ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XVIII [2020] | Fascicule 4 [November]

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

[1.]S.D. GUPTA, [2.]R. SABRIN, [3.]R.H. ARONNO, [4.]E. KABIR, [5.]M.H. NIHAL

STUDY OF PERFORMANCE ON CONCRETE PROPERTIES OF GLASS FIBER REINFORCED CONCRETE

[1,3-5.]Department of Civil Engineering, Ahsanullah University of Science and Technology, 141 & 142, Love Road, Tejgaon Industrial Area, Dhaka, BANGLADESH
[2.]Department of Civil Engineering, Military Institute of Science and Technology, Mirpur Cantonment, Dhaka, BANGLADESH

Abstract: Concrete is the most prominent construction material that is used globally. As concrete is a brittle material, it is attenuated in tension. The Glass fiber reinforced concrete (GFRC) is a new incorporation in the field of concrete technology. The inclusion of glass fibers in concrete have significantly improves its compressive as well as tensile strength. In the present study a total of 10 different mixes were prepared based on different percentages of glass fibers viz. 0.1%, 0.2% and 0.3% with different length 15 mm, 20 mm and 25 mm respectively by volume of concrete. Experimental results illustrated that adding the higher percentage of fiber (>0.2%) in the mixing, cohesiveness of the concrete matrix gets affected which slightly degrade the concrete compressive and tensile strength. Furthermore, this study also illustrated that glass fiber reinforced concrete (GFRC) abated the brittleness of concrete compared to plain concrete. Incorporation of 0.2% Glass fibers with 20 mm length have found the maximum enhancement of compressive and tensile strength by 40.73% and 90.3% respectively as well as reduction of brittleness 45.8% compared to plain concrete also observed. Therefore, the results are of potential importance in developing wide range of Glass fiber reinforced concrete (GFRC) by using optimum content (0.2%) and length (20 mm) of fiber to achieve highest benefit in response to strength and brittleness.

Keywords: fiber reinforced concrete; glass fiber; compressive strength; tensile strength; brittleness

1. INTRODUCTION

Concrete earns popularity as an essential building material because of its excellent compressive behavior and low cost-easy production. Nevertheless, having lower tensile strength, poor toughness, limited ductility and little resistance to cracking make plain concrete members ineffective to withstand the loads and stresses that structural members encounters (Kamkar & Eren, 2017; Zhou et al., 2017). Moreover, micro cracks are inherent property of the concrete; plastic shrinkage and other causes of volume changes are the main grounds of micro cracks before loading, known as early-age cracking. Under flexure, tension or impact load, these cracks open up and propagate and also additional cracks initiates in the places of even minor defects. Such propagation of micro crack is the main reason of inelastic deformations of concrete (Madhuri et al., 2017). Thus plain concrete shows brittle nature when loaded.

To mitigate these problems associated with plain concrete, various innovation (addition of fiber, admixtures, using chemicals, adopting different mixing techniques) has taken place and also accepted in modern engineering field (Gholizadeh & Dilmaghani, 2018). Addition of different types of fiber in fresh concrete, reduce the crack formation as well as crack growth and also increase the tensile and flexural properties of concrete (Lim & Oh, 1999). Composite material comprises with aggregates, hydraulic cement and discontinuous, discrete, small fibers is known as Fiber Reinforced Concrete (FRC).

Different types of fiber i.e., metallic fibers (steel, aluminium) or synthetic fibres (glass, polyester, polypropylene), natural fibers (jute, palm, coconut etc.) or hybrid fiber can be used as a reinforcing material in plain concrete.

Universitatea Politehnica Timişoara

To improve the mechanical properties of plain concrete and bridging the propagation of cracks, using steel fibers is beneficial but durability of concrete may affected due to corrosion of steel. Moreover, high dose of steel fibers may result low workability, increased cost and also increase the weight of the mass composite concrete. Unlike steel fibers, non-metallic synthetic fibers such as glass, polymer fibers provide light weight and high corrosion resistance. Besides these fibers can easily distributed in fresh concrete and can reduce the early age cracking. Having lower density and stiffness, these fibers can contribute to effectively control the micro crack propagation in the plastic stage of concrete. (Sedaghatdoost & Amini, 2017; Sivakumar & Santhanam, 2007). Besides, concrete can be reinforced with low-cost natural fibers and overcome the inherent deficiencies of artificial synthetic fibers assuring concrete strength improvement. The major shortcomings of using artificial fibers are not only relatively expensive but also having hazardous properties for health and environment. On the other hand, natural fibers are biodegradable, nonhazardous, eco-friendly, comparatively low cost, easily available as produced from the natural resources such as cotton, jute, palm, sisal or coconut trees (Zakaria et al., 2016). Hybrid combinations of steel and non-metallic fibers such as glass, polyester and polypropylene inclusion in concrete can control both micro crack formation and crack propagation, subsequently can contribute to energy absorption mechanism (Sivakumar & Santhanam, 2007).

Durable and sustainable development with desired mechanical properties of construction materials raises attention as the demands of recent years and future advances. Enhancing the ductility, durability and performance of concrete, now a days FRC is used in the field of high rise building and infrastructures (Kim et al., 2017). Increasing the mechanical properties and ductility with decreased weight of the infrastructures, attempts to utilize glass fibers is a better choice. Gornale et al. (2012) reported that addition of glass fibers in concrete improve not only the strength properties but also toughness by increasing the energy required for crack propagation. Moreover because of anti-corrosive behavior and random orientation of glass fibers in fresh concrete, glass fiber reinforced concrete (GFRC) has been used in architectural and structural concrete members. In case of addition of glass fibers, volume of the fibers, aspect ratio, concrete mix proportions, workability, curing periods are important factors affecting the mechanical properties of the fiber reinforced concrete (Kanag et al., 2016).

To this end, it is important to explore not only the effects of these (above mentioned) parameters on GFRC and but also the potential use of glass fibers for gaining enhanced mechanical properties of concrete. This study aims to investigate the contribution of glass fiber with different length (15 mm, 20 mm, 25 mm) and different volume fraction (0.1%, 0.2% and 0.3%) on the mechanical properties of reinforced concrete composites.

2. MATERIALS

— Aggregates

In this experiment, 19 mm nominal size stone chips were used. According to ASTM C33, gradation of crushed stone chips was conformed. Fine aggregate is course sand type and collected from Sylhet, Bangladesh. Table 1 shows the basic physical properties of the aggregates used in this study.

Table 1. Physical properties of aggregates

Property	Bulk Specific Gravity (OD Basis)	Absorption Capacity (%)	Fineness Modulus (FM)	Dry Rodded Unit Weight (kg/m³)
Stone Chips	2.66	0.69	-	1550
Sand	2.54	1.34	2.8	1590

— Cement

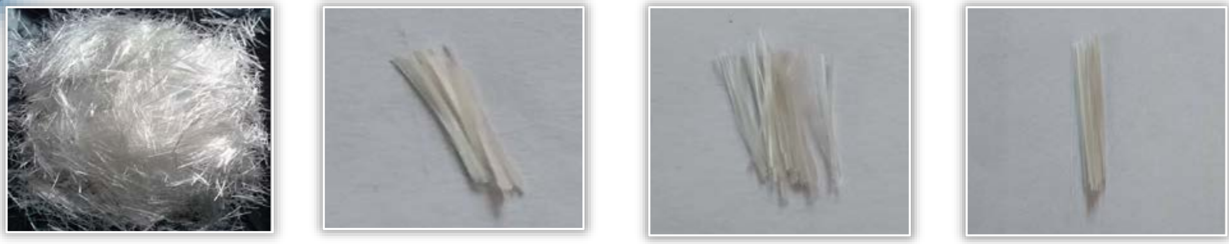
Ordinary Portland cement with specific gravity of 3.12 and strength class of 52.5 N was used. Clinker of 95–100% and gypsum of 0–5% is present in this cement.

— Glass Fiber

Raw glass fiber was collected and cut into three different lengths (15, 20 and 25 mm) as shown in Fig 1. Properties of this fiber are provided in Table 2. In this study, three different volumetric percentage 0.1%, 0.2% and 0.3% glass fiber are used in concrete mixture.

Table 2. Properties of glass fiber used in the experimental works (textilelerner. 2012)

Length (mm)	15 20 25
Diameter (mm)	0.015 (15 μm)
Aspect Ratio (l/d)	1000 1333 1666
Density (gm/cc)	2.5
Tenacity	6.3-6.9 gm/den
Tensile Strength (MPa)	2500-3500
E-Modulus (GPa)	70.0
Color	White to Off-white
Elongation at break %	3



(a) (b) (c) (d)

Figure 1. (a) Raw Glass Fiber (b) Glass Fiber (15 mm) (c) Glass Fiber (20 mm) (d) Glass Fiber (25 mm)

3. METHODOLOGY

— Concrete mixing, casting and curing

As per American Concrete Institute (ACI 211, 2009), Concrete with target strength 20 MPa (at 28 days) and target slump value of 75–100 mm was mix-designed. Fine & course aggregates were in SSD condition.

Three different lengths of glass fiber (15 mm, 20 mm, 25 mm) and three variable volume fractions (0%, 0.1%, 0.2%, 0.3%) were used in concrete composites. Detail mix proportions of the plain and composite concretes used in this experiment is presented in Table 3.

Table 3. Mix proportions of the concrete used in this study

Mix		Water (kg/m³)	Cement (kg/m³)	Coarse aggregate (kg/m³) [SSD]	Fine aggregate (kg/m³) [SSD]	Fiber (kg/m³)
Plain Concrete GF0 (0%)		196	456	1000	689	0.0
Glass Fiber (15 mm)	GF1 (0.1%)	202	456	1000	689	2.35
	GF2 (0.2%)	217	456	1000	689	4.70
	GF3 (0.3%)	226	456	1000	689	7.05
Glass Fiber (20 mm)	GF4 (0.1%)	206	456	1000	689	2.35
	GF5 (0.2%)	235	456	1000	689	4.70
	GF6 (0.3%)	240.5	456	1000	689	7.05
Glass Fiber (25 mm)	GF7 (0.1%)	210	456	1000	689	2.35
	GF8 (0.2%)	241	456	1000	689	4.70
	GF9 (0.3%)	245	456	1000	689	7.05

With the help of hand scissor, glass fibers were cut manually to the mentioned length. Mixing operation for all concrete trial mix was done by using mixer machine considering a volume of 40 liter. After 2 minutes of dry mixing of an appropriate amount of course aggregate (SSD), fine aggregates (SSD) and cement, water and glass fibers were added gradually for uniform distribution of fibers throughout the concrete. This mixing was conducted for 4 min until uniformity was achieved. To assess the workability of concrete, slump test is carried out.

150 mm cubic specimens were prepared to perform compressive and tensile strength tests. To prepare these specimens, steel moulds having smooth base plate to support were used. Assembling the molds joints, a thin coat of mold oil was applied the contact faces between the sections of the mold and the base plate of the mold to ensure no water leakage during filling. Similar mold oil was thinly coated the interior surfaces of the assembled mold to prevent adhesion of concrete. After placing the concrete into the molds, temping was done using standard rod. Fresh concrete surface was finished with smooth steel trowel. The samples were kept in an ambient temperature for 24 h. The specimens were immersed in clean fresh water for 7 days and 28 days after removing of molds.

— Compressive Strength testing

After curing, strength tests were conducted using compression testing machine. Compressive strength is the measure of concrete strength against static load. The test of compressive strength was performed using 6-inch (150-mm) cubes by following the guideline of ASTM C39. During the compression test, the load is applied gradually and ultimate load of each concrete specimen was noted. Experimental set up for compression test is shown in Figure 2.

Figure 2. Set up for compression test

— Tensile Strength testing

Concrete brittleness makes it abortive to strive against tension. Therefore, it is imperative to measure the splitting tensile strength of concrete. The split tensile strength was assessed as per EN 12390-6 (2000). The equation of tensile splitting strength is given as Equation (1) below:

$$f_{ct} = \frac{2F}{\pi L d} \quad (1)$$

where, f_{ct} is the tensile splitting strength, in MPa or N/mm²; F is the maximum load, in Newtons; L is the length of the line of contact of the specimen, in millimeters; d is the designated cross-sectional dimension, in millimeters.

4. RESULT AND DISCUSSION

— Compressive Strength of Glass Fiber Reinforced Concrete

The mean target strength for laboratory was set to 20 MPa. Figures 3 and 4 illustrate the compressive failure and compressive strength between Glass Fiber Reinforced Concrete (GFRC) and plain one with respect to three different volumetric dosing of glass fiber. The compressive strength test results are presented in Table 4. From the test results, increment of glass fiber up to 0.3% the compressive strength was also raised up compared to plain concrete.

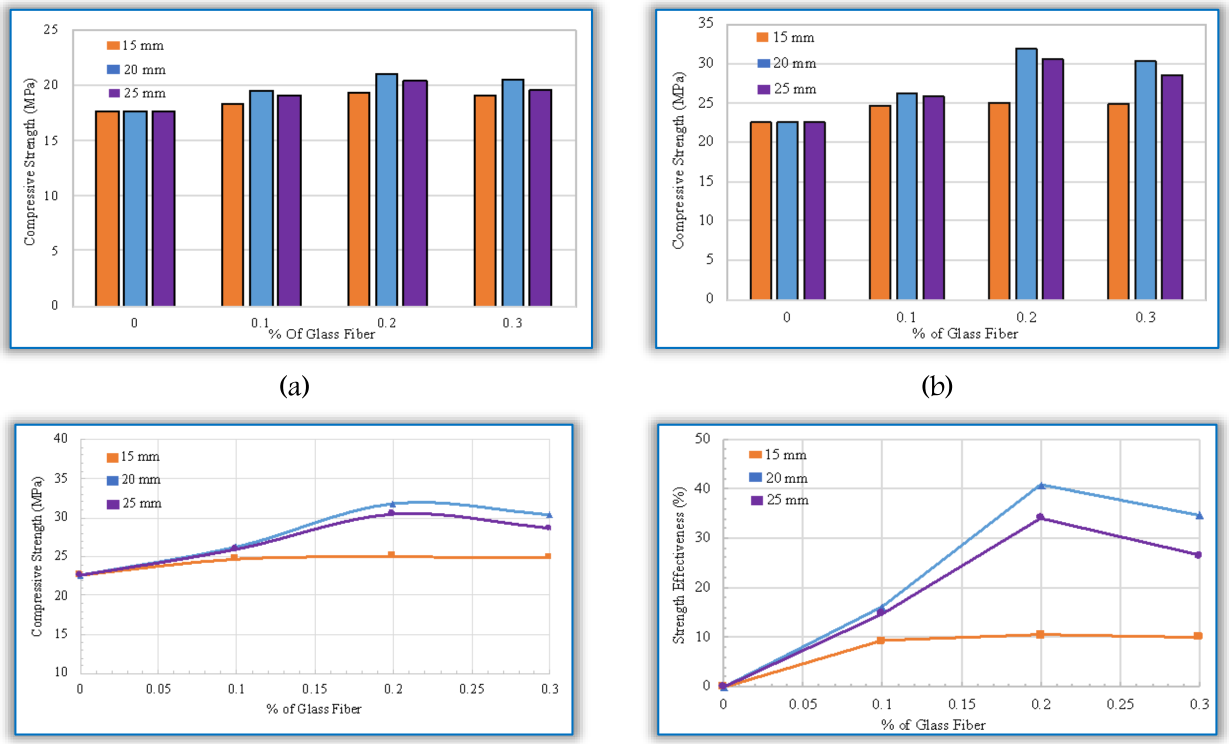


Figure 3. (a) Comparison of 7-days Compressive strength among 15 mm, 20 mm and 25 mm length of glass fiber (b) Comparison of 28-days Compressive strength among 15 mm, 20 mm and 25 mm length of glass fiber (c) Variation of 28-days compressive strength with fiber volume fraction (d) Comparison of strength effectiveness among 15 mm, 20 mm and 25 mm length of glass fiber

(a) (b)

Figure 4. Specimen after compression failure (a) Plain Concrete (b) GFRC (0.2%)

Table 4. Test Results of Compressive strength

Fiber Length (mm)	Type in concrete	Comp. Strength at 7 days (MPa)	Comp. Strength at 28 days (MPa)	28 days Strength Effectiveness (%)	Steel fiber & Poly-Propylene fiber*	Comp. Strength at 28 days (MPa)*
-	GF0	17.61	22.59	-	0	21.67
15	GF1	18.28	24.68	9.25	0.5%SF (35 mm)	24.40
	GF2	19.54	24.95	10.44	0.5%SF (30 mm)	24.92
	GF3	19.13	24.84	10.0	0.5%SF (50 mm)	26.43
20	GF4	19.36	26.22	16.07	0.4% PF (15 mm)	23.33
	GF5	21.05	31.79	40.73	0.4% PF (20 mm)	24.02
	GF6	20.34	30.44	34.75	0.4% PF (24 mm)	26.04
25	GF7	19.04	25.92	14.74	-	-
	GF8	20.54	30.29	34.09	-	-
	GF9	19.59	28.59	26.56	-	-

*Vairagade V S et al., 2013

Note: strength-effectiveness (%) = [(strength of fiber concrete – strength of pure concrete)/strength of pure concrete] × 100%

Figure 3(d) shows strength increment of the compressive strength of GFRC specimens at 28 days. As the unification of fiber content increased, the compressive strength rose steadily from 9.25% to 10.44% for 15 mm, 16.07% to 40.73% for 20 mm and 14.74% to 34.09% for 25 mm length of glass fiber compared to plain concrete. Finest result achieved for 0.2% (20 mm length) fiber addition and approximately 40.73% increase in the compressive strength was noted. Addition of glass fiber in concrete in discrete form, scattering of crack is restrained due to the entanglement of fiber with the concrete matrix (Fig.4). Moreover, adding the higher percentage of fiber in the mixing, porousness of the concrete may get increased as well as cohesiveness of the concrete matrix also get affected which slightly abate the concrete compressive strength. On the other hand, previous research on steel fiber and polypropylene fiber showed significant improvement of compressive strength (Table 4). Compressive strength rose compared to plain concrete up to 22% when 0.5% steel fiber with 50 mm length was used on contrast with 20.2% increment of compressive strength by adding 0.4% polypropylene fiber with 24 mm length.

— Tensile Strength of Glass Fiber Reinforced Concrete

Concrete splitting tensile strength test results are given in Table 5 and graphical representations of variation of tensile strength incorporating different length (15 mm, 20 mm and 25mm) of glass fiber with various mix proportions have shown in Figure 5.

Table 5. Test Results of Tensile strength

Fiber Length (mm)	Type in concrete	Tensile splitting Strength at 7 days (MPa)	Tensile splitting Strength at 28 days (MPa)	28 days Strength Effectiveness (%)	Steel fiber & Polypropylene fiber*	Tensile splitting Strength at 28 days (MPa)*
	GF0	1.20	1.87	-	0	2.12
15	GF1	1.33	1.92	2.67	0.5%SF (35 mm)	2.46
	GF2	1.81	2.59	38.5	0.5%SF (30 mm)	2.62
	GF3	1.72	2.14	14.4	0.5%SF (50 mm)	3.24
20	GF4	1.79	2.33	24.6	0.4% PF (15 mm)	2.89
	GF5	2.12	3.56	90.3	0.4% PF (20 mm)	2.97
	GF6	1.92	3.19	70.5	0.4% PF (24 mm)	2.09
25	GF7	1.46	2.12	13.4	-	-
	GF8	1.97	3.14	67.9	-	-
	GF9	1.86	2.89	54.5	-	-

*Vairagade V S et al., 2013

Note: strength-effectiveness (%) = [(strength of fiber concrete – strength of pure concrete)/strength of pure concrete] × 100%

As glass fiber content in concrete mix was increased up to 0.3%, splitting tensile strength of GFRC has also risen up. Figure 5 (d) shows strength effectiveness of the splitting tensile strength of GFRC specimens at 28 days. Since the incorporation of fiber content increased, the tensile strength increased steadily from 2.64% to 38.5% for 15 mm, 24.6% to 90.3% for 20 mm and 13.4% to 67.9% for 25 mm length of glass fiber compared to plain concrete. Best result obtained for 0.2% (20 mm length) fiber addition and approximately 90.3% increase in the tensile splitting strength was noted. As the large length of fiber with the higher content affect the concrete matrix during concrete vibration and casting, the tensile strength of concrete slightly decreased. However, it was remained elevated than the plain concrete. On the other hand, previous research on steel fiber and polypropylene fiber showed significant enhancement of splitting tensile strength (Table 5). Tensile strength raised compared to plain concrete up to 52.8% when 0.5% steel fiber with 50 mm length was used on contrast with 40.1% increment of tensile strength by adding 0.4% polypropylene fiber with 20 mm length.

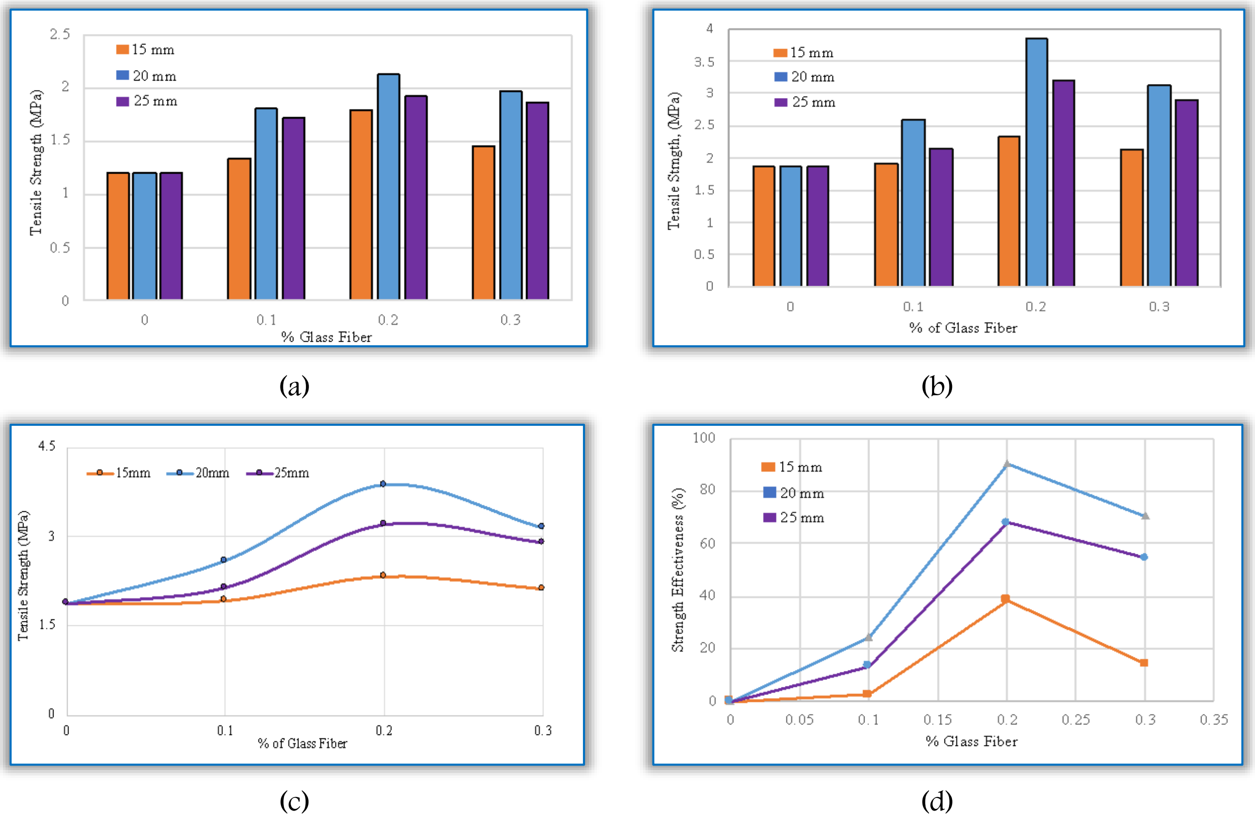


Figure 5. (a) Comparison of 7-days tensile strength among 15 mm, 20 mm and 25 mm length of glass fiber (b) Comparison of 28-days tensile strength among 15 mm, 20 mm and 25 mm length of glass fiber (c) Variation of 28-days tensile strength with fiber volume fraction (d) Comparison of strength effectiveness among 15 mm, 20 mm and 25 mm length of glass fiber

Furthermore, from the Figure 6 the difference of tensile failure pattern of plain concrete and GFRC are clearly conspicuous. Due to the grasping conception of glass fiber in the concrete matrix, GFRC hinders the concrete from complete splitting.

Figure 6. Specimen after tension failure (a) Plain Concrete (b) GFRC (0.2%)

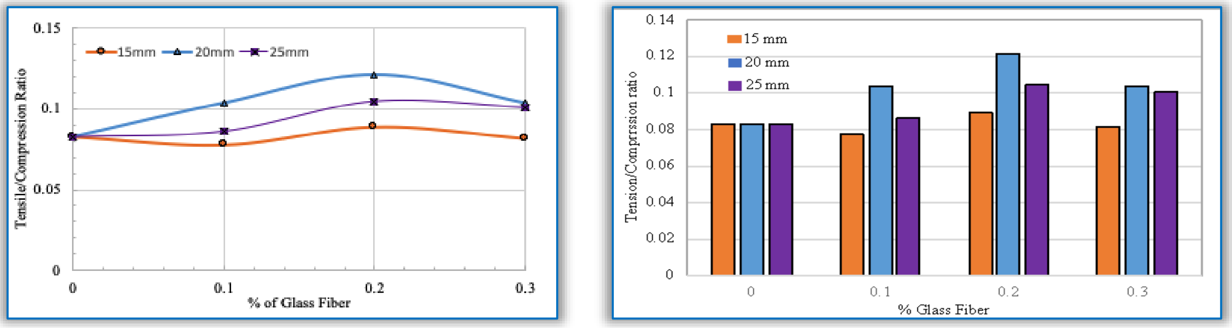
— Effect of Glass Fiber on Brittleness of Concrete

As concrete with high strength shows high brittleness, the abrupt changes of temperature beget concrete cracking. In order to assess the concrete performance, the tension to compression ratio can be a better representative of brittleness. The low brittleness of concrete reflects the high tension to compression ratio. A recapitulation of tension to compression ratio of glass fiber reinforced concrete (GFRC) is shown in Table 6. A comparison of the tension to compression ratio is also presented in Figure 7.

From the Figure 7, it is observed that the ratio rises with the increase of fiber proportion. Glass fiber attenuates the brittleness of concrete. Though addition of 0.1% glass fiber (15 mm length) slightly increased the brittleness, the other mix proportions of glass fiber reinforced concrete (GFRC) abated the brittleness compared to plain concrete. This is due to the fact of improvement of mechanical entrapment of glass fiber with concrete. The maximum tension to compression ratio was found 0.121 for 0.2% mixing of glass fiber with 20 mm length. However, the abatement of brittleness using 25 mm length of glass fiber shows better than 15 mm length of glass fiber. Moreover, from the Figure 6, it is worth visible that the tensile failure of plain concrete is completely brittle in contrast with ductile failure mode in GFRC.

Table 6. Test Results of tensile to compression ratio

Length of fiber (mm)		Type of concrete	Fiber content (%)	Tensile to compression ratio
	-	GF0	0	0.083
Glass Fiber	15	GF1	0.1	0.078
		GF2	0.2	0.108
		GF3	0.3	0.086
	20	GF4	0.1	0.089
		GF5	0.2	0.121
		GF6	0.3	0.105
	25	GF7	0.1	0.082
		GF8	0.2	0.104
		GF9	0.3	0.102



(a) (b)

Figure 7. (a) Variation of tensile to compression ratio with fiber volume fraction (b) Comparison among 15 mm, 20 mm and 25 mm tension to compression ratio of glass fiber

5. CONCLUSIONS

This paper illustrates experimental results of compressive strength, tensile strength and brittleness of concrete incorporating of Glass fiber. The following conclusions can be recapitulted from the results discussed earlier:

- Incorporation of glass fiber the compressive strength raised up 9.25% - 10.44% for 15 mm, 16.07% - 40.73% for 20 mm and 14.74% - 34.09% for 25 mm length compared to plain concrete.
- The optimum content of glass fiber is 0.2% with the length of 20mm of which the maximum increment of compressive strength was found 40.73%.
- Improvement of tensile strength was noticed by 2.64% - 38.5% for 15 mm, 24.6% - 90.3% for 20 mm and 13.4% - 67.9% for 25 mm length of glass fiber compared to plain concrete.
- The most efficient content of glass fiber for tensile strength is found 0.2% with the length of 20 mm of which the maximum enhancement was found 90.3%.
- With the addition of glass fiber in concrete maximum tension to compression ratio was found 0.121 by incorporating 0.2% mixing with 20 mm length in which 45.8% reduction of brittleness was noticed.
- In general, inclusion of 0.2% Glass fiber (20 mm) was found to be advantageous considering compressive (40.73% increase), tensile (90.3% increase) strength and brittleness (45.8% reduction) properties of concrete under this study.

Acknowledgement

The laboratory support provided by Ahsanullah University of Science & Technology (AUST) is gratefully acknowledged.

References

[1] ACI 211.1-91. (Reapproved 2009). Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete. American Concrete Institute, Farmington Hills, MI, 48331-3439 USA.
[2] ACI 224.1R-07. (Reapproved 2007). Causes, Evaluation, and Repair of Cracks in Concrete Structures. American Concrete Institute.

[3] Chandramouli, K., Srinivasa Rao, P., Pannirselvam, N., Seshadri Sekhar,T., and Sravana, Priyadrashini, T. P, (2010), Strength and durability characteristic of glass fibre concrete. International Journal of Mechanics of Solids, 5(1): 15-26.
[4] Chawla, K. and Tekwari, B. (2012), Glass fibre Reinforced concrete, Civil Engineering Portal, pp. 1-7.
[5] Dr. P. Perumal and Dr. J. Maheswaran. 2006, Behavioural study on the effect of AR-Glass Fibre reinforced concrete, NBW & CW, pp. 174-180.
[6] Fiber-reinforced concrete; Wikipedia; (modified at 2013)
[7] Gholizadeh H, Dilmaghani S. (2018). The Study of Mechanical Properties of High Strength Concrete Containing Steel and Polypropylene Fibers. Civil Engineering Journal, 4(1): 221-230.
[8] Gornale A., Quadri S. I., Quadri S. M., Ali S. M. A., Hussaini S. S. (2012). Strength Aspects of Glass Fibre Reinforced Concrete. International Journal of Scientific & Engineering Research, 3(7): 1-5.
[9] Kamkar, S., Eren, Ö. (2018). Evaluation of maturity method for steel fiber reinforced concrete. KSCE Journal of Civil Engineering, 22: 213–221.
[10] Kanag S. Y., Anandan Y. K., Vaidyanath P., Baskar P. (2016). Strength properties of coated E-glass fibres in concrete. GRAĐEVINAR, 68 (9): 697-703.
[11] Kim J. S., Cho C. G., Moon H. J., Kim H., Lee S. J. and Kim W. J. (2017). Experiments on Tensile and Shear Characteristics of Amorphous Micro Steel (AMS) Fibre-Reinforced Cementitious Composites. International Journal of Concrete Structures and Materials, 11:647–655.
[12] Lim, D. H. and Oh, B. H. (1999). Experimental and theoretical investigation on the shear of steel fiber reinforced concrete beams. Engineering Structures, 21(10): 937-944.
[13] Madhuri M., Jaya C. K. and Balakrishna B. B. (2017). Comparison of Performance of Non Metallic Fibre Reinforced Concrete and Plain Cement Concrete. International Research Journal of Engineering and Technology (IRJET), 4: 3388-3393.
[14] Muthuawamy K. R. and Thirugnanam G. S. (2013). Mechanical properties of hybrid fibre reinforced high performance concrete. Indian Concrete Journal, 87(4): 50-55.
[15] Nemati K. M., (2013). Fiber Reinforced Concrete (FRC), CM-425, concrete technology, University of Washington.
[16] Nilson A. H., Darwin D, Dolan C. W. (2013). Design of concrete structures, ISBN-007-123260-5, Mc-Graw-hill, America.
[17] Rouhi J., Jamshidi M., Kakooei S. (2011). The effects of polypropylene fibers on the properties of reinforced concrete structures. Construction and Building Materials, 27: 2586-2481.
[18] Vairagade S V and Kene S K, 2013. Strength of Normal Concrete Using Metallic and Synthetic Fibers, Procedia Engineering, Elsevier, Vol-51, pp. 132-140.
[19] Sedaghatdoost A., Amini M. (2017). Mechanical Properties of Polyolefin Fiber-Reinforced Light Weight Concrete. Civil Engineering Journal, 3(9): 759-765.
[20] Sinha, D.A., Varma, A.K and, Prakash, K. B. (2013). Properties of ternary blended steel fiber reinforced concrete. The Indian Concrete Journal, 87: 26-30.
[21] Sivakumar A. and Santhanam M. (2007). Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibers. Cement and Concrete Composites, 29(8): 603-608.
[22] Surendra P. Shah, James I. Daniel, Darmawan Ludirdja, (1987). Toughness of Glass Fiber reinforced concrete panels subjected to accelerated aging. PCI Journal, pp: 83-88.
[23] Zakaria M., Ahmed M., Hoque M. M. and Islam S. (2016). Scope of using jute fiber for the reinforcement of concrete material. Textiles and Clothing Sustainability, 2:11.
[24] Zhou X., Saini H. and Kastiukas G. (2017). Engineering Properties of Treated Natural Hemp Fiber-Reinforced Concrete. Front. Built Environ: 3(Art. 33):1-9.

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665
copyright © University POLITEHNICA Timisoara,
Faculty of Engineering Hunedoara,
5, Revolutiei, 331128, Hunedoara, ROMANIA
http://annals.fih.upt.ro