West Africa Built Environment Research (WABER) Conference
WABER 2021 Conference, 9-11 August 2021, Accra, Ghana
Proceedings Edited by Laryea, S. and Essah, E.
ISBN 978-0-620-95367-2

EFFECTS OF MAXIMUM AGGREGATE SIZES ON FLEXURAL STRENGTH OF RECYCLE IRON AND STEEL SLAG CONCRETE

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The needs for sustainable development to meet the increasing demand of granite for infrastructural development couple with environmental degradation and pollution caused by depletion of natural igneous deposit.Studies on structural integrity of recycled iron and steel slag (RISS) as aggregate in concrete have not been adequately investigated especially flexural characteristics of RISS concrete. The study adopted experimental approach to evaluating the effects of maximum aggregate sizes (MAS) on flexural strength of RISS concrete.Laboratory tests conducted on both granite and RISS aggregate include aggregate crushing value (ACV),aggregate impact value (AIV), Sieve analysis and X-ray fluorescence (XRF);flexural strength test was conducted on the concrete prism. Two sets of 600mm × 150mm × 150mm concrete prism were cast viz control and treatment; treatment concrete contains RISS aggregate at 10, 20, 40 and 60 % replacement level. The concrete prism were subjected to flexural strength test at 28 day curing.The results obtained for ACV, AIV and Sieve analysis showed that RISS aggregate are durable, tough, hard and well graded. Flexural strength values for mix ratios 1:1½:3, 1:2:4 and 1:3:6 ranges from 0.229 – 0.255 MPa, 0.210 – 0.219 MPa and 0.152 – 0.215 MPa for treatment concrete and 0.225 – 0.234 MPa, 0.202 – 0.205 MPa, and 0.134 – 0.174 MPa for control concrete these values were within the values of 0.130 – 0.250 MPa specified by BS 8500 -2: 2015. In conclusion flexural strength for both concrete increases as the maximum aggregate size decreases. RISS concrete can be use in road pavement and where high flexural strength is required.

Keywords: flexural strength, maximum aggregate size, riss aggregate, steel slag, x–ray fluorescence

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Olowu, *et al.* (2021) Effects of maximum aggregate sizes on flexural strength of recycle iron and steel slag concrete In: Laryea, S. and Essah, E. (Eds) Procs West Africa Built Environment Research (WABER) Conference, 9-11 August 2021, Accra, Ghana, 557-568

INTRODUCTION

Demand for granite aggregate used in many Building and Civil Engineering works have been on the increase due to Industrial revolution and Technological advancement in the production and manufacturing of tools and machines for obtaining granite. Depletion of stock of natural igneous rock which is the source of granite aggregate on daily basis is cause for concern as it resulted into environmental degradation and pollution hence the introduction of alternative aggregate to granite.

Alternative aggregate to granite include Conditioned Pulverised Fuel Ashe (PFA) was investigated by Dhir, McCarthy and Tittle (2000); Textile waste sludge by Kulkarni et al. (2012) and Copper slag by Alnuaimi (2012) to mention but a few. Recycled Iron and Steel Slag (RISS) aggregate which is the focus of this study is industrial by-product generated from the production of iron and steel products from iron and steel scraps which litters our towns and cities instead of from iron-ore which is derived from the earth. The supply of iron-ore surfer setback from the iron and steel beneficiation plant located at Itakpewhich is down and unable to supply iron ore to the two Integrated Steel companies namely: Ajaokuta Steel Company, Ajaokuta, Ogun State and Delta Steel Company, Ovwian, Aladja, Delta Stateand the supplies from Brazil and Liberia is epileptic and unable to supply billets to the three governments owned inland rolling mills in Oshogbo, Kastina and Jos (Mohammed, 2002). Hence the rolling mills resorted to the use of waste scrap of iron and steel referred to as RISS aggregate.

Study by Norgate et al. (2007) show that production of iron and steel via blast furnace slag / converter / electric arc furnace requires energy demand of 23 Mj/kg and global warming pontifical of 2.3 kg Co2/kg. Fenton (2002) reported that using recycled steel saves 75% of energy, 90% of raw materials, reduces air pollution by 86%, water use by 40%, water pollution by 76% and mining wastes by 97%.

Similar study by Raheem et al. (2021) evaluated the effects of Water Cement Ratio on Strength Characteristics of Concrete Produced with Recycled Iron and Steel Slag Aggregate;Rao and Bhandare (2014) investigated the application of blast furnace slag sand in cement concrete; the study involve Granulated Blast Furnace Slag (GBFS) sand application as a partial substitute for Crushed Stone Sand (CSS) in cement concrete.Kothai and Malthy (2014) considered the utilization of steel slag as partial replacement for fine aggregate in M20 concrete grade.Khalid et al. (2014) conducted study using iron slag aggregate replacement for granite aggregate in M40 concrete grade.This study evaluates the effects of maximum aggregate sizes on flexural strength of recycled iron and steel slag (RISS) concrete. Though, standards and specifications to slag aggregate usage have been established such as BS EN 12620: 2002 for Air-cooled Blast Furnace Slag and JIS A5011-1:2013 for Slag Aggregate Concrete; more research are needed to be carried out to established the structural integrity of RISS concrete in relation to its strengths.

EXPERIMENTAL PROCEDURE

Materials

Materials used for this study includes: RISS aggregate and granite aggregate as (coarse aggregate), sharp sand (fine aggregate), Ordinary Portland Cement, OPC (cement) and water.

RISS aggregate was sourced from 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 RISS aggregate were crushed and sieved into three maximum aggregate sizes 37.5, 20 and 12 mm; One third of each RISS aggregate maximum aggregate sizes (MAS) was thoroughly mixed together and used for the study.

Sharp sand for the study was obtained from Ogun River at Owode. Granite aggregate was obtained from Ratcon Limited quarry site along Lagos - Ibadan expressway, sieved into the three maximum aggregate sizes (MAS) of 37.5, 20 and 12 mm. OPC used as the binding agent for the study complied with NIS 444-1: 2003. The cement was sourced from Lafarge Cement Company, Ewekoro, Ogun State, Nigeria. Water for the study was obtained from the tap at the Construction Workshop, Nigeria Building and Road Research Institute (NBRRI), Otta, Ogun State. The water was free of dirt and impurities.

Specimen preparation

The specimens (RISS and granite aggregate) for X ray fluorescence (XRF) were crushed and sieved into three maximum aggregate sizes 37.5, 20 and 12 mm; One third of each RISS and granite aggregate maximum aggregate sizes (MAS) was thoroughly mixed together. Specimens for ACV and AIV tests (RISS and granite) were dried, crushed and passed through 12.5 mm sieve and retained on 10 mm sieve. The materials for concrete were batched, mixed and cast into rectangular prism moulds of size 600 mm × 150 mm × 150 mm; the concrete specimens were de-moulded after 24 hours, cured at temperature of 250C + 20C as per BS EN 12390 Part 2 (2000) in curing tank until testing date for flexural strength tests. Total of 135 concrete beams were cast.

X-Ray Fluorescence (XRF)

XRF was used to determine the percentage oxide composition in the samples of the aggregate; the test conforms to BS EN ISO 12677 (2011). The prepared samples of RISS A, B and C were excited with x-ray; and consequently their atoms were ionized, electrons were ejected from the lower energy level which are K and L energy levels which were replaced from an outer higher energy level; energy were released because of decrease binding energy of the inner electron orbital compared to the outer energy orbital. The energy released according to the types of atom present in the sample was of the form of emission of characteristic x-rays. Wavelength dispersive spectrometer was used because complex emitted x-ray of elements was present in the samples. The intensity of the wavelength emitted by the x-ray was measured using both gas flow proportional and scintillation detectors. The gas flow detector measure long wavelength greater than 0.15 nano-micron which are x-ray of K spectra and element lighter than zinc; while scintillation detector was used to analyze shorter wavelengths in the x-ray spectrum which

includes element from Niobium (Nb) to Iodine (I) of the K spectra; Thorium (Th) and Uranium (U) of the L spectra. X-rays of middle wavelength were measured using both detectors in tandem. The exact value of each element was derived by comparing with mineral or rock standards whose composition is known using other techniques.

Aggregate Crushing Value (ACV) test

The ACV test was carried out as prescribed by BS EN 1097-2: 1998; the prepared samples of RISS and granite aggregate were filled in cylindrical moulds measure 11.5 cm in diameter and 18 cm high in three layers, each layer was tampered with a standard rod 25 times. The test samples were weighed (W1) and place in the test cylinders (15.2 cm diameter). The specimens were subjected to compressive load of 40 tonnes (400 kN) gradually applied in 10 minutes. The materials passing through 2.36 mm sieve were separated and weighed (W2). The weight of these materials (fines), expressed as a percentage of the weight of the total sample (W1), gives the aggregate crushing value (ACV).

Aggregate Impact Value (AIV) test

The AIV test was carried out as prescribed by BS 812-112: 1990 and BS EN 1097 – 2: 1998; the prepared samples (RISS and granite aggregate) were filled into cylindrical moulds, 10.2 cm internal diameter and 5 cm height in three layers, each layer being given 25 strokes with a rod. The impact was provided by dropping a hammer of weight 14.0 kg through a height of 380 mm. The samples were transferred to the cups of aggregate impact testing machine and were tapped 25 times with the rod. The crushed aggregate were sieved on 2.36 mm sieve, the weight (W1) of materials passing through 2.36 mm sieve expressed as a percentage of the total weight (W2) of the sample gives the aggregate impact value. Aggregate Impact value is expressed as the ratio of weight of materials passing through 2.36 mm (W1) to the total weight (W2) of the samples.

Sieve analysis (gradation)

In coarse aggregate analysis a predetermine quantity (weight) of prepared samples (RISS and granite) aggregate was put on top of set of 50, 37.5, 28, 20, 14, 12, 10, 6.3 and 2.36 mm British Standard (BS) sieves placed 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 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.

Flexural strength test

Flexural strength test was carried out as prescribe by BS EN 12390: Part 5: 2000 the machine used conforms to (pr EN 12390: Part 4: 2000). The third point loading of the machine was set-up, the specimen (600 mm × 150 mm × 150 mm) concrete beam was put in place; the actuator gradually released the load steadily and without shock at 0.06 ±0.04 N/ (mm2 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, 135 concrete beams were tested for flexural strength.

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

RESULTS AND DISCUSSION

X-Ray Fluorescence (XRF)

Table 1 show the result of X-ray fluorescence on samples of RISS and granite aggregates; from the table, it can be observed that the predominant oxides in RISS aggregate are: Calcium oxide (CaO), Iron II oxide (FeO), Silicon oxide (SiO2) and Iron III oxide (Fe2O3) in the following proportions 45.16, 24.08, 13.70 and 10.32 %, 40.22, 18.78, 10.10, and 13.76 %, 46.30, 18.85, 15.09 and 10.08 % for RISS A, B and C respectively. Granite aggregate has Silicon oxide (SiO2), Iron III oxide (Fe2O3), and Potassium oxide (K2O) and Sodium oxide (Na2O) as predominant oxides with 70.20, 11.56, 3.41 and 3.28 % respectively. The metallic elements in the oxides of RISS aggregates are more ductile in nature, ability to be drawn into wire, hence concrete produced with RISS aggregate are likely to have high tensile strengths compared with granite aggregate.

From the presented result it was observed that the oxides in RISS aggregate which are in high percentage are contained in low percentage in the granite aggregate; CaO and FeO were predominant in RISS while SiO2 and Fe2O3 were the predominant oxide in the granite aggregate which attested to the differences in their physical and chemical properties though both contained non reactive silicon oxide which makes RISS aggregate better and an alternative to granite aggregate (Nippon Slag Association, 2015). The result of this study confirms the result of similar study by Olonade et al. (2015) that the chemical composition of steel slag includes SiO2 (42 %), Ferric oxide Fe2O3(32 %), CaO (5 %) and K2O (2 %). Yongchang et al. (2019) reported that the major constituent of steel slag are Di calcium Silicate (C2S), Tri calcium silicate (C3S) and Tetra calcium aluminates (C4AF) which are major constituent of cement participated in hydration process and enhance the strength of concrete; the oxide of these compounds were confirmed present in the RISS aggregate used by this study.

Tahir and Ana (2011) identified the following minerals in steel slag which include Wustile (FeO), Calcium ferrite CaFe2O4/ (CF); Screbrodolskite Ca2Fe2O5/ (C2F); Larnite Ca2SiO4/ (C2S); Alite Ca3SiO5/ (C3S); Mayenite Ca12Al14O33/ (C12A7) and Brownmillerite Ca2Al, Fe2O5/ (C4AF) using XRD analysis; Wang et al. (2013) reiterated that steel slag aggregate consist of C2S, C3S, phase CaO, FeO, MgO, MnO and C2F. Sezer and Gulderen (2015) identified the major elemental composition of the steel slag to include Iron III oxide (Fe2O3), Calcium oxide (CaO), Silicon oxide (SiO2) and Aluminum Oxide (Al2O3) which was in the following proportion 35.22,24.62, 17.79 and 7.82 percent. This study confirms the findings of the afore-mentioned studies on the oxides present in the RISS aggregate. From all indications RISS aggregate contains similar composition in different proportions and non reactive silica.

Table 1: Chemical composition ofRISS and granite aggregates samples

S/N	PARAMETER	LEVEL DETECTED (%)				
		RISS A	RISS B	RISS C	AVERAGE VALUE	GRANITE
1.	Colour	Dark Brown Solid	Black Solid	Dark Brown Solid		Grey Solid
2.	SiO_2	13.70	10.10	15.09	12.96	70.20
3.	Al_2O_3	1.68	1.02	1.72	1.47	11.56
4.	Fe_2O_3	10.32	13.76	10.08	11.39	1.19
5.	FeO	24.08	18.78	18.85	20.57	1.12
6.	CaO	45.16	40.22	46.30	43.89	0.96
7.	MgO	7.31	5.32	7.15	6.59	0.75
8.	Na_2O	0.19	0.04	0.22	0.15	3.28
9.	K_2O	0.04	0.01	0.05	0.03	3.41
10.	S	0.03	0.01	0.04	0.03	0.00
11.	P_2O_5	0.81	0.52	0.75	0.69	0.08
12.	MnO	5.89	5.21	6.34	5.81	0.05

Aggregate Crushing Value (ACV)

Table 2 shows the result of aggregate crushing value test on RISS and granite aggregate. From the table, both RISS and granite aggregate have ACV values of 9.64 and 8.58, respectively. These values are less than 10 as specified by BS EN1097 – 2: 2000. Hence, both are classified as exceptionally strong and can withstand crushing force under load. These two aggregates are durable and can be used for aggregate in concrete production. The result of this test confirms the result obtained byOmopariola and Jimoh (2018) for ACV which is within 6.2 and 9.45; the results met the requirement specified in BS EN 1097-2: 2000.

Aggregate Impact Value (AIV)

Table 3 shows the result of aggregate impact value test on RISS and granite aggregate. From the table, the average AIV for RISS and granite aggregate are 24.33 and 20, respectively. This revealed that the aggregate can be used for heavy duty concrete flooring, concrete pavement floor and any other concrete works as specified in BS 812 – 112 (1990). Pajgade and Thakur (2013) and Subathra and Gnanavel (2014) had 23.21 and 4.3, and 25.26 and 9.03 for AIV of steel slag and granite aggregate respectively in their studies. Omopariola and Jimoh (2018) had all the AIV in their study to be less than 30 and came to the conclusion that the aggregate used for their study are suitable for concrete works relating the result of their study to the specification in BS EN1097-6: 2000.

Sieve Analysis

The results of the sieve analysis conducted on RISS aggregates were presented in Figure 1. As shown in the figure, the coefficient of uniformity, CU were 4.00, 4.61 and 4.35 and coefficient of concavity, CC were 1.33, 1.01 and 1.00 for maximum aggregate sizes of 37.5, 20 and 12 mm respectively. These values were greater or equal to 4.00 for CU and less than 3 for CC (Michael and John, 2006) hence the RISS aggregate are well graded and the resulting concrete produced are dense and of high strength.

Also the particle size distribution for granite aggregate used to produce concrete in this study was as presented in Figure 2. From the figure, the coefficients of uniformity for granite aggregate are 4.64, 4.00 and 4.00 and coefficients of concavity are 1.76, 1.16 and 1.01 for maximum aggregate size of 37.5, 20 and 12 mm respectively. These values were greater or equal to 4.00 for CU and less than 3 for CC (Michael and John, 2006) hence the granite aggregate are well graded and the resulting concrete produced are dense and of high strength.

Particle size distribution for sharp sand was presented in Figure 3. From the figure, it can be deduced that the coefficient of uniformity for sharp sand was 13.3 which was greater than 6, hence the sand is well graded and the resulting concrete produced is dense and of adequate strength.

Table 2: Aggregate crushing value for RISS and granite aggregate

PARAMETER	RISS AGGREGATE									GRANITE AGGREGATE		
	RISS A			RISS B			RISS C					
	1ST Trial	2ND Trial	3RD Trial	1ST Trial	2ND Trial	3RD Trial	1ST Trial	2ND Trial	3RD Trial	1ST Trial	2ND Trial	3RD Trial
W_1(Kg)	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25
W_2(Kg)	0.30	0.31	0.32	0.33	0.32	0.30	0.31	0.32	0.31	0.28	0.27	0.29
ACV	9.23	9.54	9.85	10.15	9.85	9.23	9.54	9.85	9.54	8.50	8.31	8.92
Av. ACV	9.54			9.74			9.64					
Av. ACV (A, B & C)	9.64									8.58		

Where:

W1 = Total weight of aggregate

W2 = Weight of aggregate passing 2.36 sieve size; ACV = Aggregate crushing value; Av.$ACV = \frac{W_2}{W_1} \times 100$; Av. ACV (A, B & C) = Average Aggregate value (A, B & C)

Table 3: Aggregate impact value (A.I.V) for RISS and granite aggregates

PARAMETER	RISS AGGREGATE									GRANITE		
	RISS A			RISS B			RISS C					
	1st Trial	2nd Trial	3rd Trial	1st Trial	2nd Trial	3st Trial	1st Trial	2nd Trial	3rd Trial	**1st Trial**	**2nd Trial**	**3rd Trial**
M1	235	232	235	234	235	236	235	234	232	234	235	233
M2	54	56	62	52	61	59	54	52	60	47	47	49
AIV	23	24	26	22	26.0	25	23	22	26	20	20	21
Av. AIV	25			24			24					
Av. AIV (A, B & C)	24.33										20	

Where:

M1 = Oven dried Sample (g)

M2 = Oven dried Sample Passing 2.36mm Sieve

Aggregate Impact Value (AIV) $= \frac{M_2}{M_1} \times 100$

Av. AIV (A, B & C) = Average Aggregate Impact Value (A, B & C)

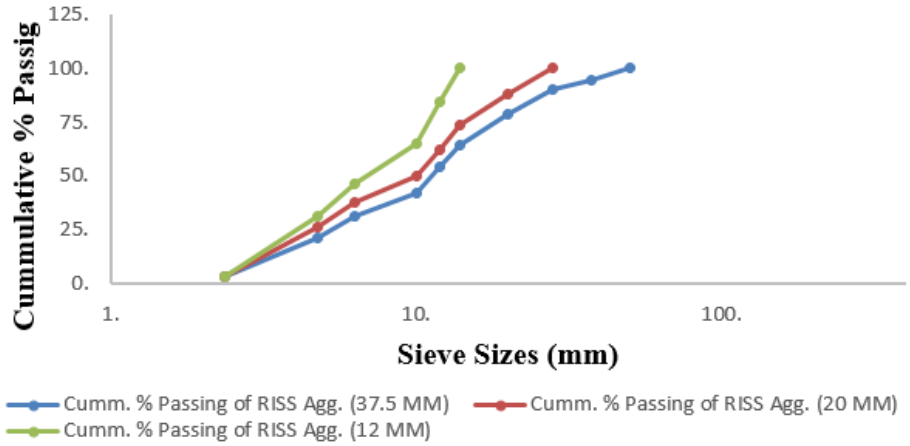


Figure 1: Particle size distribution graph of RISS aggregate for 37.5, 20.0, and 12.0 mm

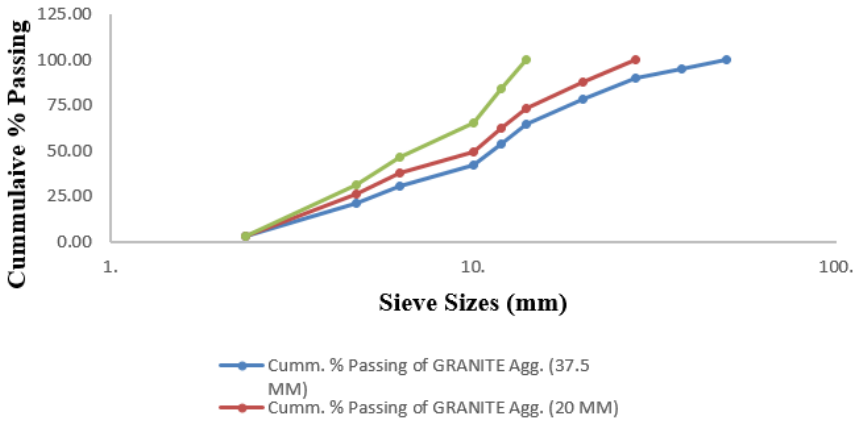


Figure 2: Particle size distribution graph of granite aggregate for 37.5, 20.0, and 12.0 mm

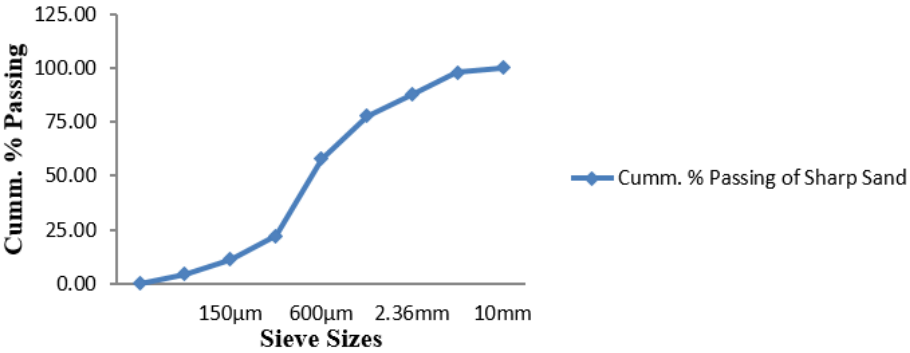


Figure 3: Particle size distribution graph for sharp sand

Flexural Strength

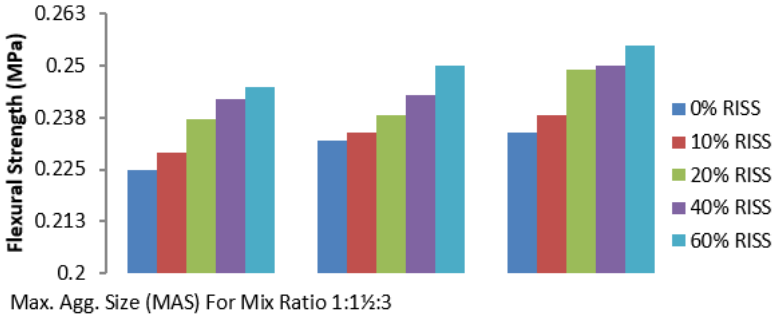
Effect of maximum aggregate size (MAS) on flexural strength of concrete

Figure 4 a, b and c present the result of the Effect of MAS of 37.5, 20 and 12 mm on the flexural strength of concrete beam samples of 100 mm × 150 mm × 500

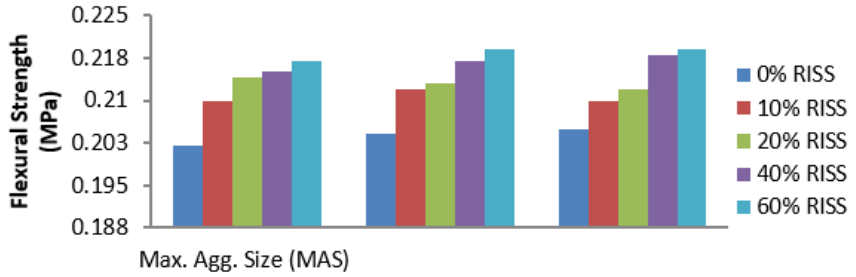
mm at 28 days of curing. From Figure 4a it was observed that the flexural strength values for 37.5, 20.0 and 12.0 mm MAS for mix ratio 1:1½:3 at 0, 10, 20, 40 and 60 % granite aggregate replacement with RISS aggregate increases by 7.76%, 8.89% and 8.97% respectively from 0 – 60% RISS replacement while from Figure 4b the values of flexural strength for mix ratio 1:2:4 at MAS of 37.5, 20 and 12 mm increases from by 7.35%, 7.43% and 9.5%respectively from 0 – 60% RISS replacement; and from Figure 4c for mix ratio 1:3:6 at MAS of 37.5, 20.0 and 12.0 mm the values of flexural strength increases by 5.47%, 5.67% and 5.75% respectively from 0 – 60% RISS. It was observed that the flexural strength increases as the maximum aggregate sizes decreases; the flexural strength values of concrete beam with MAS of 37.5 mm are less than the values obtained for MAS of 20 mm and the values of flexural strength obtained for MAS of 20 mm are less than those obtained for MAS of 12 mm. Hence, the lesser the maximum aggregate sizes the higher the flexural strength of concrete beam.

It was also observed that the flexural strength of treatment beams (beams with RISS aggregate) were higher than control beams (beams without RISS aggregate), these could be attributed to the higher percentage of Iron II oxide (FeO) and Iron III oxide (Fe2O3) which formed major composition of RISS aggregate and the rough texture of the surface of RISS aggregate could be another factor that resulted into stronger bond of the aggregate and the cement paste.

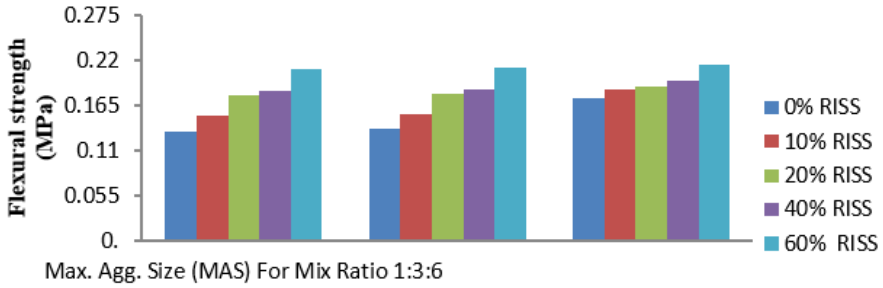
Jabbar and Habeeb (2015) and Sneka et al. (2018) concluded that the flexural strength of concrete of high strength concrete increases as the maximum aggregate size decreases. Warudkar and Nigade (2015) observed increase in flexural strength at 28 day when steel slag was used to replace granite aggregate up to 75%. Kumar and Kumar (2016) observed 6 % increment in flexural strength when 30 and 35 % of slag by weight of coarse aggregate in concrete; Adedokun et al. (2018) confirms that flexural strength increase between 20 to 60 % of steel slag inclusion. The results of this study confirm the results of all these studies that the flexural strength increases as the size of aggregate decreases.



a. Mix Ratio 1:1½:3



b. Mix Ratio 1:2:4



c. Mix Ratio 1:3:6

Figure 4: Effect of maximum aggregate sizes on the flexural strength of concrete

CONCLUSIONS

From the results of tests conducted on the aggregate and concrete beams the following conclusions were drawn:

1. It was concluded that both aggregate contains silicon oxide (SiO2), calcium oxide (CaO), iron II oxide (FeO), iron III oxide (Fe2O3) and aluminium oxide (Al2O3) as the predominant oxides.
2. Both RISS and granite aggregate are strong and durable and can be used for aggregate in concrete
3. Both aggregate are well graded and the resulting concrete produced are dense and of high strength.
4. The flexural strength increases as the maximum aggregate sizes decreases
5. RISS concrete has higher flexural strength than granite concrete

CONTRIBUTION TO KNOWLEDGE

The study had shown that RISS concrete has higher flexural strength than granite concrete; Flexural strength of concrete is favored by decrease in maximum aggregate size.

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