A comparative analysis of compressive and tensile strengths of concrete made with natural aggregates and electric arc furnace steel slag produced in Trinidad

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Abstract

This paper compares the compressive and tensile strengths of concrete made with natural aggregates and electric furnace steel slag. This comparison was conducted in order to examine the effectiveness of using by-products in making concrete production more sustainable. As such, electric arc furnace slag was utilized as a coarse aggregate in concrete mixtures. The physical characteristics of the natural aggregates and the electric arc furnace slag were analysed. Conventional concrete mixtures using natural aggregates and electric arc furnace steel slag were prepared. This was done for water to cement ratios of 0.4, 0.45 and 0.5 respectively. A comprehensive evaluation of the compressive and tensile strengths of the concrete specimens was done for the respective water to cement ratios. Blended cement and ordinary Portland cement were used in the concrete mixtures. For both types of cement used, the concrete made with the electric arc furnace steel slag exhibited higher compressive and tensile strength values. The highest compressive and tensile strength values were 80.5MPa and 4.77MPa respectively. These values were attained when the electric arc furnace steel slag was used as a coarse aggregate with the ordinary Portland cement for 0.4 water to cement ratio.
Keywords: concrete, electric arc furnace slag, aggregates, cement, compressive strength, tensile strength.

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1 Introduction

Concrete is a composite material which consists of coarse and fine aggregates, cement and water. Water and cement forms a paste which acts as a binder and fills the space between the aggregate particles.

The types of aggregates used in the formulation of a concrete mixture significantly affects the strength of the concrete produced. As such, the type of aggregates determines the performance of the concrete when it is used on different structures. One crucial feature of concrete is that it could be tailor made to meet specific design requirements depending on its application [1].

The manufacturing process of concrete requires energy and it utilizes significant quantities of natural resources. Energy is utilized in the extraction of the natural aggregates and in the processing of the cement. This energy is supplied by fossil fuel sources. The use of these sources generates carbon dioxide emissions which are responsible for the global warming phenomenon that is presently being experienced on a worldwide basis.

One fundamental measure that could be taken to minimize the energy consumed and the carbon dioxide emissions generated during the manufacture of concrete is the use of byproducts in its preparation.

One of the byproducts that is presently under investigation for use in concrete is electric arc furnace steel slag. The produced slag is obtained by cooling the electric arc furnace steel liquid slag in air at production site [2]. This is a byproduct of the steel making process in which its quality depends on its origin [3]. Therefore, the quality of the slag generated at each steel manufacturing facility will vary because it depends on the production process of steel used. Presently, studies are being undertaken to deduce the feasibility of using the byproducts from industrial processes in the concrete mixtures.

However, few investigations have been conducted to examine the effectiveness of using electric arc furnace steel slag as an aggregate in concrete mixtures in the construction industry [3]. Additionally, no previous studies were done to compare the compressive and tensile strengths of concrete manufactured using electric arc furnace slag produced in Trinidad.

As such, this study seeks to deduce the tensile and compressive strengths of concrete manufactured using electric arc furnace steel slag as aggregates as compared to when natural aggregates are utilized in concrete mixtures.

2 Materials and methods

The materials used in the concrete mixtures were blended cement, water, natural aggregates and electric arc furnace steel slag used as coarse aggregates.

2.1 Cementitious materials

Cement is the ultra-fine gray powder which binds the fine and coarse aggregates into the matrix of concrete [4]. The two types of cement used were ordinary Portland cement and blended cement. The cement was obtained from a local cement factory (Trinidad Cement Limited). The cement is manufactured by using a burned mixture of limestone and clay [5]. However, the difference between these two types of cement used is that during the manufacturing process of blended cement up to 30% fly ash (a byproduct of power plants) is used [6]. The use of fly ash significantly reduces the quantity of carbon dioxide generated during its production process.

2.1.1 Aggregates

The aggregates used in the concrete mixtures were natural aggregates and electric arc furnace steel slag. The natural aggregates used were quartzite and were used as fine aggregates and the electric arc furnace steel slag were used as coarse aggregates.

2.1.2 Electric arc furnace steel slag

The electric arc furnace steel slag used was obtained from a local steel factory (Arcelor Mittal Steel) located in Point Lisas, Trinidad. The quantity of steel produced annually is 1,500,000 tonnes. This quantity of steel generates approximately 300,000 tonnes of slag on annually. As such, one tonne of steel produces 0.2 tonnes of slag. The steel is produced in an electric arc furnace which uses scrap metal parts to generate the steel.

The experimental investigations which were done are the:

1. Performance of a sieve analysis on the natural aggregates and the electric arc furnace steel slag
2. Determination of the specific gravity and the water absorption of the natural aggregates and the electric arc furnace steel slag
3. Formulation of concrete mixtures containing the natural aggregates and the electric arc furnace steel slag
4. Testing of the tensile and compressive strengths of the concrete mixtures formulated using natural aggregates and electric arc furnace steel slag for different water to cement ratios

2.2 Performance of a sieve analysis on the natural aggregates and the electric arc furnace steel slag

Samples of the fine and coarse natural aggregates and the electric arc furnace steel slag were taken according to BS 812: Part 102:1984 [7]. The sieve analysis conforming to BS 812: Part 103: 1985 [8] was conducted on the fine natural aggregates and the produced electric arc furnace steel slag. This was done in order to examine the gradation of aggregates. The gradation was evaluated using the ASTM C33 limits [9].

2.3 Determination of the specific gravity, water absorption of the natural aggregates and the electric arc furnace steel slag

The specific gravity and the water absorption tests of the fine natural aggregates and the electric arc furnace steel slag was conducted according to BS 812: Part 2: 1984 [7].

2.4 Formulation of concrete mixtures containing the natural aggregates and the electric arc furnace steel slag

For each concrete mixture, ten cylinders (diameter 101.6mm and height 203.2mm) and ten cubes (100mm × 100mm × 100 mm) of concrete samples were prepared using three different water to cement ratios which were 0.4, 0.45 and 0.5 respectively. Different concrete mixtures were formulated using electric arc furnace steel slag, natural aggregates, with blended cement and ordinary Portland cement respectively. The aggregates, cement and water were mixed in a rotary drum mixer, using identical mixing times for each of the water to cement ratios. After mixing, a slump test was conducted according to ASTM C 143 – 90a [10] and the height of the slump was measured for each of the prepared concrete mixtures. The mix designs of the concrete mixtures are described in Table 1.

Table 1: Measurements of the height of slump and density of concrete using natural aggregates with blended cement for the different water to cement ratios.

water to cement ratio	height of slump (mm)	density of concrete (kg/m^3)
0.4	165	2239
0.45	40	2358.2
0.5	10	2479.1

Table 2: Measurements of the height of slump and density of concrete using natural aggregates with ordinary Portland cement for the different water to cement ratios.

water to cement ratio	height of slump (mm)	density of concrete (kg/m^3)
0.4	215	2365.7
0.45	110	2365.7
0.5	20	2441.1

Table 3: Measurements of the height of slump and density of concrete using electric arc furnace slag with blended cement for the different water to cement ratios.

water to cement ratio	height of slump (mm)	density of concrete (kg/m^3)
0.4	190	2608.4
0.45	2	2574.6
0.5	0	2567.2

Table 4: Measurements of the height of slump and density of concrete using electric arc furnace slag with ordinary Portland cement for the different water to cement ratios.

water to cement ratio	height of slump (mm)	density of concrete (kg/m^3)
0.4	105	2559.7
0.45	15	2649.3
0.5	20	2679.1

The concrete mixture was poured into cylindrical and cubical moulds. Proper compaction of the concrete mixture in the cylinders and cubes was ensured by vibrating the samples. More vibrating time was given to the lower water–cement ratios in order to remove any possible air spaces present in the concrete specimens. They were then de-molded from the cylinders and cubes after a twenty four hour period. The specimens were cured in water at a standard temperature of 20°C for a twenty eight day period.

2.5 Testing of the compressive and tensile strengths of the concrete samples

The testing of the compressive and tensile strengths of the concrete mixtures were performed after a twenty eight day period. The compressive strength of the concrete was performed according to ASTM C 39/C 39M [11] on the cubical specimens. The tensile strength was evaluated by conducting a split tensile strength test on the cylindrical concrete specimens according to ASTM C 496 [12].

Figure 1: Hardened cubical and cylindrical specimens after twenty eight days.

3 Results and discussion

Figure 2 illustrates the grading of the fine natural aggregates according to the ASTM C33 upper and lower limits. The grading of these aggregates falls within the range of the upper and lower limits of the ASTM C33 standards and as such, meet the gradation requirements. The value of the upper limit of the grading is

97.4%. This means that 97.4% of the aggregates pass through the 5.0mm. However, the grading showed that 2.1% of the aggregates pass through the smallest sieve size which is 0.150mm. There is evidence of continuous grading occurring between the upper and lower limits with a decrease in the percentage of the aggregates passing through the respective sieve sizes. Additionally, there is no indication of gap grading (missing aggregates in the sieve size) in the respective sieve sizes.

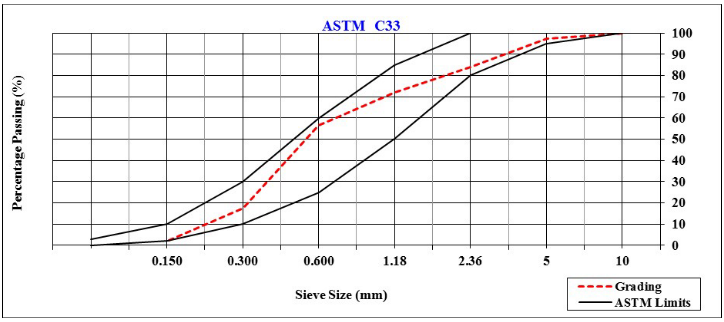

Figure 2: Grading of the natural fine aggregates according to ASTM C33 limits.

Calculation of the Fineness Modulus of the Fine Natural Aggregates:
Sum of the cumulative percentage retained/100
2.6 + 16 + 27.9 + 41.4 + 82.7 + 97.9 / 100 = 2.69

This value of the fineness modulus conforms with ASTM C 33 requirements of the fineness modulus being within the limit of 2.3 and 3.1. This is necessary since the value of the fineness modulus affects the workability of the concrete mix.

Figure 3 illustrates the grading of the coarse natural aggregates according to the ASTM C33 standards [9] in which the representative sample size was within the range of the specification for the 10mm and 20mm sieve size. However, the coarse aggregates were out of the boundary for the 5mm sieve size. Based on

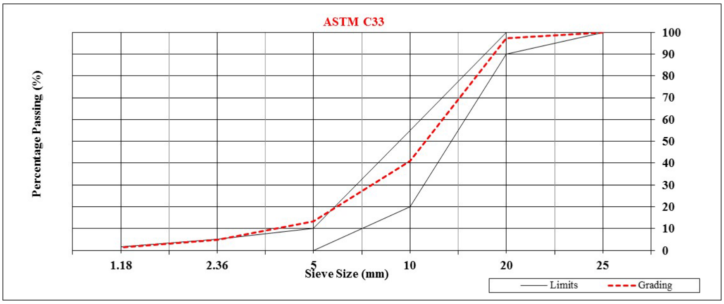

Figure 3: Grading of the coarse natural aggregates according to ASTM C33 limits.

the graph, 51% of the aggregates pass through the 20.0mm and 0.3% of the aggregates pass through the smallest sieve size which is 0.150mm. There is evidence of continuous grading occurring between the upper and lower limits with a decrease in the percentage of the aggregates passing through the respective sieve sizes. However, there is some indication of possible gap grading of the between the 0.15mm and 0.30mm sieve sizes since the same percentage of the aggregates pass through these sieve sizes.

Figure 4 illustrates the size distribution of the slag according to the ASTM C33 standards [9] in which the gradation of the aggregates was within the upper and lower limits. Based on Figure 4, 95.1% of the aggregates pass through the 20.0mm. However, the grading showed that 0.3% of the aggregates pass through the smallest sieve size which is 0.150mm.

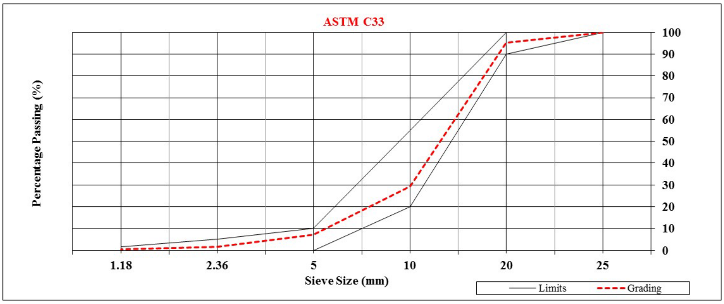

Figure 4: Grading of the electric arc furnace steel slag (coarse aggregate).

Table 5: Specific gravity and water absorption properties of the natural aggregates and the electric arc furnace slag.

Sample	Specific Gravity on an Oven Dried Basis	Specific Gravity on a Saturated Surface Dried Basis	Apparent Specific Gravity	Water Absorption
Natural Aggregate	2.60	2.61	2.62	0.32
Electric Arc Furnace Steel Slag	3.39	3.44	3.56	1.44

The apparent specific gravity depends on the specific gravity of the minerals present in the aggregates and the number of voids present in the aggregates. The typical values of the specific gravity of the natural aggregates is between 2.6 and 2.7. Based on the results from the tests, it can be deduced that the specific gravity lies in this range.

Based on Figure 5 for each concrete specimen tested, the compressive strength containing the slags was distinctly higher than those containing the natural aggregates only. Additionally, the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were

77MPa and 68.5 respectively and that for the concrete mixtures with the natural aggregates was 64MPa and 50MPa respectively.

However, according to Figure 6, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags were 3.69MPa and 2.2MPa respectively and that for the concrete mixtures with the natural aggregates was 2.52MPa and 3.26MPa respectively.

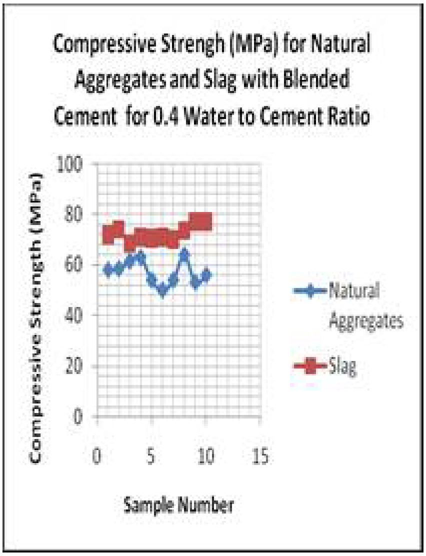

Figure 5: Compressive strength.

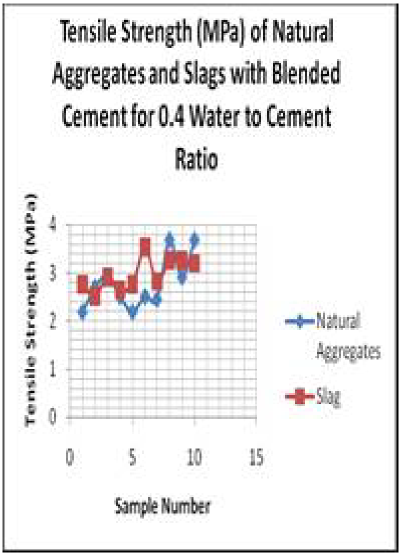

Figure 6: Tensile strength.

Based on Fig. 7 the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were 58.2MPa and 45.8MPa respectively and that for the concrete mixtures with the natural aggregates was 52.2MPa and 32.2MPa respectively.

However, according to Fig. 8, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags were 3.69MPa and 2.2MPa respectively and that for the concrete mixtures with the natural aggregates was 2.52MPa and 3.26MPa respectively.

Based on Figure 9 the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were 53.5MPa and 43.0MPa respectively and that for the concrete mixtures with the natural aggregates was 56.2MPa and 32.3MPa respectively.

However, according to Figure 10, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags were 4.18MPa and 2.03MPa respectively and that for the concrete mixtures with the natural aggregates was 3.08MPa and 2.0MPa respectively.

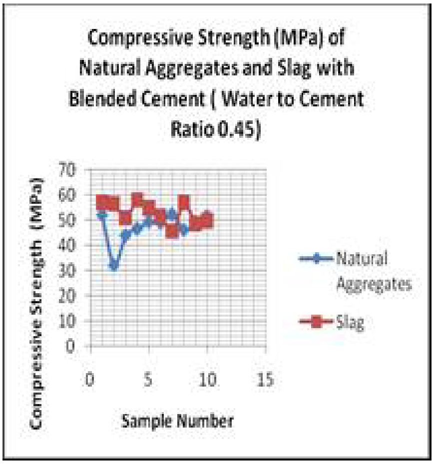

Figure 7: Compressive strength.

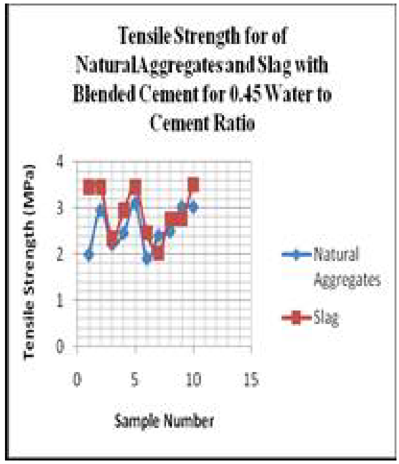

Figure 8: Tensile strength.

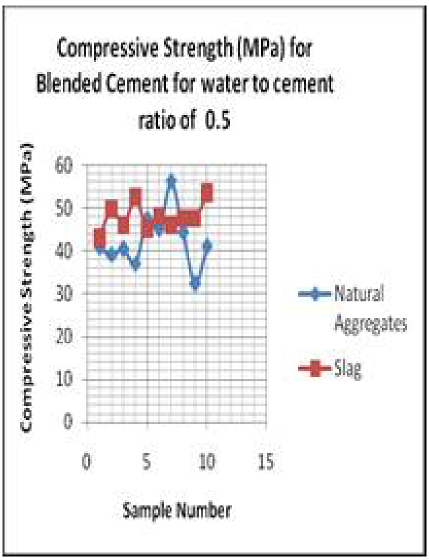

Figure 9: Compressive strength.

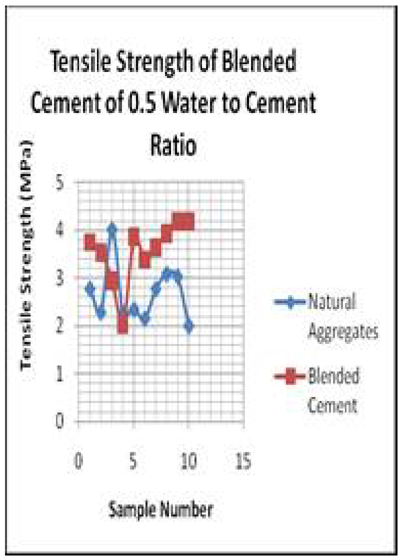

Figure 10: Tensile strength.

Based on Fig. 11 the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were 80.5MPa and 52MPa respectively and that for the concrete mixtures with the natural aggregates was 70MPa and 52MPa respectively.

However, according to Fig. 12, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags were 4.77MPa and 3.23MPa respectively and that for the concrete mixtures with the natural aggregates was 4.68MPa and 2.62MPa respectively.

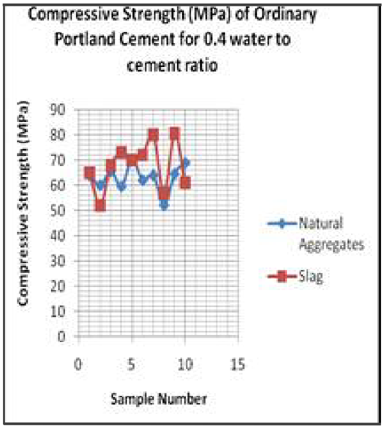

Figure 11: Compressive strength.

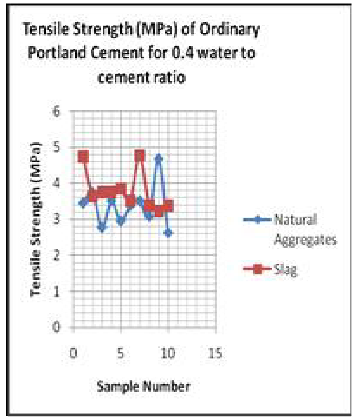

Figure 12: Tensile strength.

Based on Figure 13, the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were 57.7MPa and 46.2MPa respectively and that for the concrete mixtures with the natural aggregates was 67.8MPa and 51.4MPa respectively.

However, according to Figure 14, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags were 4.25MPa and 2.4MPa respectively and that for the concrete mixtures with the natural aggregates was 3.23MPa and 2.15MPa respectively.

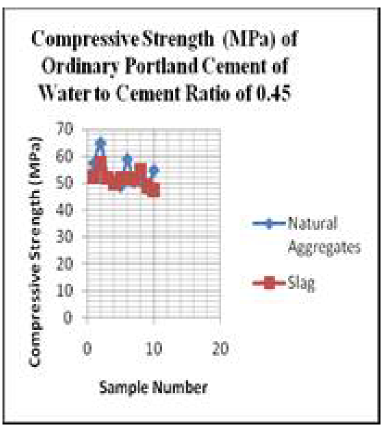

Figure 13: Compressive strength.

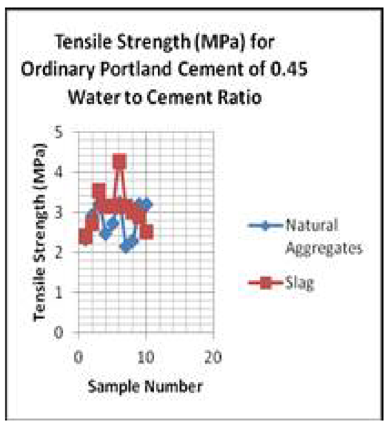

Figure 14: Tensile strength.

Based on Figure 15, the highest and lowest values of the compressive strength of the concrete for the electric arc furnace slags were 61.5MPa and 39.5MPa respectively and that for the concrete mixtures with the natural aggregates was 53.6MPa and 39MPa respectively.

However, according to Figure 16, the highest and lowest values of the tensile strength of the concrete for the electric arc furnace slags 4.06MPa and 2.62MPa respectively and that for the concrete mixtures with the natural aggregates was 3.63MPa and 1.48MPa respectively.

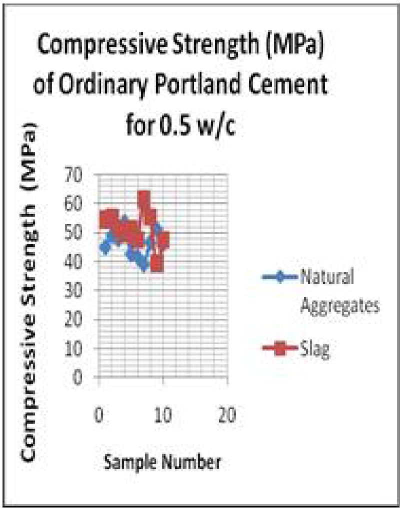

Figure 15: Compressive strength.

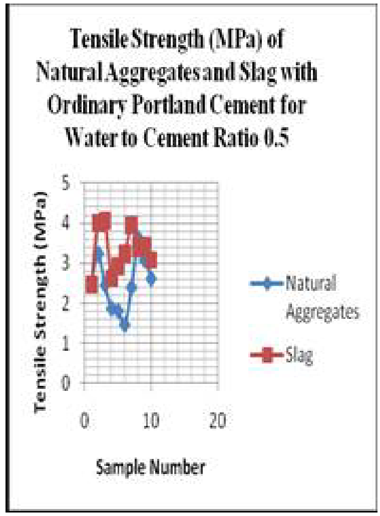

Figure 16: Tensile strength.

For the measured values of the compressive and the tensile strengths of the concrete, the concrete mixtures made with the electric arc furnace slag as coarse aggregates were higher as compared to those mixtures made with the natural aggregates only. Additionally, these strengths were independent of the type of cement used to formulate the concrete mixtures. Both the tensile and the compressive strengths of the concrete were higher for the lower water to cement ratios with the highest values of both these strengths being for the 0.4 water to cement ratio. According to [1], this could be due to greater interlocking between slag aggregate and cement paste. Additionally, the concrete produced using electric arc furnace steel slag had higher density values than the conventional concrete mixtures.

4 Conclusion

Tests were executed to deduce the effectiveness of using electric arc furnace steel slag as coarse aggregates in concrete mixtures for water to cement ratios of 0.4, 0.45 and 0.5 respectively. A comprehensive evaluation of the compressive and tensile strengths of the concrete prepared with the slag was done. This was achieved by using blended cement and ordinary Portland cement with the electric arc furnace slag as coarse aggregates. For both types of cement used, the concrete made with the electric arc furnace steel slag had higher compressive and tensile strength values. The highest compressive strength value was 80.5MPa and this was obtained using the electric arc furnace steel slag as a coarse aggregate with the ordinary Portland cement for 0.4 water to cement ratio. These high values of the strengths of concrete shown by the use of electric arc furnace steel slag opens applications for its use in the construction industry.

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