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FLEXURAL PERFORMANCE OF TEXTILE REINFORCED CONCRETE WITH HYBRID FABRIC MESH

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ABSTRACT

The main aim of this study is to develop a high strength cement mortar with a new composite material of cement matrix. This study focuses on the flexural behavior of textile reinforced concrete with hybrid fabrics (Basalt fabric and S Glass fabric) under elevated temperatures at 100°C, 200°C and 300°C. To evaluate the flexural performance, tests were conducted on conventional mortar beam which is a reference mix, one layer of basalt textile reinforced beam specimens, one layer of S-glass textile reinforced beam specimens and two layers of basalt and S-glass textile reinforced beam specimens which are treated at 100°C, 200°C and 300°C. On experimentally comparing the textile fabric reinforced specimens with non-reinforced specimens, the textile fabric with the combination of basalt and S Glass fabric reinforcement have higher flexural strength in all the temperatures compared to reference specimens.

Keywords: textile reinforced concrete, basalt fabric, s-glass fabric, flexural strength, elevated temperature.

1. INTRODUCTION

Concrete is the composition of materials like cement, fine and coarse aggregate with density of 2400 kg/m^3. The reinforced concrete is a composition of concrete and reinforcement, which together increases the tensile capacity of the structural element in addition to compression capacity. Freshly prepared reinforced concrete has its versatility to cast it into different shapes, which is commonly used in cast in-situ and precast auxiliary segments (Hassan *et al.* 2017). Concrete is generally strong in compression, whereas weak in tension. The tensile strength of reinforced concrete is normally one-tenth of the compressive strength. The term flexural strength is basically bending strength, is also measuring the tensile strength indirectly, which is mainly used in concrete structures (Sabah Ben Messaoud *et al.* 2017). The concrete with higher grades is generally prone to plastic shrinkage cracks and hence there will be a loss in strength. These higher-grade concretes are highly brittle in nature and to reduce the brittleness fibres are usually added to the concrete. Fibers are generally a thin material which are like a continuous filament or as a separate elongated pieces, which are similar to thread pieces. These fibers can be used in composite materials as an ingredient. They can be mould into different shapes which maybe in the form of sheets also. The main role of fibers is to provide strength, stiffness, thermal stability, ability to carry the load and other structural properties to the fiber reinforced polymer composites. Fibers are used in the various applications which may include sports, marine, biomedical, industries, automobile and construction. The other way of reducing the brittleness is to reinforce the concrete with high strength textile fabric. There are many advantages in usage of high strength textile fabric materials for the reinforcement of concrete structures. The textile material reduces the utilization of material and its cost, and it increases the strength characteristics, mainly in cases where large loads act on the elements by increasing the load carrying capability and to decrease the development of shrinkage crack. On comparing with conventional building materials, the textile reinforced concrete is light weight and has high corrosion resistance and minimal concrete covering (Anna Volkova *et al*. 2016).

To contrast from regular steel reinforced concrete, the textile reinforced concrete is generally slender. Generally, the thickness of steel reinforced concrete structure varies from 100-300 mm which can be reduced to a thickness of 50 - 100 mm in the case of textile reinforced concrete (Marko Butler *et al*. 2009). Due of its thinner cross section, the material usage is reduced and hence decreasing the expense of concrete usage. The micro cracks are formed in textile reinforced concrete compared to steel reinforced concrete. The textile reinforced concrete using AR glass textile fabric under three-point loading indicates that the energy absorbed by using two or three layers of textile fabric specimen is 9% higher compared to single layer of textile fabric is used (Deju Zhu *et al*. 2009). The pre-stress on textile material decreases the ultimate deflection and increases the ultimate load of the specimen. Prestress of carbon textile material improved extreme deflection condition and reduced the ultimate load of the specimen. The width of crack at failure cannot fulfil the needs of normal serviceability (Pannirselvam *et al*. 2009). Therefore, pre-stress on saturated carbon material improves the ultimate load and the time of first crack occurrence in the specimen, also diminishing the crack width and extreme deflection of specimen. As indicated by the outcomes, saturated carbon textile is most suitable for prestressed textile reinforced concrete (Hans *et al*. 2003).

The cementitious composites which is reinforced with four layers of basalt textile fabric as reinforcement indicates that a spacing and width of cracks is decreasing. The results also show that by pressurising the textile fabric and by increasing the layers of textile fabric in the concrete specimens have shown a positive impact on the specimens such as reduced crack width (Pello Larrinaga *et al.* 2014). The outcomes demonstrate that, the effect of tensile properties of BTRC having lesser imperative components than the number of layers present, the main advantages of pre stress on textile reinforced concrete is controlling the pre stress level at sensible range whenever it is required (Yunxing Du *et al.* 2018). The oil coated textiles and styrene butadiene latex were examined and it showed a decrease in the flexural durability of textile reinforced concrete samples and also decreases the post cracking strengths of the composites. Hence at low textile volume content, the flexural behavior of textile reinforced concrete increases (Mana Halvaei *et al*. 2018; Ranchard *et al.* 2015). When preparing the textile reinforced concrete, four important factors should be considered essential, they are nature of the mortar, interaction between the mortar and textile, course of action of textile fabric rather than steel reinforcement inside the cement mortar, and the amount of fabrics used. Silica fume also known as micro silica was utilized as an added substance in the mortar. This makes it around multiple times smaller than the normal bond molecule. Silica fume has turned out to be one of the necessary ingredients for making high strength and high-performance concrete. Silica fume is added to Portland bond cement to improve its properties, exactly to its bond quality, compressive quality and scraped spot obstruction (Lingling Liu *et al.* 2018). Super plasticizer is a type of chemical agent which is used for construction process, Super plasticizer is mainly used to decrease the water content in the concrete and also by adding the super plasticizer in the concrete the workability used to increase, the principal component in super plasticizer is surface active agents. Due to addition of super plasticizer in the cement mortar the water binder ratio is used to be low (Kannan Rajkumar *et al.* 2017). The performance of textile reinforced concrete (TRC) is based on the reinforcement ratio. The TRC prepared by using three and five fabric layers displays an effective crack control and therefore there is a notable increase in tensile response and increases the overall ductility of the composite materials. The heating and cooling regimes used in this present work affects the tensile properties of TRC, after the exposure to temperatures of 600ºC and 1000ºC. The behavior of TRC develops brittle, giving smaller tensile strength compared to room temperature (Dimas Alan Strauss Rambo *et al*. 2015; Jamal Khalafa *et al*. 2015; Bhuiyan Mohammad Golam Kibria *et al*. 2020).

In this research the Basalt and S-glass textile fabrics are used in single textile and combination of the both with the cement matrix, to increase the flexural capacity. The good mixture of basalt and S-glass fabric textiles material with fine grained cement exposes an invention for the designing of lightweight structures. The selection of the size of mesh in the textile fabrics matters a lot (Amir Si Larbi *et al*. 2016). If the mesh size is too small, the cement will not be able to penetrate the structure. The larger the cell size of textile fabric, more the flow of cement into the structure (Shipingxu *et al.* 2014). Different shapes of reinforcing fabric mesh cells such as triangle, rectangle, circle, etc., are available. The available sizes of the textile fabrics are 8, 10, 16, 20, 25, & 30 mm, for the rectangular type of textile fabric mesh cells (Pello Larrinaga *et al.* 2014). It is necessary to study the impact of high performance of S-glass textile fabric material and basalt textile fabric material on the flexural behavior of thin specimens with the thickness of about 50 mm, moreover styrene butadiene latex could be applied for a better bonding between the textile fabric material and cement mortar.

2. MATERIALS USED

The cement used in this experiment was ordinary Portland cement of grade 53 conforming to IS12269:1987 (IS 12269) along with silica fume. The fine aggregate used was river sand and super plasticizer was used to improve the workability. Styrene butadiene latex was used for bonding in between the fabric mesh and mortar. TRC specimens used in this work were consists of one layer of basalt textile reinforcement fabric, one layer of S-glass textile reinforcement fabric and the combination of one layer of basalt reinforcement fabric with another one layer of S-glass textile reinforcement fabric implanted in a fine-grained cement mortar (Natalie Williams Portal *et al*. 2014; ShailJeelani *et al*. 2019). In this whole experimental study, commercially available basalt and S-glass textile fabric was used. The material properties for the textile reinforcement are discussed in the following sections.

2.1 Textile Reinforcement Fabric

A relatively new method of concrete reinforcement is the use of textile reinforcement. Fine-grained mortar joined with an open mesh structure of textile (Natalie Williams Portal *et al*. 2017). This means that it is likely to cast very thin structural elements because textile reinforcement does not enforce any requirements on the concrete cover since there is no risk for corrosion. The mesh may consist of different materials such as basalt and S-glass, the mesh size of the basalt textile fabric was 25 mm × 25 mm and mesh size of S-glass textile fabric was 5 mm × 5 mm. To use textiles efficiently, they have to be impregnated into fine grained cementations matrix (Mesticou *et al.* 2016; Balamuralikrishnan 2015). The impregnation mix is very finer than the concrete, can able to penetrate the core of the roving and able to activate the inner filaments for load dissipation as well. Impregnation with Styrene-Butadiene latex has proven particularly effective for improving the quality of composite material.

2.2 Basalt Textile Fabric Mesh

The basalt mesh Geo-grid reinforcement increases the overall safety, reliability and the cutting process output. The strength of basalt mesh is same as that of metal reinforcement and it is 2.6 times lighter, therefore it simplifies the transportation and handling in construction (Yunxing Du *et al*. 2017, Santhoshkumar *et al*. 2020). The elasticity modulus of the basalt fabric mesh is 117 GPa and Poisson's ratio is 0.26. The properties of

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the basalt textile fabric mesh are shown in Table-1 and Basalt textile fabric mesh reinforcement is shown in Figure-1.

Table-1. Properties of basalt textile fabric mesh.

Property	Value
Textile Structure	Biaxial 0º / 90º
Density (kg/m^3)	2900
Modulus of Elasticity (GPa)	117
Poisson's Ratio	0.26
Tensile Strength (MPa)	3700
Elongation at break (%)	6.67
Mesh size (mm)	25

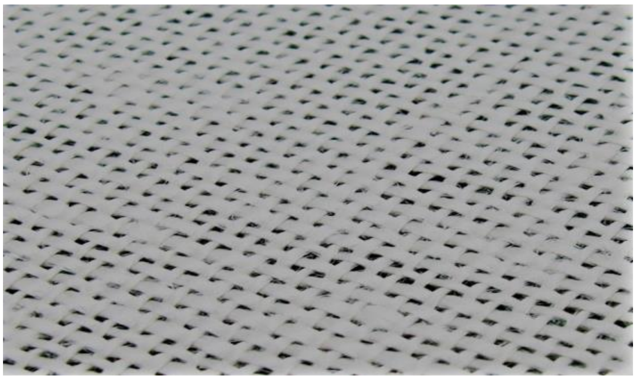

Figure-1. Overview of the basalt textile fabric mesh.

2.3 S-Glass Textile Fabric Mesh

S-Glass Fabric Mesh has 30 - 40% higher tensile strength on comparing with C-Glass fiber. It has 15-20% high modules of elasticity and higher temperature range varies from 300ºC to 1750ºC (Papanicolaou Catherine G *et al.* 2010; Haubler-Combe *et al.* 2007). It has 10 times higher fatigue resistance and also, they have outstanding impact resistance because of higher elongation to break, corrosion resistance and high ageing comparing with C-Glass fiber. The properties of the S-Glass textile fabric mesh are shown in Table-2 and S-Glass textile fabric mesh reinforcement is shown in Figure-2. The mix composition of concrete matrix composition is shown in Table-3.

Table-2. Properties of s-glass textile fabric mesh.

Property	Value
Textile Structure	Biaxial 0º / 90º
Density (kg/m^3)	2540
Modulus of Elasticity (GPa)	86
Tensile Strength (MPa)	3200 – 4100
Elongation at break (%)	5.3
Mesh size (mm)	5

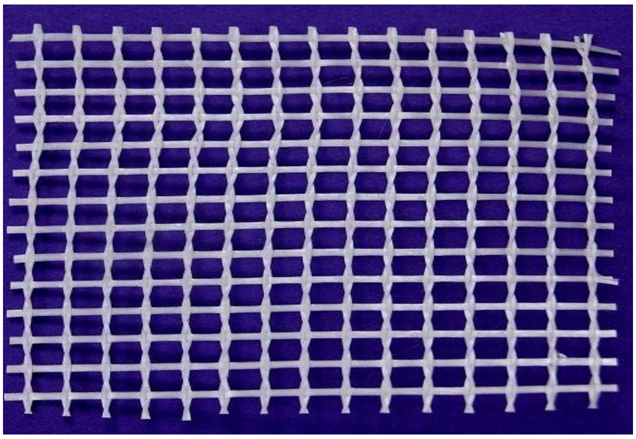

Figure-2. Overview of the S-Glass Textile Fabric Mesh.

Table-3. Concrete matrix composition.

Component	Cement (OPC) (kg/m^3)	River sand (kg/m^3)	Silica fume (kg/m^3)	Super plasticizer (kg/m^3)	Water (kg/m^3)	Compressive Strength (MPa)
Content	500	1730	100	14	170	76.5

3. PREPARATION OF TEST SPECIMENS

This present work consists of an experimental study on the flexural performance of cement mortar beams with two types of textile fabric mesh (Shanthi Vengadeshwari R *et al*. 2019). The dimensions of all the Basalt TRC and S-Glass TRC specimens had the same dimensions of length 700mm, width 130mm and depth 50mm. A total of four mix proportions were cast in which one is conventional beam which is a reference mix, one layer of basalt textile reinforced beams with fabric reinforcement at 20mm from bottom of beam, one layer of S-glass textile reinforced beams with fabric reinforcement at 20mm from bottom of beam and two layers of basalt and S-glass textile reinforced beams with reinforcement at 15mm from both top and bottom of beam. The basalt fabric is placed at the bottom layer of specimen and S-glass fabric is placed at the top layer of specimen because basalt fabric has high load carrying capacity compared to S-glass fabric. The arrangement of fabrics is shown in Figure-3. Then the specimens were cured for 28 days. At the end of curing, the respective beam specimens were heated under the temperature of 100°C, 200°C, and 300°C and the beam specimens were tested in the UTM under the two point loading arrangement for determining the ultimate load and the corresponding deflection. As well as the specimens were heated in different temperatures and

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compared with the values in different elevated temperature. Figure-4 shows the conventional beam specimen and placing of textile mesh while casting the specimen is shown in Figure-5.

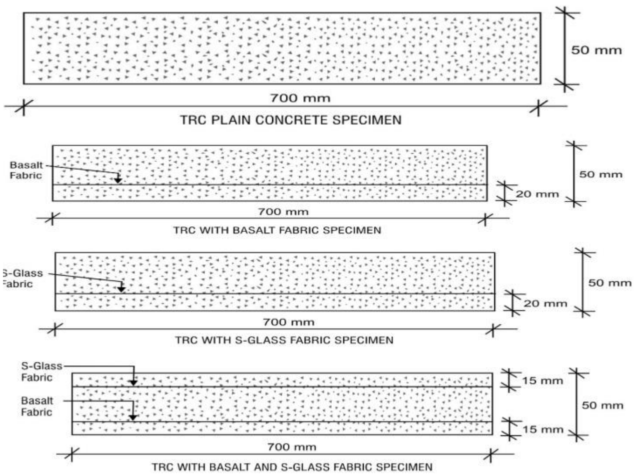

Figure-3. Arrangement of fabrics in beam specimens.

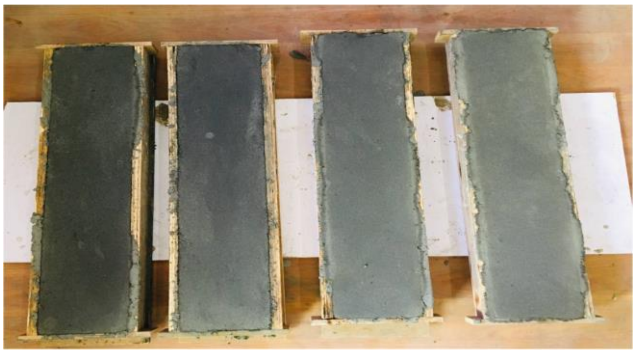

Figure-4. Conventional beam specimen.

Figure-5. Placing of textile mesh while casting the specimen.

4. EXPERIMENTAL INVESTIGATION

4.1 Flexural Test

The flexural tests on beam under two point loading were carried out by using universal testing machine of capacity 1000 kN. The flexural test set up used for the study is shown in the Figure-6. In the flexural test, maximum stress will occur below the point of loading on beam specimen where the bending is maximum. The load was applied on the beam specimen and load was applied gradually in a uniform rate till the specimen fails at ultimate strength. The specimens were organized in simply supported conditions with an effective span of 600mm. The dial gauge of least count 0.01mm was used to measure the deflections of the beam at the center of the specimen. The two point loading arrangement for the beams is shown in Figure-7.

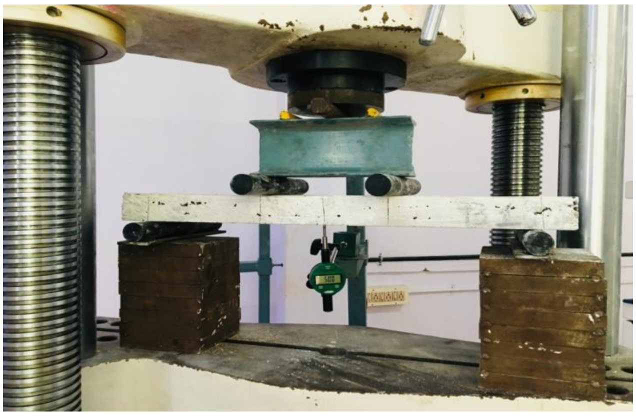

Figure-6. Flexural test setup.

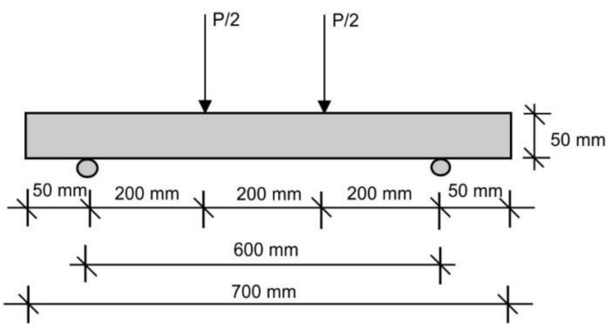

Figure-7. Two point load arrangement setup.

5. RESULTS AND DISCUSSIONS

The results were obtained from the two point bending tests conducted on cement mortar beam specimens of with a compressive strength with conventional beam (TRC-PC), reinforced with Basalt textile fabric (TRC-B1) and S-Glass textile fabric (TRC-S1) and combination of Basalt textile fabric and S-Glass textile fabric (TRC-B1S1) at different temperature. The behavior of load and deflection of thin beams of TRC specimen varies with different textile layers and the results are discussed below.

Table-4 shows the flexural strength of the specimens at different temperatures. The conventional specimen without textile reinforcement showed a sudden brittle failure at all temperatures and the flexural strength suddenly drops within the pure flexural zone. From the results it was found that TRC-PC has the flexural strength of 2.47 MPa with ultimate displacement of 0.44 mm. The flexural strength of TRC-S1 is 3.38 MPa with ultimate displacement of 1.1mm. TRC-B1 has the flexural strength of 3.70 MPa with the ultimate displacement of 1.2 mm. The results of TRC with basalt reinforcement was in trend with Yunxing Du *et al* (Yunxing *et al.* 2018) where he has used in basalt textile with one to five layers of reinforcement. However, on comparing all mix combinations at room temperature, TRC-B1S1 has the maximum flexural strength of 4.23 MPa with ultimate displacement of 1.7 mm at room temperature. The Load vs deflection curve of textile reinforced concrete at room temperature is shown in Figure-8.

Table-4. Flexural strength of the specimen at elevated temperatures.

S. No	Mix Designation	Flexural strength (MPa)	Ultimate Load (kN)	Residual Load (kN)	Yield displacement (mm)	Ultimate displacement (mm)	Ductility	% increase in Ductility	Energy Absorption Capacity (kN-mm)
Flexural Strength of Specimen at Normal Room Temperature									
1.	TRC-PC	2.47	1.75	-	0.40	0.44	1.10	-	0.419
2.	TRC-S1	3.38	2.4	1.1	0.45	1.1	2.44	121%	1.79
3.	TRC-B1	3.70	2.6	1.25	0.47	1.2	2.55	131.8%	1.96
4.	TRC-B1S1	4.23	3	1.6	0.6	1.7	2.83	157%	2.88
Flexural Strength of Specimen subjected to elevated temperature at 100ºC									
5.	TRC-PC-100	1.97	1.40	-	0.35	0.37	1.05	-	0.245
6.	TRC-S1-100	2.96	2.1	0.85	0.45	0.8	1.77	68%	0.555
7.	TRC-B1-100	3.67	2.6	1.1	0.38	0.9	2.36	124%	0.96
8.	TRC-B1S1-100	3.45	2.45	1.25	0.4	1.1	2.75	161%	1.40
Flexural Strength of Specimen subjected to elevated temperature at 200ºC									
9.	TRC-PC-200	1.83	1.30	-	0.31	0.30	1.03	-	0.195
10.	TRC-S1-200	2.67	1.9	0.75	0.32	0.50	1.56	51.4%	0.53
11.	TRC-B1-200	2.82	2.0	0.95	0.33	0.65	2.0	94.1%	0.81
12.	TRC-B1S1-200	3.20	2.25	1.1	0.39	1.0	2.56	148.5%	1.30
Flexural Strength of Specimen subjected to elevated temperature at 300ºC									
13.	TRC-PC-300	1.55	1.1	-	0.22	0.24	1.09	-	0.121
14.	TRC-S1-300	1.97	1.4	0.6	0.26	0.40	1.53	40.3%	0.322
15.	TRC-B1-300	2.18	1.55	0.8	0.3	0.50	1.66	52.2%	0.497
16.	TRC-B1S1-300	2.46	1.75	0.95	0.33	0.80	2.42	122%	0.935

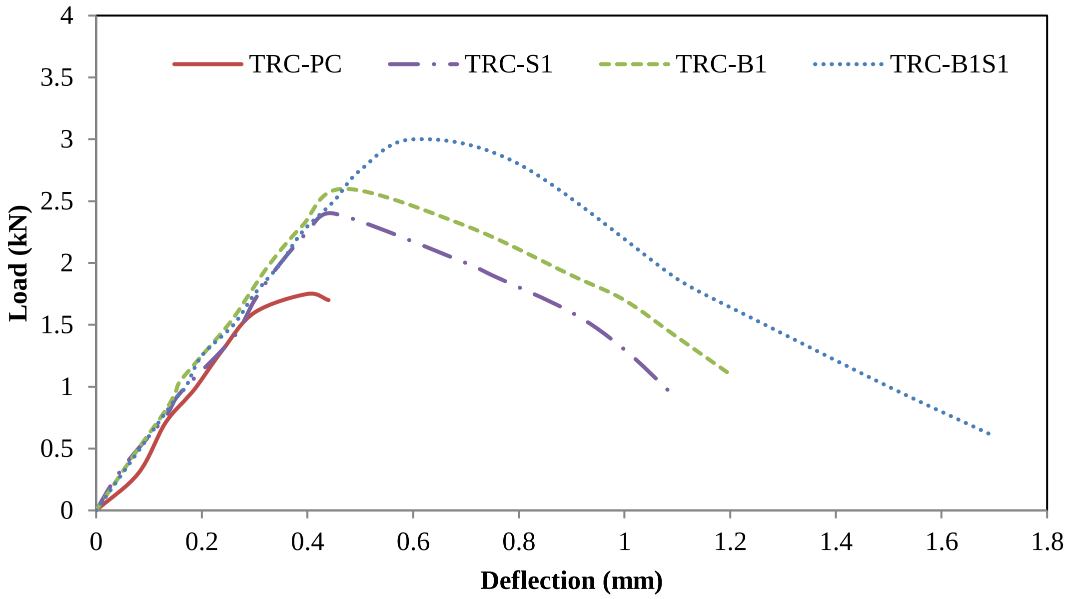

Figure-8. Load vs deflection curve of textile reinforced concrete at room temperature.

The flexural strength of TRC-PC-100, TRC-S1-100, TRC-B1-100 and TRC-B1S1-100 are 1.97 MPa, 2.96 MPa, 3.67 MPa and 3.45 MPa with ultimate displacement of 0.37 mm, 0.8 mm, 0.9 mm and 1.1 mm respectively at 100ºC. From the results it was found that the TRC-B1-100 has the ultimate flexural strength which is 75% higher than the conventional beam specimen. The Load vs deflection curve of textile reinforced concrete at 100ºC is shown in Figure-9.

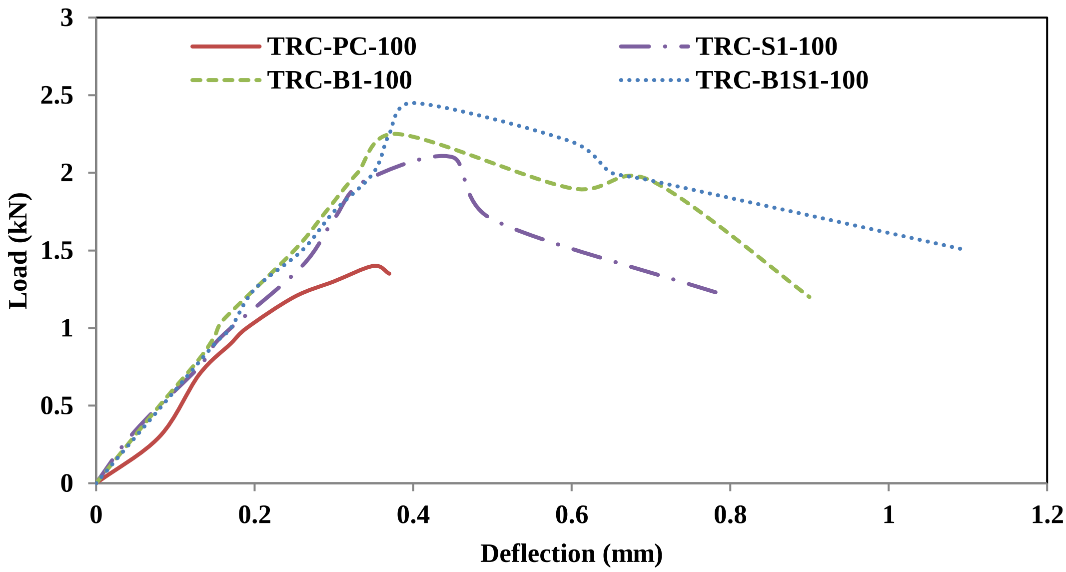

Figure-9. Load vs deflection curve of textile reinforced concrete with elevated temperature at 100ºC.

The flexural strength of TRC-PC-200 is 1.83 MPa with ultimate displacement of 0.30 mm and the flexural strength of TRC-S1-200, TRC-B1-200 and TRC-B1S1-200 are 45.9%, 54%, 74.8% higher than conventional beam mix with ultimate displacement of 0.50 mm, 0.65 mm and 1.0 mm respectively at 200ºC. From the results it was found that the TRC-B1S1-200 has the ultimate flexural strength which is 74.8% higher than the conventional beam specimen. The Load vs deflection curve of textile reinforced concrete at 200ºC and 300ºC are shown in Figure-10 and Figure-11 respectively. The results were in line with Sai Liu *et al*. (Sai Liu *et al*. 2018) where the energy absorption capacity has increased using multiple layers of basalt fibres when subjected to impact.

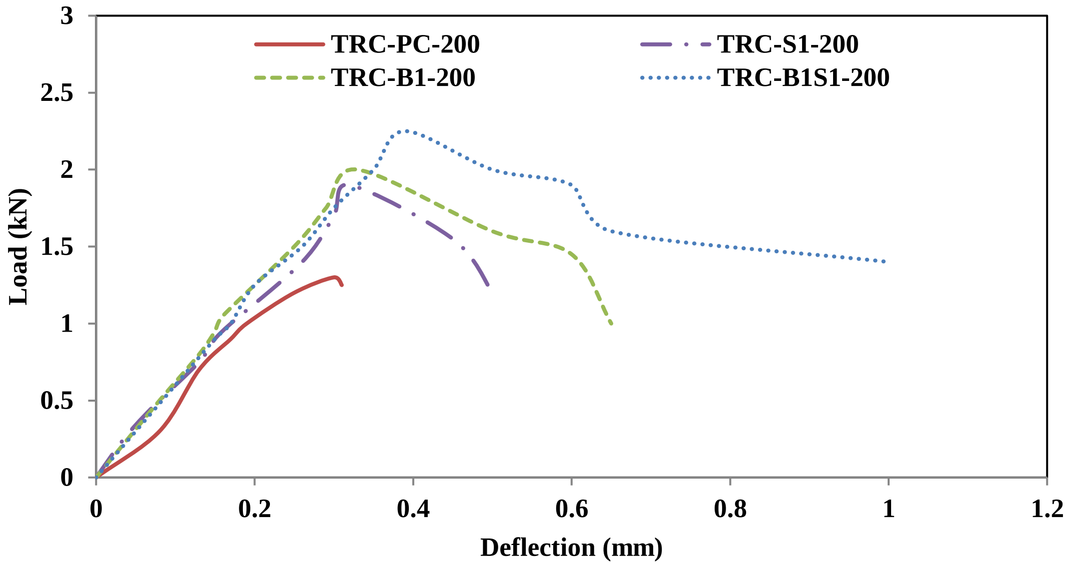

Figure-10. Load vs. deflection curve of textile reinforced concrete with elevated temperature at 200°C.

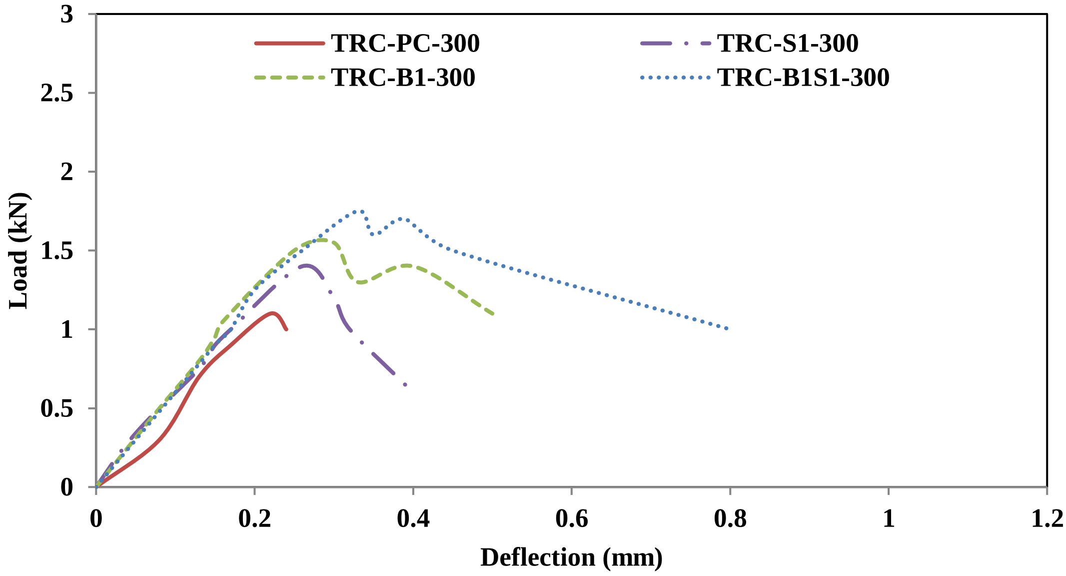

Figure-11. Load vs. deflection curve of textile reinforced concrete with elevated temperature at 300°C.

The flexural strength of TRC-PC-300 is 1.55 MPa with ultimate displacement of 0.26 mm and the flexural strength of TRC-S1-300, TRC-B1-300 and TRC-B1S1-300 are 1.27, 1.40, 1.58 times higher than conventional beam mix with ultimate displacement of 0.40 mm, 0.50 mm and 0.80 mm respectively at 300°C. From the results it was found that the TRC-B1S1-300 has the ultimate flexural strength which is 58.7% higher than the conventional beam specimen.

6. CONCLUSIONS

Based on the experimental results the following conclusions have been made.

- On comparing all the specimens in all temperature, TRC-B1S1 (with Basalt and S Glass Fibres) has achieved the higher flexural strength. It indicates that the hybridization of fiber influences the strength of the specimen
- By using the TRC specimens, the weight of specimen can be reduced where density of basalt and S-glass reinforcement mesh is low when compared with conventional reinforced concrete.
- At 300°C, the ultimate flexural strength of TRC-B1S1-300 is 58.71% higher when compared with conventional TRC specimen.
- The flexural strength of the specimens decreases with increases in temperature is due to the evaporation of water molecules present in the voids of specimen.
- Complete failure did not take place in TRC Specimens. The most suitable use of Textile

Reinforced concrete will be in flexure where the crack widths are limited, and generally high resistances can be achieved.

- Finally, the TRC specimen behave more flexible than the control specimen i.e., when load is applied on the specimen it bends and when load is released the specimen regains a new position but not to the original position indicates the good energy absorption capacity. This indicates that the fabrics present in the specimen can able to take certain amount of load applied over the specimen.

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CONFLICT OF INTEREST

On behalf of all the authors, the corresponding author states that there is no conflict of interest. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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