



Compressive Strength Characteristics of Concrete in Which Cement is Partially Replaced by Steel Slag

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ABSTRACT

Cement has been identified in literature as the most important ingredient in concrete, which acts as a binding material. Furthermore, cement has been identified as the second-largest industrial source of CO₂ on earth. Consequently, there has been a global quest for the partial or full replacement of cement with an environment-friendly material to protect the environment. However, an experimental investigation was performed in this study to evaluate the compressive and flexural strength of concrete in which cement was partially replaced with Ground Granulated Blast Furnace Slag (GGBS). Concrete specimens containing 0%, 5%, 10%, 20%, 30%, & 40% replacement of cement by steel slag were prepared and used for the analysis performed in this study. Moreover, the tests were conducted at 7 and 28 days of curing age. The results obtained in this study show a decrease of 14% in compressive strength and 10.5% in flexural strength for 10% replacement vis-à-vis control specimens at 28 days. For 20% replacement, the decrease in compressive and flexural strength were 25.5% and 31%, respectively. Notwithstanding, it was established that the steel slag has the potential to partially replace the cement especially when it is crushed into smaller particles, passing through BS sieve #200.

ARTICLE INFO

Article History

Received: September, 2022

Received in revised form: January, 2023

Accepted: March, 2023

Published online: March, 2023

KEYWORDS

Cement, Concrete, Steel Slag,
Compressive Strength and Flexural
Strength.

INTRODUCTION

Concrete is the most important construction material serving humanity since ages ago. Concrete has varieties of uses in the construction industry and is known to be the most widely used material after water. According to Affan et al. (2019), about 12 million tons of concrete are used annually with the amount increasing incessantly due to increasing global population. Consequently, the construction industry is constantly making many efforts to increase cement and natural aggregates production to meet the rapidly growing demand for cement. However, cement manufacturing

requires a huge amount of energy and releases hazardous gases into our environment.

Similarly, pollution of the environment occurs at the quarry sites where natural aggregates and the raw materials for cement are acquired, thus causing depletion of our natural resources. The emission of lots of greenhouse gases from industries results in several adverse impacts on climate, which has changed people's minds. So currently, people are trying to convert the mass-production, mass-consumption, mass waste society of the past decades into a zero-emission society. The production of concrete generates emissions which can be

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harmful to human health, and the release of those emissions into the surroundings can cause environmental pollution and degradation (Mahasenan et al., 2003). To reduce these effects on the environment and humans, a by-product of steel Ground Granulated Blast Furnace Slag (GGBS), may be used to produce a different type of concrete by replacing cement with this waste material (steel slag).

In this study, steel slag is used as a partial replacement for cement. Steel slag is a by-product of steel making processes in the steel manufacturing industry. Steel slag is a by-product that is readily available and low-priced due to a large amount of steel produced worldwide every year. The slag consists of elements such as sulphur, phosphorus, silicon and aluminium ash, which are formed during different stages of the manufacturing process. Therefore, slag possesses properties that make it a suitable substitute for cement in concrete production. This by-product is then used to replace cement in concrete manufacturing at different percentages. This paper aims to determine the compressive strengths and flexural strengths of concrete by partially replacing cement with steel slag at varying percentages.

LITERATURE REVIEW

With the rapidly advancement of civil engineering technology, many alternative building materials are emerging like fibre concrete, high-strength aluminium alloy, sea-sand concrete, FRP materials, steel-slag concrete, recycled concrete etc. (Sha et al., 2021; Xiong et al., 2022; Lin et al., 2020; Xiong et al., 2022; Rotimi & Tijani, 2022). Among them, steel-slag concrete is an environmental protection material (Sha et al., 2021). Steel slag is a by-product of the steelmaking

industry, accounting for emissions of about 10% to 20% in steel production (Jiao, W. et al., 2020; Guo et al., 2018). In recent years, how to turn waste steel slag into valuables has become a prominent area. Steel slag contains tricalcium silicate and dicalcium silicate mineral phases with a similar composition to cement and a slight amount of free calcium oxide and metallic iron (Xiong et al., 2022; Liu et al., 2020). Some researchers have proposed the use of steel slag as a coarse and fine aggregate for concrete or finely ground into powder as cement admixture as an effective way to improve the comprehensive utilization of steel slag (Parron-Rubio, M.E. et al., 2018; Miah et al., 2020).

Several studies from previous literature have shown that when the steel-slag powder is used as a cementitious material instead of cement, the steel-slag powder has a cementing activity that occurs under the mixture system with continuous hydration, which not only effectively reduces the amount of cement, but also improves the mechanical properties of concrete (Roychand et al., 2020; Roslan et al., 2020 and Peng et al., 2010). Although, it is not that the higher steel-slag-powder replacement ratio is better. However, it was found that when the steel-slag-powder replacement ratio is 10%, the compressive strength of slag powder-cement-based concrete is better than that of ordinary concrete and has good compatibility (Roslan et al., 2020; Roslan et al., 2016). It is better because the steel-slag powder makes the concrete denser and effectively improves its impermeability. However, the compressive strength gradually decreases with the increase in the steel-slag-powder replacement ratio. In addition, steel slag significantly improves the compressive

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strength, water absorption, and durability of concrete when used either as a coarse or fine aggregate (Maslehuddin et al., 2003; Khalaf et al., 2020).

MATERIALS AND METHODS

This section presents all tests carried out and details of all materials and procedures adopted therein. All tests/experiments were conducted in accordance with applicable standards/specifications in the field of Civil Engineering.

Materials

The materials used in conducting the research comprise cement, fine aggregate, coarse aggregate, water and steel slag.

Concrete Mix Design

The mix ratio used throughout the research was 1:2:4. The mix ratio was used to determine the proportion of cement, fine aggregate and coarse aggregate in the concrete preparation. Thus, the mix ratio determines the strength of concrete to be achieved. Hence, the mix ratio used for both test and control samples is 1:2:4.

Batching

The materials were carefully batched according to weight using a mix ratio of 1:2:4. The process was achieved by first calculating the volume of cube moulds. With a density of concrete as 2400kg/m³, the mass of each constituent (i.e. cement, fine aggregate and coarse aggregate) required was calculated for the total 54 cube moulds, for each percentage of the steel slag replaced (i.e. 0%, 5%, 10%, 20%, 30% and 40%) respectively.

Concrete Mix Design

The concrete mix design was done having a ratio of 1:2:4. The method employed in the design is a

mass method. The process was done as shown below:

Cubes casted using 150mm x 150mm x 150mm mould:

0% 3 cubes for 7 days and 28days curing, **Total of 9 cubes**

5% 3 cubes for 7 days and 28days curing, **Total of 9 cubes**

10% 3 cubes for 7 days and 28days curing **Total of 9 cubes**

20% 3 cubes for 7 days and 28days curing, **Total of 9 cubes**

30% 3 cubes for 7 days and 28days curing, **Total of 9 cubes**

40% 3 cubes for 7 days, and 28days curing, **Total of 9 cubes**

Mixing

A tray of 900mm × 900mm × 50mm deep of rigid construction and made from a non-absorbent material not readily attacked by concrete was used. The tray was cleaned and dried to remove particles of dust and water. The sample was thoroughly mixed using a shovel to form a cone on the sampling tray and turned over with the shovel to form a new cone, the operation being carried out three times. This was done in accordance to BS 1881, part 106.

Casting

All parts of the mould were robust enough to prevent distortion. Before assembly for use, the joints between the sides of the mould and the base plate were oiled to prevent water loss. The materials after batching were thoroughly mixed manually in the laboratory using a shovel and tray. The mixed concrete was then cast into 150mm × 150mm × 150mm cube moulds, and each mould was filled in using three layers of approximately equal quantity.

Compaction

After filling each layer, the concrete was compacted manually with a tamping rod of 16mm diameter and 600mm long for 35 strokes. When compacting each layer, the strokes of the tamping rod were divided uniformly over the cross-section of the mould and ensure that the tamping rod does not penetrate significantly any previous layer nor strike the bottom of the mould when compacting the first layer.

Curing Of Concrete Cast

The cubes cast were detached from their moulds 24 hours after casting and inserted in a curing tank. This curing lasted for 7, 14 and 28 days, respectively. After which, the cubes were removed, air dried, and the density of each cube was determined before the compressive strength test was carried out.

Tests

After the curing of the concrete cast, the following series of tests were subsequently carried out:

- Sieve analysis for fine aggregate
- Specific gravity test
- Slump test
- Compressive Strength Test
- Flexural Strength

Sieve Analysis for Fine Aggregate

Apparatus

- Mechanical sieve shaker
- Weighing balance sensitive to 0.1 g.
- BS test set of sieves ranging from 28mm to 5mm for coarse aggregate
- Scoop and brush

Test Procedures

- The soil sample was dried, and BS sieve ranging from 10mm, 6.3mm,

5.0mm, 3.35mm, 2.0mm, 1.18mm, 0.6mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm to 0.063mm were stacked and arranged in order of decreasing diameter from the top.

- The soil sample was weighed, poured onto the upper sieve and agitated for some time.
- The sample passing through 6.3mm was weighed and riffled. 150g of the sample was passed through the remaining sieves and agitated.
- The weight of the soil sample retained on each sieve was weighed and recorded.
- The percentage passing each sieve in the stack was computed and plotted a graph against grain diameter on a semi-logarithmic plot.
- With the obtained, the zone of the sand is determined.

Specific Gravity Test

This test was conducted in accordance to BS 1877: 1975

Apparatus used include

- Pycnometer,
- Cylindrical bottle (1000ml),
- Digital weighing balance,
- Rubber stopper (cork),
- Oven
- Dried sample of sand.

Test Procedures

- The cylinder was clean and dried, the empty cylinder was weighed, and the weight was noted as W1
- The cylinder was now filled with water at a temperature within plus or minus two degrees of the average room temperature,
- The water and the cylinder was then weighed, and the

- weight was also noted as W4, the cylinder was then emptied and dried.
- iv. The considerable amount of the sample was then added to the cylinder and weighed; this weight was recorded as W2.
 - v. Water within plus or minus two degrees Celsius of room temperature was introduced in the cylinder up to the 500ml mark.
 - vi. The sample was corked with a rubber stopper and thoroughly shaken to remove air bubbles and suspended particles in the soil solution; with this done, the stopper was removed and particles sticking to the side of the cylinder walls were washed back carefully into the cylinder such that the water level rose to about 2mm from the 1000ml mark.
 - vii. This mixture is allowed to settle for about 2 minutes before more water is added to the mixture to the 1000ml mark.
 - viii. The cylinder was then dried outside with a cloth and weighed; that weight was recorded as W3.

The above procedure was repeated twice per sample for all other samples collected. Specific gravity is thus calculated.

SLUMP TEST

Slump test is the most commonly used method for determining the workability of concrete. However, it is used conveniently as a control test and

indicates the uniformity of concrete from batch to batch.

Apparatus

- i. Slump cone of height 30cm, open at both ends.
- ii. Baseplate
- iii. Scoop
- iv. Meter rule
- v. Hand trowel.

Test Procedures

- i. The slump cone, tapping rod, base plate and scoop were wetted before setting it up.
- ii. The slump cone was then filled in 3 layers; each layer gave 25 blows using the tapping rod.
- iii. The slump cone was then levelled, shaken and removed at the rate at which a count of 10 was completely removed.
- iv. Finally, the slump was then placed beside the concrete, and a meter rule was used to measure the falling distance from the top of the concrete midpoint and was neatly recorded

COMPRESSIVE STRENGTH TEST

This is the most common test conducted on hardened concrete, partly because it is easy to perform and partly because most of the desirable characteristic properties of concrete are quantitatively related to its compressive strength. Compressive strength is the fundamental property of concrete (others are generally defined from it) which is mostly used in concrete design. It is also a property for quality control for lightweight concrete. Compressive strength may be defined as the maximum measured resistance of a concrete specimen to axial loading. It is determined by measuring the highest compression stress supported by a test cylinder or cube. Three types of test can be used to

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determine compressive strength; cube, cylinder, or prism test. The concrete cube test' is the most familiar test and is used as the standard method of measuring compressive strength for quality control purposes.

Apparatus

- i. Weighing balance
- ii. Compressive strength testing machine

Test Procedures

- i. The test cubes was brought out from the curing tank and allowed to surface dry.
- ii. The test cubes were then weighed, and their various weights recorded.
- iii. The test cubes were then placed in the compressive testing machine, establishing contact with the machine's plate.
- iv. The machine pointer was set to zero and was loaded.
- v. The load was released when the pointer began to recede, indicating that the concrete had failed. The crushing load corresponding to this was then taken and recorded.
- vi. The crushing strength was determined at 7, 14, and 28 days of curing. The compressive strength is determined in accordance with BS 1881: part ii: 1983, using the formulae below.

FLEXURAL STRENGTH

This is the ability of a beam or slab to resist failure in bending. The flexural strength is expressed as the modulus of rupture. For this study, the test was conducted in accordance with British Standard (BS EN 12390-5: 2000).

Apparatus:

- i. The Compression Testing Machine.

Test Procedures

- i. The test was conducted on the specimen immediately after being taken out of the curing condition to prevent surface drying, which declines flexural strength.
- ii. The specimen was placed on the loading points. The hand-finished surface of the specimen was ensured not to be in contact with the loading point so as to ensure an acceptable contact between the specimen and loading points.
- iii. The loading system was centred in relation to the applied force.
- iv. The block applying force was adjusted to have contact with the specimen surface at the loading points.
- v. The specimen was loaded continuously without shock till the point of failure at a constant rate, and the load at failure was recorded.

RESULTS AND DISCUSSION

This section presents a logical, convincing analysis of the discussion and presentation of results obtained from the study based on the methods described in section three.

Sieve Analysis Result

Sieve Analysis of Aggregates were performed as follows;
Weight of sample retained, (g) = (weight of sieves + sample) - (weight of empty sieves)

$$\% \text{ Weight retained} = \frac{\text{weight of sample retained}}{\text{Total weight of sample}} \times 100$$

Total weight of sample = 1

% weight passing = 100- cumulative percentage weight retained weight of the sample before sieving = 500g

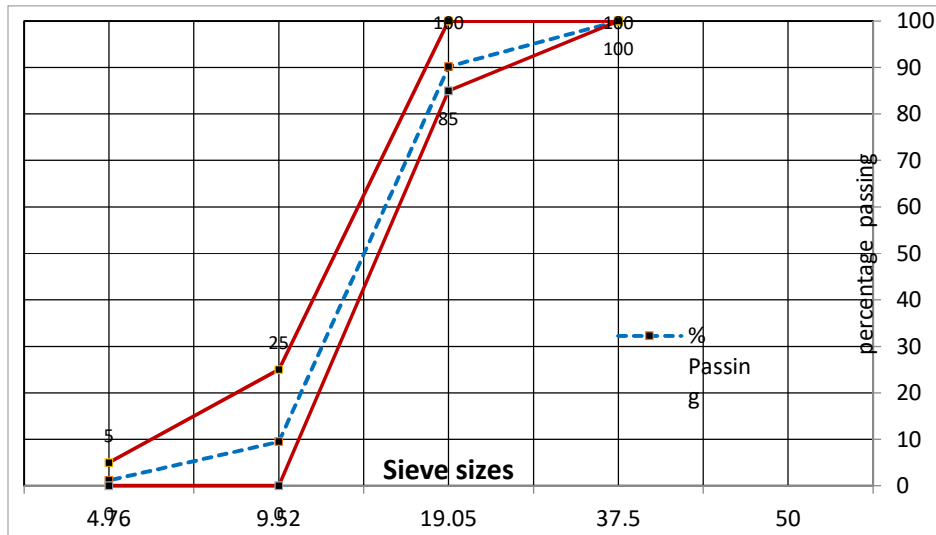


Figure 4.1: Particle Size Distribution of Fine Aggregate

The pattern of the graph in Figure 4.1 reveals that the sand used is

well-graded sand, containing a wide range of particle sizes.

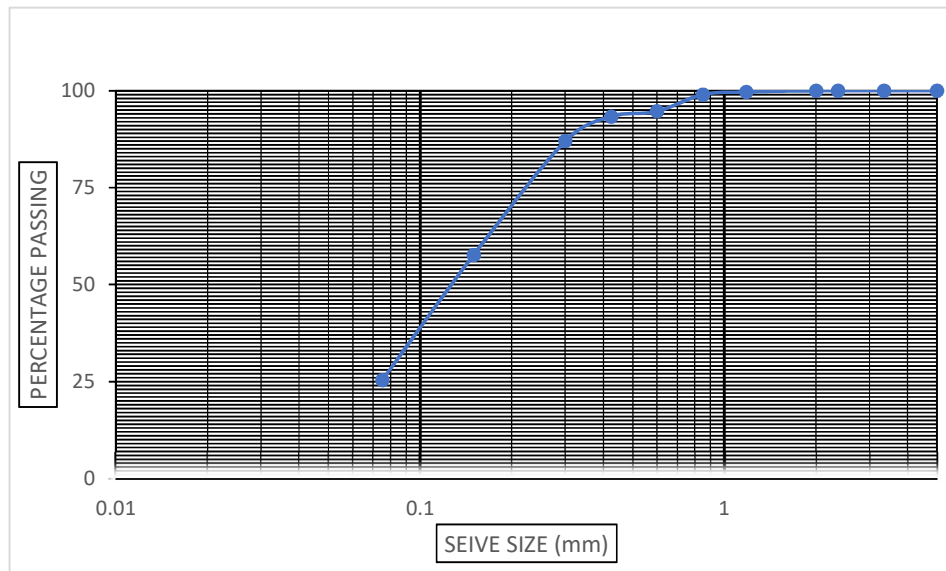


Figure 4.2: Particle Size Distribution of steel slag

The graph shown in Figure 4.2 represents the particle size distribution curve of the steel slag sample. The curve indicates that the steel slag sample is well-graded, containing a good representation of all particle sizes

between maximum and minimum sizes.

Fineness of Cement

The maximum percentage of residue is 10%, as prescribed by British Standard (BS812:1972 part3), for ordinary Portland cement. From the



result obtained in Table 4.1, the fineness of cement used conformed to the international standard; the finer the

cement, the greater the rate of hydration, the coarser the cement, and the greater the period of hydration.

Table 4.1: Fineness of Cement

| S/No. | Weight of Sample (g) | Weight of residue (g) | Fineness (%) |
|----------------------|----------------------|-----------------------|--------------|
| 1 | 100 | 6 | 6 |
| 2 | 100 | 8 | 8 |
| 3 | 100 | 4 | 4 |
| Average fineness (%) | 6% | | |

Consistency of Standard Paste and Setting Times of Ordinary Portland Cement

Consistency of Standard Paste

Both the British standard (BS 4550: Part 3:5:1978) and American standard (ASTM C150-85) stated that the depth of penetration for a consistency of standard paste should be between 5-7mm deep.

Initial Setting Time

A maximum of 45minutes is prescribed by British standard (BS

12:1978), for ordinary Portland cement; a maximum of 60minutes is often prescribed by the American standard (ASTM C 150-84) for an ordinary Portland cement. From the result obtained in Table 4.3, the initial setting time for the various brands of cement was to the British standard only, which is a result of using the British standard in Nigeria more than the American standard.

Table: 4.2: Setting Time and Consistency Test Result

| Cement Name | Water Cement Ratio | Initial Setting Time(min) | Final Setting Time (min) | Depth of Penetration (mm) | Consistency |
|-----------------|--------------------|---------------------------|--------------------------|---------------------------|-------------|
| Portland cement | 0.35 | 32 | 225 | 6 | OK |

Final Setting Time

A maximum of 10hours is prescribed for ordinary Portland cement, by both British standard (BS 12: 1978) and American standard (ASTM C 150-84). From the result obtained in the table the final setting time for the brand of cements conform to both the British standard (BS12: 1978) and American standard (ASTM C 150-84) of not exceeding 10hours.so

also, the cement sets in less than 5hours, which shows a strong compliance to the earlier mentioned standards.

FINENESS OF SLAG

The maximum percentage of residue is 10% as prescribed by British Standard (BS812:1972 part3), for ordinary Portland cement. From the result obtained in the Table 4.3, the

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fineness of slag used conformed to the international standard, the finer the cement, the greater the rate of

hydration, the coarser the cement, the greater the period of hydration.

Table: 4.3: Fineness of Slag

| S/No. | Weight of Sample (g) | Weight of residue (g) | Fineness (%) |
|------------------|----------------------|-----------------------|--------------|
| 1 | 100 | 8.5 | 8.5 |
| 2 | 100 | 9.0 | 9.0 |
| 3 | 100 | 6.8 | 6.8 |
| Average fineness | 8.1% | | |

Table: 4.4: Aggregate Impact Value Test

| S/NO. | DESCRIPTION OF MATERIAL | A | B | B |
|-------|----------------------------------------------|-----------|------|------|
| 1 | Mass of The Sample Before Test (A) | 1680 | 1675 | 1675 |
| 2 | Mass of Retained on No. 7 Sieve (B) | 425 | 387 | 395 |
| 3 | Mass of sample passing No. 7 Sieve (A-B) = C | 25.3 | 23.1 | 23.6 |
| 4 | Impact Value $C/A \times 100 \%$ | 24 | | |

From the table shown in Table 4.4, it can be seen that the values impact value of coarse aggregate obtained is within the permissible values recommended by British Standard (BS812:1972 part3).

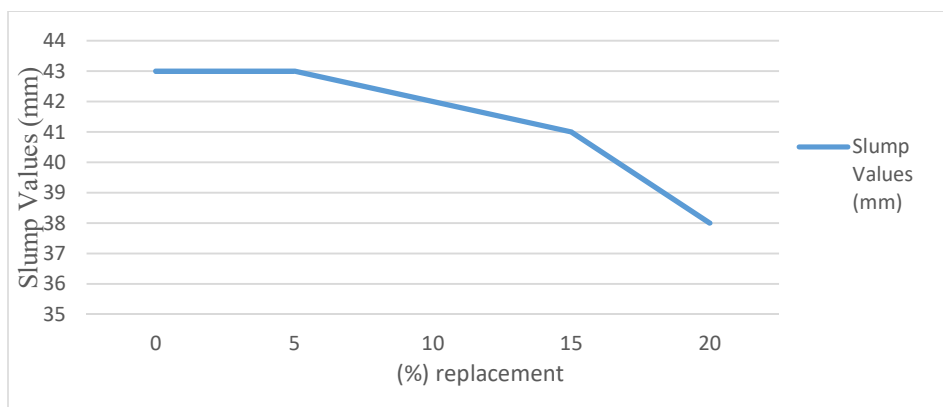


Figure 4.3: Slump Test Values

The workability result indicated that control mix has highest workability values of 43mm as shown in Figure 4.3 and reduces subsequently

to the highest percent replaced of 20% with a value of 38mm.

Compression Strength Test Result

After performing a test on cubes of M30 grade concrete for a varying percentage of steel slag by

volume of cement results obtained are illustrated in Figure. 4.4, Figure. 4.5 and Figure 4.6, respectively.

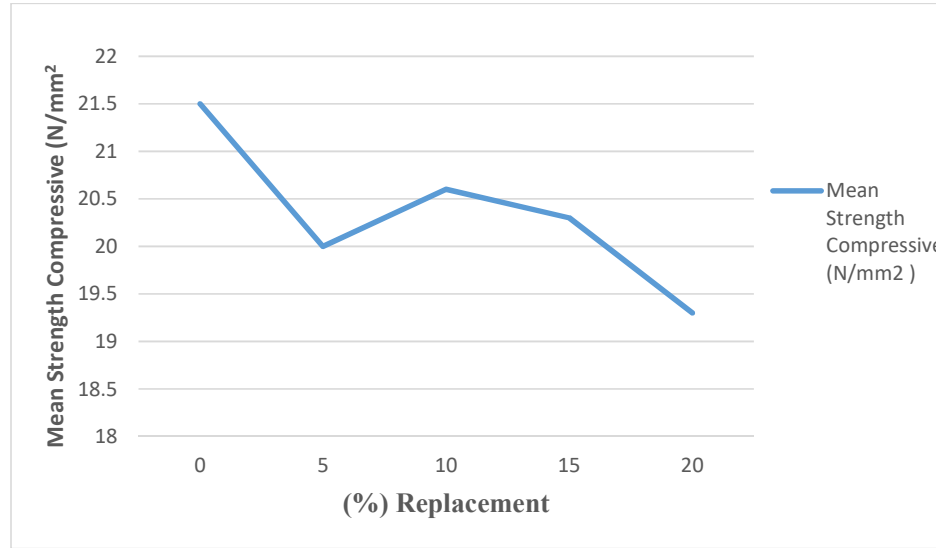


Figure 4.5: The Mean Compressive Strength of Specimen at 7days of curing

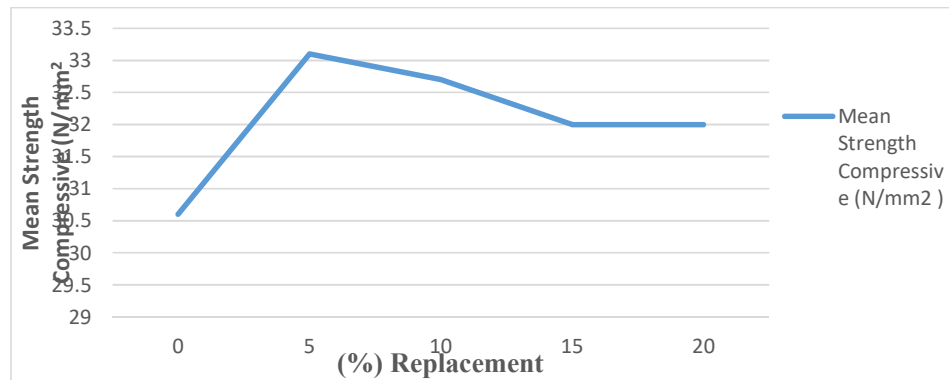


Figure 4.6: The Mean Compressive Strength of Specimen at 28days of curing

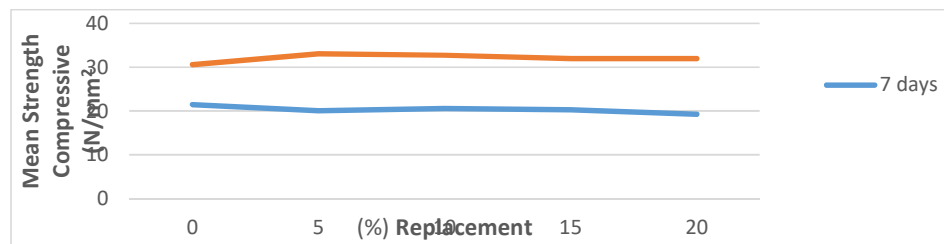


Figure 4.7: The Mean Compressive Strength of Specimen at 7 and 28days of curing



Specimens of control concrete and concrete with replacement of cement with steel slag at different level of 0%, 5%, 10%, 15% and 20% were tested for compressive strength. The test was performed at the ages of 7-days and 28-days. It was observed that with the increase in the steel slag in concrete, compressive strength of concrete at that the age of 28-days with a replacement level of 5% was more than at the age of 7-days of M35 Concrete mix; after that, it keeps decreasing. Results of the Investigation indicate that compressive strength increases up to 20% replacement. Therefore, from the Figures and graphs plotted, a strength equivalent to that of 28 days' strength at a high volume replacement level was achieved at 5%. And the value is 33.1N/mm², where the percentage increased to the control is 9.3%. This was a result of the steel slag having more strength compared to cement due to its constituent, as presented in the literature.

CONCLUSIONS

A comparison was performed between concrete having natural coarse aggregates and concrete with various percentages of steel slag aggregates replaced by the weight of cement. The results of this research were encouraging since it showed that using steel slag as cement in concrete has no negative effects on the short-term properties of hardened concrete. Hence, after performing all the tests and analysing the results, the following inferences were made:

- i. The workability result indicated that the control mix has the highest workability values of 43mm and a minimum value of 38mm at 20% replacement.
- ii. The optimum compressive strength value was achieved at 10% replacement of steel slag for

7days with a value of 20.60N/mm². in contrast, optimum compressive strength was achieved at 5% for 28days with a value of 33.10N/mm²; this behaviour was attributed to the steel slag being of more strength compared to cement.

- iii. Also, the concrete of M30 was also obtained using the steel grade as replacement of cement when it is replaced with an optimum percentage at all replacements used.

Steel slag is a by-product, and using it as cement in concrete might be an economical and environmentally friendly solution. The demand for cement is increasing rapidly, and so is the demand for concrete. Thus, it is becoming more important to find suitable alternatives for cement in the future. The results showed that it has properties similar to conventional cement, and it would not cause any harm if incorporated into concrete. The present study was undertaken to study the limited aspects of steel slag concrete.

However, future studies may be planned to cover the following aspect; Investigation into the higher percentages ranges from 50, 60, 70, 80, 90 and 100% replacement of cement in the production of concrete. Effect of steel slag replacement on the abrasion resistance of concrete with higher aggregates size and Chemical analysis/ microscopic study of steel slag concrete to study its microstructure.

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