Effectiveness of Using Slag as Coarse Aggregate and Study of its Impact on Mechanical Properties of Concrete

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Abstract

*Traditional coarse materials like stone chips, brick chips are very costly. Huge amount of stone chips are being withdrawn regularly from different sources. As a result one day the amount of stone chips will be gradually finished possessing a great threat to the concrete construction sector. Industries which use ferroalloys, fabricates a large amount of slag as by product every year. This iron slag deals with third class hazardous waste category that requires a large place for dumping. Solid waste slag is transformable into resources for sustainable construction works which is also environment friendly. Perk of using low iron slag as coarse aggregate has immense effect on both environment and economy. By this means environmental pollution due to the waste slag can be minimized significantly and also there will be a solution of filling the paucity of natural aggregate in the construction industry. In this paper we observed the strength properties of slag incorporated concrete with different mix ratio. The proportion of stone chips and slag used in this investigation as coarse aggregate are 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90 and 0:100. A total of 396 specimens (4*4*4 cube) were cast using plain water in normal environmental temperature and kept for the periods of 7 days, 14 days, 28 days and 6 months respectively due to curing purposes. W/C ratios were varied as 0.60, 0.50 and 0.42 for making 20MPa, 30MPa and 40MPa concrete respectively and compressive as well as tensile strength were evaluated after specific exposure periods. The strength results of the specimen provide some important information regarding strength development of slag-aggregate concrete as computed as conventional concrete.*

Keywords: coarse aggregate; concrete; compressive strength; curing period; slag; tensile strength; w/c ratio.

1.0. Introduction

In Bangladesh, aggregates have huge demand mainly for road and concrete constructions. It is becoming a matter of headache due to the unavailability of coarse aggregate for construction purposes. Various waste management strategies have been developed to find out the alternative of coarse aggregates for specific need. Natural resources are diminishing worldwide while at the same time the waste production rate from the industry is increasing by a considerable amount.

There are two important methods of sustainable development for construction and compensation the scarcity of natural resources – (1) the use of nonconventional and unique materials and (2) recycling of waste materials. Construction industry consumes natural resources and hence, environment gets polluted day by day. Main scope of sustainable construction is to reduce this large negative environmental impact. Waste management is a complicated and demanding dilemma which has negative impacts on both the habitants and the climate. Different Industries generate different kinds of environmentally hazardous waste by-products which initiates storage problem of wastes. Such waste by-products have been used in significant amounts by various infrastructure developing companies as raw materials in a sustainable way as always.

Using slag as coarse aggregate in concrete mixtures has two benefits – (1) reduces greenhouse gases and (2) helps in producing eco-friendly material. There are silicates, alumino-silicates, and calcium-alumina silicates in slag which is an inactive and non-metallic waste material. An important characteristic of molten slag is that if it consumes enough sulphur from the mixture then around 20% of slag by mass is produced during the production of iron. If we are able to use the slag in place of natural stone chips then we can successively obtain a material to replace the coarse aggregate, which is eco-friendly and cost effective. Hence there is a growing need to find the alternative solution for the slag management. In the present study, it is proposed to study the effect of addition of waste slag in concrete mixture.

2.0. Study Scope

In this experiment, 20MPa, 30MPa and 40MPa grades concrete were taken for a water cement ratio of 0.60, 0.50 and 0.42 correspondingly for the replacement of 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 % of crumbled coarse aggregate mixed with slag materials. Properties like compressive as well as tensile strengths were studied for these concrete mixes for the specific curing periods of 7 days, 14 days, 28 days and 6 months.

3.0. Materials and Methods

3.1. Cement

Ordinary Portland Cement (OPC) which is ASTM type 1 and in line with ASTM C-150 was taken throughout the experimental investigations as binding element. Properties and chemical compositions of Ordinary Portland Cement (OPC) are given in Table-1 and Table-2 respectively.

3.2. Fine Aggregate

In this experiment, sand went through 4.75 mm sieve and contained on 0.015 mm sieve was used as fine aggregate. Natural sand collected from regional areas used in the concrete mixture.

Table.1: Properties of Ordinary Portland Cement (OPC)

Characteristics	**Unit**	**Value**
Specific gravity	-	3.15
Fineness modulus	%	2.5
Standard consistency	%	27.5
Initial setting time	minutes	167
Final setting time	minutes	203
Compressive strength	N/mm^2	46.27

Table.2: Chemical compositions of Ordinary Portland Cement (OPC)

Chemical compound	Amount (%)
Calcium Oxide, CaO	64.5
Silicon Dioxide, SiO_2	20.6
Aluminum Oxide, Al_2O_3	6.4
Ferric Oxide, Fe_2O_3	4.5
Magnesium Oxide, MgO	1.2
Sulfur Trioxide, SO_3	1.7
Insoluble Residue	0.5

3.3. Coarse Aggregate

Table.3: Physical properties of coarse aggregate

Properties	Unit	Value
Specific gravity	-	3.22
Fineness modulus	-	8.01
Crushing value	%	26.37
Impact value	%	30.75
Water absorption	%	1.63

In this experiment, locally available stone chips which passed through 20 mm sieve was used as coarse aggregate. The test results on coarse aggregate are presented in **Table.3**.

3.4. Slag

Slag from the local steel making plant was collected and mixed with concrete in this experiment. Chemical compositions of slag are given in Table-4. Average masses of chemical analysis during certain intervals are given in the table. In the laboratory some positive influences of using slag as aggregate are found, for example:

- Reliable quality.
- Impurities like chlorides, organic matters, clay and shells cannot be found in slag. These
- impurities may reduce the strength and sturdiness of concrete over time.
- Slag helps in increasing strength of materials over time.
- Does not generate alkali-aggregate reactions.

Table.4: Chemical analysis of steel slag

Compound	Mass (%)	Compound	Mass (%)
CaO	50-57	Fe	15-19
Fe_2O_3	10-13	SiO_2	9-11
MnO	4-5	P_2O_5	3.2-2.3
MgO	1-2	Al_2O_5	1.4-0.7
S	0.12-0.1	K_2O	0.04-0.01
Na_2O	0.04-0.02		

3.5. Mix Proportions

Table.5: Mix proportions of control mixes

Ingredients (Kg/m^3) (1 Kg/m^3 = 0.143 lb/ft^3)	20MPa	30MPa	40MPa
Cement	576	518	665
Water (W/C ratio 0.60, 0.50 and 0.42)	346	259	280
Mass of normal coarse aggregate	7618	7618	7618
Mass of slag	7618	7618	7618
Mass of fine aggregate	978	1035	890
Total weight	17136	17048	17071

A balanced mixture of slump 4 ± 1 in. (100 ± 25 mm) was used to prepare mixture proportions for the concrete of 20MPa, 30MPa and 40MPa grade for water cement ratio of 0.60, 0.50 & 0.42 correspondingly by following IS-10262-2009 standard of mix design. Details of mixture proportions for balanced mixes are given in **Table.5**.

4.0. Results and Discussion

4.1. Compressive Strength

Compressive strength of various types of mortar made with different coarse aggregate replacement level by slag has been graphically presented in Fig.1 to Fig.3. In total 330 blocks were tested for compressive strength test. Fig.1 shows that for 20MPa, 7 days strength of the mix 40 and 60 has increased by 4% each. For 30MPa of the mix 30, 40, 50, 60 and 70 has increased by 7%, 4%, 3%, 11% and 2% respectively. For 40MPa of the mix 40 has increased by 6%. Fig.2 shows that for 20MPa, 14 days strength of the mix 40, 50 and 70 has increased by 5%, 1% and 4% respectively. For 30MPa of the mix 30 and 40 has increased by 6% and 4% respectively. For 40MPa of the mix 30, 40 and 50 has increased by 1%, 5% and 6% respectively. Fig.3 shows that for 20MPa, after 28 days of curing strength of the mix 10, 20, 30, 40, 50, 60 and 70 has increased by 9%, 5%, 13%, 18%, 8%, 15% and 10% respectively. For 30MPa of the mix 30, 40 50, 60 and 70 has increased by 6%, 12%, 2%, 13% and 5% respectively. For 40MPa of the mix 30, 40, 50 and 70 has increased by 4%, 7%, 1% and 3% respectively. 180 days compressive strength data shows almost similar trend. This study has pointed out that steel slag could be a good stand in for coarse aggregate to improvise the compressive strength of concrete apparently as well as it can be concluded that strength gaining rate is lower for the higher grade of mortar.

4.2. Tensile Strength

Fig.4 to **Fig.6** shows the variation of tensile strength of different grades of mortar with different slag content as partial replacement of coarse aggregate for various curing ages. In total 165 blocks were tested for tensile strength test. Fig.4 shows that for 20MPa, 7 days strength of the mix 40 has increased by 3%, 14 days strength of the mix 30, 40, 50 and 60 has increased by 1%, 8%, 6% and 7%, 28 days strength of the mix 10, 20, 30, 40, 50, 60 and 70 has increased by 3%, 5%, 8%, 11%, 8%, 11% and 5% respectively. **Fig.5** shows that for 30MPa, 7 days strength of the mix 30 and 40 has increased by 7% and 4%, 14 days strength of the mix 30, 40 and 50 has increased by 2%, 3% and 2%, 28 days strength of the mix 30 and 40 has increased by 2% and 3% respectively. Fig.6 shows that for 40MPa, 7 days strength of the mix 40 and 50 has increased by 4% and 2%, 14 days strength of the mix

40, 50 and 70 has increased by 5%, 6% and 2%, 28 days strength of the mix 30, 40, 50 and 70 has increased by 2%, 4%, 5% and 2% respectively. Thus it is seen that tensile strength gaining is relatively faster for lower grade mortar as compared to higher grade in case of longer curing period.

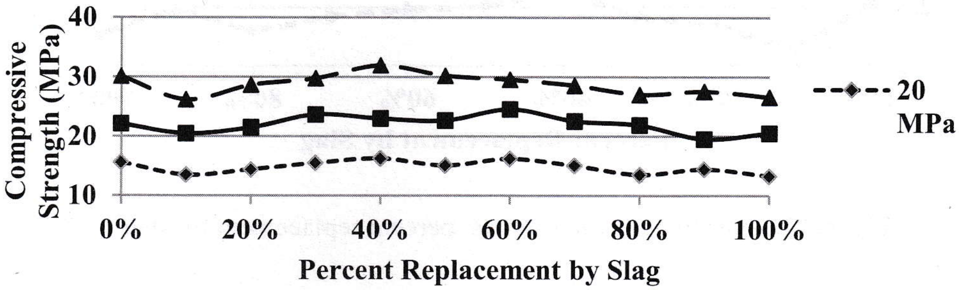

Fig.1. Compressive strength variation vs. percent replacement by slag of coarse aggregate for curing age of 7 days

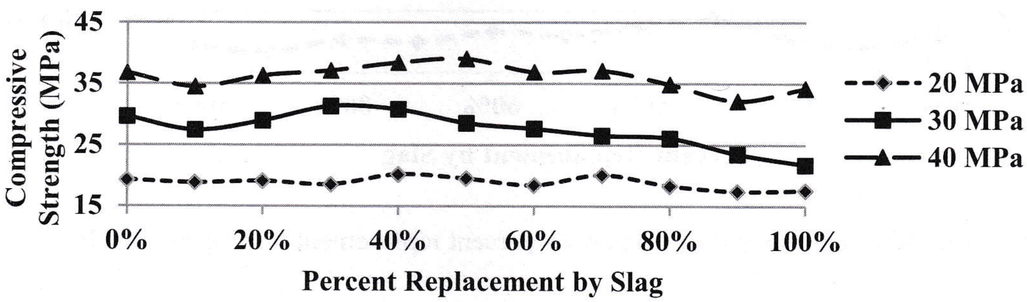

Fig. 2. Compressive strength variation vs. percent replacement by slag of coarse aggregate for curing age of 14 days

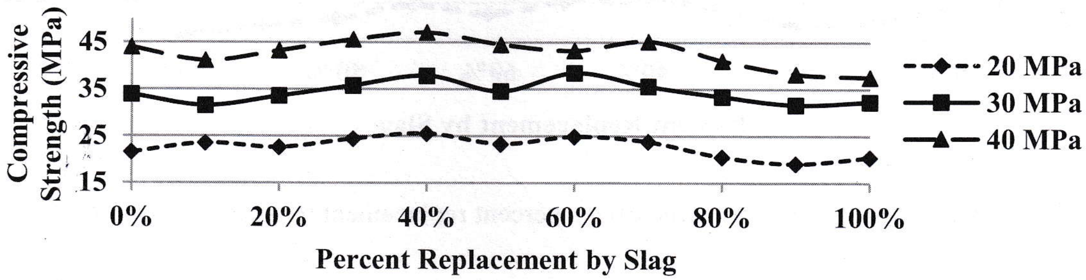

Fig. 3. Compressive strength variation vs. percent replacement by slag of coarse aggregate for curing age of 28 days

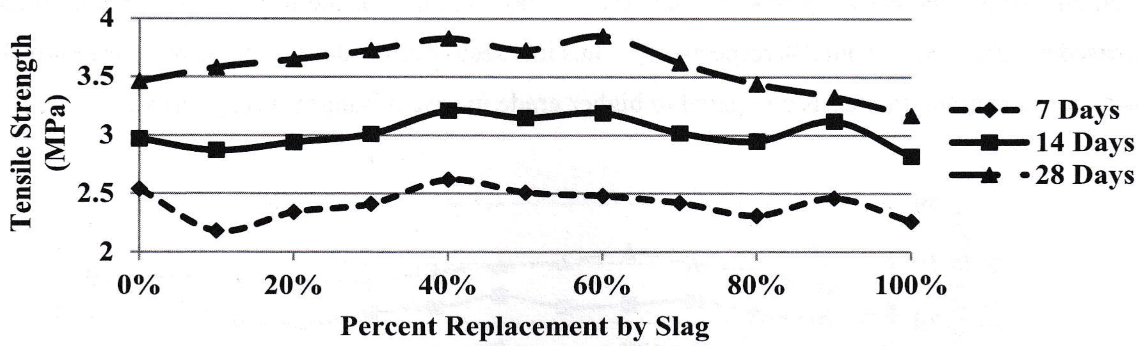

Fig. 4. Tensile strength variation vs. percent replacement by slag for 20MPa

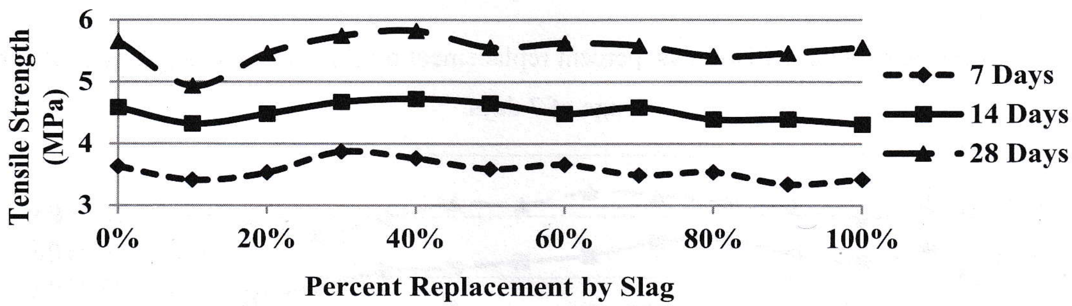

Fig. 5. Tensile strength variation vs. percent replacement by slag for 30MPa

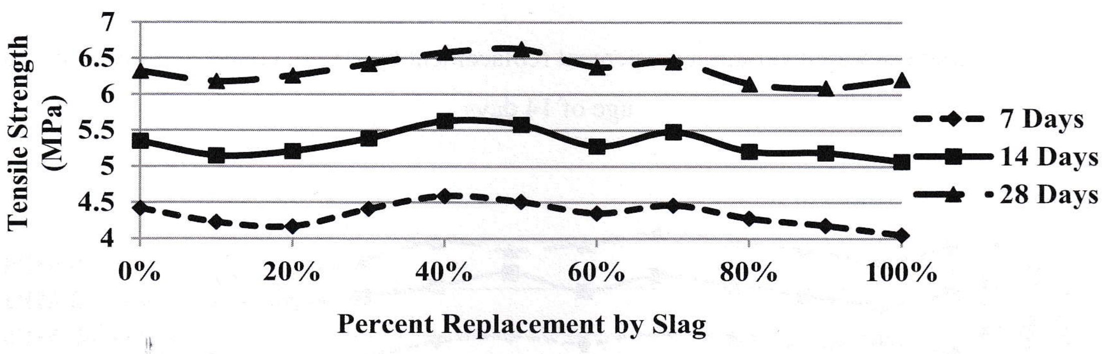

Fig. 6. Tensile strength variation vs. percent replacement by slag for 40MPa

5.0. Conclusion and Recommendation

- Slag mixing with mortar having various amount of coarse aggregate replacement level up to 70% showed satisfying outcomes for both compressive and tensile strength.

- The study presents that using steel slag instead of natural coarse aggregate at all the percent, helped in improving compressive strength of concrete by 1 to 18%.
- Meanwhile tensile strength improved by 1 to 11% at the particular percent replacements of coarse aggregate with waste steel slag.
- Steel slag costs almost half of natural aggregates. So it is cost-effective to use the waste by-product coming from steel industry.
- Behaviour of slag as an accelerator need to be experimented. In this research, Type I Ordinary Portland Cement (OPC) was used. It is recommended to find out the effect of slag on other types of cement.

6. References

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