Compressive Strength Response Surface Model of Concrete with Metallic Dusts

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Abstract: With the growth of the construction industry in the country, a high demand for construction materials requires more excavation on quarry sites which puts a strain on our environment. In an attempt to conserve natural resources, intensive researches have been made towards the utilization of waste materials as substitutes. In this study, metallic dust wastes were used to substitute as fine aggregates in concrete. A series of laboratory tests and experiments were done in accordance with the ASTM Standards. A Response Surface Model for the compressive strength of concrete was formulated for estimating the concrete strength at a given percent substitution of the fine aggregate and days of curing.

Key Words: metal; concrete; waste; civil engineering; response surface model

1. INTRODUCTION

With the growth of the construction industry in the country, a high demand for construction materials requires more excavation on quarry sites which puts a strain on our environment. Natural resources play a major role in a country's construction development. With nature as its primary provider of resources, it is most affected by our increasing need of construction supplies. There have been multiple complaints and studies done regarding the effects of aggregate extraction on the environment (Esguerra, Amistad, & Rabena, 2008). By making use of waste materials as possible substitutes or additives, it would be of great impact in sustaining and preserving some natural resources. 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. In an attempt to conserve natural resources, intensive researches have been made towards the utilization of waste materials as substitutes, and with that, successful researches have turned waste materials into valuable resources (Gilliam and Wiles (1996), Maslehuddin, Sharif, Shameem, Ibrahim, and Barry (2003), Qasrawi, Shalabi, & Asi, (2009), and Singh, Das, Ahmed, Saha, & Karmakar (2015)); reducing cost for waste disposal and reducing the strain on the supply of natural resources. However, there are wastes that are least considered since they could sometimes be hazardous as it may be conductive, combustible, or explosive. One of the examples these wastes are metallic dust wastes produced from blacksmithing, which are produced either in large forms or in dust.

There have been several studies regarding the use of metal waste materials as fine aggregates in concrete. These studies differ in the type of waste material (i.e. slag, ore tailings), methodologies, concrete type and usage, and the original fine aggregate type. Many of the studies are conducted under the local conditions relative to the study's country of origin and this affects the waste's material properties and subsequent results. One way of giving a relationship with the properties of the metallic dust wastes and its subsequent results is to use response surface modelling. Response surface modelling will forecast or predict the causal relationship of using metallic dust waste in this study, specifically its compressive strength and the days of curing. Thus, in this study, it is aimed to create a response surface model that will forecast the compressive strength of concrete given the percentage of metallic dust used and its days of curing. An equation for the compressive strength of concrete can be determined and used for estimating the concrete strength at a given percent substitution of the fine aggregate and days of curing.

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, shown in Figure 1, 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.

Figure 1. Metallic Dust Wastes used in the study

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 7^{th}, 14^{th}, 21^{st} and 28^{th} day curing. The matrix of laboratory specimen is shown on Table 2.

Table 2. Matrix of Specimens

Percent Substitution by Volume	Number of Trials			
	7th Day	14th Day	21st Day	28th Day
0	3	3	3	3
25	3	3	3	3
75	3	3	3	3
100	3	3	3	3
Total	48			

Lastly, a response surface model was used to create a forecasting model to determine which variables have an impact on the compressive strength of the concrete mixed with metallic wastes.

3. RESULTS AND DISCUSSION

The unit weight of the metallic dust wastes is 1,761.71 kg per cubic meter. As compared to sand, with a unit weight of 1,555.54 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 2.

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 3. 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.

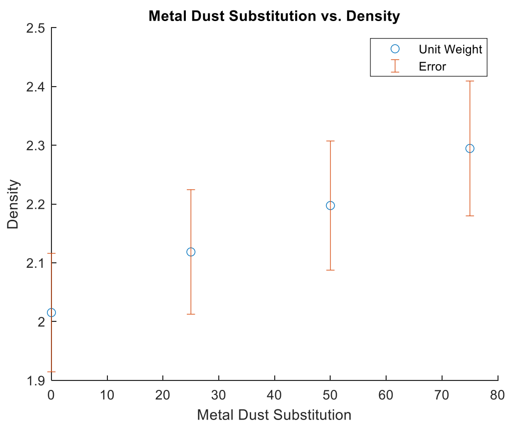


Figure 2. Density of materials with metal dusts substitution

Figure 3. 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.

Table 3. Compressive Strength of Concrete Mixed with Metallic Dust Wastes

Percent Substitution	**Testing/Curing Days**			
	7	**14**	**21**	**28**
0%	18.65	25.86	31.54	34.53
25%	21.73	26.09	34.69	40.28
50%	24.08	30.5	33.11	33.66
75%	17.27	24.16	27.71	28.4

A Response surface model graph was used to illustrate the strength development curve for each percent substitution, shown in Figure 4.

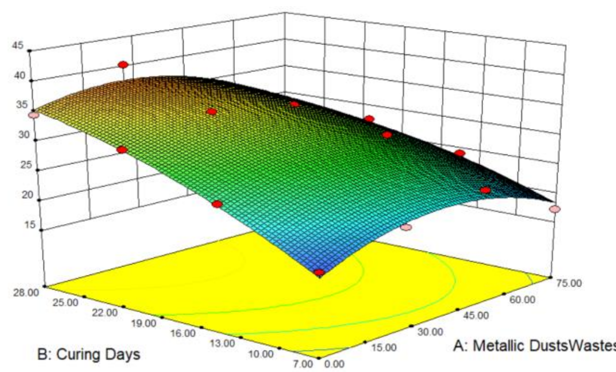


Figure 4. Response Surface Model Graph of the Compressive Strength

It could be seen that the concrete with 50% metallic dust waste substitution exhibits the highest compressive strength at testing days 7 and 14, while the concrete with 25% metallic dust wastes substitution has the highest compressive strength at the 21st and 28th testing day.

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. 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 considered to be the most permeable area.

However, increasing the amount of metal dust would mean an increase in the number 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.

As visualized in the Figure 4, 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 7-day compressive strength of 17.27 MPa, a 7.40% drop from the control specimen and a 28-day compressive strength of 28.4 MPa, a 17.75% drop in compressive strength compared to the control specimen.

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.

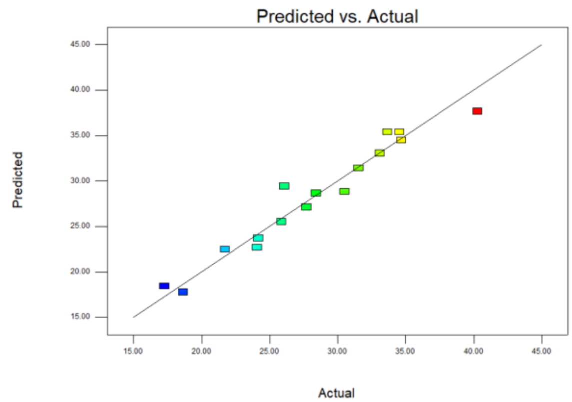
A Response Surface Model for the compressive strength of concrete was used for estimating the concrete strength at a given percent substitution of the fine aggregate and days of curing. An equation was created to forecast the compressive strength of concrete given the percent substitution of the fine aggregate and days of curing, shown in Eq. 1.

$$\begin{aligned} \text{Compressive Strength} = \; & +8.13700 + 0.31163 * MDW + 1.51191 * CD \\ & -4.68800E\text{-}003 * MDW * CD \\ & -3.60200E\text{-}003 * MDW^2 \\ & -0.019209 * CD^2 \end{aligned} \qquad \text{(Eq.1)}$$

Where:
MDW is Metallic Dust Wastes in Percentage
CD is the Curing Days

The Response Surface Model has an R^2 value of 0.9243 which shows an agreement between the model and the observed parameters.

Figure 5. Equality Line of the study



An equality line was also used to validate the predicted versus the actual data, shown in Figure 5.

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 %.

It could be seen that the concrete with 50% metallic dust waste substitution exhibits the highest compressive strength at testing days 7 and 14, while the concrete with 25% metallic dust wastes substitution has the highest compressive strength at the 21st and 28th testing day.

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. 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.

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