

INTRODUCTION:

Fiber reinforced concrete is a concrete made of hydraulic cements containing fine aggregate or fine and coarse aggregate and discontinuous discrete fiber. It may contain pozzolans and other admixtures (**ACI 544 IR-84**). The main emphasis on research and particle application of glass fiber in cement paste has been concerned with the behavior of the fibers in ordinary Portland cement. The physical performance of the fibers in this matrix and as a result, the performance of composite is critically dependent on the microstructure of the matrix and fibers in the interfacial region where the fibers and matrix make contact. This region is important not only on the external surface of the fibers bundle, but also within bundle itself (**Hannat**). ASTM standard defines glass fiber in general terms as: "An inorganic product of fusion which has cooled to a rigid condition without crystallizing". The last two words are particularly important in that they relate to the principle morphological of glass (i.e. its amorphous nature) (**Shand 1958**). The concrete building construction could be exposed to the effect of fire. Human safety is one of the considerations in the design of buildings. The effect of fire on structural members depends on different factors such as; the amount, nature, and distribution of fire, loading, ventilation, and compartment size. One of these structural members is reinforced concrete slabs. This type of structural member may be subjected to high temperatures during fire, which will cause change in properties of its constituents namely concrete and reinforcement material. Therefore, in reinforced concrete structural design of buildings it may be necessary to design not only for the dead and live loads, but also for fire resistance (**Salse and Lin 1975**).

RESEARCH SIGNIFICANCE:

The main objective of this investigation is to develop fundamental information on the behavior of glass fiber reinforced mortar slab specimens after exposure to different periods of fire flame.

LITERATURE REVIEW:

Mechanism of Fibers Reinforced Concrete:

Previous works on fiber reinforced concrete revealed that the properties of concrete such as strength and deformation are improved when fiber are included to the concrete. Such improvements are caused by transfer of load from concrete to the fibers, thus controls the crack growth. The load is transferred by interfacial shear stress and longitudinal tensile stress developed on the fibers as shown in Fig. 1. The transfer of load from concrete to fibers depends on the following considerations (**Ghazy 2000**):

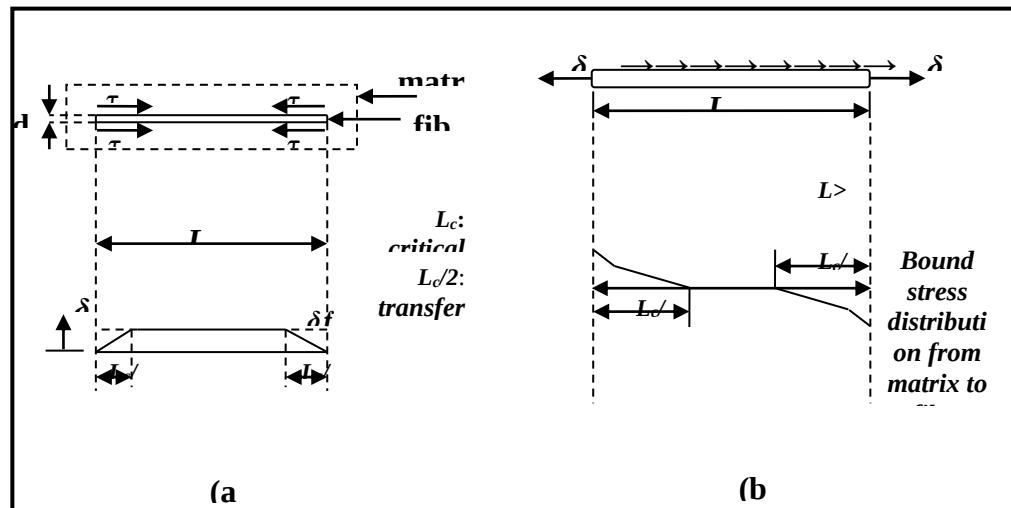


Fig.1. (a) Stress distribution for fiber in a discontinuous, aligned fiber composition, (b) Bound stress distribution at fiber-matrix interface, (Ghazy 2000).

1. Critical fiber length or the fiber transfer length. If the fiber length is greater than the critical length, fiber should yield at the failure of the composite. At equilibrium condition:

$$L_c = \frac{\sigma_{ult} \cdot d}{2\tau} \quad \dots\dots (1)$$

Where; L_c : critical length, d : fiber diameter, σ_{ult} : ultimate tensile strength of the fiber, τ : interfacial shear stress.

2. The interfacial bond between fibers and concrete in the vicinity of the crack increases to maximum and then decreases with increasing distance from crack edge.

The failure of the fiber reinforced concrete occurs either by simultaneous as yielding of the fibers and crushing of concrete or by bond failure at the concrete-fiber interface. The criterion that determines whether yielding or bond failure occurs is the fiber length and surface geometry.

Composite Materials Concept:

The two most important factors which influence the maximum load are the volume percentage of fibers and their aspect ratio (*ACI 544 IR-84*). While the main factors controlling the theoretical performance of the composite material are the physical properties of the fibers and the matrix, and the bond strength between the two. It is apparent that the elongation at break of all the fibers are two or three order of magnitude than the strain at failure of the matrix and hence the matrix will crack

long before strength is approached. This fact is the reason for the emphasis on post-cracking performance in theoretical treatment (**Hannat 1978**).

Mechanical Properties of Fiber Reinforced Concrete:

When fiber reinforced concrete specimens are loaded in flexure, four zones in load-deflection diagram can be observed as shown in Fig. (2) (**Ghazy 2000**):

- a) Before cracking the curve is sensibly linear up to point “A” which is called “first crack strength”, “elastic limit”, or “proportional limit”. The area under this part of the curve is the external work required to initial cracking and it is equal to $(1/2 P_c \cdot V_c)$, where P_c is the cracking load and V_c the corresponding deflection. The end of the zone is signaled by a drop in the load at constant deflection.
- b) After cracking the load again increases but the slope gradually decreases to zero at point “B” which is called “ultimate strength”. At a typical crack the tensile force supplied by the fiber may exceed that of the uncracked composite.
- c) A horizontal region in which the internal couple comprising the compressive force in the uncracked composite and the tensile force in the fiber is relatively constant. This zone is characterized by fiber pull-out and load transfer between fibers.
- d) A progressive failure zone in which increase of deflection results in fall-of load. This is region of stable crack growth of the progressive failure of fibers.

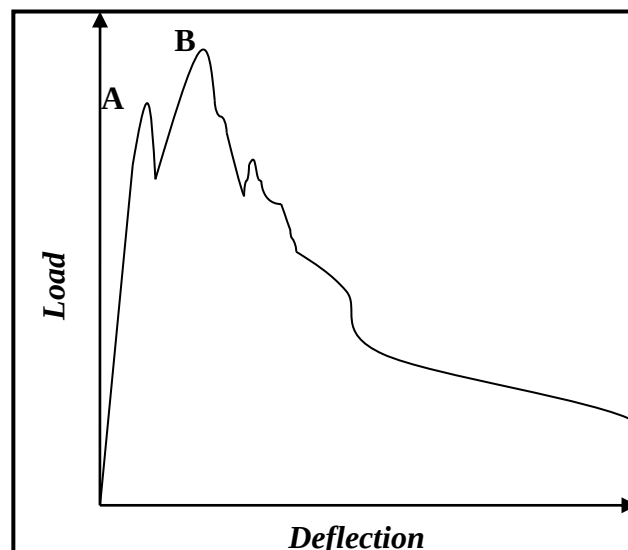


Fig.2. Schematic load-deflection diagram for a concrete beam reinforced with fibers, (**Ghazy 2000**).

Compressive Strength of Glass Fiber Reinforced Concrete:

Different types of fibers (organic and inorganic) were used to improve the properties of concrete. But steel and glass fibers were found to be the most favorable types of fibers for structural concrete. **Takagei (1994)** in his investigation on the effect of length of randomly distributed glass fibers and their content on the performance of concrete, observed that the compressive strength of concrete increases as the glass fiber content increased to 0.75% by weight of cement at length of 6mm and 25mm fibers. **Henry and Lawrence (1979)** reported that when the glass fiber content increases the compressive strength rises to maximum. In most instances the maximum strength occurs at fiber content of 0.5% by volume. The compressive strength at highest fiber volume percentage is equal to or slightly less than that of non reinforced concrete. At 0.5% by volume of glass fiber, the composite strength measured were 20% and 25% greater than these of plain concrete. The compressive strength of glass fiber reinforced concrete depends primarily on the properties of matrix. The orientation of the fiber also has some significance, since fibers aligned in the same direction as the force will weaken the compressive strength. While fibers at right angles to the applied load will help to keep the material together, and also improve its fracture resistance.

Flexural Strength:

Theoretical principles of fiber reinforced composite in flexure:

Major applications of cement-bound fiber composites are likely to be subjected to flexural stress in addition to direct stress. Hence an understanding of the mechanism of strengthening in flexure may be more important than an analysis of the direct stress situation. The need for special theoretical treatment for flexure arises because of the large differences which are observed experimentally between the modulus of rupture and the direct tensile strength, both in glass reinforced cement and in steel fiber concrete. In both of these materials the “modulus of rupture” can be up to three times the direct tensile strength. The main reason for the discrepancy in fiber-cement composites is that the post-cracking stress-strain curve on the tensile side of a fiber cement or fiber concrete beam is very different from that in compression. The flexural strengthening mechanism is mainly due to this quasi-plastic behavior of fiber composite in tension as a result of fiber pull-out or elastic extension of fiber after matrix cracking. The main principles are outlined in Fig.(3). Consider a fiber reinforced beam subjected to an increasing load (P). As the tensile strain increases cracks are formed. But unlike plain cement or concrete, a proportion of the load is maintained across the crack by these fibers spanning the crack and

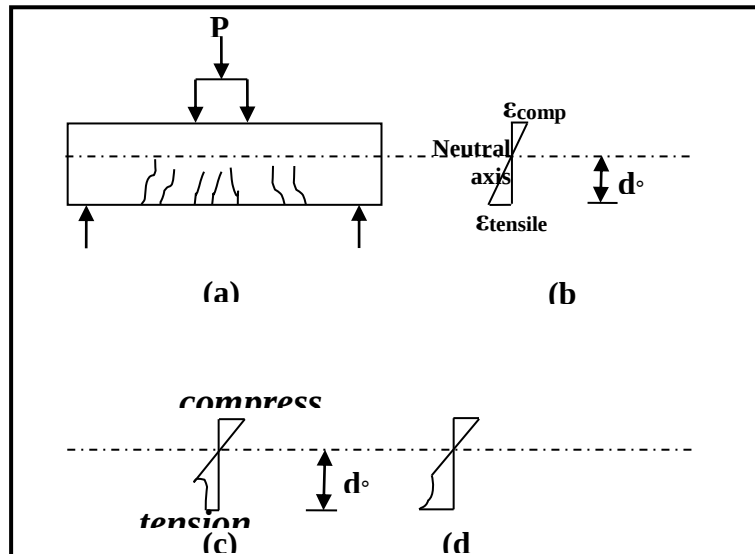


Fig.3. Strain and stress distribution in cracked fiber-cement or fiber-concrete section subjected to flexure, (Ghazy 2000).

hence equilibrium is maintained. Due to the formation of these cracks, the measured tensile strains increase and the value of (d_o), the distance of neutral axis from the tensile surface, increases. As further load is applied to the beam, the measured tensile strain increases at the greater rate than compressive strain, Fig. (b). Until there is no simple relationship between the measured strain and the apparent stress sustained across the crack. Figs. (c) and (d) are more appropriate for glass reinforced cement, where the fiber content is just below or well above $V_{f(crit.)}$ respectively. As a first approximation it is assumed that the compressive stress block is triangular although this may not be entirely accurate at ultimate load for fibers volume above $V_{f(crit.)}$ (Hannat 1978).

Flexural Strength of Glass Fiber Reinforced Concrete:

Flexural strength or modulus of rupture is the flexural stress computed at ultimate load base on a linear elastic assumption (Henry and Lawrence 1979). It was obtained from two-third points loading on (76×102)mm beams with 305mm span. The ultimate strength increases with increasing of fiber volume fraction up to 2%. The 12mm fiber length generally gave the lowest strength for a given fiber content. But the effect of the fiber length was not very consistent, possibly because of the interaction effects of decreasing workability and increasing bond area, Fig.(4). However, the 38mm fiber were probably most promising in terms of ultimate flexure strength (Hannat 1978). Henry and Lawrence (1979), showed that at first, flexural strength increased with the addition of glass fibers up to 3 times the strength of non-reinforced concrete. In general the rate of strength increased then tends to decrease as volume percent of fiber increased.

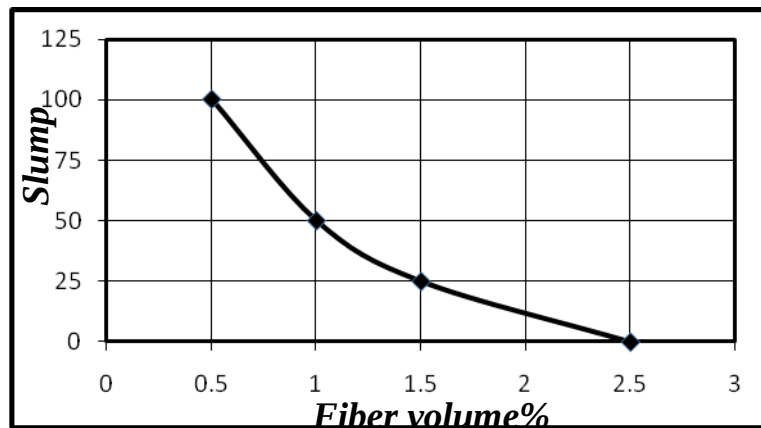


Fig.4. Effect of fiber content on slump, (Hannat 1978).

Effect of Fire on Concrete Properties:

Many studies have been carried out to investigate the effect of high temperature on concrete, and reinforced concrete members. It is clearly stated that both concrete and reinforcement material are affected by exposure to elevated temperature. **Essa (1999)**, studied the effect of burning by fire flame on some mechanical properties of concrete. The specimens were heated up to two temperature levels 500°C (achieved by subjecting the cubes to direct fire flame from petroleum gas burner), and 800°C (achieved by using an oven). The heating durations were 1 and 2 hours for the specimens exposed to 500°C, while it was 1 hour for the specimens exposed to 800°C. He found that the reduction in compressive strength ranged between (23-31)% and 39% at 500°C, when the periods of burning were 1 and 2 hours respectively. At 800°C, the reduction at 1 hour was 77% from the original strength. **Hidayat (1994)** carried out experimental and theoretical investigation concerning the behavior of reinforced concrete slabs subjected to high temperatures. The experimental part included fabricating and testing 18 reinforced concrete slab specimens having dimensions of (600×600×40)mm, with different steel ratios. The specimens were heated and cooled, then were tested to failure under uniformly distributed load. He observed that all the heated slabs were found to be capable of resisting the service loads. The ultimate flexural strength of the slab specimens was decreased with the increase of temperature. **Karim (2005)** studied the effect of fire flame on the behavior of reinforced concrete slab specimens during and after exposure to fire flame. The experimental work includes casting and testing twenty four reinforced concrete slab specimens with dimensions of (600×600×40)mm, with different steel ratios. Sixteen reinforced specimens were subjected to fire flame at the lower surface only to reach temperatures around of (400, 500, and 600°C) for one hour, then they were cooled gradually to room temperature. The specimens were tested to failure under uniformly distributed load. Based on the results of the study, she concluded that the ultimate load capacity of the reinforced slab specimens decreased with the

increase in fire temperature. The higher decrease occurred in slab specimens having higher steel ratio and subjected to 600°C.

EXPERIMENTAL WORK:

Materials:

Cement: Ordinary Portland cement (O.P.C.) manufactured by New Kufa Cement Plant was used throughout this investigation which complied with Iraqi specification (***IQS No.5 : 1984***). Tables (1) and (2), show the chemical analysis and physical properties of the cement used in this study, respectively.

Table 1. Chemical analysis of the cement used throughout the present study

oxide	(%)	Limit of Iraqi specification (<i>IQS No.5 : 1984</i>)
CaO	62.64	
SiO ₂	20.64	
Fe ₂ O ₃	3.03	
Al ₂ O ₃	6.06	
MgO	2.93	≤ 5.0
SO ₃	2.36	≤ 2.8
Free lime	1.35	
L.O.I.	1.55	≤ 4.0
IR	0.81	≤ 1.5
Compound composition	(%)	Limit of Iraqi specification (<i>IQS No.5 : 1984</i>)
C ₃ S	39.72	
C ₂ S	29.21	
C ₃ A	10.47	
C ₄ AF	10.04	
LSF	0.88	0.66-1.02

Table 2. Physical properties of the cement used throughout the present study

Physical properties	Test results	Limit of Iraqi specification (<i>IQS No.5 : 1984</i>)
Fineness (Blain method) cm ² /gm	3090	≥2300
Setting time (Vicat method)		
Initial hrs:min	1:30	≥0:45
Final hrs:min	4:16	≤10:00
Compressive strength		
3 days MPa.	18.21	≥15
7 days MPa.	23.45	≥23

Fine Aggregate: Al-Akhaidur well-graded natural silica sand was used in this investigation. Its grading conformed to the Iraqi specification (*IQS No.45 : 1984, zone 2*).

Glass Fiber: Glass Fiber, chopped strands with (5-25) mm length. The reinforcement fiber ratio was (0.5%) by weight of cement.

Water: Tap water was used for both mixing, and curing.

Mortar Mixing , Casting and Curing:

The mortar was mixed in a horizontal drum laboratory mixer, with a capacity of 0.1m^3 . The interior face of mixer was cleaned and moistened before placing the mix contents. The mix proportion was 1:2 (cement:sand) and water/cement ratio($w/c=0.5$). The mortar specimens were cast in (600×600×40)mm steel moulds and (70×70×70)mm cubs in addition to (25×25×250)mm steel prism moulds. They were divided into three series as illustrated in Table (3), the difference between these series was in the period of fire flame exposure. Each series consisted of two plates, two prisms, and three cubs. The moulds were thoroughly oiled to facilitate demoulding and obtain a fair face of casting. Compaction was achieved by using a vibrating table. The glass fiber reinforcement was uniformly distributed and placed in two layers at depth of (13and27)mm from the bottom surface. The specimens were stored in laboratory conditions and covered with polyethylene sheet for 24 hours to prevent evaporation of moisture from the fresh mortar. Then, the specimens were demoulded and immersed in tap water tanks having relating constant temperature of about $(20\pm 2)^\circ\text{C}$ for (14) days. Finally the specimens were exposed to normal weather condition until they complete (28) days which is the age of fire processing.

Table 3. Details of specimens series and period of exposure to fire flame

Symbol of a specimens series	Period of exposure to fire flame (min)
A₁	0
A₂	30
A₃	60

Burning and Cooling:

The mortar specimens were subjected to fire flame from a network of methane burners. The fire flame hit the lower face of the specimens. The columns of flame were intended to simulate the heating condition in actual fires. The temperature was continuously measured by thermometers, which were positioned in the bottom surface of the specimen in contact with the flame. When the temperature reached to 500°C , the specimens of series A₂ were kept in this fire exposure for one

hour, while they were kept for two hours for series A₃. **Mohamadbhai (1986)** stated that although the maximum temperatures reached during fires of buildings are in the order of 1000°C to 1200°C, such high temperatures occur only at the surface of the members. Considering the relatively small size molding of the specimens tested, it was decided to limit the temperature of the specimens to 800°C. After burning, the specimens were allowed to cool in the laboratory to the room temperature which is in the range of 25°C.

Compressive Strength Test:

The compressive strength was determined according to **(IQS) No. 198 : 1990**, by using (70×70×70)mm cubes. The test was achieved by using a machine of 200kN maximum capacity. The load was applied without shock and gradually increased at a constant rate of 0.34 MPa. Each compressive strength value was the average of compressive strength of three cubs at age of 28 days.

Flexural Strength (Modulus of Rupture):

Modulus of rupture test was performed according to **ASTM C348-88**. It was carried out on (25×25×254)mm simply supported prisms with clear span of (100)mm, under one point loading by using (10)kN capacity. Each value of flexural strength was the average of the test results of two prisms at age of 28 days. The flexural strength was calculated from the relationship:

$$f_{ct} = \frac{2pl}{3bd^2} \quad \dots (2)$$

Where; f_{ct} : flexural strength, N/mm²., P: breaking load, N., l: clear span, mm., b: width of prism, mm., and d: thickness of prisms, mm.

Uniform Load Flexural Test:

The slab specimens were tested by using a rigid steel frame with I-section, which was designed as a supporting system, Fig(5). Four bars of steel with diameter of 12mm were welded on the top of the square steel base to obtain a simply supported condition. The distance between each parallel bars was 560mm, which represents the clear dimension of the square shape slab. The steel supports were covered by red silicon to furnish a continuous touch between the support and the slab. A box of (560×560×100)mm dimensions, made of steel plate with thickness of 5mm. This box was opened from the upper and lower square areas and coated by a sheet of polyethylene in the inner surfaces, used to hold the sand to be placed over the slab to uniformly distribute the applied load. A load cell with capacity of (70 tons) was used to measure the load applied by a hydraulic jack which transmits the load to the four loading points using a loading base. The loading base consisted of three steel

members with I-section of (120×80)mm and length of 360mm. Two of these members were paralleled and the other welded perpendicularly upon them. The parallel steel members were connected to four steel legs of (50)mm diameter by (30)mm height. These legs were connected by welding to four steel plates of (140×140×5)mm, and were fixed over a steel plate of (480×480×5)mm by welding. This steel

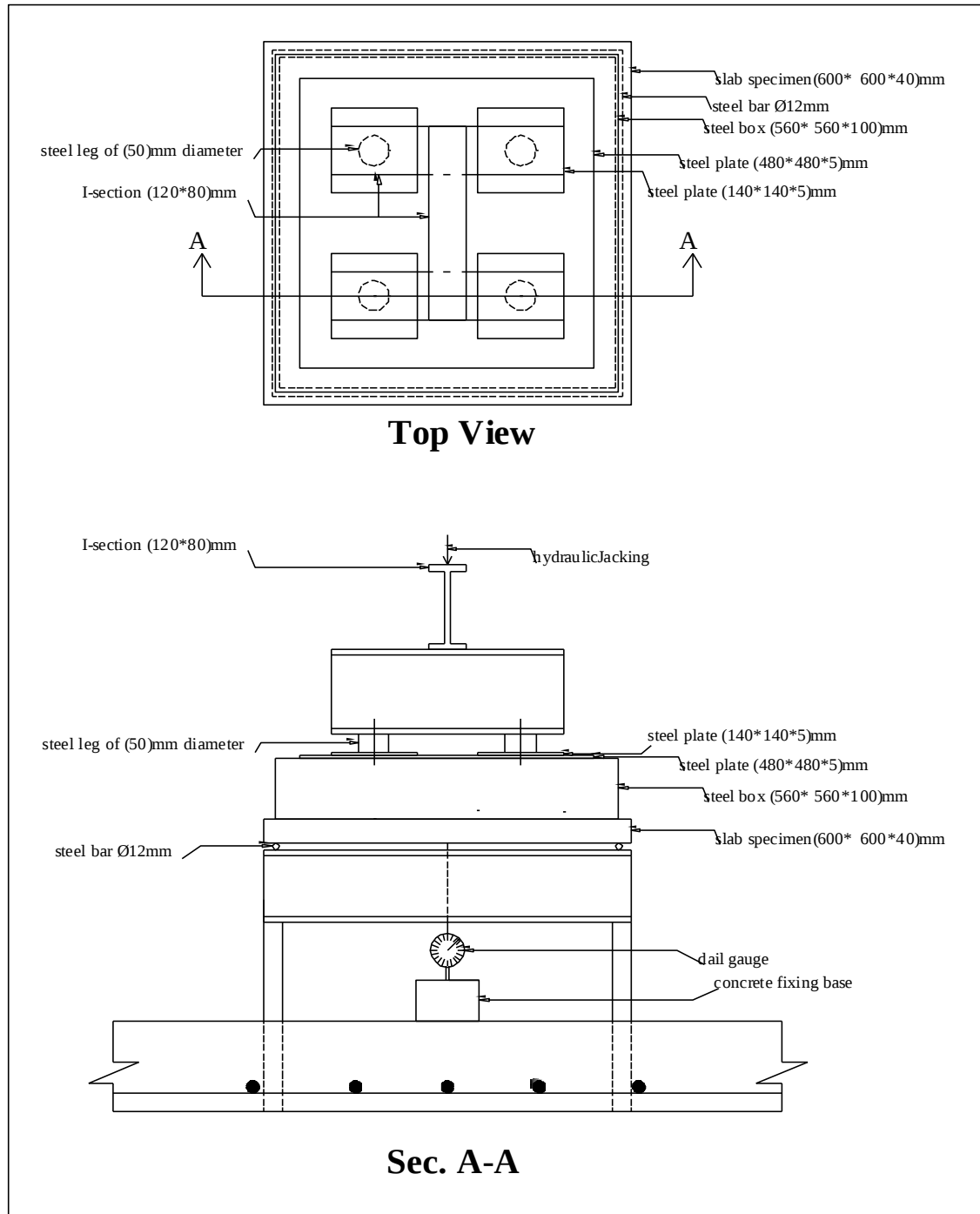


Fig.5. Loading arrangement for uniform load test, (Hidayat (1994), Karim (2005)).

loading base transmitted the load to the (100)mm layer of sand used between the loading base and the slab specimen. This method of loading was adopted by **Karim (2005), Hidayat (1994), Abdul-**

Wahid (1989), and **Al-Shadidi (1985)**. Deflections were measured at all load stages using a dial gauge with capacity of (25.4)mm and accuracy of (0.025)mm at mid span of the slab specimen. The dial gauge was fixed in such a way that can contact the lower surface of the slab specimens.

RESULTS AND DISCUSSION:

Compressive strength:

The compressive strength test results are abstracted in Table (4). Fig (6) shows the relationship between the compressive strength and periods of the exposure to fire flame. Compared with series A₁ the percentages of residual compressive strength were 76% and 69% for series A₂ and A₃ respectively. It is obvious that the specimens exhibit a further loss of compressive strength after one hour of burning. The most reduction in compressive strength occurs at the first 30 min. of burning. The decrease in compressive strength is attributed to the breakdown of interfacial bond due to incompatible volume change between cement paste and aggregate (fine or/and course aggregate) during heating and the formation of relatively weak hydration products. Also, dehydration of the calcium silica hydrate shrinkages of cement paste (**Morley and Royels (1983)**, **Venecanin (1977)**).

Table 4. Compressive strength results

Series	Compressive Strength (MPa.)	Residual Ratio of Compressive Strength
A ₁	38.21	1
A ₂	29.12	0.76
A ₃	26.50	0.69

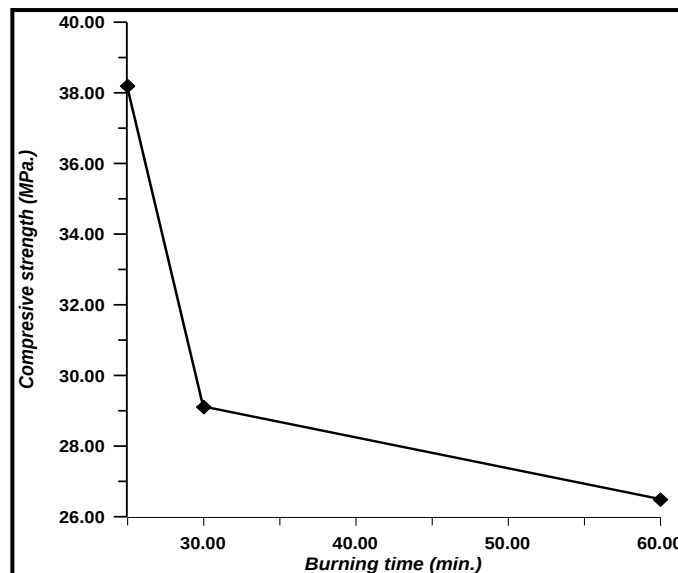


Fig.6. The effect of burning time on the compressive strength.

Flexural strength:

The test results of the flexural strength are summarized in Table (5). Fig. (7) shows the relation between flexural strength and the periods of exposure to fire flame for the three series A₁, A₂, A₃. It is clear that the reduction in flexural strength is more pronounced than that in compressive strength. The percentages of residual flexural strength were 60% and 57% for series A₂ and A₃ respectively. The reduction in flexural strength can be explained by the fact that during exposure to fire temperate, the evaporable water is causing triaxial tension within the concrete. When a flexural load is applied the tensile stresses due to the applied load become additive to the triaxial tension resulting in drop in flexural strength (*Akhtaruzzaman 1989*). It was noticed that the specimens were multi cracked before failure (multiple crack failure) due to the presence of glass fibers.

Table 5. Flexural strength results

Series	Flexural Strength (MPa.)	Residual Ratio of Compressive Strength
A ₁	4.40	1
A ₂	2.64	0.60
A ₃	2.50	0.57

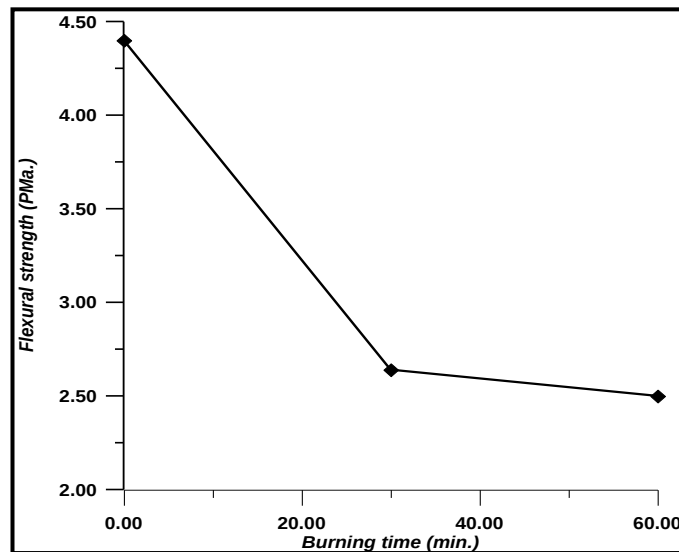


Fig.(7): The effect of burning time on the flexural strength.

Load-Deflection Test:

After the slab subjected to fire flame, two types of cracks developed, the first was thermal cracks appearing in a honeycomb fashion all over the surface. They originated from top or bottom edges and terminated near the mid depth of the slab. The crack width was about (1mm). the patterns of fine cracks were consistent with the release of moisture being grater in outer layer than in the interior, resulting in differential shrinkage. The second type of cracks were flexural tensile cracking due to loading developed in the mid span region, and then extended diagonally toward the corners

rapidly. As loading increased, more cracks initiated in this region and extended towards the corner. While formation of new cracks, the earlier cracks became wider. The effect of burning time on the load deflection relationship of slab specimen is illustrated in Fig.(8), and Table (6). It can be seen that under a certain load the deflection increases with increasing the burning time. This can be attributed to the fact that the fire causes a reduction in slab stiffness which is essentially due to the reduction in the modulus of elasticity of concrete and the effective moment of inertia of the specimens (*Karim (2005), Umran (2002), Hidayat (1994), Ass'ad (1986)*). This can lead to a softer stiffness response of the glass fiber reinforced mortar slab specimens.

Table 6. Load-deflection test results

A ₁	Applied load (kN)	0	3.5	7	10.5	14	17.5	20
	Deflection (mm)	0	0.1	0.18	0.23	0.6	1.1	1.7
A ₂	Applied load (kN)	0	3.5	7	10.5	14	17.5	19.2
	Deflection (mm)	0	0.23	0.34	0.68	1.1	1.7	2.4
A ₃	Applied load (kN)	0	3.5	7	10.5	14	17.5	18.7
	Deflection (mm)	0	0.41	0.6	1.1	1.5	2.2	3.2

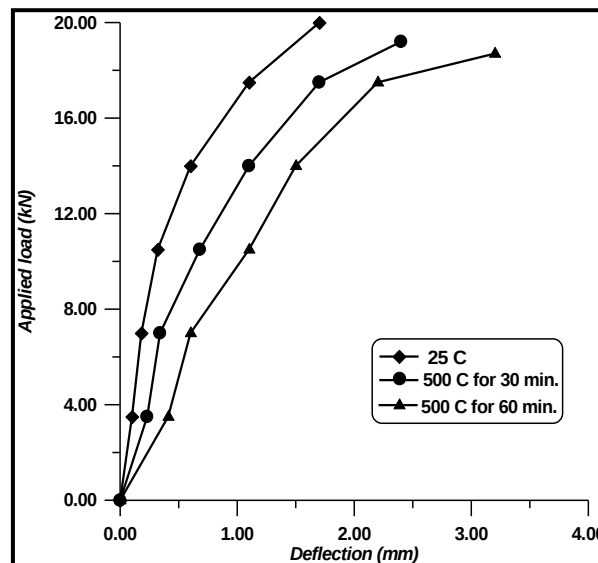


Fig.8. Load deflection relationship for the slab specimens of different periods of burning .

Load Carrying Capacity:

Table 7 presents values of ultimate resisted load (load failure) of the different glass fiber reinforced slab specimens and the percentages of residual ultimate load after exposure to fire flame for different periods of exposure. It can be clearly seen that the ultimate load decreases with the increase of burning time. This behavior can be attributed to the thermal cracking due to the fire exposure and may some loss of the tensile strength and rigidity of the glass fibers. These factors

reduce the flexural stiffness and load carrying capacity of the samples and accelerate failure for the fired specimens.

Table 7. Ultimate load values

series	Ultimate load (kN)	Residual Ratio of Ultimate Load
A1	20	1
A2	19.2	0.96
A3	18.7	0.94

CONCLUSIONS:

Fire flame exposure to glass fiber reinforced slab specimens can cause the following effects:

1. The most reduction in compressive and flexural strength occurs at the first 30 min of burning.
2. The reduction in flexural strength is more pronounced than that in compressive strength.
3. The percentage of residual compressive strength was 76% and 69% for A₂ and A₃ respectively.
4. The percentage of residual flexural strength was 60% and 57% for A₂ and A₃ respectively.
5. The deflection increases with the increasing of burning time under a certain load. Indicating softer response of the specimens.
6. The load carrying capacity is adversely affected by exposure to fire flame. The percentage of residual ultimate load was 96% and 94% for A₂ and A₃ respectively.

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