to their water absorption capability. Preliminary results suggest that WFS is an environmentally sustainable solution both for the cast metal industry and the construction sector, as it repurposes a material otherwise disposed of into a raw material for durable concrete production.

Keywords:
Agricultural waste, concrete, strength, durability.

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INTRODUCTION

WFS is mainly made of siliceous sand (up to 95%) and additives (binders, clays, etc…). In the past decade, research has been carried out worldwide to evaluate the effect of WFS in aggregate replacement in concrete [1]. It has been found that replacement of river sand with WFS up to 30% in concrete resulted an increase of compressive strength [2]. On the other hand, replacement up to 60% resulted in a decrease in strength, however acceptable within certain limits for non structural applications (<35 MPa) [3], [4]. WSF was also studied as a fine aggregates replacement (up to 40%) in self-compacting concrete, resulting in increased mix segregation, albeit with a 40% improvement in strength [5].

Although WFS is classified in the EU as a non-hazardous waste and its replacement up to 60-100% in concrete has been proposed at lab-scale, current standards in the construction sector allow only up to 30% by weight [6] [7]. One obvious reason to this limitation is the variability of the WFS physico-chemical properties, not only on an international level, but also within the same foundry activities. In fact, the composition of WFS depends on the foundry location, on the type of casting activity and binders used. Another factor of influence is the presence of organic and inorganic contaminants in the WFS that might migrate from the hardened concrete with time [8].

This work seeks to i) assess the variability of WFS stream composition from the Weir Minerals Europe Ltd Todmorden foundry to determine its physical properties (specific surface area and particle size) and chemical composition (sulphates, phosphates, phenols, chromium, etc.), and ii) incorporate WFS into concrete as a partial (but >30% current limit) or total replacement of fine aggregates.

MATERIALS AND METHODS

The study used various methods to analyse the physical and chemical properties of river sand and two waste foundry sands (WFS), quartz and chromite (as shown in Fig. 1). Particle size analysis showed that the WFS were finer than the river sand. XRF and XRD analysis revealed differences in elemental and mineral compositions among the sands, with the WFS containing more iron and heavy metals. Loss on ignition and total carbon analyses showed that the organic content and carbonaceous material were lower in the WFS compared to the river sand. Finally, pH and electroconductivity measurements of leachate from the sands suggested that the WFS would behave similarly to the river sand when used in concrete.

Concrete specimens were prepared by mixing Portland cement (CEM II, A-L, class 32.5 MPa) with a content of 400 kg/m3, fine and coarse aggregate, respectively river sand (680 kg/m3) and crushed limestone (920 kg/m3), at a water to binder (w/b) ratio in the range of 0.42 – 0.62. Fine aggregate was replaced chromite and quarts waste foundry sand at level of up to 100%.

Several tests were carried out to determine the properties of the concrete. The bulk density was determined using ASTM C138 by measuring the dry and saturated unit weight along with its Archimedes weight. Compressive and splitting tensile strength tests were conducted by crushing and splitting the cubes and cylinders, respectively. Rapid chloride ion penetration was tested by sandwiching the samples between two chambers in a test cell and exposing them to NaOH and NaCl solutions with a current of 60V applied for 6 hours. Thermal conductivity was measured using a 50 mm probe, portable sensor, and computer application software. Lastly, the water absorption was determined by immersing samples in a water tank and recording their mass at regular square intervals of time. Freezing and thawing were tested by placing oven-dried samples in a water bath for 8 hours and freezing them overnight for 20 cycles.

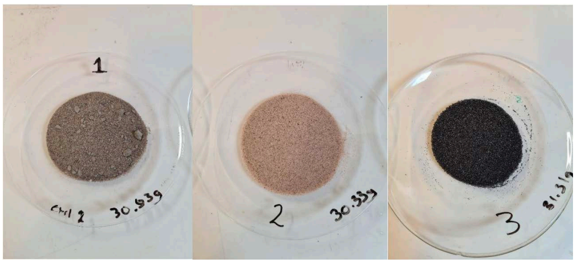

Fig. 1. River sand (1), Quartz WFS (2) and Chromite WFS (3).

RESULTS AND DISCUSSION

Initial studies on the chemical analysis of the WFS incorporated in concrete showed that Barium concentration increases with age in the samples, as it is present in Portland Cement, but this poses an environmental issue since the WHO drinking standards set a limit of 0.7 ppm for heavy metals in drinking water. Control samples and samples with high percentages of Chromite and Quartz show barium levels three times higher than the safety limit. Samples with Selenium also exceeded the WHO drinking standard limit of 0.01ppm, but the concentration reduces with curing age and can be reduced by increasing WFS. Although the trace amount of Chromium detected cannot be relied on due to LOD, the results suggest that concrete can sequester harmful contaminants, with curing age playing a role in containment.

Tests on the mechanical properties showed that compressive strength (Fig. 2) and splitting tensile strength decreased as the substitution level increased due to the high-water content and fineness of the sands. Thermal conductivity decreased with increasing substitution levels, but water absorption decreased at all substitution levels. Lowering the amount of water added to the mixtures containing WFS could increase strength, but excessive water added to 100% chromite sand led to total collapse.

Waste foundry sands as a substitute for natural sands in concrete can improve its properties. The study found that a full substitution rate is possible, and the resulting concrete is more durable and resistant to water and harsh chemicals. The concrete with waste foundry sands also performed better under stress and showed less internal degradation due to its higher density and less porous structure. The study also conducted tests on the concrete's ability to withstand freezing and thawing cycles, which further boosted its mechanical properties.

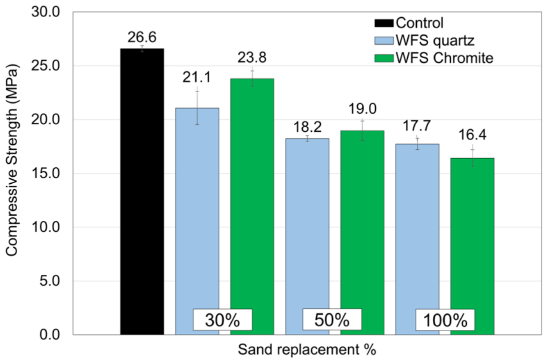

Fig. 2. Compressive strength of specimens at different levels of fine aggregate replacement.

CONCLUSIONS

Overall, using waste foundry sands in concrete can be a viable and beneficial alternative to using natural sands. This work suggests that WFS is an environmentally sustainable solution for both the cast metal industry and the construction sector, as it repurposes a material that would otherwise be disposed of into a raw material for durable concrete production. Future work will include:

investigating the water transport properties and conducting a detailed life cycle assessment to evaluate the environmental benefits of unprocessed rice husk ash in construction.

Mechanical and durability testing (simulated harsh environment) to evaluate the full extent of 100% WFS substitution and re-grading by combining different WFS types and/or standard sand.

Life cycle assessment to target infrastructure applications (retaining wall, pavement).

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Conflicts of interest
The authors declare no conflict of interest.

REFERENCES

[1] D. Kumar and S. Kumar, 'Robustness of self-compacting concrete containing waste foundry sand and metakaolin : A sustainable approach', *J Hazard Mater*, vol. 401, no. April 2020, p. 123329, 2021. doi.org/10.1016/j.jhazmat.2020.123329

[2] N. Thamaraiselvi, N. Sakthieswaran, and O. G. Babu, 'Materials Today : Proceedings Improving the performance of mortar containing industrial wastes', *Mater Today Proc*, vol. 37, pp. 1062–1065, 2021. doi.org/10.1016/j.matpr.2020.06.294

[3] F. Friol Guedes de Paiva, J. R. Tamashiro, L. H. Pereira Silva, and A. Kinoshita, 'Utilization of inorganic solid wastes in cementitious materials – A systematic literature review', *Constr Build Mater*, vol. 285, 2021. doi.org/10.1016/j.conbuildmat.2021.122833

[4] M. A. de B. Martins, R. M. Barros, G. Silva, and I. F. S. dos Santos, 'Study on waste foundry exhaust sand, WFES, as a partial substitute of fine aggregates in conventional concrete', *Sustain Cities Soc*, vol. 45, no. November 2018, pp. 187–196, 2019. doi.org/10.1016/j.scs.2018.11.017

[5] P. R. de Matos, R. Pilar, L. H. Bromerchenkel, R. A. Schankoski, P. J. P. Gleize, and J. de Brito, 'Self-compacting mortars produced with fine fraction of calcined waste foundry sand (WFS) as alternative filler: Fresh-state, hydration and hardened-state properties', *J Clean Prod*, vol. 252, p. 119871, 2020. doi: 10.1016/j.jclepro.2019.119871

[6] British Standard Institution, 'BS EN 206:2013+A2:2021 - Concrete. Specification, performance, production and conformity', London, UK, 2021.

[7] British Standard Institution, 'BS EN 12620:2002+A1:2008 - Aggregates for Concrete', London, UK, 2002.

[8] M. F. Iqbal *et al.*, 'Prediction of mechanical properties of green concrete incorporating waste foundry sand based on gene expression programming', *J Hazard Mater*, vol. 384, no. June 2019, p. 121322, 2020. doi.org/10.1016/j.jhazmat.2019.121322

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