Sustainable Concrete: Enhanced Concrete Strength with Metal Dusts

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Abstract: The strength property of concrete was investigated with the use of metal aggregate from blacksmith forging wastes. Metal aggregates were used to replace sand as fine aggregates in concrete mixed by volume substitution. Concrete mixing was done in accordance to ASTM Standards and cured at recommended 28 days. Test results showed that there is improved performance, by almost 17%, in the compressive strength for the concrete specimen. With the utilization of wastes such as metal aggregate from blacksmith forging, it can produce a sustainable concrete that can enhance strength.

Key Words: Metal, Sustainability, Concrete, Waste Utilization, Philippines

1. INTRODUCTION

Wastes pose a significant threat to the environment, especially non-biodegradable wastes, as it may contaminate different natural resources. Metallic dust wastes produced from blacksmithing are example of these non-biodegradable wastes. In an attempt to conserve raw materials, limited intensive researches have been made towards the utilization of waste materials as substitutes (Gilliam and Wiles (1996), Maslehuddin, Sharif, Shameem, Ibrahim, and Barry (2003), Qasrawi, Shalabi, & Asi, (2009), and Singh, Das, Ahmed, Saha, & Karmakar (2015)).

With the growth of the construction industry in the Philippines, a high demand for construction materials requires more excavation on quarry sites which puts a strain on our environment. Metal is a common material used for different applications. These metals are manufactured to suit their different purposes and at the process of doing so, metallic wastes are produced either in large forms or in dust. These wastes could sometimes be hazardous as it may be conductive, combustible or explosive. Disposal of these kinds of wastes requires special procedures and equipment in order to prevent it from becoming a hazard to the environment and to the community. There are limited studies that used metallic wastes such as use of metal slag that raises both compressive and tensile strengths of concrete (Maslehuddin, Sharif, Shameem, Ibrahim, and Barry (2003)), utilization of iron ore tailings in ultra-high performance concrete that made an eco-friendlier concrete with 10-32% reduction in energy consumption and up to 29-63% reduction in carbon dioxide emissions (Zhao, Fan, & Sun (2014)), and others. Thus, in this study, successful utilization of metallic dust wastes as substitute for fine aggregate would help reduce the strain on the environment caused by the increase in demand for construction materials while at the same time utilizing these kinds of non-biodegradable wastes.

The increasing demand and extraction of natural sand used for construction purposes have negative impacts on the environment, to overcome this problem, the possibility of replacing partially, or completely, the sand by metallic dust wastes is considered here. The successful utilization of metallic dust wastes for fine aggregate would reduce the strain on the supply of natural sand and reduce the high cost of waste disposal; economy in concrete production.

2. METHODOLOGY

All data were gathered from a series of laboratory tests and experiments; all of which are in accordance with the ASTM Standards. From the ASTM tests, the following parameters were obtained for the proposed alternative aggregate: grain size distribution curve, moisture content, specific gravity, unit weight, moisture content and absorption, shown on Table 1. The concrete testing is in accordance with the ASTM Standards for concrete mixing, curing, and testing. The compressive strength was garnered.

Table 1. Laboratory Experiments Performed for Metallic Dust Wastes Properties

Experiment	Number of Trials
Grain Size Analysis	1
Moisture Content	3
Absorption	3
Unit Weight	3
Specific Gravity	3

Metallic dust wastes were gathered locally from the blacksmith houses or "pandayan" in the Philippines, wherein the metallic dust wastes produced are observed to be fine in texture which is comparable to sand and has a reddish hue due to the presence of rust.

The results of the laboratory experiments were used to compute for the concrete mix design with target strength of 3000 psi or 21 MPa to meet the minimum requirement for structural members. Replacement percentages of 0%, 25%, 50% and 75% were used for the study. Six (6) inches in diameter and twelve (12) inches in height concrete cylinders were used for compressive testing on their 28th day. The matrix of laboratory specimen is shown on Table 2.

Table 2. Matrix of Specimens

Percent Substitution by Volume	Number of Trials
0	3
25	3
75	3
100	3
Total	**12**

3. RESULTS AND DISCUSSION

The unit weight of the metallic dust wastes is 1761.706 kg per cubic meter. As compared to sand, with a unit weight of 1555.543 kg per cubic meter, the metallic dust wastes weigh 13.25% more than the fine aggregate. The overall weight of the concrete will increase due to the heavier weight per volume of the metallic dust wastes, shown on Figure 1.

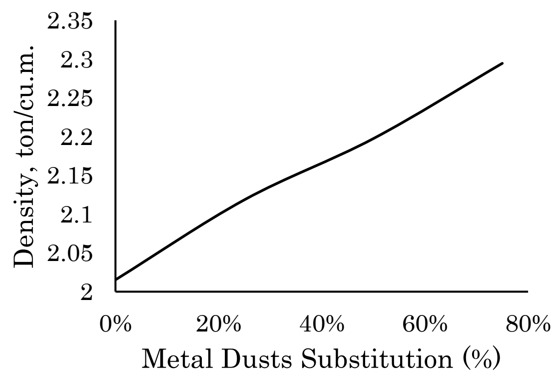

Figure 1. Density of materials with metal dusts

substitution

Having a 25% substitution will yield a concrete that is 5% heavier than the control mix, a 50% substitution will be 9% heavier than control mix and lastly, a 75% substitution will yield 14% heavier than the control mix. It is therefore concluded that substituting sand with metallic dust wastes by volume would result into a heavier concrete due to the metallic dust wastes having a higher weight than sand per volume. A sample of metallic dusts mixed with water is shown on Figure 2. The moisture content of the fine aggregate is 0.65%. Its absorption is determined to be at 4.03%, during the actual testing of the physical properties of the metallic dust wastes, it was observed that the metallic dust wastes require more water due to its fineness.


Figure 2. Metallic dusts mixed with water

Slump test was done after each mix design to determine the effect of increasing metal dust content on the workability. The recorded slump for our control mix is 13.5 cm, after substituting 25% of the fine aggregate with metallic dust wastes, the recorded slump is 11.75 cm, a 13% drop from the control mix. Further increasing percent substitution to 50% yielded a sum of 7.3 cm, a 46% drop from the control mix. A 75% substitution on the fine aggregate would cause the mix to lose most of its workability. The recorded slump for the 75% mix is 1.8 cm, a drop of 87% from the control mix. The drop in the workability was caused by higher absorption and fineness of the metal aggregate. To maintain the workability of the mix, it would be best to limit the percent substitution of the metal aggregate to only 25%.

With the use of 6" x 12" cylinders tested for compressive strength using the Universal Testing Machine, the following results are obtained and presented in Table 3. The result from the experiment shows that the 28-day compressive strength of concrete with 50% substitution yielded 33.66 MPa, 97.48% of the 28-day compressive strength of the control specimen. At 75% substitution, the 28-day compressive strength of the specimen further decreased to 28.4 MPa, which is only 82.25% of the 28-day compressive strength of the control specimen.

Based on previous studies with similar materials, the increase in the strength is caused by the finer particles of the metal aggregate compared to the sand therefore garnering a higher compressive strength compared to the control specimen of 21MPa. The finer particles act as micro-fillers which lessens the void and transition zone between aggregate and paste found in ordinary concrete. This micro-filling effect or also called as "particle packing" makes the concrete more impermeable and improves the paste-to-aggregate bond. The transition zone is the weakest component in concrete and also considered to be the most permeable area.

However, increasing the amount of metal dust would mean an increase in the amount of fine particles in the mix. Smaller particles require more water to wet the larger surface area causing increase in absorption and reducing the actual amount of water available for active materials to hydrate. This is the main cause of decrease in the strength as the volume of metal aggregate in the mix increases.

The compressive strength of concrete increased by about 17% when 25% metallic dust wastes were substituted for sand. The average 28-day strength of the control specimen is 34.53 MPa as compared to the 40.28 MPa of the concrete with 25 % metallic dust wastes.

The specimen with 50% substitution exhibits early strength gain during its first week of curing, 29% higher than the control specimen, but slowed down afterwards, with only 1.7% increase in strength on the last week of curing.

The specimen with 75% substitution has the lowest performance. On its first week of curing, the specimen exhibits a 28-day compressive strength of 28.4 MPa, a 17.75% drop in compressive strength compared to the control specimen. The average results are shown on Figure 3.

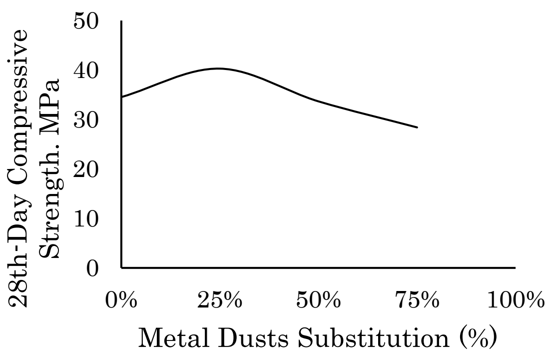

Figure 3. 28th-Day Compressive Strength

The strength development curve also showed that the 50% and 75% metallic dust wastes substitution showed minimal compressive strength gain on its last week of curing, as compared to the strength development curve of the 25% that has manifested a slower compressive strength development on its early weeks of curing but managed to achieve the highest 28-day compressive strength. Also, further increasing the percent substitution of the metallic dust wastes would result to a lower 28-day compressive strength of concrete.

4. CONCLUSIONS

The effects of the partial substitution of metallic dust wastes as fine aggregates in concrete was investigated. The physical properties studied were the metallic dust wastes' grain size distribution, unit weight and absorption were studied. Based on the grain size analysis, it was found that the metallic dust waste samples were much finer than sand. This was also evident in the shape of the sample's microstructure. However, its unit weight was 13.25 % higher than that of sand. Its absorption was found to be 4.05 %.

The compressive strength of the concrete was investigated, fine aggregates were substituted with metallic dust wastes in 25 % increments, up to 75 %. It was found that after a 28-day curing period, samples with 25 % substituted aggregates yielded higher results, as compared to the control group.

The optimal substitution rate must be kept at 25% of the fine aggregates. Substituting this amount of metallic dust wastes in concrete, increases the compressive strength. The effect on the strength of concrete by the metal dust wastes may be attributed to their particle size and the presence of iron. The pozzolanic activity of the metal dust wastes was because of the fineness of the particles. This gave the particles more surface area per volume, which in turn, affects the pozzolanic activity of a material. The presence of iron also reacts chemically with concrete, allowing the concrete to become denser; thus, increasing its strength.

Metallic dust wastes were used to strengthen concrete used in compression. However, due to the nature of the study, the effect of such a substitution under service loads was not investigated. Furthermore, it is recommended that the effects of oxidation and corrosion on the metallic dust wastes may be a consideration for future research.

5. ACKNOWLEDGMENTS

The research group would like to extend their deepest gratitude to the various experts who have helped them in this research. To their students: Martin Teotimo C. Bron, Edward H. Chua, Robert Marri B. Coloso and Juan Lorenzo F. Navarro, for carrying out the experiments and analyses needed for this research. To their friends, for helping them in conducting some experiments and sharing some ideas to them. To their parents, for supporting them in all our needs and inspiring us to finish our studies. And to God, who made all things possible.

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