Performance Optimization of Recycled Polymeric Reinforced Concrete Under Compressive Loads

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Abstract: Waste tyre is one of the most notable environmental nuisances the world has to contend with today due to its non-biodegradability in nature. The traditional indiscriminate methods employed in disposing these waste materials constitute serious environmental hazards and is severely threatening our health, safety and environment. Therefore, recycling these waste tyres into construction materials serve as a suitable means to properly disposed of this vast amount of used rubber tyres. This work therefore presents a comprehensive review of the engineering properties of recycled waste rubber tyres. used for reinforced composite concrete production in civil infrastructural works. The experimental research method was adopted in this study, where composite concrete of grade 25 in a nominal mix of 1:2:4 with varying proportions of the polymeric chips as partial replacement to coarse aggregates, ranging from 5%, 10%, 15%, 20%, 30%, up to 60% were used to produce concrete cubes of 150 x 150 x 150mm as specimens and subjected to slump test, and compressive strength test, in order to determine the workability, strength and structural integrity of the concrete. The result of this experiment showed that replacing 5% of natural aggregates with polymeric material in concrete production improved its compressive strength by 3.1%, at 7 days curing and 3.5%. at 28days curing. But with further increment of the polymeric material to 10%, 20% and above, the compressive strength reduced drastically below the minimum permissible levels. It is hereby recommended that to produce a sound composite lightweight concrete with improved compressive strength for structural stability, a moderate percentage, precisely less than 10% of this polymeric material should be used as partial replacement.

Keywords: *Recycled Polymeric Material, Reinforced Concrete, Material Sustainability, Concrete Composite, Compressive Strength, Stress- Strain Behavior, Mechanical Performance.*

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I. INTRODUCTION

With the development of the automotive industry, tyres have become an integral part of our everyday life and are being used daily, and in different spheres of transportation. However, after being used, these tyres become great nuisance in our environment because they are non-biodegradable [1]. Waste tyre is one of the most significant environmental hazards the world has to contain with, as a result of the increase in automobile production [2]. there is great need to properly disposed of this vast amount of used rubber tyres for a cleaner Environment. The available sites for waste disposal are rapidly depleting and several countries have already outlawed the retention of waste rubber tyres in disposal areas. Hence efforts are being made to discover the prospective use of waste tyre rubber in construction industry and here, rubber crumbs and chips are being considered to be potential materials for use in concrete technology [3,4].

The use of recycled waste tyres as a constituent for reinforced concrete in Civil Engineering applications is based upon their unique characteristics which include: their lightweight compared to conventional aggregates (coarse or fine) in concrete, good insulation properties, very high ability to resist water, durability and high compressibility due to their elasticity [5,6].

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In an effort to improve the durability and resilience of concrete, efforts have made to use recycled rubber tyres for concrete mix and the results have been positive, stating this mix can help extend the lifespan of concrete structures, road pavements, bridges, as well as providing a convenient method of these wastes disposal [7,8,9]. Subjecting this concrete containing polymeric materials to compressive test and also predicting the creep behavior of this concrete is very important for engineering designs especially the advanced reinforced composite concrete materials. The term creep described the phenomenon that the deformation of a material increases with time under constant stress and temperature [10,11]. Creep- Strain is conventionally defined as the difference between the dimensional changes of a stressed specimen and an unstressed specimen irradiated under identical condition [12]. The apparent strength of concrete is affected by the rate at which it is loaded. In general, for static loading, the faster the loading rate, the higher the indicated strength [13]. The increase of polymeric waste materials generation (plastic and rubber) in the world led to the need to develop suitable methods to reuse these waste materials and decrease their negative effects by simple disposal into the environment [14]. Combustion and landfilling as traditional methods of polymer waste elimination have several disadvantages such as the formation of dust, fumes, and toxic gases in the air, as well as pollution of the underground water resources [15]. From the point of energy consumption and environmental issues, polymer recycling is the most efficient way to manage these waste materials [16]. In the case of rubber recycling, the waste rubber can go through size reduction, and the resulting powders can be melted blended with thermoplastic resins to produce thermoplastic elastomers (TPE) compounds [17]. Recycling is a key component of modern waste reduction and is the third component of the “Reduce, Reuse, and Recycle” waste hierarchy. It promotes environmental sustainability by removing raw material input and redirecting output in the economic system [18]. There are some ISO standards related o recycling, such as ISO 15270:2008 for plastic waste and ISO 14001: 2015 for environmental management control of recycling practice [19].

In this study, different samples of reinforced composite concrete made of polymeric materials shall be subjected to compressive test to find a suitable material combination that serves as an alternative or an additive to the natural stone aggregate for reinforced composite concrete with durability, strength and structural stability, which are in limited supply. The research also aims to provide an avenue for waste recycling, a way of waste to wealth creation for humanity.

II. THEORETICAL FRAMEWORK

Concrete like any other material is subject to expansion, contraction, and elastic deformation the elastic deformation or failure of concrete under continuous loading uses the modulus of elasticity model as the governing equation, where Modulus of elasticity (E) = stress/strain

$$[E] = \text{“}\sigma\text{"} / \text{"}\epsilon\text{"} \qquad (1)$$

Where, *E = Modulus of elasticity*
σ = *Stress*
ϵ = *Strain*

Modulus of elasticity is a measure of a material’s stiffness or resistance to elastic deformation which is defined as the ratio of stress (force per unit area) applied to the resulting elastic strain (a measure of deformation relative to the original length of the material) [20].

➢ *Mechanical Properties of Polymeric Concrete*

The Mechanics of Polymer Concrete (PC) rely on the polymer resins acting on the binder between aggregates undergoing polymerization (Chemical reaction) to form a hardened, strong composite material. Unlike conventional concrete which uses cement hydration. This polymerization creates a vast void-free structure with high strength, chemical resistance and good adhesion [21]. The Mechanical response properties of polymer materials covers a variety of important physical behavior exhibited under the influence of external load [22].

This indicate how much a material can be stretched, and fully recover its original shape after releasing the external load. The stress-strain relationship describes how much a material deforms (strain) in response to an applied force (stress) and it is characterized by a stress-strain curve.

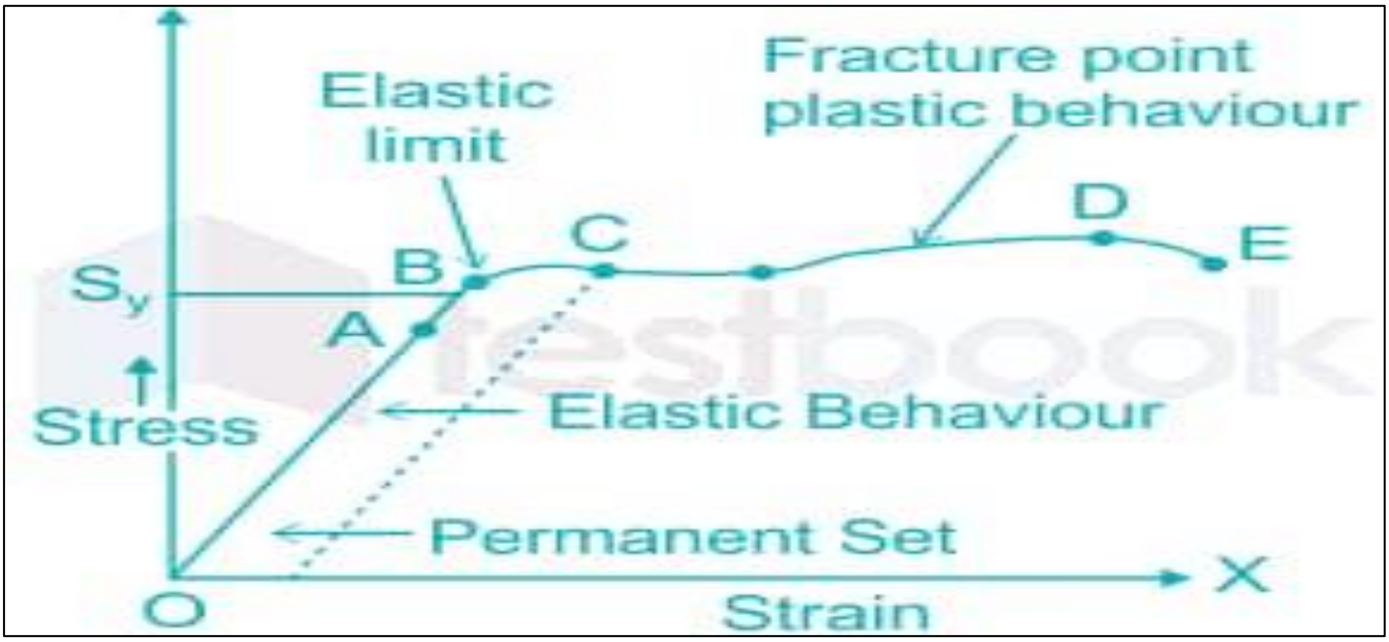

Fig 1 Stress- Strain Curve

The stress- strain curve reveals the material's mechanical properties and this relationship starts with a linear, elastic region, point O to A, point B is the elastic limit, where the deformation is reversible. C is the strain hardening zone; D is the fracture zone and E represent the fracture point where the deformation is permanent. This is governed by Hooke's Law which states: Provided the elastic limit is not exceeded, the deformation of a material is directly proportional to the force applied to it [23]. This relationship is expressed by the equation:

$$F\_s= - 〖kx〗 \_ \quad (2)$$

Where:
F_s=Spring Force (N)
k =Spring Constant (N/m)
x =Spring Stretch or Compression (m)

The minus sign indicates that the restoring force acts in opposite direction to the displacement and always trying to return the object to its original position [24]. It simply shows that the strain of a material is proportional to the applied stress within the elastic limit of the material.

III. MATERIALS AND METHODS

This work is basically to verify the workability and compressive strength of the Concrete with partial replacement of polymeric materials, specifically recycled waste rubber tyres as an alternative or additive to the conventional fine and coarse aggregates in composite concrete.

➢ *Applied Method*

The Experimental Research Method was adopted using polymeric material as partial replacement to natural coarse aggregates for the production of composite concrete which as subjected to compressive strength test in the laboratory to determined its strength and structural integrity.

➢ *Techniques of Data Collection and Analysis*

The waste rubber tyres were hewed into chips and crumbs and produced reinforced composite concrete with varying proportions of the polymeric chips as replacement to natural coarse aggregates, ranging from 5%,10%, 15%, 20%, 30%, up to 60%. And these were subjected to Slump test, and compressive strength tests to determine their workability and yield strengths under varying magnitudes of loads according to the variables obtained from the reinforced concrete material specimens, at various mix proportions and mix ratios,

➢ *Experimental Mix Design*

The target design Concrete for this work was grade 25 concrete with the mix ratio of 1: 2: 4 B.S standard using Portland Cement, Natural Sea Sand as fine aggregates, Crush Rock with partial replacement of polymeric materials as coarse aggregates and potable water. The percentage composition of polymeric materials to natural coarse aggregates is as shown below:

Rc.0 = Pure Natural Coarse aggregates only

Rc.5 = 5% replacement of polymeric materials to coarse aggregates

➢ *Selection of Materials*

The materials used for this work includes:

- Portland cement Class 42.5 of BSI
- Natural sea sand of 0'45 to 4.75mm
- Crush Rock (chippings) of 5 to 20mm
- Clean Potable water
- Rubber chips from waste tyres shredded into 5 mm to 20 mm diameter

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Fig 2 Heap of Waste Tyres in the Environment

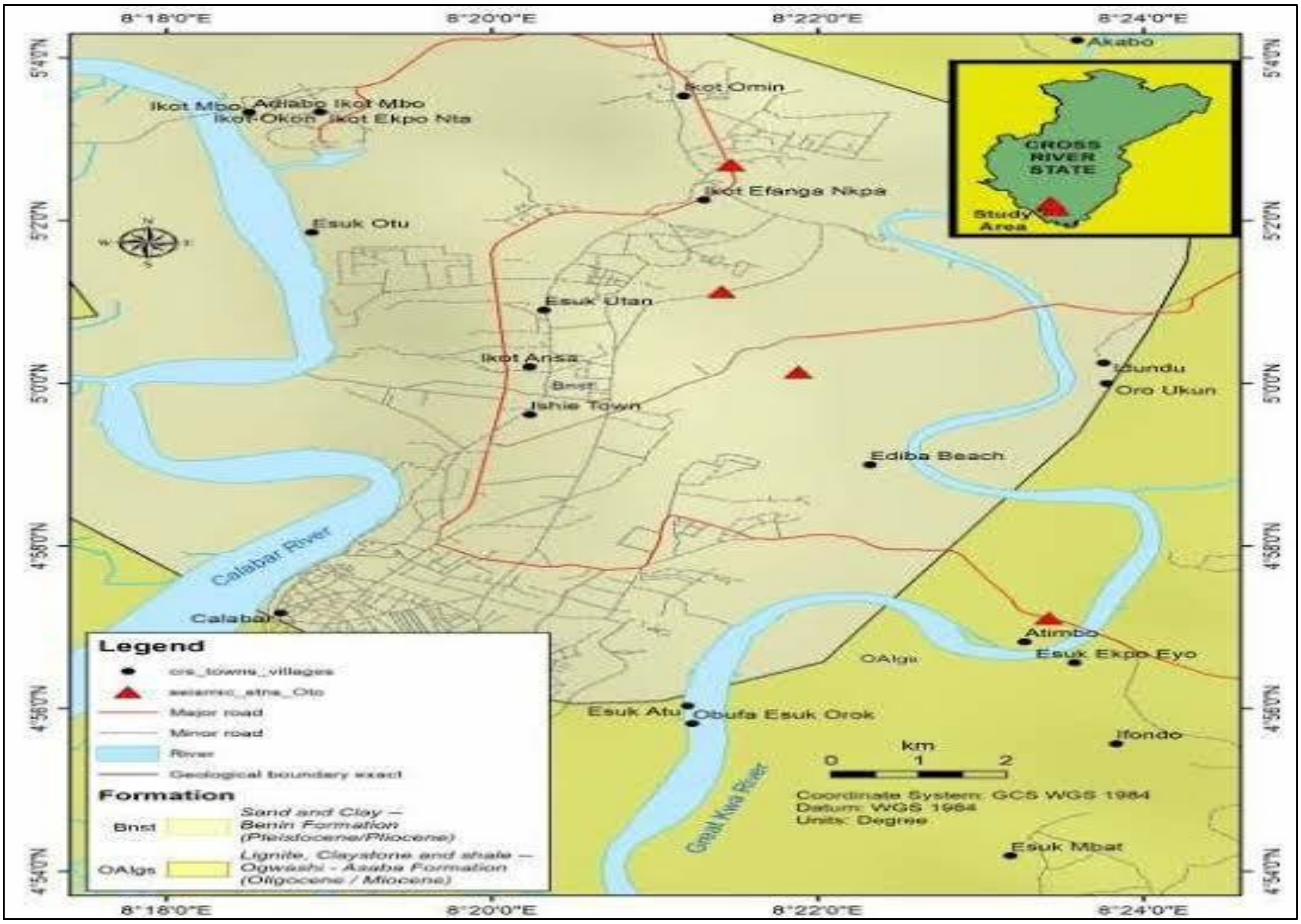

Fig 3 Map of Tyre dump site, Esuk Utan, Calabar Municipality

Fig 4 Shredded Rubber Chips from waste tyres

Fig 4 showing a heap of rubber chips, already chopped and shredded into different sizes of 4.75 to 15.0 mm from waste tyres to be used as partial replacement to coarse aggregates in composite concrete mix

➢ *Slump Test*

Slump test is a widely used method to measure the workability of a fresh concrete. It is a test that measures how much freshly mixed concrete settles when a mold is removed.

➢ *Equipment to conduct Slump Test*

- Slump Cone of (300mm height, 100mm Top diameter and 200mm Bottom diameter
- Tamping Rod of (600mm length and 16mm diameter)
- Concrete mixing bucket, head pan, shovel and Trowel
- Measuring Tape/ Ruler
- Mold of (150mm x150mm)
- Calibrated water Jar
- Recording book

➢ *Test Preparation*

- The slump Cone was well cleaned and moisten to receive fresh concrete.
- A representative sample was collected from the freshly mixed concrete
- The slump Cone was filled with the freshly mixed concrete sample in three layers, each of 100mm high and appropriately compacted

➢ *Testing Procedure*

- The tamping rod was used to compact each layer of concrete inside the cone and 35 strokes were applied to each layer to ensure even spreading on the surface
- The tamping rod was also used to level and smooth the top surface of the concrete
- The slump cone was carefully removed vertically without shaking or disturbing the concrete.
- The distance from the Top of the cone to the Top of slumped concrete after removing the cone was measured and recorded
- This process was repeated with different samples of fresh concrete mix with rubber chips at different proportions of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 60% respectively. And the results were recoded accordingly as shown in table

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Fig 5 Slump Measurement

Fig 5 shows the freshly mixed concrete, removed from the cone and place side by side with the cone to measure the level of fall for the determination of the slump test.

Table 1 Experimental Test of Concrete mixed with Rubber chips

S/N	Polymeric Material (Kg) (%)	Natural Aggregate (Kg) (%)	Cement (Kg) %	Natural Sea Sand (Kg) (%)	Potable Water (L)
1	Rc .0	100	100	100	2
2	Rc.5	95	100	100	2
3	Rc.10	90	100	100	2
4	Rc.15	85	100	100	2
5	Rc.20	80	100	100	2
6	Rc.30	70	100	100	2
7	Rc.40	60	100	100	2
8	Rc.50	50	100	100	2
9	Rc.60	40	100	100	2

Table 2 Slump Test of Concrete Mixed with Rubber Chips

S/N	Polymeric Material (Kg) (%)	Natural Aggregate (Kg) (%)	Slump (Mm)
1	Rc.0	100	282
2	Rc.5	95	281
3	Rc.10	90	279
4	Rc.15	85	277
5	Rc.20	8	275
6	Rc.30	70	273
7	Rc.40	60	270
8	Rc.50	50	265
9	Rc.60	40	260

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➢ *Compressive Strength Test*

Compressive strength test measures the strength of the concrete and is one of the commonest tests used to verify the quality of concrete. It is a type of mechanical testing that involves applying a compressive force to a material and measuring its response. The compressive force tends to reduce the size of the material and the test is designed to determine the behavior of the material under the type of load applied.

The compressive strength is the maximum compressive load that the cube can carry per unit area and is calculated as shown in equation 1

$$F\_Cu=P\_max/A \quad (3)$$

Where,
F_Cu = Compressive strength (N/mm2)
P max = Magnitude of failure load (N)
A_ = Cross sectional area of the cube specimen (mm2)

➢ *Equipment to conduct Compressive strength Test*

- Compression testing Machine (which consist of a load cell, a Crosshead, Compression test tools and an electronic recorder)
- Cube Molds
- Curing Tank
- Weighing Machine

Fig 6 Compression Testing Machine with Concrete Cube

Figure 6 shows the Compressive strength testing machine with the door widely open and made up of applied load, the regulator, the soft weir counter, the bottom plate to hold the cube in place and the concrete cubes ready for crushing.

➢ *Test Preparation for Compressive Strength*

- Removal of the cubes (specimen) from the water where they were immersed for 7days and 28days curing
- Plug and Set up the crushing machine
- Positioning the specimen
- Setting up test parameters
- Pre-loading and pre-conditioning Compressive test execution
- Data collection for Analysis.

➢ *Procedure for conducting Compressive Strength Testing*

During the compressive test, a sample or specimen of the material (Cube) was first weighed in a weighing machine and the value recorded and then the cubes were placed in a crushing machine where it was compressed between two

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plates. The machine applies a gradually increasing load to the specimen and the change or deformation in the dimension of the material increased at various points, until it begins to fail or deform permanently. This process was repeated with different samples of concrete cubes mix with rubber chips at different proportions of 5%, 10%, 15%, 20%, 30%, 40%, 50% and 60% respectively. The exercise was conducted at the 7th day and at the 28th day with the specimen designation.

IV. RESULTS AND DISCUSSIONS

➢ *Slump Test*

From the slump test conducted to determine the workability and consistency of the concrete mix using natural coarse aggregates in addition to the partial replacement of polymeric materials to produce a composite concrete, the results were obtained from the following:

- *Slump Values:*

The Slump value is the difference between the height of the concrete before the cone was removed and after the cone was removed and is usually measured in millimeters (mm). The height of the Cone minus the height of freshly molded concrete after carefully removing the Cone.

- (Rc.0): For Concrete with only natural aggregates without additives

- (RC.): For Concrete mix with natural and rubberized aggregates

$$F\_2 = F\_1 - F\_0 \quad (4)$$

Where
F_2 is the height of the Cone filled with freshly molded concrete (mm)
F_1 is the height of the molded concrete after removing the cone (mm)
F_0 is the level of slump after removing the cone (mm)

Table 3 Result of Slump Test of Concrete mixed with Rubber Chips

S/N	Polymeric Material (Kg) (%)	Natural Aggregate (Kg) (%)	Slump Value(mm)
1	Rc.0	100	18
2	Rc.5	95	19
3	Rc.10	90	21
4	Rc.15	85	23
5	Rc.20	80	23
6	Rc.30	70	27
7	Rc.40	60	30
8	Rc.50	50	35
9	Rc.60	40	40

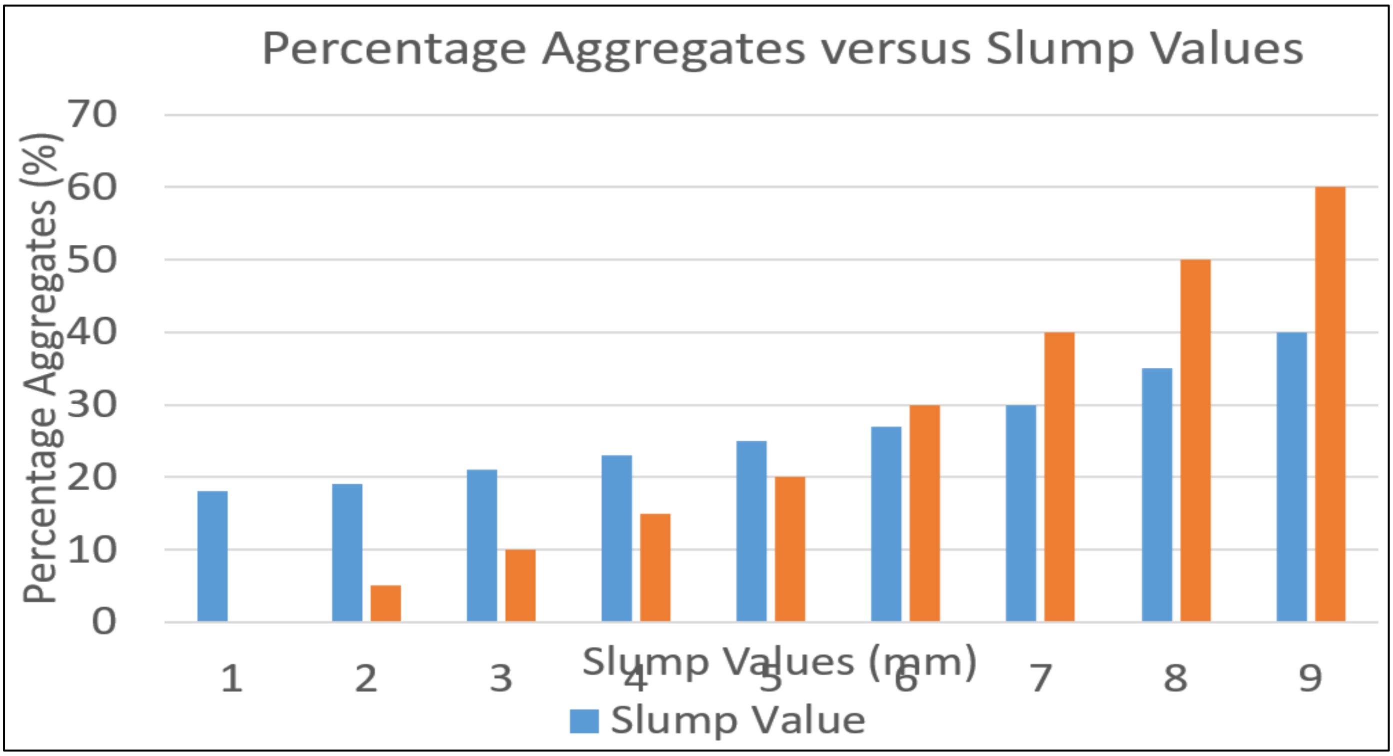

Fig 7 Percentage Aggregates versus Slump Values

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Figure 7 indicate the Bar Chart of the Percentage Aggregates versus Slump Values as obtained from the slump test, showing the blue bar representing the slump value and the yellow bar representing percentage rubberized aggregates used. At 100% natural aggregates and 0% rubber chips, the slump value is 18cm while at 5% replacement with rubber chips, the slump increased to 19cm. with further increment of the polymeric material to 60%, the slump value increased to 40cm, showing a very high workability.

➢ *Compressive Strength Test*

Compressive strength test measures the strength of the concrete and is used to verify the quality of concrete. It is the maximum compressive load that the cube can carry per unit area before failure

From the compressive strength test conducted on the 7th day of curing, the results were obtained and used for the calculations as shown in equation 3.

$$F_{Cu} = \frac{P_{max}}{A} \quad (5)$$

Where,
F (Cu) = Compressive strength (N/mm2)
P max = Magnitude of failure load (N)
A = Cross sectional area of the cube specimen (mm2)

Table 4 Result for Compressive Strength Test of Concrete at 7 days

S/N	Polymeric Material (Kg) (%)	Natural Aggregate (Kg) (%)	Compressive Strength (MPa)
1	Rc.0	100	17.46
2	Rc.5	95	17.73
3	Rc.10	90	16.92
4	Rc.15	85	16.54
5	Rc.20	80	13.00
6	Rc.30	70	10.47
7	Rc.40	60	8.08
8	Rc.50	50	6.93
9	Rc.60	40	5.72

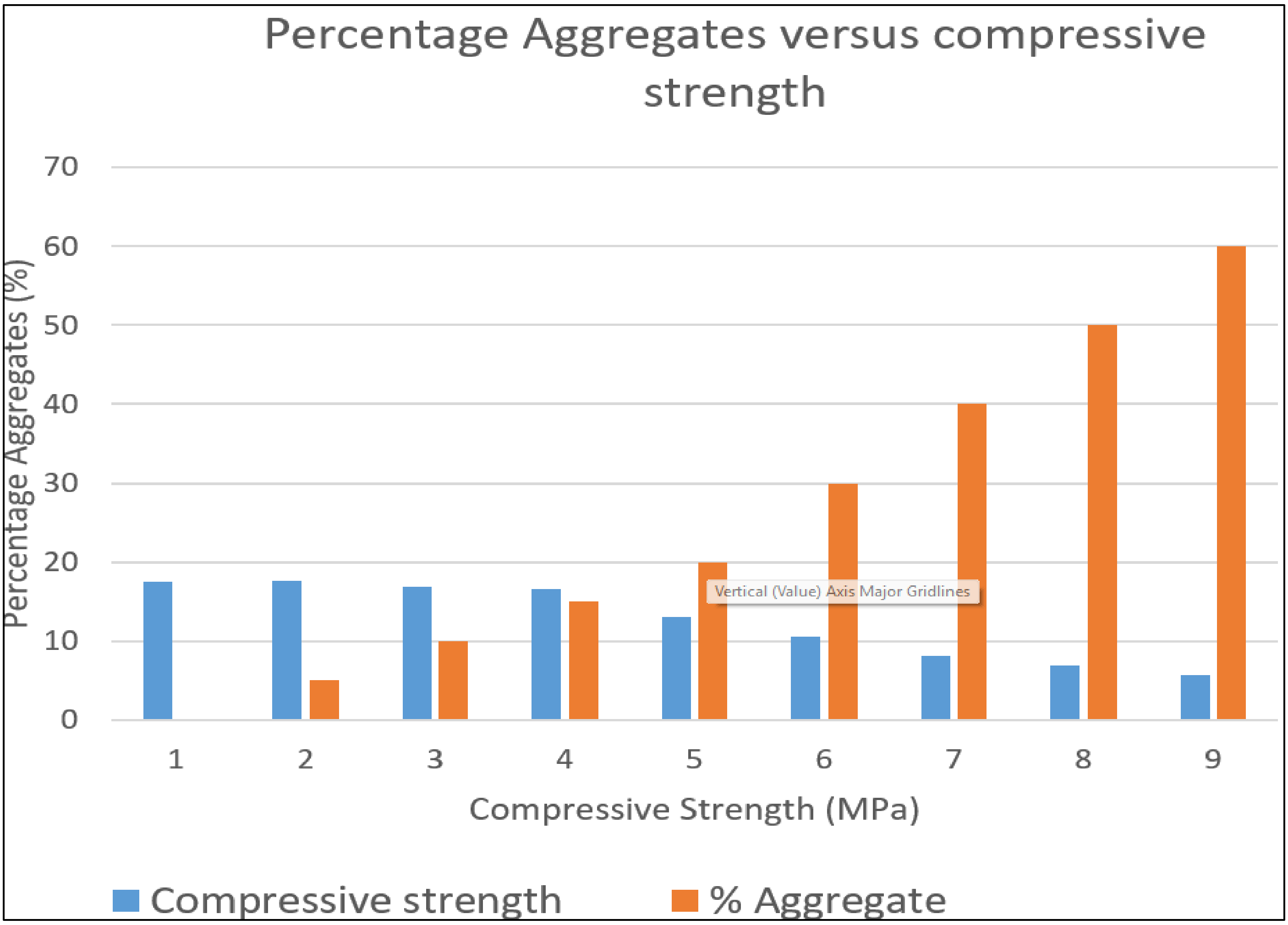

Fig 8 Percentage Aggregates Vs Compressive Strength at 28 days Curing

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Fig 8 indicate the bar chat of Percentage aggregates versus Compressive Strength conducted after 7 days Curing, showing that for the mixture with 100% natural aggregates and 0% rubber chips, the compressive strength of the concrete is 17.5Mpa. and at the replacement of the natural aggregates with 5% polymeric materials, the compressive strength increased to 17.7%. But with further increment of rubber chips to 10%, the strength decreases to 16.9%

From the compressive strength test conducted on the 28th day curing, the result was obtained and used for the calculations as presented in equation 4.

$$F\_Cu=P\_max/A \quad (6)$$

Where,

Fcu = Compressive strength (N/mm^2)
P max = Magnitude of failure load (N)
A = Cross sectional area of the cube specimen (mm^2)

Table 5 Result of Compressive Strength Test of Concrete at 28 days

S/N	Polymeric Material (Kg) (%)	Natural Aggregate (Kg) (%)	Compressive Strength (MPa)
1	Rc.0	100	17.8
2	Rc.5	95	18.1
3	Rc.10	90	17.0
4	Rc.15	85	16.7
5	Rc.20	80	13.3
6	Rc.30	70	11.8
7	Rc.40	60	8.4
8	Rc.50	50	7.2
9	Rc.60	40	6.2

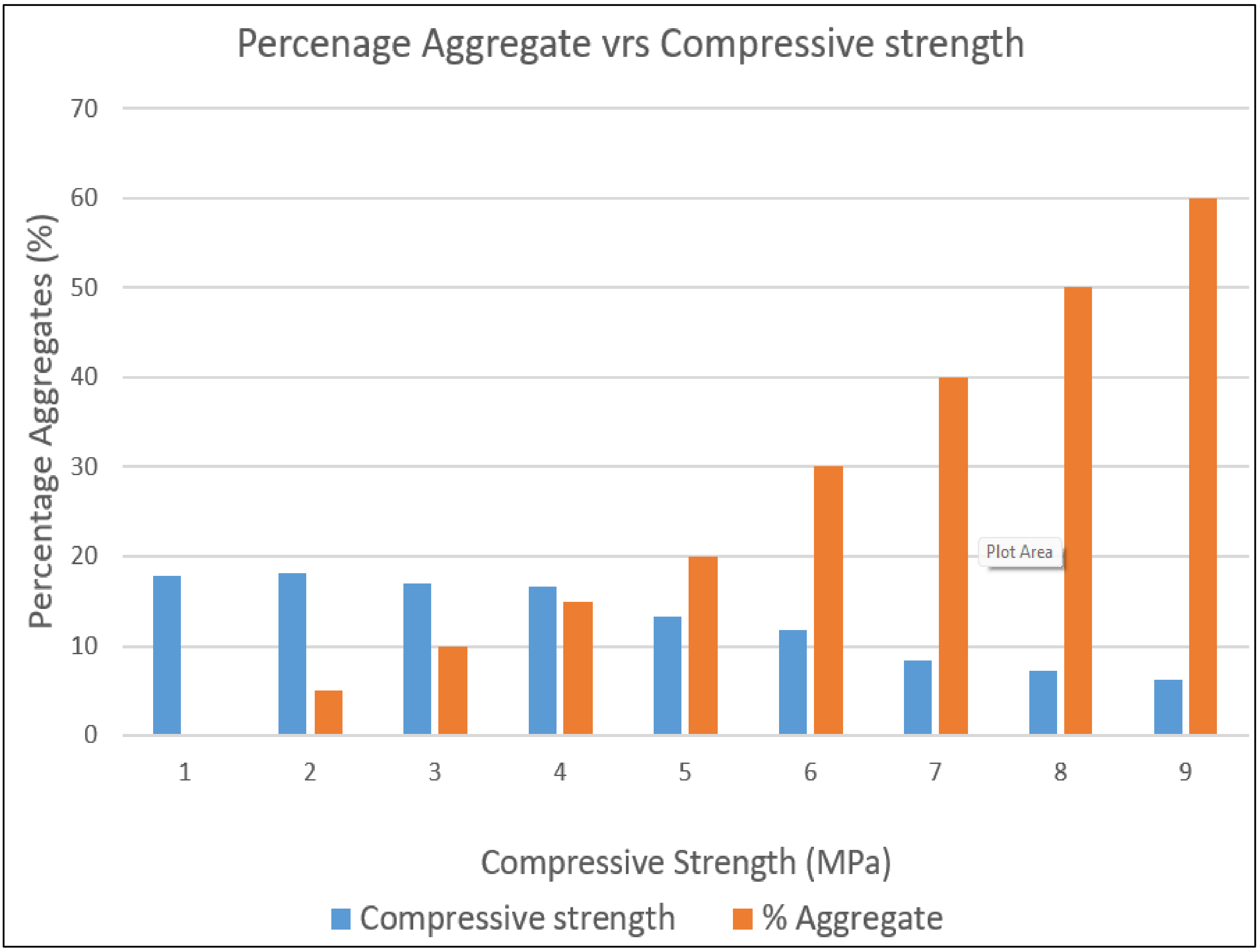

Fig 9 Percentage Aggregates Vs Compressive Strength at 28 days curing

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The result of the compressive strength test conducted showed that the conventional Concrete mix without any addition of rubberized chippings has a compressive strength of 17.5MPa while the specimen mixed with a replacement of 5% rubber chips is 17.7MPa, signifying an increase in compressive strength of 1.2%. But with further increment in the replacement of natural aggregates with rubberized chips, from 10%, 15%, 20%, 30% up to 60%, the compressive strength decreased drastically to 16.9MPa, 16.5MPa, 13.0MPa and down to 5.7MPa respectively, indicating a corresponding percentage decrease in strength of 3.4%, 5.7%, 25.7%, 40% down to 67.4% for 7^{th} day curing. While the test conducted at 28^{th} day curing showed a compressive strength of 17.8MPa of the conventional concrete without any admixture. And the specimen mixed with 5% polymeric material replacement had a compressive strength of 18.1MPa. Also, with increment of polymeric material replacement to 10%, 15%, 20%, 30% up to 60%, the strength reduced to 17.0MPa, 16.7MPa, 13.3MPa, 11.8MPa down to 6.2MPa. This signifies a reduction in strength from 1.7% to 4.5%, 6.2%, 25.3%, 33.7% down to 65.2%. respectively.

V. CONCLUSION

The use of recycled waste tyres as a constituent for reinforced concrete in Civil Engineering applications is based upon their unique characteristics which include: their lightweight compared to conventional aggregates (coarse or fine) in concrete, good insulation properties, very high ability to resist water, durability and high compressibility due to their elasticity. In an effort to improve the durability and resilience of concrete, it has become very necessary to use recycled rubber tyres for concrete mix and the result is positive, This work is basically to verify the workability and compressive strength of the Concrete with partial replacement of polymeric materials, specifically recycled waste rubber tyres as an alternative or additive to the conventional fine and coarse aggregates in composite concrete. Different samples of reinforced composite concrete made of polymeric materials were subjected to compressive test to find a suitable material combination that serves as a replacement to the natural stone aggregate for reinforced composite concrete which are in limited supply. This study also found a convenient means of eliminating the challenge of the disposal of waste tyres in our environment since they are non-biodegradable and occupy much space in landfills, and Ocean dump. The research also provided an avenue for waste recycling, a way of wealth creation for sustainable development.

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