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THE IMPACT RESISTANCE EFFECT OF PARTIALLY REPLACING COARSE AGGREGATE WITH GROUND-RUBBER AGGREGATE IN CONCRETE

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ABSTRACT
The effect of ground-rubber used as aggregate on the impact resistance of concrete when partially replaced volume of mineral coarse aggregate (granite) was investigated. A total of six mix batches (using a mix ratio of 1:2:4 and a water-cement ratio of 0.45) of concrete containing 0%, 5%, 10%, 15%, 20% and 25% ground- rubber aggregate by volume of granite were subject to impact resistance test using the Repeated Drop-weight Test method on circular concrete disc samples (150mm x 64mm). Fifty four (54) circular disc samples were cast for the impact resistance test after 14, 21 and 28 days of standard curing in water. The test results show that the density of the specimens at 28 days reduced by about 16%, having a value of 2072kg/m³ at 25% ground rubber content when compared to the control mix at 0%. The results also reveal that the incorporation of ground-rubber aggregate in concrete enhanced the impact resistance of the concrete greatly with the average no of blows to indicate failure ranging from 189 – 409 blows for 5 – 20% ground rubber content as compared to the control mixes, which had no ground rubber required an average of 106 blows at 28 days. The application could be practical if the rubber content is limited to a range of between 5-20% (Average of 13%) for structures which are exposed to impact loads in other to mitigate, minimize and dampen its effect on the structure. It is recommended for use in the construction of industrial floors.

Keywords: *Concrete, Density (Unit weight), Energy Absorption, Ground-Rubber, Impact Resistance, Toughness.*

1. INTRODUCTION

Concrete is the most commonly used construction materials in the world is inherently good in compression, stiffness, low thermal and electrical conductivity but some applications of concrete demands that it should have low unit weight, high tensile strength, high toughness, and high impact and abrasion resistance. However, these requirements, are not always satisfied by concrete; and one way to satisfy these is by improving its properties through the addition of randomly orientated particles and fibres [10]. Application of ground rubber aggregate from waste automobile tyre in concrete may be considered as a possible way of enhancing the impact resistance of concrete and also a better way of disposing waste materials by converting it into a constituent material for concrete production.

Incorporation of waste rubber-tyre in concrete will also have an additional advantage of conserving natural resources (mineral aggregate used in concrete production) which are becoming increasingly scarce. Hence, the re-use of waste rubber-tyres in concrete could have both environmental advantages and at the same time ensure economic viability. According to [26], in each year about 9 million tonnes waste rubber-tyres are disposed all over the world, and an estimated number of 1 billion tyres is withdrawn from use in the world annually [13].

It was reported that an estimated 5 million scrap tyres from trucks, cars and motorcycles existed in Nigeria in 1983 with an annual generation rate of 15% each year about 21 million scrap tyres are estimated to exist in Nigeria by 2011 [11].

In Nigeria today one of the most common ways of disposing waste tyres is through disposal and open air combustion. The latter is practiced most especially at the abattoir and local commercial quarry sites where the tyres serve as source of fire for processing slaughtered animals and mining activities. These disposal methods produce greenhouse gases such as H_2, CO, CO_2, C_4H_6, CH_4 and C_2H_6 with lower concentration of other hydrocarbon gases which are

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responsible for the depletion of the ozone layer hence contributing to global warming.

Previous investigations have shown that the addition of waste rubber tyre aggregate into the concrete mixture produces an improvement in toughness, plastic deformation, impact resistance and cracking resistance of the concrete. It is observed that the higher the strength, the lower the toughness [11 – 13]. It is difficult to develop high strength and high toughness concrete without modifications. Owing to the very high toughness of waste tyres, it is expected that adding ground-rubber aggregate into concrete mixture can increase the toughness of concrete considerably. Laboratory tests have shown that the introduction of waste tyre rubber into concrete considerably increase toughness, impact resistance, and plastic deformation of concrete [20].

It was also observed that Concrete containing rubber aggregate has a higher energy absorbing capacity referred to as toughness. In all failure tests, the rubber-concrete specimens stayed intact (did not shatter) indicating that the rubber particles may be absorbing forces acting upon it [21]. Such behaviour may be beneficial to a structure that requires good impact resistance properties. The increase in the energy absorbing capacity was more pronounced in concrete samples containing larger-size rubber aggregates [16, 18].

The effect of waste rubber-tyre as partial replacement by volume of aggregate (sand and gravel of equal proportion) on the modulus of elasticity and impact resistance of this type of concrete was investigated by [13]. Three mixes of waste rubber-tyre concrete where selected partial replacement ratio (PRR) of 30%, 40% and 50% . The study showed that incorporating waste rubber-tyre in concrete decreases the compressive strength, modulus of elasticity and impact resistance. The dynamic modulus of elasticity and rigidity decreased with rubber content, indicating a less stiff and less brittle materials as observed by [15]. They further reported that damping capacity of concrete (a measure of the ability of the materials to decrease the amplitude of free vibrations in its body) seemed to decrease with rubber content but [25] recommended the use of rubberized concrete in circumstances where vibration damping is required. Similar observations were also made by [14, 24].

The addition of rubber aggregate into concrete resulted in a significant increase in impact resistance when compared with the control concrete as reported by [17]. The study suggested that rubber particles may function as a distribution of mini expansion joints inside the concrete. Thus, the rubber concrete may exhibit good characteristics in controlling crack initiation and propagation. An analysis was carried out on rubberized concrete that used 15% replacement of waste tire for an equal volume of mineral coarse aggregate. It was used as a two phase material as tyre fibre and chips dispersed in concrete mix. The result indicated that there is an increase in toughness, plastic deformation, impact resistance and cracking resistance. However, the strength and stiffness of the rubberized sample were reduced. The control concrete disintegrated when peak load was reached while the rubberized concrete had considerable deformation without disintegration due to the bridging caused by the tyres. The stress concentration in the rubber fibre modified concrete is smaller than that in the rubber chip modified concrete. This means that the rubber fibre modified concrete can bear a higher load than the rubber chip modified concrete before the concrete matrix breaks [19]

This study investigates the impact resistance effect of replacing coarse aggregate with ground-rubber aggregate and its t effect on density and toughness.

2. MATERIALS AND METHODS

2.1 Materials

The materials used are cement, natural aggregate (fine and coarse), waste ground rubber-tyre derived aggregate and water.

2.1.1 Cement

Ordinary Portland cement (Dangote Brand) sourced from a retail outlet and tested to ensure that it conforms to BS 12 [4] was used throughout the investigation.

2.1.2 Fine Aggregate

Natural sharp river quartzite sand smaller than 4.76mm but larger than 75μm that is free of clay, loam, dirt and any organic or chemical matter with average specific gravity (SSD) of 2.65 and bulk density of 1,454.55Kg/m^3 was used as fine aggregate. The fine aggregate (sand) falls in zone two (medium sand) according to BS 882 [5] (Plate 1).

2.1.3 Coarse Aggregate (Granite)

Natural crushed (granite) with nominal maximum sizes of 19-20mm (3/4inch) sourced from a local commercial quarry with average specific gravity (SSD) of 2.67 and bulk density of 1500kg/m^3 was used as coarse aggregate (Plate 2).

Plate 1: Fine Aggregate (Sand)

Plate 2: Coarse Aggregate (Granite)

Plate 3a &3b: Plain and Coated Ground-Rubber

2.1.4 Ground-Rubber Aggregate

Coarse rubber aggregate (ground rubber) from scrap tyres with nominal maximum sizes of 19-20mm (3/4inch), specific gravity of 1.14 and bulk density of 945Kg/m^3 was used for this research. The coating of ground rubber aggregate with cement paste was adopted for this research, as a surface treatment of the rubber aggregate as depicted in Plate 3a and 3b. This is a simple method of improving the strength performance of the material as implemented by [18] thereby avoiding the use of additional or costly additives which may adversely affect the production costs.

2.1.5 Water

Ordinary tap water (potable drinking water) which is fresh, colourless, odourless, tasteless and free from organic matter of any kind sourced from Civil Engineering Laboratory Ahmadu Bello University, Zaria Nigeria was used for all concrete mixes and curing. The water is therefore fit for concrete work according to specifications in BS 3148 [8]

2.2 Mix Proportion

The mix design for the concrete is based on an Absolute volume method according to BS 5328 [9]. Based on a preliminary estimate of the concrete mix design, a mix ratio of 1:2:4, compressive strength of 30N/mm^2 at 28 days (Grade 30 Concrete) with water/cement ratio of 0.45 and aggregate/cement ratio of 4:1 was used to produce a trial mix which was tested for workability, strength, density and finishing properties and eventually subjected to adjustment and applied to all the concrete mixes. A total of six (6) mixes were prepared: One control mix with no ground-rubber aggregate (0%) and five concrete mixes in which the 19-20 mm coarse aggregate (granite) was replaced by ground-rubber aggregate at 5%, 10%, 15%, 20% and 25% by volume. The mix proportions was constant in terms of mix design ratio, water/cement ratio, sizes, type of natural and rubber-tyre aggregate used for the study.

The result computation for the concrete based on 1 cubic meter are shown in Table 2 while the results of computation of the material weight for the specimens (0.00113112m^3 per specimen) are shown in Table 3 . The results took into consideration 10% inclusion for waste and shrinkage. Three mixes were prepared each for each ground rubber mix of concrete at 14, 21 and 28days giving a total of 54 circular disc specimens prepared for the study.

Table 2: Mix Proportion for a Cubic Meter (1m^3) of Concrete Mix

Mix No	Mix Ratio	W/C Ratio	Rubber Aggregate (%)	Rubber Aggregate (Kg)	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)
A	1:2:4	0.45	0	0	331.09	662.18	1,324.36	148.99
B	1:2:4	0.45	5	45.86	331.09	662.18	1,258.14	148.99
C	1:2:4	0.45	10	91.72	331.09	662.18	1,191.92	148.99
D	1:2:4	0.45	15	137.57	331.09	662.18	1,125.71	148.99
E	1:2:4	0.45	20	183.43	331.09	662.18	1,059.49	148.99
F	1:2:4	0.45	25	229.29	331.09	662.18	993.27	148.99

Table 3: Weight of material forconcrete disc specimen

Mix Ratio:1:2:4, W/C = 0.45, Curing Age: 14, 21 and 28 Days						
Mix No	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Rubber Aggregate Replacement		Water (Kg)
				(%)	(Kg)	
(Control) A	3.72	7.44	14.82	0	0	1.68
B	3.72	7.44	14.10	5	0.48	1.68
C	3.72	7.44	13.38	10	0.93	1.68
D	3.72	7.44	12.63	15	1.41	1.68
E	3.72	7.44	11.88	20	1.86	1.68
F	3.72	7.44	11.13	25	2.34	1.68

2.3 Casting, Curing and Testing of Samples

The mould for the concrete specimens used in the study were cut from 150mm diameter PVC pipes with a height of 64mm for all the cast specimens. The PVC moulds were coated with lubricating oil before use in casting the concrete disc specimens. Hand mixing method was adopted due to the volume of concrete required (Table 3). The materials were first thoroughly mixed dry with a trowel for about five minutes then water was added and thoroughly mixed into a homogenous concrete mix for about five (5) to ten (10) minutes. The fresh concrete mix was filled into the PVC moulds in three layers and compacted with a tamping rod, after which a trowel was used to smoothen the top of the mould.

The disc samples were then covered with a polythene sheet for 24 hours to prevent evaporation of water after which they were carefully de-moulded and taken to the curing room and cured in a water tank at a constant temperature of 20°C in accordance with [2]. The disc samples were categorized by the curing age of the concrete which was limited to 14, 21 and 28 days at the day of testing.

The disc samples are then air dried after curing and the diameter and height of each sample measured. The volume (V) was the computed and the weight (W) of sample measured. The density of the concrete disc specimens was determined using the formula in equation 1. The results are presented in Table 4.

$$D(Kg/m^3) = \frac{W(Kg)}{V(m^3)} \quad (1)$$

Concrete disc samples for the impact test (Plates 4 & 6) were removed from the curing tank and wiped with a damp cloth. The same concrete disc samples were placed in a set up similar to that by [3] as shown in Figures 1 and 2 using the repeated drop weight method as recommended by ACI committee 544 [1, 2] for impact compression testing.

The specimens were coated on the bottom with a thin layer of petroleum jelly and placed on the base plate within the positioning lugs with the finished face up. The positioning bracket was then bolted in place, and the hardened steel ball was placed on top of the specimen within the bracket.as depicted in Plate 5. The standard Marshall drop hammer was placed with its base upon the steel ball and held there with just enough downward force to keep it from bouncing off the ball

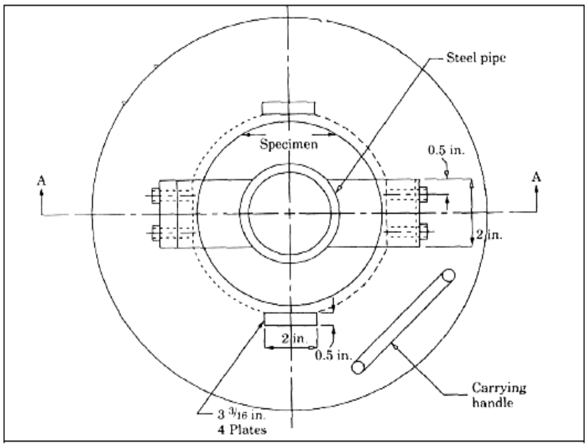


Figure 1: Plan View of the Experimental Setup
(Source [3])

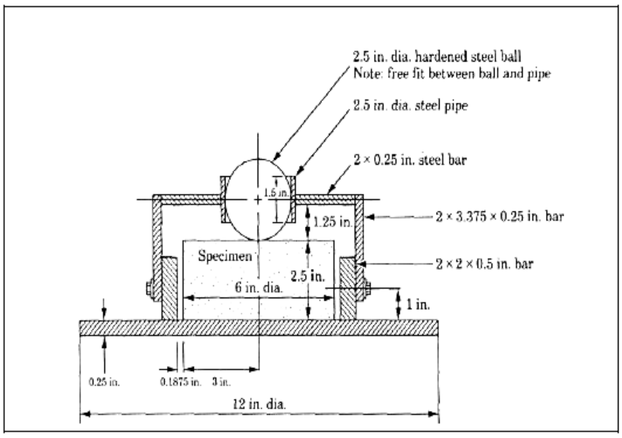


Figure 2: Sectional View of the Experimental Setup
(Source [3])

Plate 4: Circular Discs Samples for Impact Test

Plate 5: Test Setup for Impact Test

Plate 6: Circular Disc Concrete Specimen

Table 4: Density and Impact Resistance Test Result

Mix Ratio (1:2:4) Water-Cement Ratio (W/C): 0.45												
Specimen No	% Rubber Content	Curing Age (Days)	Density (Kg/m³) *P*	Mean Height Sample (mm)	No of Blows To Cause First Crack				No of Blows To Cause Ultimate Failure			
					1	2	3	Average	1	2	3	Average
Control A	0%	14	2,440	64.00	29	31	27	29	32	34	31	32
		21	2,493	64.00	52	58	49	53	60	62	57	60
		28	2,478	64.00	99	102	105	102	103	108	107	106
B	5%	14	2,419	64.00	96	99	92	96	105	109	96	103
		21	2,420	64.00	110	102	123	112	115	109	125	116
		28	2,411	64.00	186	174	193	184	191	176	199	189
C	10%	14	2,352	64.00	140	153	138	144	145	157	141	148
		21	2,363	64.00	212	241	226	226	217	249	231	232
		28	2,352	64.00	266	294	281	280	271	297	289	286
D	15%	14	2,284	64.00	149	160	151	153	156	163	154	158
		21	2,299	64.00	237	254	231	241	240	256	236	244
		28	2,299	64.00	326	319	372	339	330	321	375	342
E	20%	14	2,151	64.00	150	154	161	155	152	155	166	158
		21	2,137	64.00	273	291	288	284	278	296	293	289
		28	2,122	64.00	399	403	412	405	404	405	418	409
F	25%	14	2,084	64.00	91	86	97	91	93	90	101	95
		21	2,072	64.00	161	135	141	146	168	140	146	151
		28	2,072	64.00	193	220	201	205	195	224	206	208

The load was transferred from the hammer to the specimen through a steel ball 64mm in diameter (Plate 5). The number of blows to cause the first visible crack on the surface of the specimen was recorded as the first crack strength. Loading continued until the specimen cracks open so that they touch three of the four positioning lugs indicating state of failure. The number of blows to cause failure of the specimen is recorded as the ultimate strength as presented in Table 4

3. RESULTS AND DISCUSSION

3.1 Density (Unit Weight)

The average densities of specimen for 14, 21 and 28 days are plotted against the respective percentage of ground rubber aggregate as shown in Figure 3. Results shows that the density (Unit Weight) reduces with increase in of ground-rubber aggregates in the concrete mix. The control mix has an average density of 2,478Kg/m^3 after 28 days of standard curing in water while 25% rubber-cement mix have an average density of 2,072Kg/m^3 for the same 28 days curing in water, amounting to a 16% reduction in the density. The reduction in density can be linked to the low specific gravity of the rubber aggregate with respect to the coarse aggregate (granite). Low unit weight can be a desirable feature in a number of applications, including architectural applications such as nailing concrete, false facades, stone backing and interior construction according to [22].

3.2 Impact Resistance (Toughness & Energy Absorption)

Low Impact resistance strength of concrete has been enhanced with incorporation of ground-rubber aggregate as exhibited in this study. The first crack and ultimate failure strength in terms of number of blows for the mix series A-F are plotted in Figure 4. The number serves as a quantitative estimate of the energy absorbed by the specimen at the levels of distress specified. The results indicate that the addition of coarse rubber aggregate resulted in an increase in the impact resistance compared to that of the control mixes. The increments is noticed in the 5%, 10%, 15% and 20% rubber-concrete mix while a decrease in impact resistance is observed in the 25% rubber-concrete mix. The control mix (0% rubber aggregate), required less blows for all the days considered when compared to 5 – 25% ground rubber content as shown in Figure 4. The first crack required less number of blows than those required to indicate failure for all the ground rubber content investigated the results obtained are consistent with the findings of [12, 17, 25]. The failure mode of the various percentage replacement of coarse aggregate with ground-rubber, as observed in Plate 7 was tensile failure through the specimens although local crushing and shearing occur in region where the falling weight made impacts.

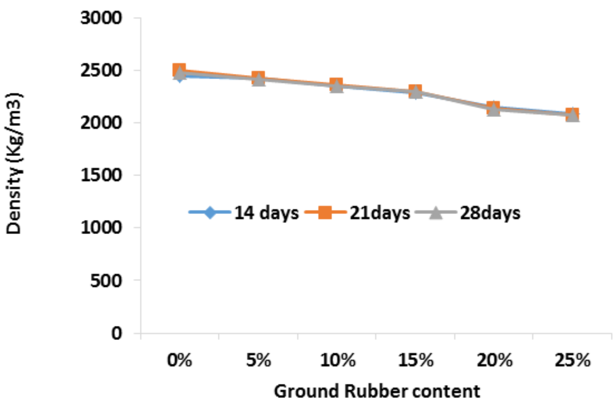


Figure 3 : Variation of concrete Density with Ground rubber content

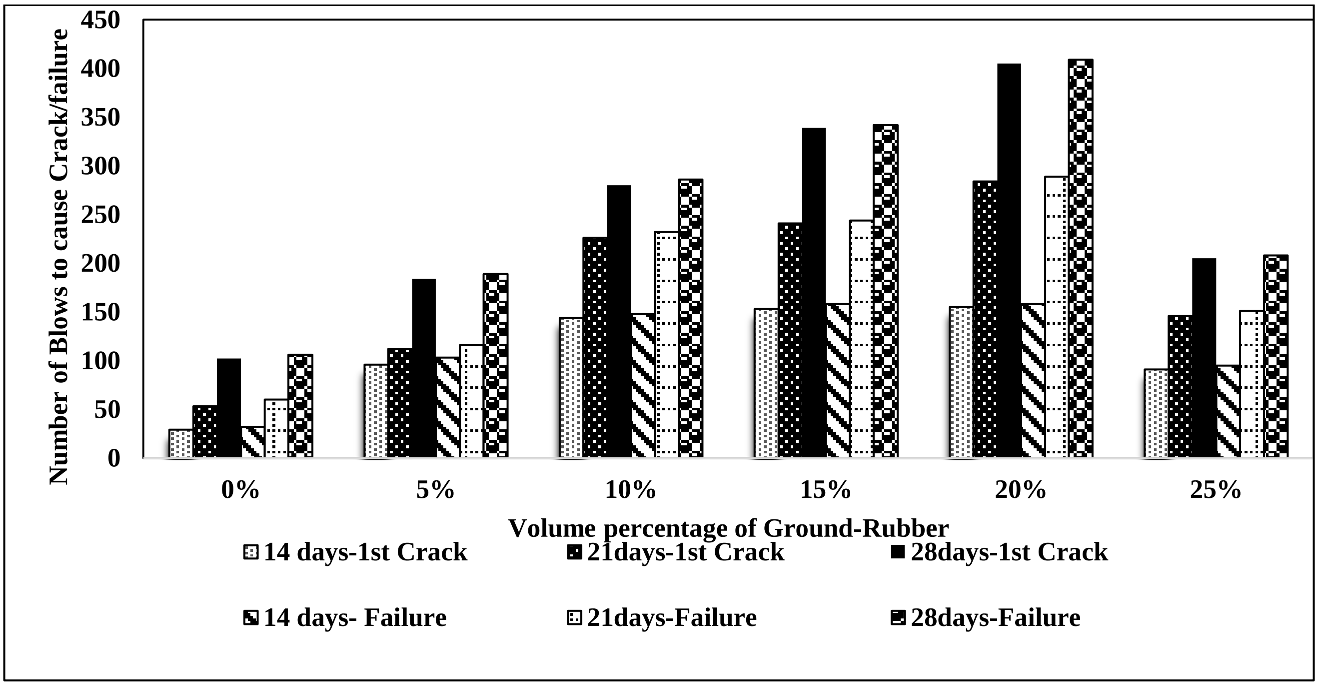
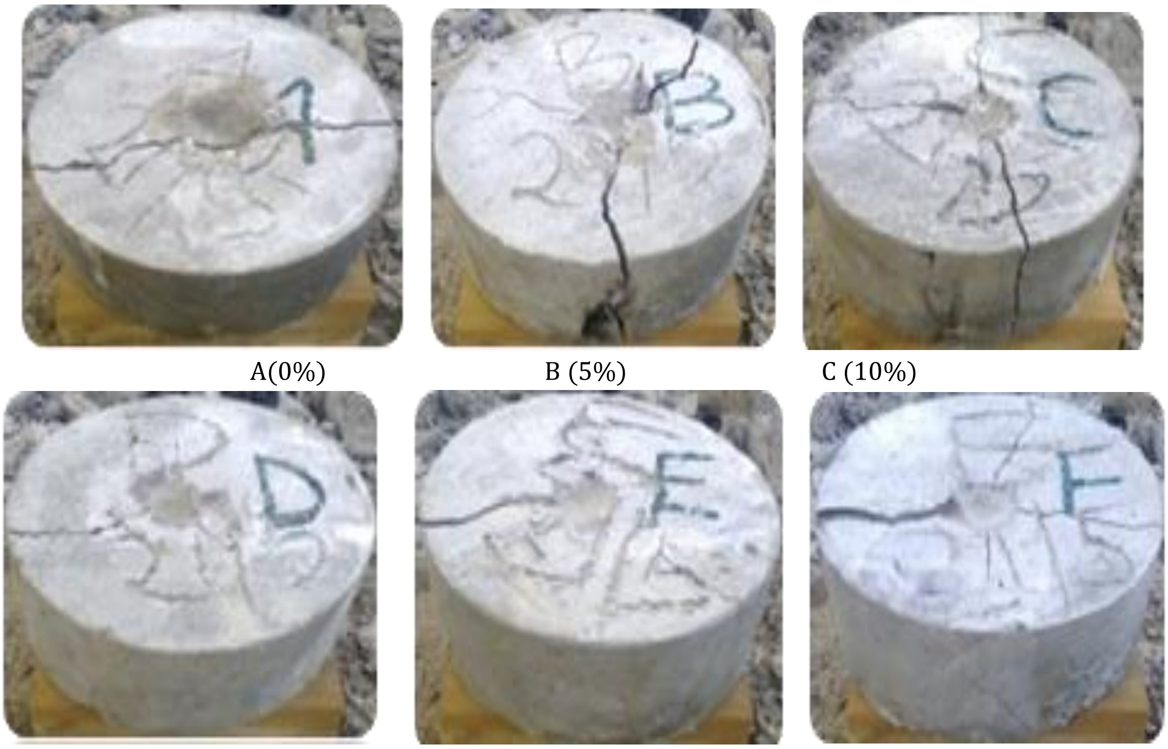


Figure 4: Impact Resistance of Rubber-Concrete to Cause First Crack and Ultimate Failure



A(0%) B (5%) C (10%)

D(15%) E(20%) F(25%)

Plate 7: Impact Resistance Test Failure Mode of Control and Ground Rubber-Concrete

4. CONCLUSION

The result of this study has highlighted the effect of ground-rubber aggregate on the impact resistance of concrete when it (rubber) partially replaces some volume of natural granite. Recycled rubber-tyres as an aggregate in concrete could be successful in its use for concrete application if the rubber content is limited to a range of between 5-20% for structures which are exposed to impact load in other to mitigate, minimize and dampen its effect on the structure. Therefore it is recommended for construction of industrial floors to reduce damages due to impact load from a sudden drop of heavy machine or equipment.

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