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Enhancing the Flexural Strength of Concrete using Recycled Iron and Steel Slag Aggregate

[1]Raheem, A. A., [2*] Olowu, O. A., [3]Oluremi, J. R., [4]Ajibi, I. J.

[1, 3]Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
[2, 4]Department of Building Technology, Yaba College of Technology, Yaba, Lagos, Nigeria.

[*] CorrespondingAuthor E-mail: oluwaleke.olowu@yabatech.edu.ng Tel: 08038198032

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Abstract

Concrete is strong in compression but weak in tension hence, considerable effort is required to improve concrete's tensile strength by the use of pre-stressed concrete and addition of admixtures or additives. In this study, the use of recycled iron and steel slag (RISS) aggregate to improve the tensile strength of concrete was considered. The paper assessed the mineralogical composition of RISS and granite aggregates, and gradation. It also determines the effects of RISS aggregate on the flexural strength of concrete beams of 150 × 150 × 600 mm containing 0, 10, 20, 40 and 60% RISS aggregate replacement in mix ratios 1:1½:3, 1:2:4 and 1:3:6 with water cement ratios 0.65,0.60 and 0.55 respectively. Diffractograph of RISS and granite aggregate showed that RISS contains Magnetite, Ilmenite and Quartz, while granite contains Quartz, Annite, Microcline and Albite as the predominant minerals. The coefficient of uniformity and concavity of RISS and granite aggregate for maximum aggregate size of 37.5 mm are 4.35 and 1.33; and 4.64 and 1.76 respectively. Both aggregates contain quartz as the predominant mineral and are well graded. The result of the Flexural strength at 28 days curing is within 0.135 – 0.250 MPa specified byBS8500 – 2:2015. Flexural strength of concrete beams cast with RISS aggregate is relatively higher than concrete cast with granite aggregate. Flexural strength, a measure of tensile strength of concrete is improved as percentage RISS aggregate increased.

Keywords: Concrete, Pre-stressed concrete, Aggregate, Recycled iron and steel slag, X-Ray Diffractometry, Flexural strength

Introduction

Concrete is a comparatively bristle material and it is weak in tension. When concrete movement is restrained, tensile stresses are developed. Shrinkage cracks are set up in concrete subjected to tensile stresses and this can be reduced by provision of control joints. Shrinkage cracks in concrete lead to loss in concrete strengths. Other factors that influence strengths of concrete include materials constituent, method of preparation, influence of curing method and test condition (Neville, 2014). Concrete's flexural strength can be enhanced when one or more influencing factors improves. Construction works that require high tensile strength include roads and airports concrete pavement, concrete for radiation insulators, noise barriers, breakwater blocks and retaining walls (Patel *et al.*, 2013; Manso *et al.*, 2006). In this study, the use of recycled iron and steel slag as replacement to granite as coarse aggregate for concrete production to improve tensile strength (flexural strength) of concrete was implored. Beshr *et al.*(2003) focuses on the effect of four coarse aggregate, namely calcareous, dolomite, quartzitic limestone and steel slag, on the compressive and tensile strength of concrete, and elastic modulus of high strength concrete; steel slag specimen gave the highest compressive strength while calcareous limestone aggregate gave the lowest strength. Similarly, the split tensile strength of steel slag aggregate concrete was the highest, followed by that of dolomitic and quartzitic aggregate concrete. Hiraskar and Chetan (2013) studied the use of Blast Furnace Slag (BFS) aggregate in grade 20 concrete, the study did not use recycled iron and steel slag generated from recycled metallic municipal waste neither did the study investigated the influence of BFS on flexural strength of concrete. Khalid *et al.* (2014) studied strength analysis of concrete by using iron slag as a partial replacement of normal aggregate (coarse) in concrete Compressive and flexural strength of grade 40 concrete was assessed at 28 days. However, desirable flexural strength was observed at 20% replacement. Sultan *et al.*(2014) studied the effect of using steel slag aggregate on mechanical properties of concrete while Olonade *et al.* (2015) studied performance of steel slag as fine aggregate in structural concrete however the effects of fine steel slag on flexural strength of concrete was not investigated. Pajgade and Thakur (2013) reported the utilization of waste product of steel industry. Saravanan and Sganya (2015) studied mechanical properties of concrete using steel slag aggregate.

Iron and steel slag is waste product obtained from metal manufacturing process using iron ore as the primary raw material. In Nigeria, what is obtainable is Recycled Iron and Steel Slag (RISS) obtained from recycling of metallic municipal waste (MMW) normally referred to as scrap iron and steel. Nigeria steel sector is being sustained through the recycling of scrap steel obtained mostly from municipal metallic wastes (MMW) because of numerous problems besieging the only iron ore beneficiation plant located at Itakpe which is down and unable to supply iron ore to the two Integrated Steel plants: Ajaokuta Steel Company (ASC) and Delta Steel Company (DSC). Supplies from Brazil and Liberia are epileptic and unable to supply billets to the three governments owned inland rolling mills in Oshogbo, Kastina and Jos (Uzondu, 2012).

Vojtech *et al.* (2020) reported that life cycle assessment (LCA) showed that replacements of natural aggregates significantly affected the utilization rate of nonrenewable raw materials and reduced the overall negative impacts of concrete on the environment up to 7%. Maslehuddin *et al.* (2003) studied comparison of properties of steel slag and crushed limestone aggregate. The study reported that concrete cast with steel slag has higher flexural strength than concrete cast with crushed limestone. Raheem *et al.* (2021) studied the effect of water cement ratio on the strength characteristics of concrete produced with RISS aggregates and concluded that low water cement ratio enhances the strength. This study implored the use of recycled iron and steel slag aggregate as partial replacement for granite aggregate in concrete production with a view to determine its effect on the flexural strength of concrete. This was achieved by assessing the mineralogical composition of the RISS and granite aggregate; conducting sieve analysis of the aggregates and performing flexural strength test on concrete beams cast.

Materials and Methods

Materials

The materials used for the study include coarse aggregate (granite and RISS), fine aggregate (sharp sand), Ordinary Portland Cement (OPC) of grade 43 complying with requirement of NIS 444 (2003) and water. The RISS aggregate were sourced from three companies: Major Engineering Company, Ikorodu referred to as RISS A; Selsa metal, Otta referred to as RISS B; and Continental Iron and Steel Company, Ikeja referred to as RISS C. The granite aggregate was sourced from Ratcon Limited Quarry site along Lagos-Ibadan expressway. The granite aggregate complied with BS EN 13055-2 (2004). The cement was source from Lafarge Cement Company, Ewekoro, Ogun State, Nigeria. The water used was obtained directly from the tap at the construction workshop of Nigeria Building and Road Research Institute (NBRRI), Otta, Ogun State where the practical works were carried out.

Specimen Preparation

The study adopted full factorial experimental design method. Batching of materials was by weight and each concrete beam specimen (control and treatment) of size 150 mm × 150 mm × 600 mm were cast in three layers; each layer was tamped 25 times with the tamping rod. After the casting, all the test specimens were finished with a steel trowel and immediately covered with plastic sheet to minimize the moisture loss. The specimens were de-moulded after 24 hours and put inside water tank for curing, maintaining temperature of $27^0C \pm 2^0C$ as per BS EN 206-1(2000).

The specimens were tested for Flexural strength test at 28 day curing; control beams did not have RISS replacement. The materials for X-ray Diffraction (XRD) were finely ground, homogenized, and average bulk composition was determined. The powdered sample was prepared using the sample preparation block and compressed in the flat sample holder to create a flat, smooth surface that was later mounted on the sample stage in the XRD cabinet. For gradation, the RISS was crushed into pieces and sieved into maximum particle sizes of 37.5 mm; one-third of each RISS A, B and C was obtained and mixed thoroughly together and was used for concrete production.

X-ray Diffraction

The prepared samples of RISS A, B, C and granite aggregate were analyzed using the reflection-transmission.

Gradation

A set of 50, 37.5, 28, 20, 14, 12, 10, 6.3 and 2.36 mm sieves was used and dry sieving was performed by arranging the various British Standard (BS) sieves one over the other in the order of their aperture, the largest aperture sieve was placed at the top and the smallest aperture sieve at the bottom. A receiver was placed at the bottom, and a cover at the top of the whole assembly. The sample (aggregate) was put on the top sieve, and the whole assembly was fitted on a sieve shaking machine. Shaking was done for 10 minutes; the portion of the sample that was retained on each sieve was weighed. The percentage of sample retained on each sieve was calculated on the basis of total weight of sample, and from these results, percentage passing through each sieve was calculated.

In the sieve analysis for fine aggregate a of set of 4.75mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and 75 µm aperture sieves were used. The analysis was done by dry sieving as in the case of coarse analysis, the various sieves were arranged one over the other in the order of their aperture; the largest sieve was placed at the top and the smallest aperture sieve at the bottom. A receiver was placed at the bottom and a cover at the top of the whole assembly. The samples were put on the top sieve and the whole assembly was fitted to a sieve shaking machine, shaking was done 10 minutes. The portion of the soil sample retained on each sieve is weighed and the percentage of the soil retained on each sieve was calculated on the basis of the total weight of the sample. From this result, the percentage passing through each sieve was calculated.

Flexural strength test

The flexural strength was determined in accordance with BS EN 12390- 5 (2000). The machine used met the requirement of EN 12390- 4 (2000). The machine used is electrically and hydraulically operated (ELE HP2 7HB, England with a maximum capacity of 70MN, Serial, No: 154721029).The beam specimen (150mm × 150mm × 600 mm) was placed on the electrically and hydraulically operated flexural strength test machine as shown in Figure1. The third point loading of the machine was set-up; the actuator gradually released the load steadily and without shock at 0.06 ± 0.04 N/ (mm^2 s). The rate of loading was maintained without change until failures occur. The result was read off from the analogue screen and tabulated. The flexural strength was calculated as shown in equation 1.

$$F_{cf} = \frac{F \times L}{d_1 \times d_2^2} \qquad 1$$

Where:
F_{cf} = Flexural strength in N/mm^2
F = Breaking load (N)
d_1 & d_2 = Width and depth of specimen (mm)
L = Distance between the supporting rollers (mm)

Figure 1: Flexural Strength Machine

Results and Discussion

Mineralogical composition of aggregate

Mineralogical composition of RISS aggregate sample was as presented in Figure 2, from the diffract-graph it was observed that RISS aggregate contains Magnetite (M), Ilmenite (I) and Quartz (Q) minerals with chemical formulae $Fe_2Fe_3O_4$, Fe_2TiO_3 and SiO_2 respectively; which indicated that RISS aggregate derived from scrap iron and steel because of high content of iron compounds. From the graph, quartz was detected at $2\theta = 28^\circ$ Theta with 3800 counts while magnetite Ilmenite was detected at $2\theta = 35^\circ$ Theta with 4000 counts. Magnetite is composed of iron ores with chemical formula Fe_3O_4 and is regarded as one of the oxides of iron while Ilmenite composed of iron- titanium oxide with chemical formula $FeTiO_3$ and Quartz composed of silicon and oxygen in a frame-work of silicon oxygen tetrahedral (SiO_4). Also observed are smeared peak of short orders and dumps suggesting that the RISS aggregate was mainly in amorphous phase with traces of crystalline structures which resulted from the rapid cooling method adopted when the slag emerges from the blast furnace.

Figure 3 shows the mineralogical composition of granite aggregate sample. Observation from the diffract-graph show that granite aggregate contains Quartz (Q), Annite (A), Microcline (M) and Albite (Al) as the predominant minerals attesting to the fact that such minerals are found in aggregate referred to as normal natural aggregate.

Figure 3 show that Quartz Albite was detected at $2\theta = 27^\circ$ with the highest counts of 15000 followed by Quartz Annite detected at $2\theta = 21^\circ$ with counts of 7500, Microcline Albite detected at $2\theta = 28^\circ$ with counts of 5000 and Quartz Microcline Albite detected at $2\theta = 42.5^\circ$ with counts of 5000. Also observed were the several peaks of short order and bumps of irregular base-line with pulse shape that confirms amorphous phase with traces of crystalline structure. Hence both aggregates contain quartz mineral as common mineral. Kasi and Poorna (2018) and Nicoletta and Maarten (2013) confirmed that both granite and steel slag aggregates contain quartz mineral.

Measures of Gradation

The results of the gradation conducted on coarse RISS aggregates, granite aggregate and sharp sand are presented in Figures 4 and 5. As shown in Figure 4, the coefficients of uniformity, C_U is 4.35 and coefficients of concavity, C_C is 1.33 for maximum aggregate size of 37.5 mm for coarse RISS aggregate. These values are greater than 4.00 for C_U and less than 3 for C_C as specified by BS 12620- 1 (2002). Hence the RISS aggregate is well graded, dense and of high strength. The C_U and C_C for RISS aggregate were calculated using equations 2 and 3.

$$C_U = \frac{D_{60}}{D_{10}} = 4.35 \geq 4.0 \qquad 2$$

$$C_C = \frac{(D_{30})^2}{(D_{10} \times D_{60})} = 1.33 < 3 \qquad 3$$

Where:

D_{60} = Largest size of the smallest 60 per cent, 11.53
D_{30} = Largest size of the smallest 30 per cent, 6.38
D_{10} = Largest size of the smallest 10 per cent, 2.65

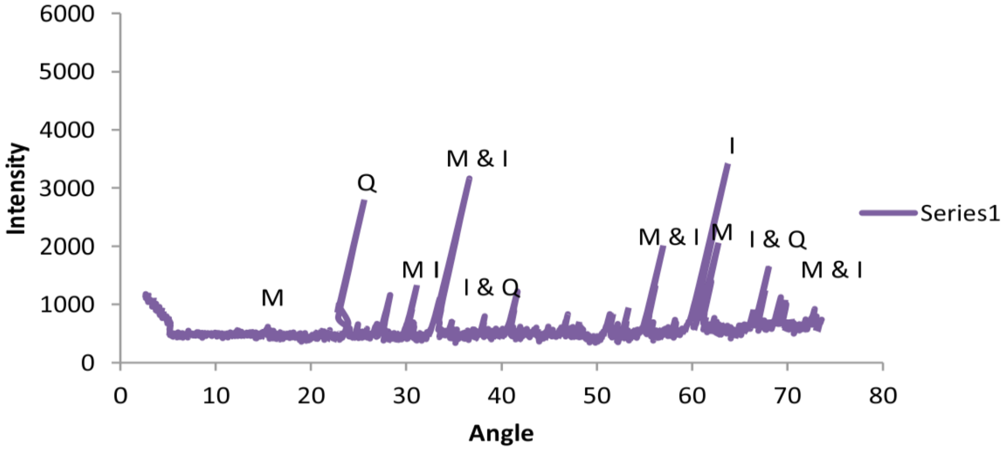


Figure 2: Peak matched diffract-graph of RISS aggregate

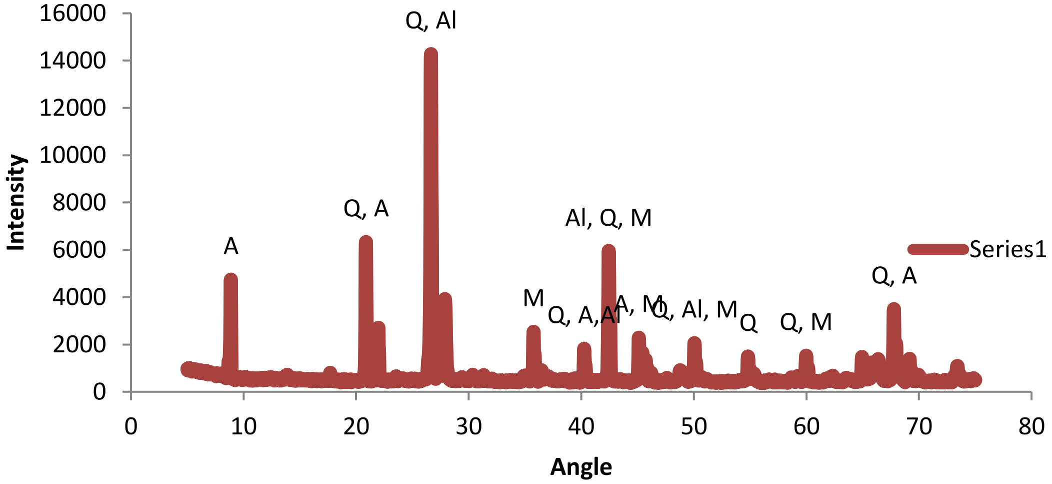


Figure 3: Peak matched diffract-graph of granite aggregate

Also the particle size distribution for granite aggregate used in this study was presented in Figure 4 and it shows that the coefficient of uniformity for granite aggregate is 4.64 and coefficients of concavity is 1.76 for maximum aggregate size of 37.5mm. These values are greater than 4.00 for C_U and less than 3 for C_C as specified by BS 12620- 1 (2002). Hence the granite aggregates is well graded, dense and of high strength. The C_U and C_C for granite aggregate were calculated using equations 4 and 5.

$$C_U = \frac{D_{60}}{D_{10}} = 4.64 > 4.0 \qquad 4$$

$$C_C = \frac{(D_{30})^2}{(D_{10} \times D_{60})} = 1.76 < 3 \qquad 5$$

Where: $D_{60} = 13.0$, $D_{30} = 8.0$, $D_{10} = 2.8$

Particle size distribution for sharp sand was presented in Figure 5 and it shows that the coefficient of uniformity for sharp sand is 13.3 which was greater than 6. The C_C for sharp sand is 1.63 which is within the range of 1to 3specified by BS 12620- 1 (2002). Hence the sand is well graded, dense and of adequate strength. The C_U and C_C for sharp sand were calculated using equations 6 and 7.

$$C_U = \frac{D_{60}}{D_{10}} = 13.3 > 6.0 \qquad 6$$

$$C_C = \frac{(D_{30})^2}{(D_{10} \times D_{60})} = 1.63 < 3 \qquad 7$$

Where: $D_{60} = 0.200$, $D_{30} = 0.070$, $D_{10} = 0.015$

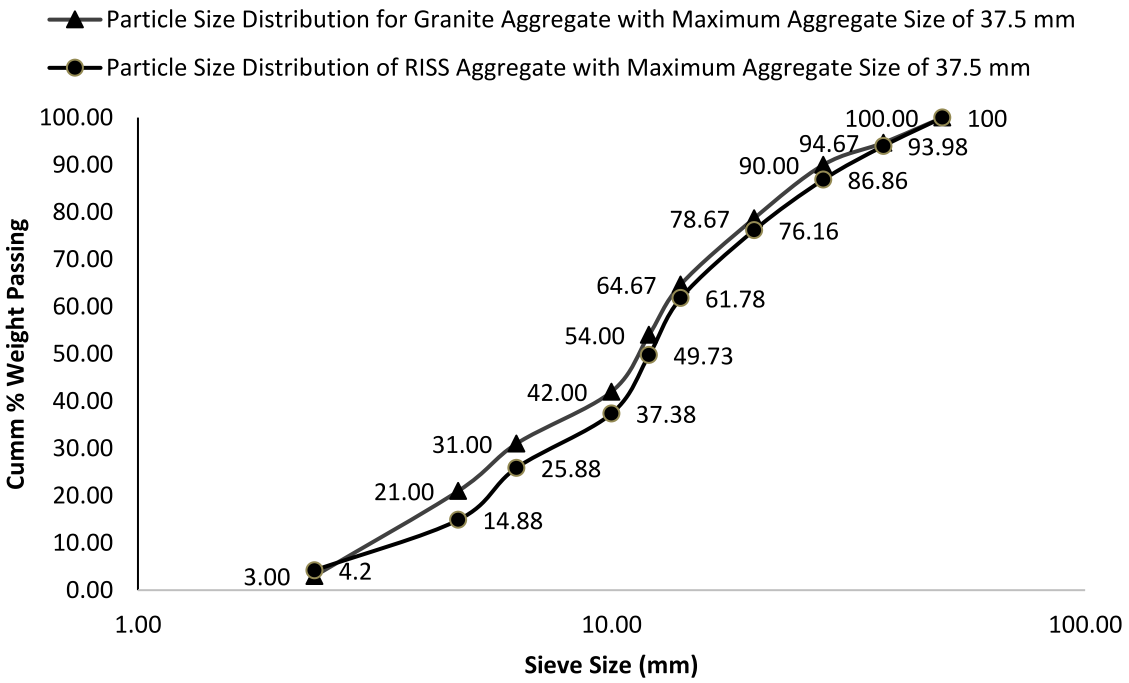


Figure 4: Particle size distribution graph of RISS and granite aggregate for 37.5 mm MAS

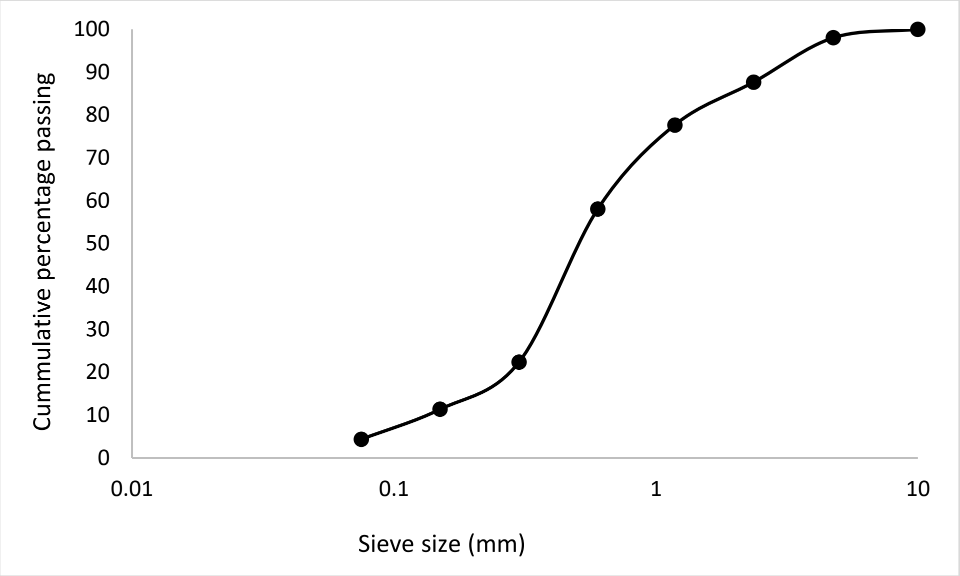
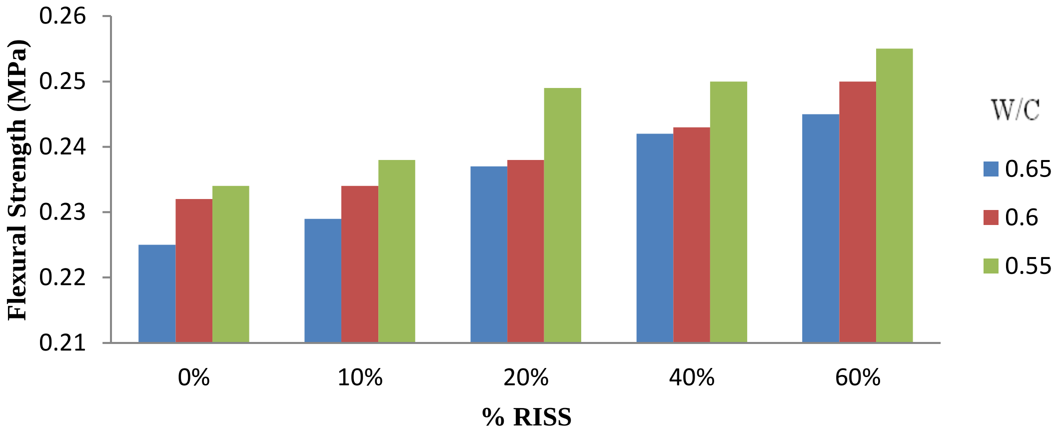


Figure 5: Particle size distribution graph for sharp sand

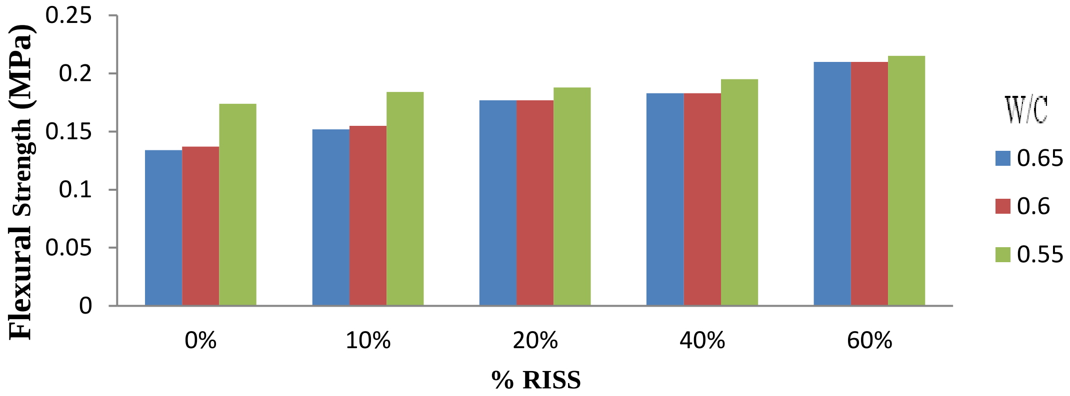
Effect of RISS aggregate replacement on flexural strength of concrete beams

Figures 6 a, b and c present the results of the effect of granite aggregate replacement with RISS aggregate on the flexural strength of concrete. Figure 6a shows that the result of percentage replacement of granite aggregate with RISS aggregate for mix ratio 1:1½:3, maximum aggregate size 37.5 mm and water cement ratios 0.65, 0.60 and 0.55 are 0.225, 0.229, 0.237, 0.242 and 0.245 MPa, 0.232, 0.234, 0.238, 0.243 and 0.250 MPa and 0.234, 0.238, 0.249, 0.250 and 0.255 MPa respectively for percentage RISS replacement of 0, 10, 20, 40 and 60 %. These results shows that RISS concrete having 60% RISS aggregate replacement has flexural strength of 7.8%, 8.9% and 9.0% greater than granite concrete for all water cement ratios adopted with the water cement ratio 0.55 having the highest increment followed by concrete cast with water cement ratio of 0.60 and lastly by concrete cast with water cement ratio of 0.65. Hence, the lower the water cement ratio the higher the flexural strength of concrete. The results are within 0.135 – 0.250 MPa specified by BS 8500 – 2: 2015. The result shows that as the % granite aggregate replacement with RISS aggregate increases the values of flexural strength increases, this was adduced to high tensile strength nature of major components of the RISS aggregate among which are Magnetite and Ilmenite. Concrete prisms produced with mix ratios 1:2:4 and 1:3:6 showed similar trends as observed in Figure 6b and 6c.

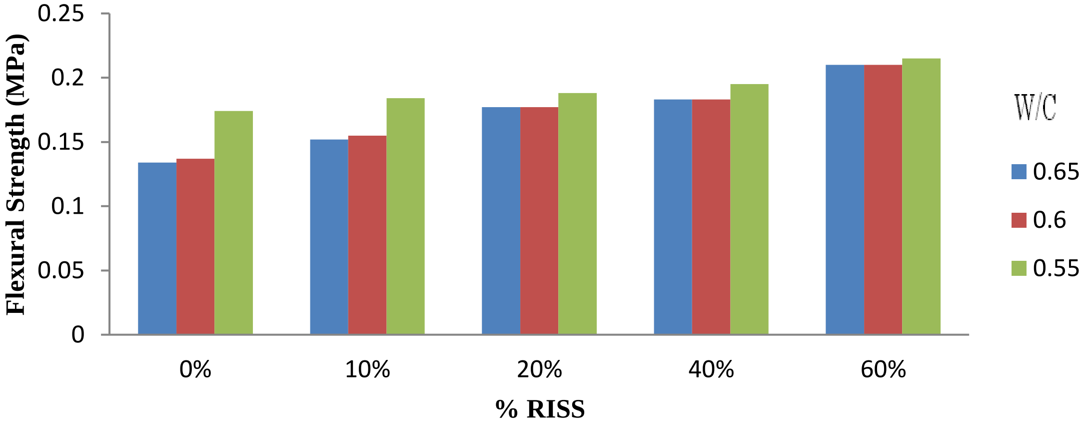
The finding of this study confirms the finding of Pajgade and Thakur (2013) which postulated that 26% increase in flexural strength was observed when the concrete contains 75% of steel slag. Other studies conducted by Beshr *et al*. (2003), Maslehuddin *et al.* (2003), Khalid *et al.* (2014), Sultan *et al.* (2014), and Saravanan and Sganya (2015) observed that the flexural strength increased as the percentage of iron and steel slag aggregate increased. The study further correlate increase in flexural strength to reduction in water cement ratio.



a. For Mix Ratio 1:1½:3



b. For Mix Ratio 1:2:4



c. For Mix Ratio 1:3:6

Figure 6: Effect of percentage RISS replacement on flexural strength of concrete.

Conclusion

From the results of tests conducted on the aggregates and concrete specimens the following conclusions were drawn:

i) Both RISS and granite aggregates contain quartz as the common mineral.
ii) Both RISS and granite aggregates are well graded, strong and durable and can be used for aggregate in concrete.
iii) Flexural strength which is a measure of tensile strength of concrete is improved as percentage RISS aggregate increased and the water cement ratio decreased.

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