International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 02 | Feb 2020 www.irjet.net p-ISSN: 2395-0072

An Experimental Investigation on usage of Steel Slag as Coarse aggregates in concrete subjected to Elevated Temperature

VADIRAJ RAO N R [1], MOHAMED RAYAN [2]

[1]Research scholar, Dept of Civil Engg, The National Institute of Engineering, Mysuru-570008, Karnataka, India
[2]Undergraduate Student, Dept of Civil Engg, The National Institute of Engineering, Mysuru-570008, Karnataka, India

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Abstract - *The present work focuses on the experimental investigation carried out on the incorporation of steel slag as coarse aggregates in concrete and subjecting to elevated temperature. The natural coarse aggregates were replaced with steel slag aggregates at percentages of 0%, 30%, 60% and 100%. For each replacement the compressive, split tensile and flexural strength of the concrete were evaluated at room temperature, 200^{0}C, 400^{0}C and 600^{0}C. From the results, it can be observed that the strength reduction in the concrete depends more on the temperature to which it is subjected rather than the percentage of replacements of slag aggregates. It can be inferred that the natural aggregates can be replaced by Slag aggregates up to a maximum of 60% for 200^{0}C. Further 30% replacement is advisable if concrete is exposed to a temperature of up to 400^{0}C. Also with the increase in replacement of slag aggregates the value of ultrasonic pulse velocity test (UPVT) increases marginally.*

Key Words: Steel slag aggregates, Elevated temperature, compressive strength, split tensile strength, flexural strength, Ultrasonic pulse velocity test

1. INTRODUCTION

Concrete being one of the most widely used material on earth is the primary material for the construction industry. The production of concrete utilizes natural resources for its raw materials. About 75% of the concrete volume is composed of aggregates and plays a vital role in concrete properties. The Usage of waste materials as alternative materials becomes a major concern and significant research is being made on the use of different materials as aggregate substitutes such as copper slag, blast furnace slag and steel slag aggregates to produce concrete. The use of fly ash and other mineral admixtures in Recycled aggregates concrete further helps to reduce the cement content [1]. The Usage of waste material is highly recommended as it helps to solve the problem of waste disposal, reduces the cost and also conserves the non-renewable natural sources.

The colour of Concrete is indicative of the intensity of temperature exposure. The compressive and split tensile strengths increased initially with an increase in exposure temperature and reached a maximum at about 200-300^{0}C and decreased subsequently. Hence the inclusion of fly ash in concrete is suitable for structures designed for temperature exposure of upto 300^{0}C [2].

T Subramani et al. concluded that the optimum strength and durability at 28 days is for the replacement of natural coarse aggregates by 60% of slag aggregates and the reduction of cost will be up to 39% is achieved [3]. Further with 100% replacement of slag aggregates, slight bleeding and segregation has been observed [4]. The increase in strength at 30% replacement is reported by Keerthi Kumar et al. The mechanical properties of the concrete will decrease marginally for less than 30% replacements and decrease by more than 25 percent for greater than 30% replacement of slag aggregates [5].

The Effect of Elevated Temperature on the Compressive Strength of Recycled Aggregate Concrete (RAC) has been studied by Adebakin Idowu H. It was concluded that the difference in the compressive strength of RAC and Natural aggregate concrete (NAC) at higher temperature is marginal. However above 25% replacements of RA should be avoided when high temperature is a design consideration [6].
The problem of waste disposal has become a major problem in the developed countries as well as developing countries like India. This is due to the enormous increase in the quantity of disposable materials, the continuing storage of dumping sites, increase in the cost of transportation and its disposal. The reduction of the natural coarse aggregates, especially in the vicinity of the construction sites and the ever increasing demand for aggregates by the construction industry further inspire the adoption of this concept of using slag aggregates. The lack of technical data, specifications and quality control guidelines in the processing of slag aggregate concrete requires better understanding of its behavior for structural elements.

OBJECTIVES OF THE STUDY

The objective of the present investigation is to study the effect of elevated temperatures on the concrete with replacement of natural coarse aggregates with Slag aggregates. Different mixes were prepared by varying the quantity of slag aggregates with

30%, 60% and 100% replacements for the coarse aggregates. Cubes, Cylinders and Prism specimens were casted for the above mixes and were subjected to elevated temperatures of 2000C, 4000C, and 6000C for duration of 2 hours. The mechanical properties of concrete at 7 & 28 days for different combinations of replacement of natural coarse aggregates with steel slag aggregates were evaluated for M 30 grade of concrete.

MATERIALS AND ITS PROPERTIES

CEMENT

Ordinary Portland cement of grade 53 conforming to 12269:1987 was used. The cement has Specific gravity of 3.14, percentage fineness of 2%, Standard consistency of 27.75%, Initial setting time of 120 min and final setting time of 255 min.

FINE AGGREGATES

Manufactured sand is a substitute of river sand for construction purposes produced from hard granite stone by crushing. M-sand pertaining to Zone-II having specific gravity of 2.63, fineness modulus of 3.5 and density of 1612 Kg/m3 conforming to IS 383-1970 has been used.

NATURAL COARSE AGGREGATES

Natural coarse aggregates (crushed granite) conforming to IS 383-1970 collected from the locally available site with uniform gradation of sizes 20mm and 12.5mm were used.

SLAG AGGREGATES

Slag aggregates have been procured from JSW steel plant near Torangal of Bellary district, Karnataka. The aggregates used are of 20 mm down size. The physical properties of slag aggregates and natural coarse aggregates are given in table 1 and the comparisons were being made.

Fig 1. Heap of Slag Aggregates

Fig 2. Slag aggregates being used in the construction of pavements

Table 1: Comparison between Slag aggregates and Natural Coarse aggregates

Sl. No	Properties	Slag aggregates	Natural Coarse aggregates	Remarks
1	Specific gravity	3.15	2.67	The specific gravity of slag aggregate is 18% higher than the natural coarse aggregates
2	Water absorption	2.06%	0.6%	The water absorption of slag aggregates is 3.5 times more than the natural coarse aggregates
3	Impact Value	25.14%	15.2%	The slag aggregates have higher impact value indicating lesser resistance to impact loads
4	Flakiness Index	4.8%	24%	The slag aggregates are 6 times less flaky than the natural coarse aggregates leading to better packing and workability of concrete
5	Elongation Index	9.2%	16%	The slag aggregates are having elongation index 0.6 times as that of natural coarse aggregates which would lead to better mixing and workability
6	Angularity Number	7.89	7.0	The slag aggregates have slightly higher angularity number than the natural coarse aggregates which leads to better interlocking of particles (less than 11)
7	Fineness Modulus	8.073	9.48	The slag aggregates have a fineness modulus lesser than the natural coarse aggregates making the concrete easier to finish
8	Abrasion Value	9.04%	8.4%	The abrasive resistance of slag aggregates is slightly higher than the natural coarse aggregates and this property is useful in pavement quality analysis

WATER

Regular available Tap water has been used for the preparation of concrete.

METHODOLOGY AND MIX DESIGN

M30 grade concrete has been considered for the present study and the mix design calculations of the concrete (as per IS 10262: 2009) are shown in Table 3. The slag aggregates is replaced for regular aggregates with different percentages as shown in table 2 and pie chart (Fig 3.) shows the percentage of materials being used.

Table2: Different percentage replacements of slag aggregates

Sl. No.	Mix Identification
1.	0% Slag aggregates, 100% Coarse aggregates
2.	30% Slag aggregates, 70% Coarse aggregates
3.	60% Slag aggregates, 40% Coarse aggregates
4.	100% Slag aggregates, 0% Coarse aggregates

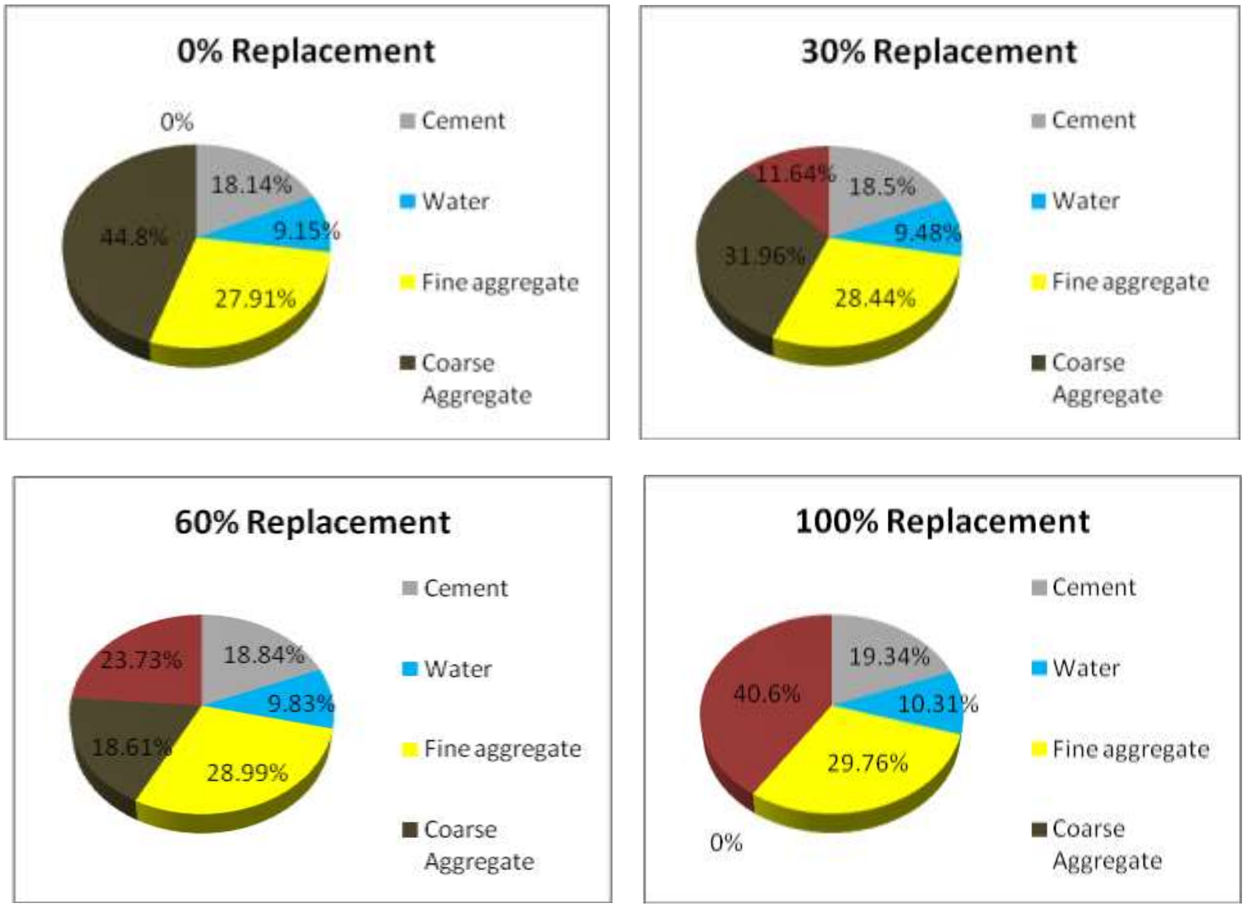

Fig 3. Pie Charts representing the usage of different materials

The Specimens from the above mixes shall be subjected to the temperatures of 200, 400, 6000C along with room temperature. The mechanical properties i.e., compressive strength, flexural strength and split tensile strength have been found for 7 and 28 days under elevated temperature for a duration of 2 hours.

Table 3: Mix Design of Concrete for casted specimens

Grade of concrete	% of replacement of slag aggregates	w/c ratio	Water in lit.	Cement kg/m3	Fine aggregates kg/m3	Coarse aggregates kg/m3	Slag aggregates kg/m3
M30	0%	0.45	221.1	438	674	1082	0
	30%		224.8			757.4	275.9
	60%		228.5			432.8	551.8
	100%		233.5			0	919.7

Fig 4. Casted specimens of Cubes, Cylinders and Prisms

Fig 5. Curing of Specimens

The specimens were tested at 7 and 28 days to get an idea about the change in strength and the variation the concrete will undergo, both physically and in terms of strength.

HEATING OF THE SPECIMENS

An electric oven capable of attaining a maximum temperature of 1000^{0}C was used to subject the specimen to high temperatures. After 28 days of curing, the specimens were allowed to dry the surface moisture and the specimens were subjected to elevated temperature.

Fig 6. Specimens placed in Electric Oven

TESTING OF SPECIMENS

Non-destructive test of concrete by Ultrasonic pulse velocity

Ultrasonic pulse velocity test (UPVT) is conducted to determine the wave velocity and in turn to assess the quality of concrete. The ultrasonic pulse is generated by an electro acoustical transducer which is induced into the concrete; it undergoes multiple reflections at the boundaries of the different material phases within the concrete. The receiving transducer detects the onset of the longitudinal waves, which is fastest. Wave velocity, depends on the distance and time taken by the wave to travel through specimens. As the voids increases, time taken to travel through the path increases. The test has been carried out according to IS 13311.

Fig 7. Ultrasonic Pulse Velocity Test of Cube

Fig 8. Specimen subjected to compressive strength

Fig 9. Specimen subjected to split tensile strength

Fig 10. Specimen subjected to flexural strength

RESULTS AND DISCUSSIONS

The mechanical properties of concrete such as compressive strength, split tensile strength, flexural strength for the replacement of natural coarse aggregates and the non destructive test i.e., UPVT results is shown from fig 11 to 14.

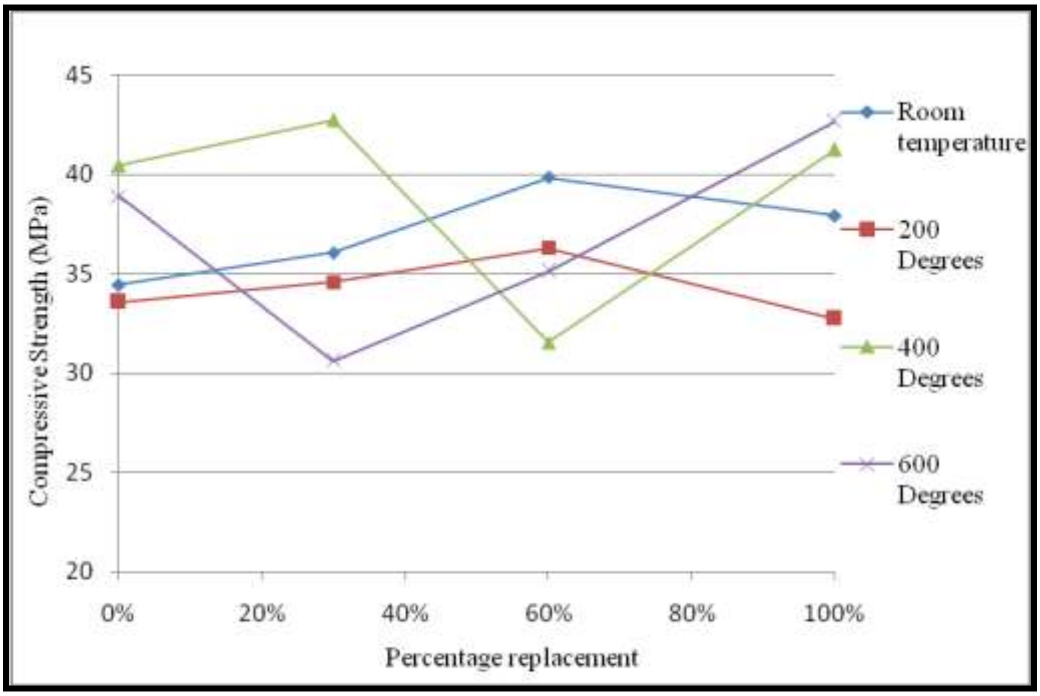

Fig 11. Residual Compressive Strength Vs. Percentage replacement

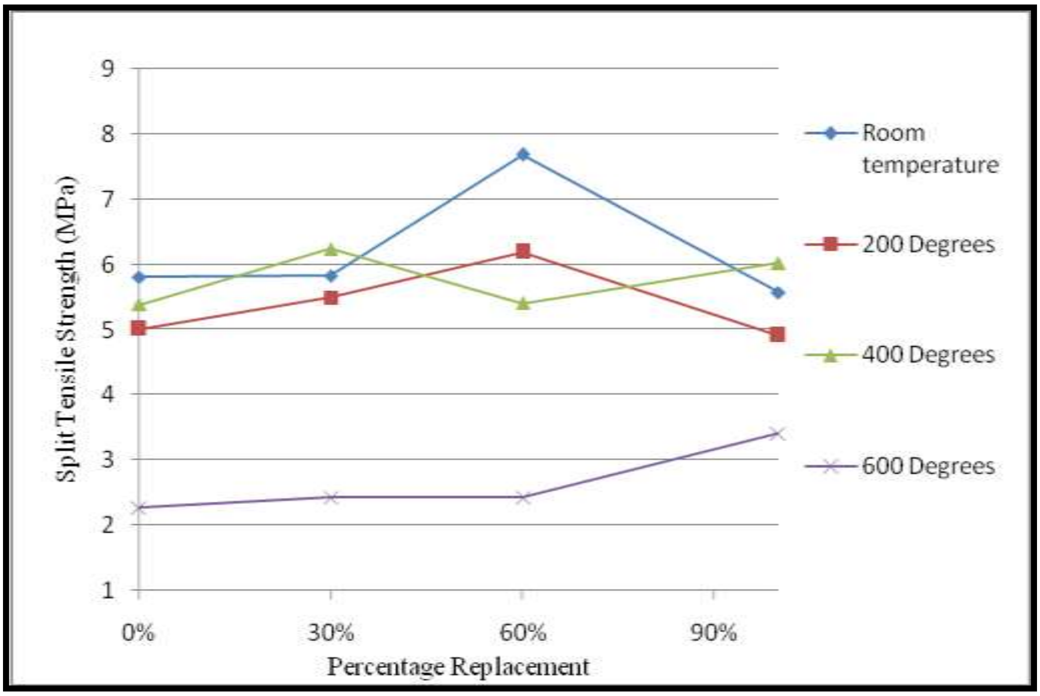

Fig 12. Residual split tensile Strength Vs. Percentage replacement

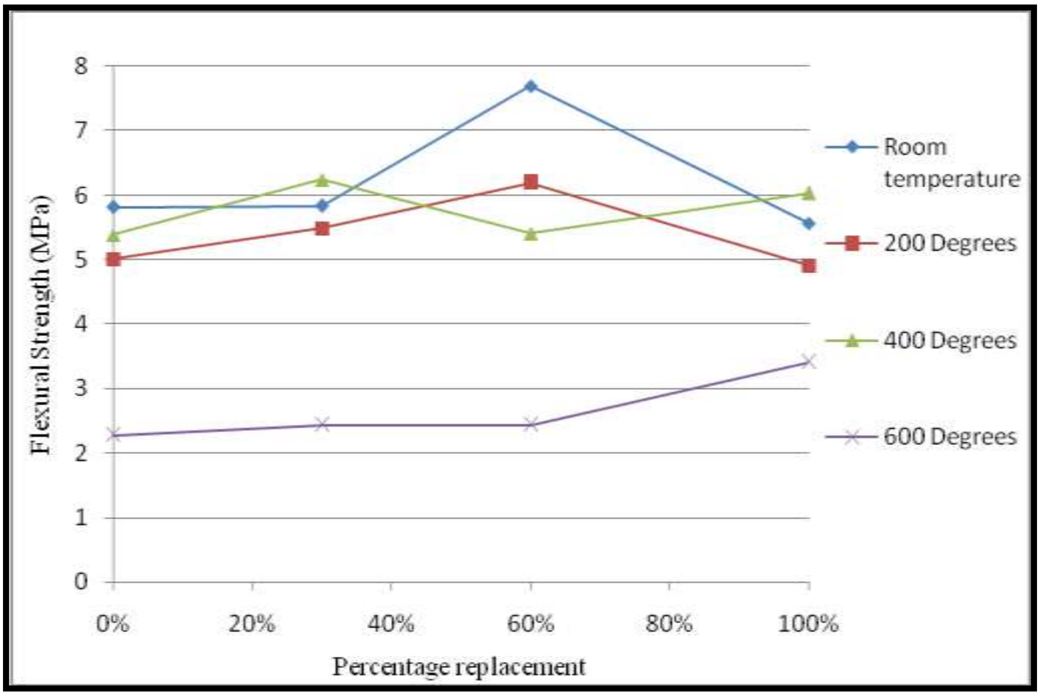

Fig 13. Residual flexural Strength Vs. Percentage replacement

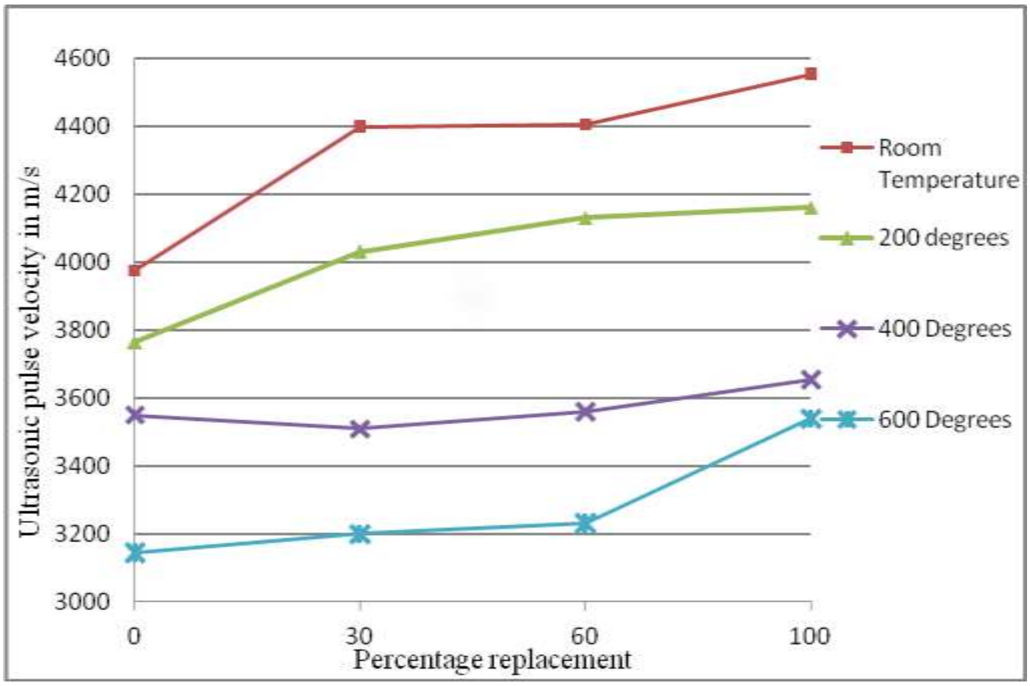

Fig 14. Ultrasonic pulse velocity Vs. Percentage replacement

CONCLUSIONS

From the present experimental investigation, the following conclusions can be drawn

1. The specific gravity & impact value of steel slag aggregates used is higher than the natural coarse aggregates. Hence it can be used in the normal concrete.
2. The slag aggregates are significantly lesser in flakiness index than the natural coarse aggregates leading to better packing and workability of concrete mixes.
3. In general, the strength of the slag aggregate concrete increases as the percentage replacement increases.
4. From the results, it can be observed that the strength reduction in the concrete depends more on the temperature to which it is subjected rather than the percentage of replacements of slag aggregates.

5. At room temperature, the Compressive Strength, split tensile strength and flexural strength of concrete is highest for 60% replacement in comparison with regular concrete (0% replacement with slag aggregates)
6. From the above test results, it can be inferred that the natural aggregates can be replaced by Slag aggregates up to a maximum of 60% for 200^{0}C and 30% replacement is advisable if concrete gets exposed to a temperature of up to 400^{0}C.
7. With the increase in replacement of slag aggregates the value of ultrasonic pulse velocity increases marginally indicating better quality of concrete.
8. Ultrasonic pulse velocity values decrease with the increase in temperature, thus indicating the deterioration of concrete.

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