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Mechanical Properties of Recycle Reactive Powder Concrete (RRPC) Containing Combined Effect of Coarse Aggregate & Dispersed Local Materials

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Abstract

Development of new concrete technology & sustainability is the main concern to give the boost to the development of RRPC. Optimum amount of CA is needed as a locally available materials to minimize the cost. Due to the rise in current RRPC technology, the methods require costly material. This paper illustrates, the utility of using local dispersed materials with coarse aggregate which is used to reduce pollutants & enhanced the mechanical property. The use of local dispersed materials such as GGBS, waste Fly Ash & waste glass powder for partial/ full replacement of cement & silica fume that has reduced the cost without affecting the strength. Furthermore, CA is used for full replacement of silica sand to find-out the combined effect of coarse aggregate with RRPC. Locally available waste, copper fiber was used as a replacement of steel fiber. Therefore, the recycling of waste material has been accentuated to sustainable development. Six types of mixing proportions were prepared & examined according to various mix proportions which was selected to investigate the mechanical properties. The result shows that using locally available dispersed materials with CA can produce a similar mechanical property to RRPC. However, the use of local dispersed materials with CA presents almost 10% lower performance, i.e. flexural strength, indirect tensile strength & compressive strength. Specimens cured at a room temperature (28°C) present approximately 7% lower compressive strength, 20% higher indirect flexural strength & 10% lower flexural strength than specimens prepare without coarse aggregate & copper fibers. With inclusion of coarse aggregate, the RRPC mixture behaves a more poor workability due to the decreased binder content. In this regard, to solve raw material shortage, a culture of using local waste raw materials in the construction sector should be adopted.

Keywords: Copper fibre, Local materials, Mechanical properties, Room temperature curing, Coarse aggregate, Sustainable development.

1. INTRODUCTION

Today, global warming and environmental devastation have become manifest harms, concern About environmental issues, and a changeover from the mass-waste, mass consumption, mass production society of the past to a zero-emanation society is now viewed as significant (Sawant & Kandekar, 2016).

The issue of sustainability is taken as the logic driving concept for the next phase of radical materials innovation. Sustainable construction has received much attention throughout the world over the last few years (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013).

In concrete production, sustainability can be achieved by innovations in substitutions of material used. Cement-based materials are the most abundant materials in the world. Due to the high demand of natural resources, engineers have growing interests in sustainable development by choosing sustainable material for eco-friendly construction & to save the environment by utilizing waste products generated by industries (Anwar, Ahmad, Husain, & Aqeel, 2015).

Hence, the use of locally available materials as well as the use of industrial and agricultural waste in the building industry has become a potential solution to the economic and environmental problems of particularly developing countries (Le, Nguyen, & Ludwig, 2014).

High demand of natural resources due to rapid urbanization and the disposal problem of agricultural wastes in developed countries have created opportunities for use of agro-waste in the construction industry. Many agricultural waste materials are already used in concrete as replacement alternatives (Jnyanendra, Sanjaya, & Basarkar, 2016). When compared to the use of primary natural resources, the valorization of industrial wastes and their up-grading to alternative raw materials can present several advantages (Andreola, Barbieri, Lancellotti, Leonelli, & Manfredini, 2016) for sustainable ways of construction. According to the study were found the following issues:

Firstly, the rapid use of concrete around the world might led a serious environmental impacts such as greenhouse effects, raw materials shortage, demolition wastages etc.

Secondly, it is a threat to develop recycle reactive powder concrete for the purpose of structural applications from local dispersed materials instead of using costly components such as silica fume, silica sand, quartz sand. Therefore, in this work the local dispersed materials are collected from construction sites, cement industries & other different sources available in Bangladesh.

Thirdly, the local dispersed materials had led to a complex challenge for Bangladesh to produce functional materials and improper disposal can create a greenhouse effects that may cause to global warming.

Finally, by creating a local dispersed recycled technologies that are help to produce traditional alternatives as RRPC.

2. Methodology

3.1 Experimental Materials

3.1.1 Coarse Aggregate (CA)

12.5mm down size are used as CA. The required size of CA are obtained from local shops. With the maximum size of CA 12.5mm having a specific gravity 2.86 and fineness modulus of 6.60 (According to ASTM C128-84). The physical properties of CA are shown in table-1.

Table-3.1: Physical properties of CA

Properties	Value
Specific gravity	2.76
Fineness modulus	6.60
Bulk density	Loose: 1450 kg/m ³ Compact: 1700 kg/m ³
Moisture content	0.5%

3.1.2 Fine Aggregate (FA)

Sylhet sand are used as FA which have a specific gravity 2.22 and fineness modulus of 2.5. All value were determined by conducting sieve analysis in the Structural and Material Engineering Laboratory (SME Lab) at KUET (According to ASTM C128-84). The physical properties of FA are shown in table-2.

Table-3.2: Physical properties of FA

Properties	Value
Specific gravity	2.22
Fineness modulus	2.5
Bulk density	Loose: 1530 kg/m ³ Compact: 1760 kg/m ³
Moisture content	0.5%

3.1.3 Ground Granulated Blast Furnace Slag (GGBS)

It is a by-product of iron & steel making from a blast furnace in steam that is dried and ground into a fine powder. GGBS was collected from Seven Rings Cement Company which is situated in Khulna. It was used as a partial replacement of cement without affecting the mechanical properties of UHPFRC. The physical & chemical properties of GGBS are shown in table-3, 4.

Table-3.3: Physical & Chemical properties of GGBS

Chemicals	Presents in GGBS (%)
CaO	30-50
SiO ₂	28-38
Al ₂ O ₃	8-24
MgO	1-18
MnO	0.68
TiO ₂	0.58
K ₂ O	0.37
N ₂ O	0.27
Specific gravity	2.86



Fig-3.1: GGBS

3.1.4 Cement

In this paper cement was partially replaced by GGBS at a ratio of 30%. This paper were investigated the mechanical properties and made less CO₂ emitting cementitious materials to incorporate in sustainable development. The physical properties of OPC are shown in table-2. It was also collected from Seven Rings Cement as OPC. The physical properties of Cement are shown in table-5.

Table-3.4: Physical properties of OPC

Property	Results
Specific gravity	3.16
Normal consistency	26%
Initial	70 Minutes
Final	266 Minutes
Fineness	330 kg/m ²
Soundness	2.5mm

3.1.5 Super plasticizer

Due to the low w/b ratio, the use of super-plasticizers is crucial to achieve a concrete which has a sufficient workability. A large quantity, which means up to 5 mass-% of the cement, is required (9). Locally available super plasticizer was collected from BARAL Chemicals Limited & were used to gain the required workability.



Fig-3.2: Super plasticizer.

3.1.6 Glass powder

Using waste glass powder can decrease the unit weight of concrete and as a fine aggregate would produce high workability in concrete due to its spherical geometry. Waste glass was collected from local glass shop that crushed to produce powder. Therefore, the use of glass powder may be a decent solution to the environmental problem for sustainable development.

Table-3.5: Chemical properties of GP

Properties	Value
SiO ₂	72.2
Al ₂ O ₃	1.54
Fe ₂ O ₃	0.48
CaO	11.42
MgO	0.79
Na ₂ O	12.85
K ₂ O	0.43
SO ₃	0.09
Loss of ignition	0.36

3.1.7 Copper fibre

Locally available waste copper fibre was collected from Bangladesh Cable Shilpo Limited for the full replacement of steel fibre. Copper fibre is used in this study.

Table-3.6: Physical properties of Copper fibre

Properties	Value
Phase	Solid
Melting point	1357.77 K (1084.62 °C , 1984.32 °F)
Boiling point	2835 K (2562 °C, 4643 °F)
Density	8.96 g/cm ³ (when liquid, 8.02 g/cm ³)
Heat of fusion	13.26 kJ/mol
Heat of vaporization	300.4 kJ/mol
Molar heat capacity	24.440 J/(mol·K)
Thermal expansion	16.5 µm/(m·K) (at 25 °C)
Thermal conductivity	401 W/(m·K)
Crystal Structure	Face-centered cubic(FCC)
Electrical conductivity	30 to 80% IACS
Tensile strength	650 to 1350 MPa

The 25mm fibre length was selected.



Fig-3.3: Copper Fibre

3.1.8 Fly ash

Fly ash was used to partial replacement of silica fume up-to 75% by mass. Waste fly ash was collected from local cement industries that is used as a binder in this study.

The physical & chemical properties of Cement are shown in table-7.

Table-3.7: Physical & chemical properties of Fly Ash

Composition	Value
SiO ₂	50.24
Al ₂ O ₃	28.78
Fe ₂ O ₃	5.72
CaO	5.86
MgO	1.74
Na ₂ O	0.96
K ₂ O	-
SO ₃	0.51
Loss of ignition	2.8
Fineness (%)	74
Density (Kg/m ³)	2250



Fig-3.4: Fly Ash

3.1.9 Water

Water is a vital issue or factor that plays an important rule between the chemical reaction with cement & others binding materials. Potable water is used for required concrete mix preparations.

3.2 Mix Design

RRPC mix design is consists of cement, water, aggregate, admixture, additives & fibres. The main difference between conventional and RRPC is super-plasticizer (SP). Super plasticizer were used in this study to attain workability of concrete when the required w/b ratio is less than 0.25. The cement were replaced by GGBS partially at an optimum rate of 30% to achieve best result. Silica fume were fully replaced by waste glass powder & waste fly ash at a rate of 25%, 50% & 75% to get the maximum dependable outcome. According to the figure-1 sand 1 were replaced by coarse aggregate & sand 2 were replaced by Sylhet sand. Furthermore, copper fibre was selected for fibre proportion.

For RRPC mix design, the mix proportion were used 2% as air, 18% water, 18% silica fume & glass powder, 28% cement, 1% super-plasticizer, 3% fibre, 22% coarse aggregate & 9% as Sylhet sand. The w/b ratios for this study was taken as 0.23. Silica fume were replaced by 25%, 50%, 75% of waste glass powder & 75%, 50%, 25% of waste fly ash such as M1, M2 & M4.

In the sample such as, M1, M2 & M4, cement (28%) were replaced by 30% GGBS and finally applied among these sample. Now the replaced, new sample were done like as M3, M5, & M6.

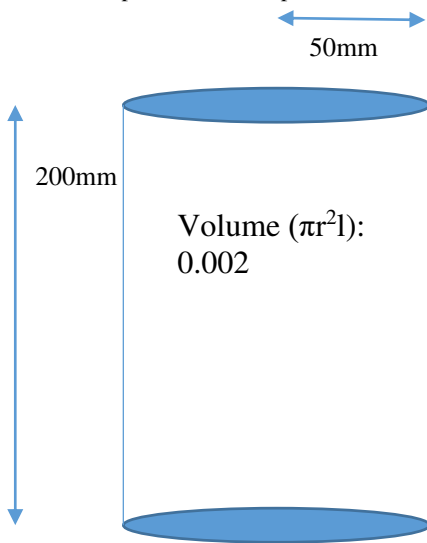


Fig-3.5: Typical Cylinder size used in this study

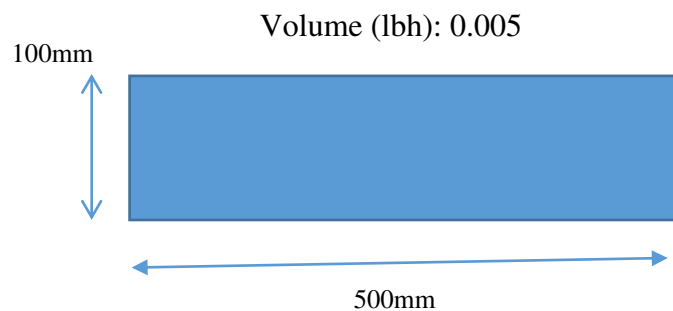


Fig-3.6: Typical prisms used in this study

Table-3.8: Unit weight of each materials under this study (Kg/m³)

Unit weight	Kg/m ³
Coarse aggregate (CA)	1550
Fine aggregate (FA)	1700
GBBS	1300
Cement	1440
Super plasticizer (SP)	-
Glass powder (GP)	3150
Copper fibre	8930
Fly ash	1500
Water	998

Total six sample with different mix proportion were shown in Table-9.

Table-3.9: Mix design of RRPC for a cylinder under this study (For a specimen in kg).

Materials	M1	M2	M3	M4	M5	M6
Coarse aggregate (CA)	0.54	0.54	0.54	0.54	0.54	0.54
Fine aggregate (FA)	0.27	0.27	0.27	0.27	0.27	0.27
GBBS	-	-	0.19	-	0.19	0.19
Cement	0.63	0.63	0.44	0.63	0.44	0.44
Super plasticizer (SP)	0.0063	0.0063	0.0044	0.0063	0.0044	0.0044
Glass powder (GP)	0.45	0.67	0.67	0.22	0.22	0.45
Copper fibre	0.10	0.10	0.10	0.10	0.10	0.10
Fly ash	0.21	0.10	0.10	0.32	0.32	0.21
Water	0.28	0.28	0.28	0.28	0.28	0.28

Based on the 7days compressive & tensile strength best result, M3, M4 & M5 were selected for 28days flexure test.

Table-3.10: Mix design of RRPC for a prisms under this study (For a specimen in kg).

Materials	M3	M4	M5
Coarse aggregate (CA)	1.7	1.7	0.78
Fine aggregate (FA)	0.85	0.85	0.714
GBBS	0.55	0	0.55
Cement	2.0	2.0	1.4
Super plasticizer (SP)	0.02	0.02	0.014
Glass powder (GP)	1.42	0.71	2.13
Copper fibre	0.893	0.893	0.44
Fly ash	0.68	1.01	0.15
Water	0.94	0.94	0.94

3.3 Mix proportion

In this study, the mix proportion arranged in table-9 & 10 were applied. The cylindrical specimen were prepared on watertight & non air-absorbent 100mm x 200mm size which is based on ASTM C39 & C496. The prisms were prepared on 500mm x 100mm x 100mm size prisms molds which is based on ASTM C78.

In order to prepare specimen, dry mixing of the all ingredient was done according to the mix design which is shown in table-9 & 10. The process of dry mixing of all ingredients was done for 2-3 minutes. After that, 70% to 80% of water according to table-9 & 10 adding to the wet mixing was done then the required super plasticizer added to the dry mixing was done for 5-7 minutes. The remaining water was added & the mixing was done until the visually acceptable was obtained. Hand mixing was done for the whole process to get the acceptable mixing for next process.



Fig-3.7: Mix Proportion

3.4 Specimen preparation

After the hand mixing was done, the uniform mixing was placed in the molds by 3 layers. When the one-third of mixing layer was placed in the molds, compacting was employed by a tamping rod by a steel compacting rod having 16mm cross-sectional diameter with length 600mm. After the finishing of the top surface of the all molds that were leave for 24hours to get dry. Each molds were marked with a notation marks for further identification of specimens.

3.5 Curing process

After the removal of all the molds, the specimens were marked by a marker with a proper notation for the curing process. Then, the specimens were cured until 7days & 28days at room temperature $24\pm 2^{\circ}\text{C}$ for testing purpose.

3.6 Test program

For testing, the test specimens placed mid points in the testing machine, remove the moisture from the surface of the specimen were controlled. All the specimens were tested for the mechanical properties of RRPC as per the American Society for Testing and Materials procedure for hardened concrete (ASTM C39, ASTM C496 & ASTM C78) in Khulna University of Engineering & Technology at Structural, Material & Foundation Engineering laboratory.

The compressive strength and the tensile strength were tested by automatically controlled universal testing machine at constant rate of loading at the age of 7 and 28 days of standard water curing and the average values were reported.

In addition to this, the flexural strength was determined after 28 days of standard water curing. For testing the flexural strength, two supporting steel rollers and two upper rollers were used for applying loads in the universal testing machine. The load arrangements were two-point loading conforming ASTM C78 arranged at a constant load rate.

4. Results and Discussions

Compressive strength

Compression test is one of the most common test carried out on concrete for easy to perform and most necessary characteristic properties that are correlated to compressive strength.

The compressive strength was carried out on 100mmx200mm cylinder in the compressive strength machine of 3000KN capacity. A loading rate of 0.15Mpa/s was applied as given in ASTM C39. The test was performed at the age of 7 & 28days. The specimen were kept under curing up to the time of testing & carried out on the dry specimen surfaces.

The strength results obtained from the experimental investigations are shown in tables. All the values are the average of the three trails in each case in the testing program of this study. The results are given in tables and discussed as follows in the figures respectively. Figure 4.1 are shown compressive strength for 7 and 28 days respectively. The observation result recorded at 7 & 28 days are given below:

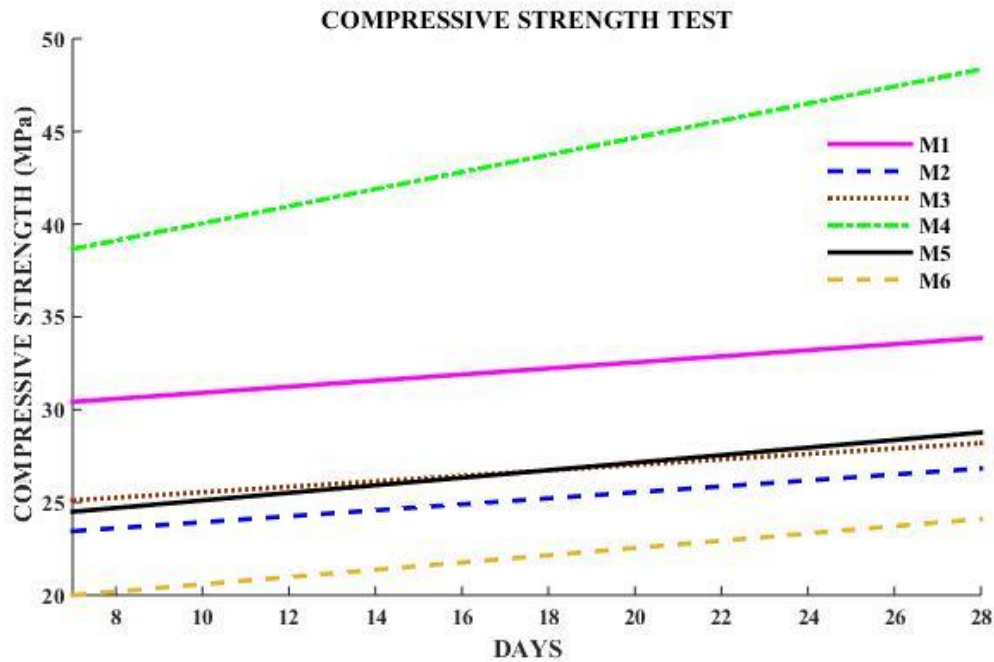


Fig4.1: Compressive strength of RRPC containing local materials

As shown in Figure 4.1, the compressive strength increases with the curing age in all mix. In early age at 7 days standard curing, 38.66 MPa were observed as a maximum mean value using in mix 4 containing 75% fly ash (FA) and 25% dispersed glass powder (GP). However, in 28 days standard curing, mix 4 gives a maximum mean compressive strength of 48.35 MPa.

Split cylinder test:

It is the standard test to determine the tensile strength of concrete in an indirect way. This test was performed according to ASTM C469.

This tensile test was carried out on concrete specimen 100mm x 100mm x 500mm. The specimen was placed horizontally between the loading surfaces of Compression Testing Machine then compression loading was applied at a loading rate of 0.7 MPa/min. The load was applied uniformly along the length of cylinder until the failure of the cylinder along the vertical diameter. The plywood was placed between the specimen and testing machine that was able to reduce the magnitude of the high compressive stresses near the applications of this load.

The test was performed at the age of 7 & 28 days. The specimen were kept under curing up to the time of testing & carried out on the dry specimen surfaces.

The strength results obtained from the experimental investigations are shown in tables. All the values are the average of the three trails in each case in the testing program of this study. Figure 4.2 are shown tensile strength for 7 and 28 days respectively. The observation result recorded at 7 & 28 days are given below:

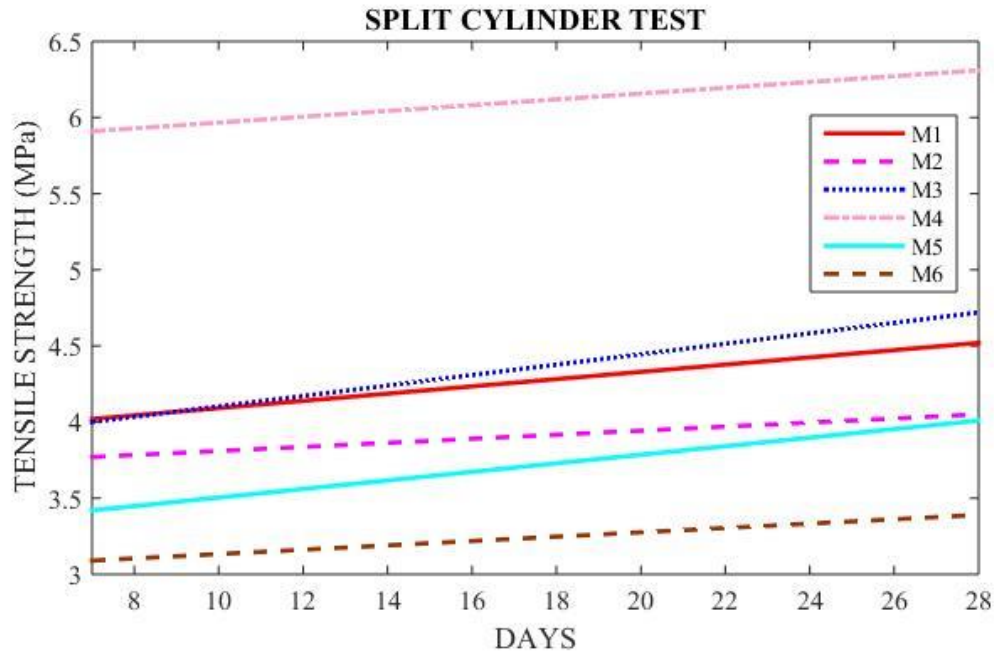


Fig-4.2: Tensile strength of RRPC containing local materials

As shown in Figure 4.2, the tensile strength increases with the curing age in all mix. In early age at 7 days standard curing, 5.91 MPa were observed as a maximum mean value using in mix 4 containing 75% waste fly ash (FA) and 25% waste glass powder (GP). However, in 28 days standard curing, mix 4 gives a maximum mean tensile strength of 6.31 MPa. From figure 4.6 shows that mix 1 gives a second maximum mean value of 4.02 MPa at 7 days standard curing containing 50% waste fly ash (FA) and 50% waste glass powder (WGP) and mix 3 shows second maximum mean value of 4.72 MPa at 28 days standard curing containing 25% waste fly ash & 75% waste glass powder.

4.3 Flexure strength

The test beam 100x100x500mm was symmetrically supported on two parallel steel rollers 38mm in diameter and the distance between the centers of the two rollers adjusted to 150mm. The load is applied through one rollers mounted at the center point of the supporting span. The load is applied without shock and increased continuously at a rate of 180 kg/cm²/minute for the specimen. The load is increased till the specimen fails and the maximum load sustained is recorded. The position of crack is observed and measured. The flexural strength is expressed as the modulus of rupture as per the ASTM C78. Observations and results recorded at 7, 28 days are tabulated below:

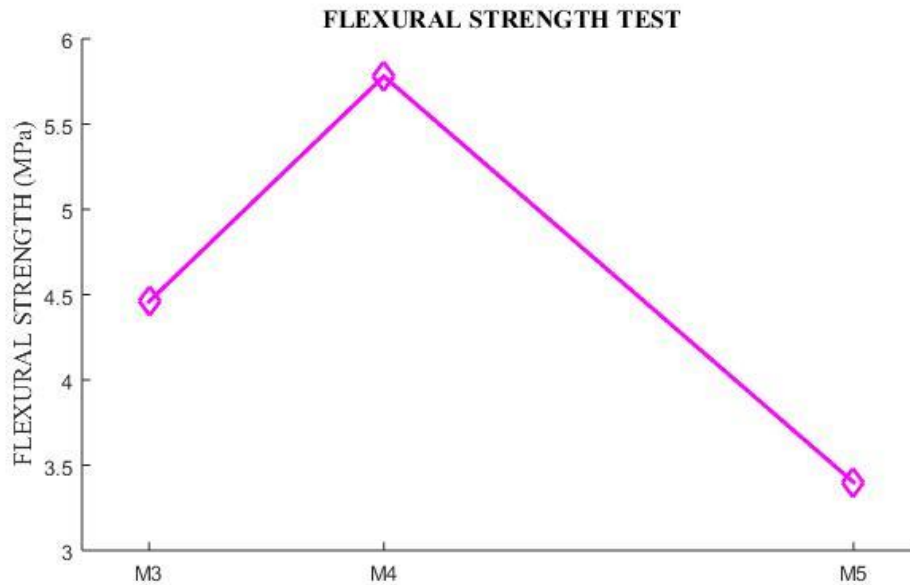


Fig-4.3: Flexural strength of RRPC containing local materials

The other mechanical strength evaluation for the developed RRPC in this study was performance evaluation by flexural strength of beams. According to dictionary of construction, flexural strength is defined as a property of a material or structural member that indicates its ability to resist failure in bending. Figure 4.3 shows the flexural strength of RRPC beams with different percentages of fly ash and finely dispersed glass powder. Accordingly, a maximum flexural strength 5.78 MPa was observed using Mix 4.

5. CONCLUSION:

In this study, mechanical behavior of RRPC incorporating coarse aggregates was investigated. Copper fibre were applied in the study. Bonding behavior between these fibers and matrix was also performed. Combined effect of coarse aggregate and fiber properties, including waste glass powder, waste fly ash and mechanical properties of RRPC was analyzed. The following conclusions could be drawn:

- (1) With inclusion of coarse aggregate, the RRPC mixture behaves a more poor workability due to the decreased binder content. With respect to compressive strength, the replacement level of coarse aggregate has a critical value of 22% and 3% fibers act almost similar.
- (2) Coarse aggregate brings impairment to the bonding strength of copper fiber in the RRPC matrix incorporating coarse aggregate.
- (3) The mechanical strengths of RRPC were increases with the curing age. Accordingly, for full replacements of silica fume by fly ash and waste glass powder, 48.35 MPa compressive strength, 6.31 MPa tensile splitting strength and 5.78 MPa flexural strength were observed after 28 days standard curing.
- (4) The result shows that using locally available dispersed materials with CA can produce a similar mechanical property to RRPC. However, the use of local dispersed materials with CA presents almost 10% lower performance
- (5) At a favorable replacement level (22%), coarse aggregate can be successfully introduced into the system of RRPC to further reduce its cost without almost impairing to its mechanical properties, regarding reference strength.
- (6) Compared with steel fiber, RRPC with copper fiber shows almost similar mechanical properties. Different

from RRPC without coarse aggregate, fiber type has almost no effect on mechanical behavior, due to combined effect of fiber bridging and coarse aggregate. Utilization efficiency of fiber is strongly dependent on the fiber geometry, especially for length and diameter.

FURTHER STUDIES:

- Encourage examination ought to be completed to understand the mechanical conduct of concrete delivered by replacement of OPC by waste glass powder with waste fly ash.
- Some different properties of beam – column Behavior.
- Durability can be researched to justify the structural performance
- Analyzing the micro properties of the materials and addition of new fiber type materials with the mixture.

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