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The Effect of Addition of Fiber Reinforcement on Fire Resistant Composite Concrete Material

Bassam Z. Mahasneh
Department of Civil Engineering, Mu'tah University, Jordan

Abstract: This study presents the benefits gained from using Fiber Reinforced Polymers on concrete technology. Fire resistance of Polymeric Fiber Reinforced Concrete (PFRC) is presented in this study. The effect of fire on compressive strength, tensile strength and pullout is investigated. Results from several cylinder specimens having different aspect ratios as well as cube specimens are also investigated. These results indicated that PFRC strength is controlled by the composite action of both fiber and concrete. This Polymeric fiber shows an increase in the ductility, fire resistance and enhancement of the composite material properties. This study provides a good understanding of the behavior of fiber polymers on composite concrete properties and the effect of polymeric reinforced polymer on unprotected concrete.

Key words: Polymeric fiber reinforced concrete, pullout, splitting, unprotected concrete, compressive strength, composite material

INTRODUCTION

The aim of this study was to give a light on some of the important properties of using fiber polymers in fiber reinforced concrete. The effect of Fiber Reinforcement Polymers on fire resistance of fiber reinforced unprotected concrete has been investigated. It reveals and enhance the structural properties of materials; compressive strength, flexural strength, tensile strength, Fire and/or heat resisting.

The Fiber Reinforced Concrete (FRC)[1] is a composite material essentially consisting of concrete reinforced by random placement of short, discontinuous and discrete fine fibers of specific geometry. Several investigations[2-6] revealed the inclusion of fiber polymers to enhance some of the structural properties of a given material, such as concrete. These properties includes; compressive strength, fracture toughness, flexural strength, tensile strength, impact strength, resistance to fatigue, thermal shock and retrofitting. The fiber acts as crack arresters, resisting the development of crack and transferring a brittle matrix into strong composite with better ductility[5].

Calculating the squash load and rigidity of concrete-filled Circular Hollow Steel (CHS) sections[7], for evaluating the load bearing capacity of a column under fire conditions. The effect of tensile membrane action in the concrete slabs[8] has been performed on a large generic composite floor under fire conditions, using different patterns of fire protection for steel beams. The analysis includes fire compartments of different sizes and locations and show that the surrounding cool structure can provide some benefits in increasing the fire resistance of fire compartment.

Tracing the behavior of High Performance Concrete (HPC) columns exposed to fire was discussed in more details[9]. A simplified approach is proposed to account for spalling under fire conditions. Composite Slabs are slabs in which profiled steel sheeting acts as a permanent formwork and as reinforcement to concrete placed on top[10]. Due to heat absorbed by the concrete, the performance is better than that of unprotected steel.

Polymeric Fiber Reinforced Polymers (PFRP) may provide a more economical technically superior alternative to the traditional techniques in many situations. The PFRP is lighter, more durable, fire resisting and higher strength to weight ratio compared to traditional reinforcing materials such as steel[11,12].

The performance of confined concrete using both plain and fiber reinforced concrete was discussed[13]. Now a days, the provision of adequate ductility in concrete structures attracts the attention of several researchers[11,14]. Repair and retrofitting of existing structures have become a major part of the construction activity in many countries[11]. This can be attributed to aging of the infrastructure and increased environmental awareness in societies.

In literature, characteristics of high strength fiber reinforced lightweight aggregate concrete have been investigated[15] as well as nondestructive evaluation on damage of carbon fiber sheet reinforced concrete[16]. It is well recognized that the damage associated with the aging of civil infrastructure is one of the most serious threats to the assurance of public safety.

Other researchers, reveals the behavior of normal and steel fiber reinforced concrete under impact of small projectiles[17]. They present the effect of steel fiber reinforcement on the impact strength. The behavior of Steel Fiber Reinforced Concrete (SFRC) beams under impact loading has been studies extensively[17]. One of the benefits of using SFRC over plain concrete is the impact resistance, or dynamic toughness.

MATERIALS AND METHODS

Fire resistance experimentation

Test setup: In this study, the effect of Polymeric Fiber Reinforced Concrete (PFRC) on fire resistance is presented. The lab results of several specimens at different aspect ratios of cylinders and concrete cube size are investigated. The test is divided into two main sets. The first set uses fiber reinforced concrete as a filling material while the second one uses plain concrete as a filling material. Furthermore, different test specimens were used to figure out the effects of fiber polymers on the characteristics of PFRC. Cylindrical specimens of a diameter of 100 and 150 mm have been studied. Three specimen lengths were used; 150, 200 and 300 mm. Also, normal cubes (150X150X150) mm. A lean concrete mix was used in the test. In the test setup, Plain and Composite Concrete were subjected to the same temperature environment and same burning time to reveal the effect of polymeric fiber on concrete strength at different heat levels as well as fire duration.

Strength of both composite and plain concrete were recorded for various temperatures (Furnace temperature), starting from room temperature up to 1000°C. Furthermore, different heat durations (1 to 7 h) were used. Each time, the furnace heated to a target temperature before placing the specimen inside.

Moreover, the effect of fire on Pullout strength of hardened concrete with and without the presence of fiber polymers was of an interest in this study. A fixed rate of loading of 1.33×10^{-3} MN/s was applied for all specimens in this test.

Design mix: The following mix proportions were used to produce the design mix. These proportions are: coarse aggregates weighing 28.5 kg passing sieve size (18.75) mm and retained on sieve size (12.5) mm; Medium aggregate size of 28.5 kg passing sieve size (12.5) mm and retained on sieve size (9.375) mm; Fine size aggregate of 38 kg passing sieve No. 8; Cement of 14.0 kg and free water of 11.75 L. Fiber to concrete ratio 0.8% was used to produce the fiber reinforced concrete specimens.

Compression test: Cube size of (150X150X150) mm was tested in compression according to the ASTM. This test was performed for both plain and composite concrete specimens. Figure 1 presents the effect of fiber reinforcement on concrete strength for one, two, three and four weeks at different temperature starting from room temperature reaches up to 1000°C. Each time there is a comparison between the concrete with and without the addition of fiber reinforcement.

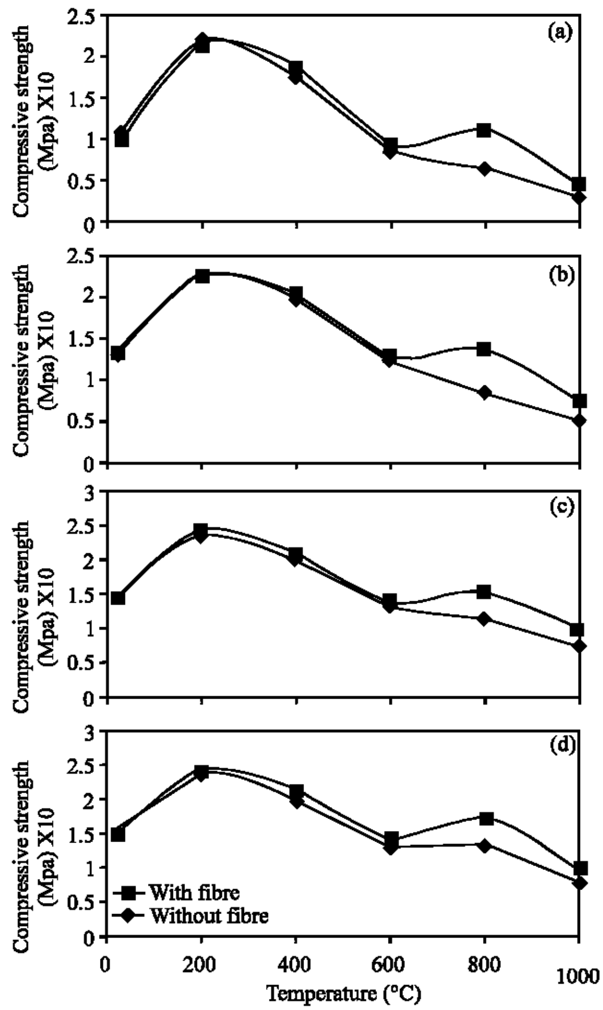


Fig. 1a-d: Effect of temperature changes on concrete compressive strength for cubes of (150X150X150) mm at (one to four weeks concrete age, respectively

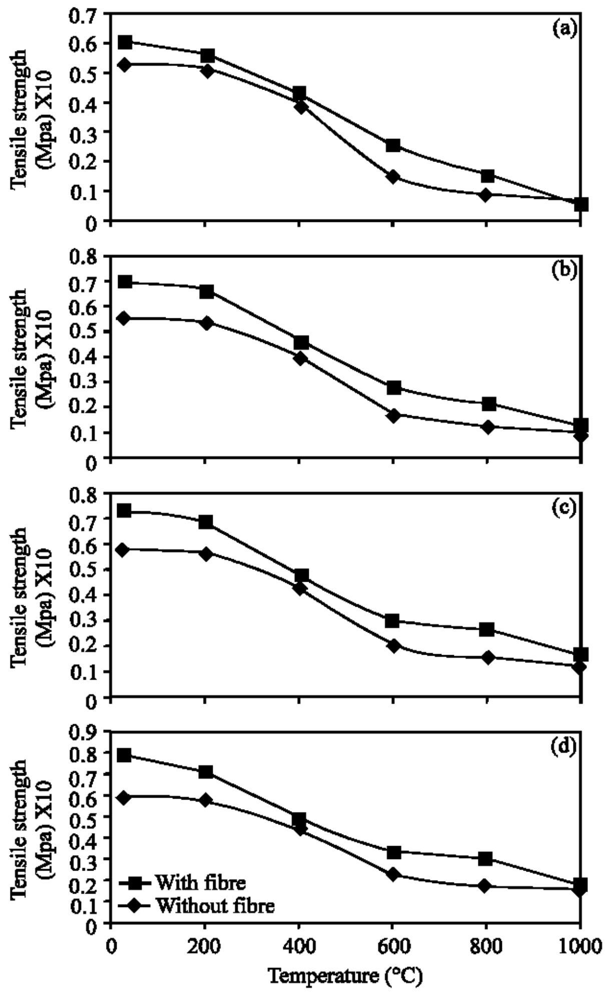


Fig. 2a-d: Effect of temperature changes on concrete tensile strength for cylinders of (150X300) mm at (one to four weeks concrete age, respectively)

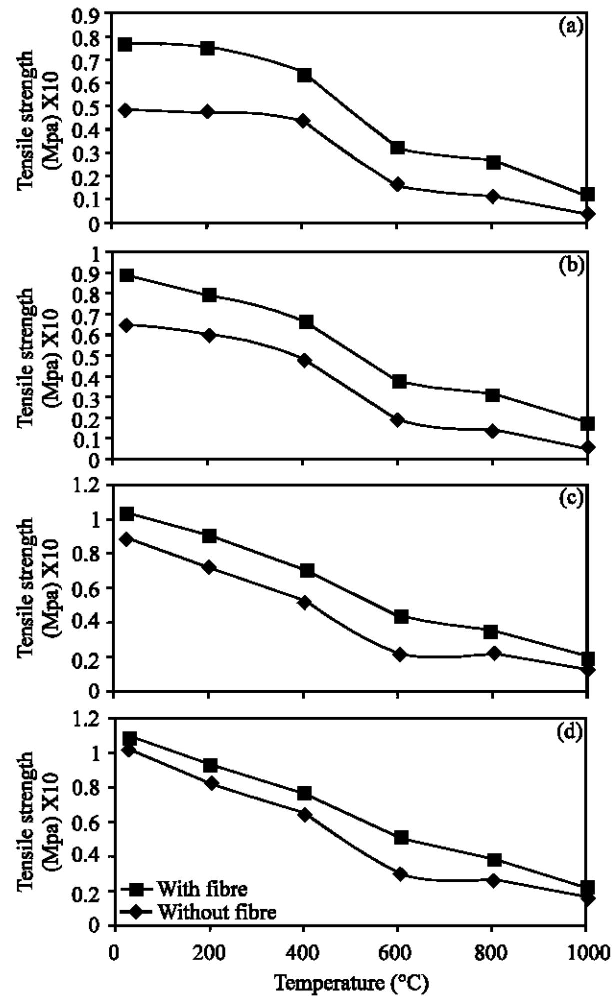


Fig. 3a-d: Present the effect of temperature changes on concrete tensile strength for cylinders of (100X200) mm at (one to four weeks concrete age, respectively)

Splitting test: According to the ASTM, splitting test was made with different cylinder aspects ratio (d/h), (150X300, 150X150 and 100X200) mm in dimension. The concrete was made with and without fiber reinforcement. Figure 2 present the effect of fiber reinforcement on concrete tensile strength for 1, 2, 3 and 4 weeks, respectively starting from room temperature reaches up to 1200°C. A comparison to see the effect of fiber on fire resistance each time is clear in Fig. 1.

Pull-out test: According to the ASTM, a concrete cube of (150X150X150) mm was prepared for the pullout purpose with the same proportion as for the compression and the splitting tests taking into account the presence of polymeric fiber reinforcement in the concrete. Each time the comparison was made for the case of with and without fiber reinforcement and the effect of fiber was clear on fire resistant (Fig. 3).

RESULTS AND DISCUSSION

As the furnace reached the target temperature before introducing the specimen to such high temperature, it become clear that such process did not encounter for any accounted thermal shock, this can be referred to the humidity inside the specimen as it was directly placed in the furnace. Such humidity inversely affected the direct thermal shock.

Figure 1a and b present the relation between concrete age and the compressive strength for (15X15X15) mm concrete cube with and without the addition of fiber reinforcement, respectively. In the Fig. 1, the effect of fiber reinforcement on concrete resisting fire is clear taking into account the effect of temperature and burning duration inside the furnace.

It is clear from the Fig. 1 the effect of polymeric fiber on concrete resisting fire. A fiber to concrete ratio of 0.8% in this research was found to be as a good ratio; in this paper only the result of 0.8% of fiber is presented. Compare the two cases (with and without PFRC) for fire resistance. It is clear that at a temperature of 1000°C and age of 5 weeks, the effect of fiber is clear in increasing the compressive strength of 15% from that without fiber. At room temperature, the effect of fiber as well is clear in increasing the compressive strength at 5 weeks with 11.3%. At 200°C, the increase of compressive strength was about 2% in compare with that for non-fibered concrete. As a distinguished result, concrete with fiber resist fire more than that without fiber at a temperature of 800°C, where the increase in compressive strength was of 20%. This can figure out that this kind of fiber (polymer) is good on the temperature of 800°C.

Figure 2a-d present the relation between concrete age and the tensile strength for (150X300) mm concrete cylinder with and without the addition of fiber reinforcement, respectively. The effect of fiber reinforcement on concrete resisting fire is clear taking into account the effect of temperature and burning duration inside the furnace (Fig. 2).

It is clear that at a room temperature and for 5 weeks time, the increase in the tensile strength was about 29% but at a temperature of 1000°C with the same age was about 10%. At a temperature of 600°C the effect of fiber is clear in increasing the tensile strength of 29% in compare with the value without fiber. A microscopic photo for the composite concrete indicated a starting melting point of the polymer in the range of 400-550°C. This phenomenon enhanced the interlocking force between the composite materials providing a direct tensile strength. At 200°C, the increase of tensile strength was about 19% in compare with that for non-fiber concrete. As a distinguished result, concrete with fiber resist fire more than that without fiber at a temperature of 600°C, where the increase in tensile strength was of 29%.

From Fig. 3, it is clear that at a room temperature and for 4 weeks time, the increase in the tensile strength was very slight, but at a temperature of 1000°C with the same age was about 25.8%. At a temperature of 600°C the effect of fiber is clear in increasing the tensile strength of 44%% in compare with the value without fiber. At 200°C, the increase of tensile strength was about 15.3% in compare with that for non-fibered concrete. As a distinguished result, concrete with fiber resist fire more than that without fiber at a temperature of 600°C, where the increase in tensile strength was of 44%.

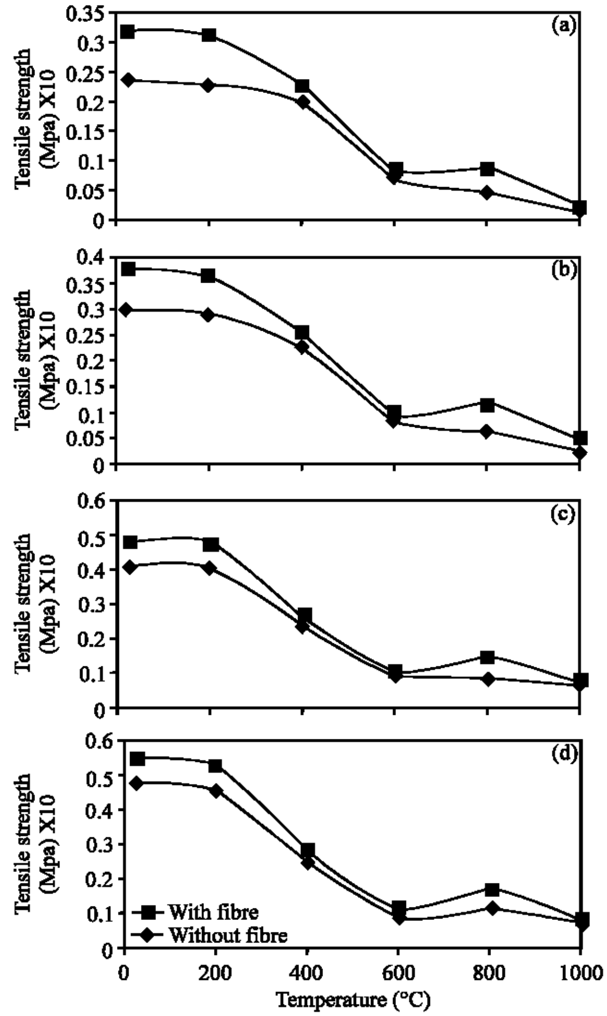


Fig. 4a-d: Present the effect of temperature changes on concrete tensile strength for cylinders of (150X150) mm at (one to four weeks concrete age, respectively)

Figure 4a-d present the relation between concrete age and the tensile strength for cylinder of (150X150) mm with different temperature, with and without fiber reinforcement effect.

From Fig. 4a and b, It is clear that at a room temperature and for 4 weeks time, the increase in the tensile strength was 12.4%, but at a temperature of 1000°C with the same age was about 17.7%. At a temperature of 600°C the effect of fiber is clear in increasing the tensile strength of 28.6% in compare with the value without fiber. At 200°C, the increase of tensile strength almost is neglected in compare with that for non-fibered concrete. As a distinguished result, concrete with fiber resist fire more than that without fiber at a temperature of 600°C, where the increase in tensile strength was of 28.6%.

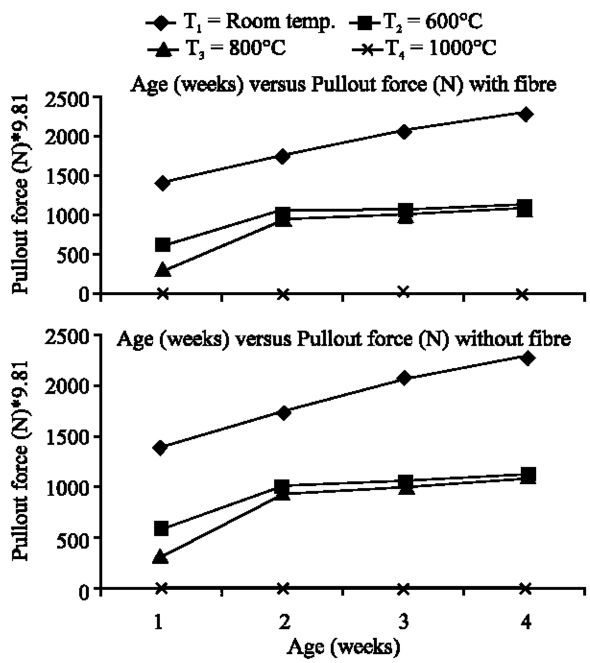
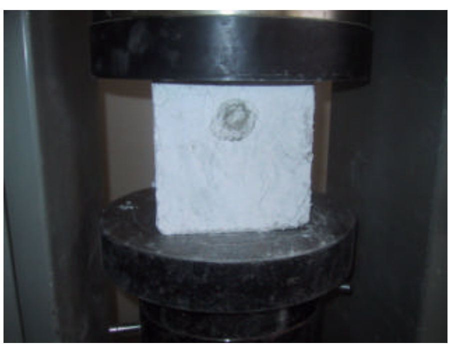


Fig. 5a and b: Relation between concrete age and the pullout force with different temperature for cube of (150X150) mm



(a) The concrete cube exactly the moment of testing

(b) The concrete cube after one day from the testing time

Fig. 6a and b: Concrete behavior at temperature of 1000°C, before and after collapsing

(a) Pullout test sample without burning

(b) Pullout test sample after burning

Fig. 7a and b: Pullout test before and after burning

Variation in specimens' size dictated a variation in the results. Variation in the specimens' size directly impacted the quantity of polymeric fiber leading to variation of the outcome results.

Figure 5a and b present the effect of temperature changes on concrete pullout force for cubes of (150X150) mm

It is clear that, at room temperature the effect of the fiber reinforcement on pullout force in not good since a decrease of 7.1% happens by the addition of fiber to concrete for the age of 5 weeks. At a temperature of 600°C an increase in the pullout force happen to the reinforced concrete with the amount of 18.2% in compare with that for the concrete without fiber. Based on the above result the existence of fiber in concrete is affecting the pullout force when the temperature is approaching 600°C.

It has been noticed that the composite concrete when burned on a temperature more than 800°C, the concrete behavior is not like the usual. In this research the researcher found that after burning the concrete at a temperature of 900, 1000 or 1200°C and testing the composite concrete for compressive strength, leaving the tested concrete cube to the other one or two days, a complete collapsing for the concrete cube was noticed. Figure 6a and b illustrates. This is due to at high temperature, burning of the concrete convert the composite material into a clay soil that is affected by the negative pressure comes from the room humidity which make the concrete behave like a soil sample under negative pressure, that makes it collapse.

Regard the pullout test; the researcher noticed the damage happens in case of room temperature in compare with that for the burned concrete was very small (Fig. 7a and b). This is due to fewer bonds between the composite particles that make the damage much more clear.

CONCLUSION

Based on the above results and discussion, the following points could be included as a conclusion for this work.

1. The existence of polymeric fiber reinforcement in concrete can increase the compressive strength up to 20% of that for concrete without fiber reinforcement with the ratio of 0.8% of fiber to concrete is recommended with a burning temperature of 800°C.
2. The tensile strength is increasing in case of using polymeric fiber reinforcement up to 44% based on the burning temperature of 600°C. As the burning temperature is increasing the above value is decreasing.
3. Regard the pullout; it is clear that at room temperature the effect of the fiber reinforcement on pullout force decreases the pullout force with 7.1%. This happens by the addition of fiber to concrete for the age of 5 weeks. At a temperature of 600°C an increase in the pullout force happen to the reinforced concrete with an increase of 18.2% in compare with that for the concrete without fiber. Based on the above result the existence of fiber in concrete is affecting the pullout force when the temperature is approaching 600°C.
4. This research is conducted on unprotected concrete, as it provided similar indicators of previous research on protected concrete, which might lead to the conclusion of less cost on the long run of such development.

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REFERENCES

1. Swamy, R.N., P.S. Mangat and C.V.S.K. Rao, 1974. The mechanism of fiber reinforcement of Cement matrices. SP 44, American Concrete Institute, Detroit, pp: 1-28.
2. Balaguru, N. and S.P. Shah, 1992. Fiber Reinforced Cement Composites. Singapore: McGraw Hill International Edition.
3. Chen, W. and J.L. Carson, 1971. Stress strain properties of random wire reinforced concrete. ACI. J., 68: 933-6.
4. Fanella, D.A. and A.E. Naaman, 1985. Stress-strain properties of fiber reinforced mortar in compression. ACI. J., 82: 475-83.
5. Ramakrishnan, V., 1987. Materials and properties of fiber reinforced concrete. In: Proceedings of International Symposium on Fiber Reinforced Concrete, Madras, India, SERC, pp: 2.3-2.23.
6. Mansur, M.A., M.S. Chin and T.H. Wee, 1997. Stress-strain relationship of confined high strength plain and fiber concrete. J. Mater Civil Eng., 51: 353-63.
7. Wang, Y.C. and V.K.R. Kodur, 2000. A simple method for calculating the fire resistance of concrete-filled CHS columns. J. Constructional Steel Res., 54: 365-386.
8. Zhaohui, H., Ian W. Burgess and Roger J. Plank, Fire resistance of composite floors subject to compartment fires. J. Constructional Steel Res., 60: 339-360.
9. Kodur, V.K.R., T.C. Wang and F.P. Cheng, Predicting the fire behavior of high strength concrete columns. Cement and concrete composite. Else, 26: 365-386.
10. Ralph, H., 1999. Fire resistance of composite slabs. J. Constructional Steel Rese., 33: 71-85.
11. Shamim, A.S., 2002. Performance of concrete structures retrofitted with fiber reinforced polymers. Elsevier J., Engineering Structures, 24 : 869-879.
12. DeRose and S.A. Sheikh, 1997. Rehabilitation of a concrete structure using fiber reinforced Plastics. Research Report, Department of Civil Engineering, University of Toronto, Toronto, Canada, pp: 170.
13. Bassam, Z.M. and E.S. Gharaibeh, 2002. The effect of concrete confinement on the strength of filled steel pipe columns. 6ICC, Jordan, 3: 857-862.

14. Ramesh, K., D.R. Seshu and M. Prabhakar, 2003. Constitutive behavior of confined fiber Reinforced concrete under axial compression. Elsevier J., Cement and Concrete Composites, 25: 343-350.
15. Kayali, O., M.N. Haque and B. Zhu, 2003. Some characteristics of high strength fiber Reinforced lightweight aggregate concrete. Elsevier J., Cement and Concrete Composites, 25: 207-213.
16. Jin-Kyung Lee and Joon-Hyun Lee, 2002. Nondestructive evaluation on damage of carbon fiber sheet reinforced concrete. Elsevier J., Composite Structures, 58: 139-147.
17. Edurado, M.A. and M.F. Canovas, 1999. Behavior of normal and steel fiber-reinforced concrete under impact of small projectiles. Elsevier J., Cement and Concrete Res., 29: 1807-1814.