JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-17, No.-6, June (2022) pp 1-11 ISSN (Print) 0973-8975

A STUDY OF CONCRETE INCORPORATING STEEL MILL SCALE WASTE

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https://doi.org/10.26782/jmcms.2022.06.00001

(Received: April 1, 2022; Accepted: June 15, 2022)

Abstract

This paper presents the effective utilization of industrial waste steel mill scale in concrete. Tests were performed on concrete specimens incorporating 10%, 20%, 30%, and 40% steel mill scale by weight of sand and a control specimen. Results were assessed in terms of workability, compressive strength, flexural strength, and durability. The compressive and flexural strength of concrete incorporating a 20% steel mill scale was recorded higher as opposed to control and other percent replacement specimens. It was also observed that the durability and resistance against sulphate attack of concrete enhanced as the replacement proportion of mill scale were increased. Furthermore, the higher specific gravity of mill scale waste makes it a suitable material for heavyweight concrete members and radiation shield structures.

Keywords : Concrete, Steel Scale Waste, Durability, Compressive Strength, Flexural Strength.

Nomenclature

SMS	Steel mill scale
EDAX	Energy dispersive X-ray analysis
Fe_2O_3	Ferric oxide
ASTM	American Society for Testing and Materials
MgO	Magnesium oxide
Al_2O_3	Aluminum oxide
SiO_2	Silicon dioxide

CaO Calcium oxide

ZnO Zinc oxide

ACI American Concrete Institute

UTM Universal Testing Machine

I. Introduction

The day-by-day rapid increase in the generation of waste is due to the population growth which as a consequence leads to an increase in agricultural activities as well as industrialization. The increase in such activities causes an enormous generation of waste. For example, various agricultural wastes can be found after harvesting crops such as wheat straw, rice husk, corn cob, etc. Similarly, the industrial process also causes the production of various types of wastes such as waste glass, fly ash, rubber, etc. An enormous amount of such solid waste is produced in different regions of the world on regular basis and if they are not appropriately disposed of, might lead to a severe impact on human health and the environment.

Researchers all over the globe are trying to utilize wastes effectively in various applications just like civil and environmental engineering researchers who have used/using industrial by-products and agricultural wastes promisingly in concrete [XII], [II], [I], [XV], [VIII], [VII], [XIV], [XXI], [V], [XX], [XVII]. Concrete is an extensively used construction material because of its mechanical and chemical properties, economy, and easy availability of its ingredients. However, the enormous usage of concrete in the construction industry is causing depletion of natural resources, damage to the landscape, and contamination of air and water [XXII]. Thus, it is necessary to prevent environmental degradation and use various by-products as a replacement for concrete ingredients (cement, fine aggregates, and coarse aggregates) which will lead to the reduction of the environmental concerns to some extent.

Steel mill scale (SMS) is one of the types of industrial wastes that are produced during the hot rolling process of steel billets in the steel manufacturing industry. Approximately 10-20 kg of mill scale is generated for each one-ton steel production [XVI], [XIII]. Previously, mill scale was considered a discarded waste and usually disposed of in landfills. However, mill scale has the potential to be incorporated into concrete as a partial replacement for aggregates. Though some researchers have used mill scale as a partial replacement of aggregates in mortar there has been little study regarding the investigation of mechanical as well as durability properties of concrete incorporating steel mill scale.

Al-Otaibi [XVIII] investigated the possible effects of replacing fine aggregates of mortar with the mill scale and concluded that 40% replacement is the optimum percentage for the mill scale to enhance the compressive strength and flexural strength of cement mortar. However, in another study Iluiu-Varvara et al., [IV] found that the increase of percent replacement of sand with the mill scale leads to a decrease in the compressive and flexural strength of mortar. The authors noted a decrease for 10% replacement of sand with the mill scale and the compressive and flexural strength further decreased for 20% replacement. Similarly, several other research studies have been conducted on the use of steel and iron industry waste material as a replacement for natural aggregates [XVII-XXII] [IX], [X], [VI], [III], [XIX], [XI]. However, less attention has been given to investigating collectively the mechanical as well as durability properties of concrete incorporating steel mill scale waste as a partial replacement of natural fine aggregates (sand). Therefore, the objective of this research was to evaluate the performance of concrete containing steel mill scale in terms of workability, compressive strength, flexural strength, and resistance to sulphate attacks.

II. Experimental Program

II.i. Collection of Mill Scale and Processing

In the present study, the mill scale was obtained from a local steel industry after a hot rolling steel operation as shown in Fig. 1. The collected sample was mostly flaky in shape, which was further ground to convert it into fine aggregate size. Sieve analyses were performed according to ASTM C 136 to determine the fineness modulus of the mill scale. The fineness modulus of the mill scale was 2.51 as compared to 2.68 of sand which indicates that the mill scale is a finer material as opposed to the sand. Moreover, the specific gravity of the mill scale is higher compared to the sand which means the mill scale can be implemented in heavy-weight concrete. The specific gravity of the mill scale was determined according to ASTM C128-15 as 4.58 as opposed to 2.46 in the case of sand. Additionally, the mill scale in fine shape was also examined under EDAX (energy dispersive X-ray analysis) analysis to determine the elemental and further oxides composition. Iron (III) oxide or ferric oxide (Fe_2O_3) was noted as the main oxide with a 71.87% value. Table 1 reports the oxides composition of the mill scale.

Fig. 1: Collection of steel mill scale

Table 1: Chemical composition of steel mill scale

Compounds	Percent Values
Fe_2O_3	71.87
MgO	0.61
Al_2O_3	1.15
SiO_2	8.17
CaO	4.80
ZnO	13.36

II.ii. Mix Design and Samples Preparation

Four different percentage replacement of sand with mill scale was chosen in the present study i.e. S10, S20, S30, and S40. The sand was replaced with 10% (S10), 20% (S20), 30% (S30), and 40% (S40) mill scale. A control specimen with no mill scale content was also prepared (S0) for comparison. Mix design was performed according to the procedure given by ACI. The ingredients were mixed at a ratio of 1:2.42:3.30 (cement: sand: aggregate) with a water to cement (w/c) ratio of 0.57.

III. Results and Discussion

III.i. Effect of Mill Scale on the Workability

This section describes the results of the fresh property of mill scale and control concrete specimens obtained using the slump cone test (ASTM-C143-05). Fig. 2 reports the variation of slump magnitude against the percent replacement of sand with mill scale. It is evident from the figure that the magnitude of slump decreases as the percent content replacement of mill scale is increased and approximately a linearly decreasing trend is observed. This is because the mill scale particles are finer than the sand and increase the surface area and water demands, hence decreasing the workability with an increase in content percent and ultimately reducing the slump magnitude. The slump values noted for S0, S10, S20, S30, and S40 are 2.05, 1.88, 1.65, 1.3, and 1.15 inches respectively.

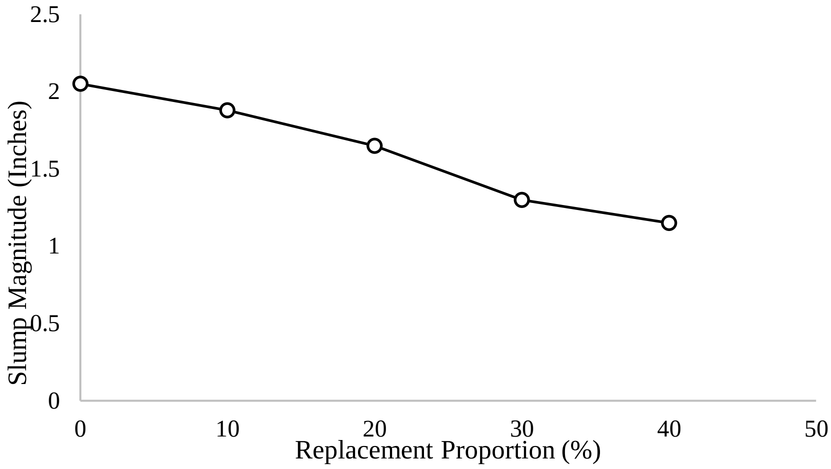

Fig. 2: Slump magnitude comparison at different replacement proportions

III.ii. Effect of Mill Scale on the Compressive Strength

Concrete cylinder tests were performed according to the ASTM C39 procedure to obtain the compressive strength of the specimens (Fig. 3). All the specimens were tested at two intervals i.e. at 7 and 28 days of curing. For each percent replacement, 3 cylinders were prepared. Fig. 4 represents the variation of compressive strength against the percentage replacement. It can be seen from the figure that the strength of S0 and S10 specimens are approximately the same, however, at 20% replacement (S20) the mills scale concrete records maximum compressive strength at both 7 and 28 days of curing. The graph follows a decreasing trend after achieving the maximum strength at 20% replacement and becomes approximately parallel at 30% (S30) and 40% (S40). This indicates that the optimum percentage of mill scale to replace sand and obtain a higher compressive strength is 20%. The noted compressive strength in the case of S0, S10, S20, S30, and S40 for 7 days was 2181, 2158, 2719, 2076, and 2056 psi respectively and for 28 days was 3066, 2914, 3786, 2829, and 2798 psi respectively.

Fig. 3: Compressive strength test using UTM

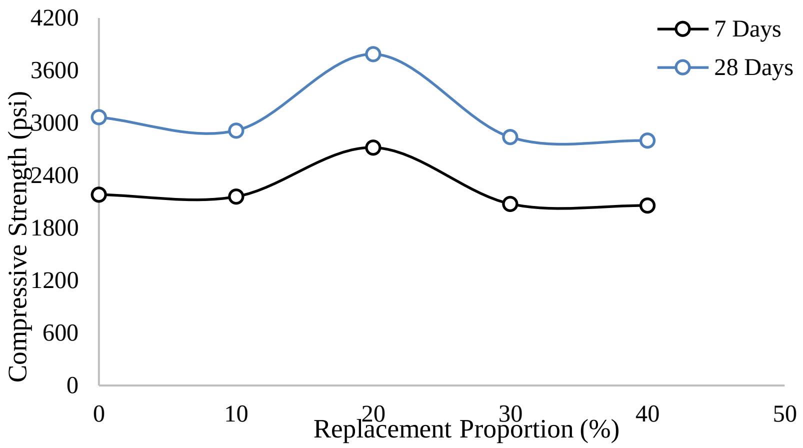

Fig. 4: Comparison of compressive strength at different replacement proportions

III.iii. Effect of Mill Scale on the Flexural Strength

Flexural strength of the mill scale and control specimens were also obtained using ASTM C 293 center point load test. 4" x 4" x 14" beams were prepared and tested under center point loading at 28 days of curing using a universal testing machine as shown in Fig. 5. A total number of 3 beams were cast for each percent replacement. The variation in flexural strength versus replacement proportion is shown in Fig. 6. It is evident from the figure that the flexural strength slightly increases when a 10% mill scale is added as opposed to a 0% proportion. The flexural strength substantially increases and reaches to peak at 20% (S20) replacement of sand with mill scale. The flexural strength significantly decreases after 20% and approximately is the same at 30% (S30) and 40% (S40) replacement proportion. The noted flexural strength in the case of S0, S10, S20, S30, and S40 was 578, 694, 1012, 549, and 513 psi respectively.

Fig. 5: Flexural strength test using UTM

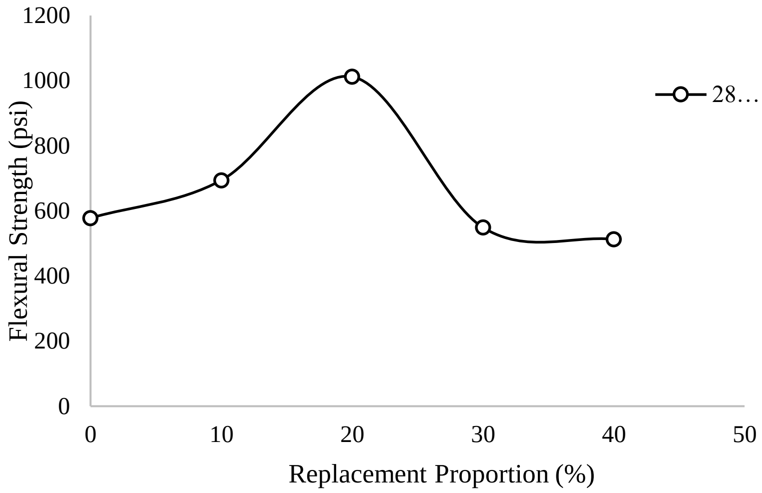

Fig. 6: Flexural strength comparison at different replacement proportions

III.iv. Effect of Mill Scale on the Durability of Concrete

Internal and external agents such as alkali-aggregate reaction, thermal variation, high temperature, electrolytic reaction, and other industries as well as natural attacks greatly affect the durability of concrete. In the present study, the durability of mill-scale concrete was assessed by measuring the resistance of concrete against sulphate attacks (ASTM C 1012). Cylindrical specimens after 28 days of curing were sun-dried for 24 hours and then the weight (W1) was recorded. Sodium sulphate solution of 4% fresh water was prepared and then the cylindrical samples were immersed in the solution for 30 and 60 days. Furthermore, the samples were dried and the weight (W2) of the specimens for both 30 and 60 days were noted. A total number of 10 samples were selected for 30 days and 10 numbers for 60 days. The percent weight loss calculated for both 30 and 60 days for each percent replacement is shown in Fig. 7. A linearly decreasing trend in percent weight loss can be observed from the figure as the replacement proportion of the mill scale is increased. This indicates that increasing the content of mill scale will lead to a more resistive and durable concrete against sulphate attack and other agents. This is due to the presence of ferric oxide (Fe_2O_3) on the mill scale and is responsible for higher resistance against internal and external attacks. The percent weight loss in the case of 30 days for S0, S10, S20, S30 and S40 was calculated 0.24%, 0.21%, 0.18%, 0.15% and 0.09% respectively, while the values increased for 60 days to 0.32%, 0.3%, 0.26%, 0.24% and 0.18% respectively.

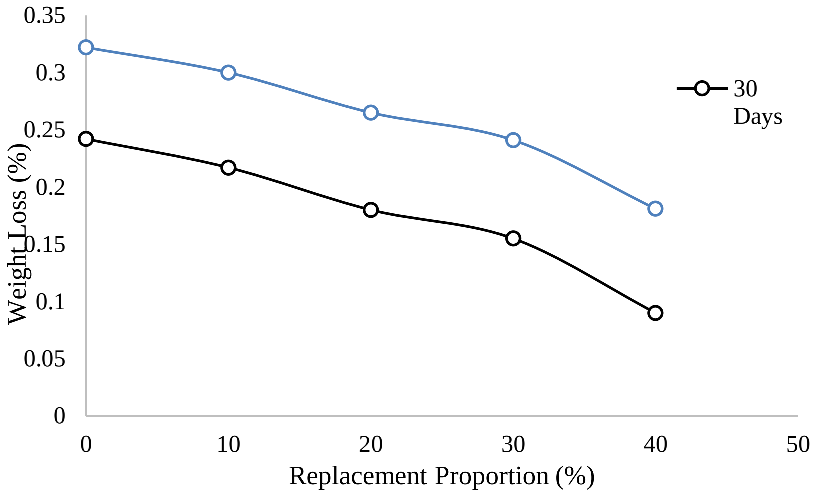

Fig. 7: Percent weight loss curves at different replacement proportions

IV. Conclusions and Future Recommendations

This paper examined the properties of concrete incorporating industrial waste steel mill scale as a partial replacement of sand. Based on the experimental study performed and presented for 0% (S0), 10% (S10), 20% (S20), 30% (S30), and 40% (S40) sand replacement with mill scale waste, the following conclusions can be drawn:

1. For fresh concrete, the magnitude of slump reduced as the mill scale content was improved and as a result, the workability was decreased. Compared to S0, the magnitude of the slump in the case of S10, S20, S30, and S40 decreased approximately by 8.3%, 19.5%, 36.6%, and 43.9% respectively. This is due to the lower fineness modulus of mill scale concrete as opposed to the ordinary (control) specimen.
2. The compressive strength of concrete for 20% (S20) replacement proportion was noted higher after 7 and 28 days of curing as opposed to control and other replacement proportion specimens. On average, the compressive strength in the case of S20 enhanced approximately 1.24 times as compared to S0.
3. Flexural strength of the beams incorporating a 20% steel mill scale was also recorded higher compared to other percent replacements. S20 increased the flexural strength approximately by 1.74 times as opposed to the control specimen (S0). Overall, 20 percent replacement of sand with steel mill scale offers higher strength properties.
4. The existence of higher content of ferric oxide (Fe_2O_3) on a mill scale offers a higher resistance against sulphate attacks. The higher the replacement proportion of the steel mill scale greater the resistance noted against sulphate attack as the percent weight loss was relatively low. The percent weight loss in the case of S40 after 30 and 60 days was noted at 0.09% and 0.18% respectively, which increased in the case S0 to 0.24% and 0.32% respectively.

5. Moreover, the specific gravity reported for the steel mill scale was approximately 1.87 times higher compared to the ordinary sand. This property makes mill scale an excellent material to be used in heavy-weight concrete members and radiation shield structures.
6. It is highly recommended to perform large-scale tests on structural members and frames incorporating steel mill scale if possible to further evaluate its performance.

V. Acknowledgements

This research received no financial support from any funding agency. The authors are grateful to the anonymous reviewers for their review of the manuscript.

Conflict of Interest:

There was no relevant conflict of interest regarding this paper.

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