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Using Slurry Infiltrated Fiber Concrete as New Technique in Repairing of Defected Concrete Structures[1]

Abstract:

Slurry infiltrated fiber concrete (SIFCON) is considered a special type of high strength high-performance fiber reinforced concrete, extremely strong and ductile. This relatively new type of concrete is produced by placing the separated steel fiber into a mold, to form a dense network which is then infiltrated with low viscosity slurry of cement mortar or paste.

This research aimed at investigating the possibility of using a relatively new type of concrete in retrofit and rehabilitation field. In this work four SIFCON mixes were molded with different steel fiber contents, metakaolin was used in one of these mixes in order to investigate its performance. Two other concrete mixes were molded these were steel fiber concrete mix with 1.5% steel fiber content and reference mix with 0% steel fiber. A number of tests were carried out, such as compressive strength test, flexural strength test, load deflection test, total absorption and permeability test. The result indicated a considerable improvement in all the mechanical properties, where the SIFCON mixes showed high compressive strength values up to 102.7 N/mm2 and extraordinary flexural strength values up to 39.5 N/mm2 at 180 days age. Using of metakaolin was beneficial in improving the mechanical properties at later age as well as in reducing the total absorption and permeability of the SIFCON mixes.

[1] I would like to thank The ***Academic Research Institute*** in Iraq for funding this research and for supporting Iraqi academics and researchers and for promoting research in Iraq.

Introduction

SIFCON was made for the first time four decades ago[2], since that time many researchers had investigated its properties, method of production and performance. Most studies agreed on the stressed the superiority of SIFCON over other types of fiber reinforced concrete, although there were some determinants about its production method. The most important advantageous of this concrete can be summarized below.[2]

1. Better behavior in stress-strain under compression as well as under tension stresses, it has a quite large strain capacity and energy absorption (toughness) could be 1 to 2 in orders of magnitude higher than that of a plain matrix,
2. Improved flexural behavior and flexural strength,
3. A superior ductility and crack resistances.
4. Increased impact resistance.
5. Improved bond strength between reinforcing bar and surrounding matrix
6. Lower drying shrinkage strain which was only about 15% to 20% that of the unreinforced paste or mortar due to restraining effect of steel fibers.
7. Enhanced freezing and thawing resistance relative to unreinforced concrete.
8. In spite of the high cost of raw materials and production techniques of SIFCON, the benefits gained by its uses and its thin layer sections considered valuable compared to other common alternatives.

On the other hand it should be noted that there were some disadvantages of this concrete which can be review as follow.[3]

1. The unit weight of SIFCON was typically higher than concrete and normal SFRC because of the relatively heavy weight of the high steel fiber content. The density could reach 3130 kg/m3 for steel fiber content up to 20 % volume fraction.
2. SIFCON matrix contained a high content of the cementitious materials which is meaning a high heat of hydration emission during the early ages. So it needs for special care after casting to avoid the harmful effect of thermal stresses.
3. It needs special skills in production.
4. Durability of this concrete had not been adequately studied especially with regards to long term performance in different environmental exposure conditions.

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[2] Lankard, D. R., 1985; Gilani, A. M., 2007; Ali, M. A, 2018

[3] As above.

Aim of the Research:

This research aims to study the possibility of using modern techniques of building materials (slurry infiltrated fiber concrete) in repairing damaged buildings. Many building in Iraqi cities have been exposed to damage either by terrorist acts or due to obsolescence. This technique will contribute to the rapid restoration of civilian life in these cities. It can be used to strengthening the damaged structural elements and restore their original performance. Due to the scarceness of the research works and the limited information in this field, this research will provide the necessary information to adopt this technique in the restoration of cities and villages destroyed in the last three decades.

Objective and scope

The objective of the study is to investigate some mechanical properties of the slurry infiltrated concrete. The scope of the study was designed in such a way to serve the planned objective. Six concrete mixes were made, these were SIFCON mixes with 6%, 8% and 10% of steel fiber as volume fraction, SIFCON mix with 8% steel fiber content as volume fraction and 10% of metakaolin as partial replacement of cement, steel fiber concrete with 1.5% steel fiber content and reference concrete with 0% steel fiber. Compressive strength, flexural strength, load deflection, total absorption and permeability were investigated at different ages. Figure 1 shows the details of the experimental program.

Materials

Ordinary Portland cement Type I, was used. Chemical and physical properties of cement are presented in Tables 1 and 2 respectively, which confirmed to ASTM C150[4]. Natural sand was used, grading and other properties of the sand is presented in Table 3 which is confirmed with Iraqi standard specification No. 45[5]. Metakaolin was used as partial replacement of cement in one of the mixes; locally available kaolin was ground by the blowing technique. The calcination time was 2 hours at 700°C, the temperature raised by rate of 2°C/min[6]. 10 % of metakaolin was used as replacement by weight of cement. The chemical and physical properties of metakaolin are listed in Table 4 which conforms to the requirements of ASTM C 618[7]. Loosed hooked end steel fiber was used as shown in Figure 2, the properties of hooked end steel fiber are

[4] ASTM C 150-15, 2015
[5] Iraq Standard Specification (IQS) No.45, 1984
[6] Al-Rubaie, M.F., 2007
[7] ASTM C 618-15, 2015

presented in Table 5 which is in complains with requirement of ASTM A820/A820M-15[8]. Also a high performance super plasticizer (Hyper plasticizer) which is commercially known as Hyperplastic PC200 was used in order to improve the fluidity of the SIFCON slurry and to break up the cement lambs. The technical properties of this product are presented in Table 6 which is complies with ASTM C494-15, type A and G[9].

Mixes proportion and procedure

In order to select the mixes proportioning in this research several trial mixes were made to select the proper proportions based on the selected materials. The design procedure can be summarized in two steps:

Step No. 1: Specifying the minimum and maximum steel fiber volume fraction. The minimum fiber volume fraction determined based on finding the minimum amount of fiber that fills the mold without using vibrator and without blockage of slurry during infiltration. While the maximum fiber volume fraction, is defined as the highest amount of fiber that can be placed in the mold under vibration and without blockage of slurry during infiltration. The minimum and maximum percentages of steel fiber were 6% and 10 % respectively. In addition to these two contents, 8 % of steel fiber was taken as an intermediate fiber volume fraction which can be achieved with slight vibration during fiber placement into the molds.

Step No. 2: preparing the slurry, several trials had been made to obtain suitable slurry that can efficiently infiltrated through the dense steel fiber network. The adopted proportion was 1: 1 by weight as (cement: sand) and the water /cementitious ratio was 0.31 in all mixes. In addition to SIFCON mixes two reference mixes were produced, one with 1.5% of steel fiber and the other without steel fiber. Both mixes prepared with the same slurry as in SIFCON mixes for comparison reasons. Designation and proportions of materials of each mix are presented in Table 7 and in Figure 3.

Test results

1. Compressive strength

The compressive strength test was determined according to B.S. 1881: part 116 10 on 100 mm cube specimens. The test results for compressive strength at 28 and at 180 days age are depicted in Figure 4. The results indicated an increase in compressive strength of SIFCON mixes

[8] ASTM A820/A820M-15, 2015
[9] ASTM C 494-15, 2015
[10] B.S.1881-Part 116, 1989.

at both ages relative to the reference mix. The percentage of increase in compressive strength is proportional with the steel fiber content, the higher steel fiber content mix was the higher compressive strength. The percentages of increase in compressive strength at 180 days for mixes F1.5, F6, F8, and F10 relative to mix R were 22.2%, 69.1%, 87.6% and 123.2% respectively. This improvement was attributed to the better confinement achieve by high steel fiber content which leading to reduce the transversal deformation of specimen and increase its compressive strength. On the other hand it was found that using of metakaolin reduce the compressive strength at 28 days age relative to mix F8 that had the same steel fiber content but without metakaolin, although the compressive strength was improved at 180 days, this behavior was attributed to the pozzolanic effect of the metakaolin. The percentage of increase in the compressive strength for mix M at 180 days age was 13.6% relative to mix F8.

2. Flexural strength

This test was carried out on 100×100×400 mm prisms. The flexural strength was calculated by using simply supported prism with a clear span of 300 mm under two third point loading consistent with B.S.1881: part 118[11]. The test was carried out at 28 and 180 days age, the test results were presented in Figure 5. The result showed that SIFCON mixes possessed significantly higher flexural strength relative to the reference mix as well as to steel fiber concrete with 1.5% of steel fiber (mix F1.5) even at 28 days age and this improvement was increased with the increment of steel fiber content. The percentages of increase in flexural strength for mixes F6, F8 and F10 relative to mix R at 28 days age were 294%, 392%, and 465% respectively, and they were 127%, 185% and 151% respectively relative to mix F1.5 at the same age. This was attributed to the steel fiber ability into arresting and preventing the progress of microcracks which is increased as the fiber content increased. Using of metakaolin in mix M showed a considerable enhancement in the flexural strength compared to mix F8 with 13% of increase at 180 days age although at 28 days mix M showed a lower flexural strength relative to mix F8. This behavior was due to the pozzolanic effect of metakaolin which is more evidence at later ages.

3. Load-deflection relationship:

Load-Deflection behavior of the specimens could be observed in Figure 6 as a load-deflection relationship curve. The deflection was measured at the center point of prism span. The ultimate loads were recorded when the specimens would not sustain deformation any more at constant load, while the first crake load was recorded depending on visual monitoring. This test was carried out for mix R, F6, F8, and F10. Reference mix showed a sudden failure in a brittle manner directly after the maximum load was reached, this behavior is attributed to the

[11] B.S.1881-Part 118, 1989.

brittle failure of concrete in the absence of reinforcement. On the other hand, SIFCON absorbed the flexural tensile stress recognized to the bending action. The first crack is initiated at the bottom surface of the prisms once the flexural tensile strength of concrete is reached as shown in Figure 7.

4. Total absorption test

This test was carried out with regards to ASTM C642[12], 100 mm cubes were used to determine the total absorption. The results are listed in Table 8 and grafted in Figure8. Mix R showed the highest total absorption values relative to mix F1.5 and SIFCON mixes. This was attributed to the role of steel fiber that may hinder the progress of crack induced permeability. Where the transport mechanisms are either gets through bulk material or through cracks. On the other hand it was noted that increasing the fiber content from 6% to 10 % slightly reduces the absorption because steel fiber acts as non- absorbent material and thereby it will reduce the volume available for water to flow through inside the SIFCON composite. All mixes showed a reduction in the total absorption test results with time due to hydration of cement, at 180 days the lower total absorption was recorded with mix M at 180 days age due to the efficiency of metakaolin in providing a dense matrix with lower absorption ability.

5. Permeability test

The permeability of concrete was determined by measuring the volume of total permeable porosity according to the experimental technique of B.S. 3921 (1985). The total porosity, p (%) expressed as the percentage of volume of permeable voids Vv (cm3) to the total volume of specimen VT (cm3). The test was carried out at 28 and 180 days age on 100 mm cubes, the result of the total porosity test were given in Table 9. The results indicated a reduction in total porosity with time due to the progress of hydration, the incorporation of steel fiber led to reduce the total porosity as the amount of the fiber increased. Where at 28 days age the percentage of reduction in total porosity for mixes F1.5, F6, F8 and F10 relative to mix R were 7%, 16%, 20% and 27% respectively. A considerable reduction in the result of total porosity was recorded with mix M even at 28 days age, this was attributed to the fine particle size of metakaolin as well as to its pozzolanic effect.

[12] ASTM C642, 2015

Conclusions and recommendations

The main conclusion that had been driven from this study could be summarized as follow:

1. Slurry infiltrated fiber concrete has a considerable higher compressive strength and flexural strength relative to steel fiber concrete and plain concrete, this improvement could be higher than five times the flexural strength and double times the compressive strength of the reference mix.

2. Steel fiber will significantly improve the ductility of the concrete and a more ductile behavior was obtained with SIFCON mixes. The higher steel fiber content was the better performance with regard to the load-deflection test.

3. Using of 10 % metakaolin improve the mechanical properties at 180 days age although a slight reduction in the mechanical tests values were recorded at 28 days age. On the other hand, incorporation of metakaolin improves the total absorption and total porosity of the SIFCON mix at all ages.

4. Increasing the steel fiber content led to reduce the total absorption as well as the total porosity.

5. Based on the above out comes, using of SIFCON with steel fiber content up to 10 % by total volume of the mix is highly recommended to applied in repair and retrofitting of the defected buildings. Using of mineral admixtures such as metakaolin as partial replacement of cement in SIFCON mixes is beneficial into reducing the impact of high consuming of cement and it will improve the mechanical properties at later ages.

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Annex 1

Table 1- Chemical Composition of Cement

Chemical Composition of Cement		
Oxide	Ordinary Portland cement	Limits of ASTM C 150
CaO	61.8	-
SiO_2	20.54	-
Al_2O_3	4.55	-
Fe_2O_3	3.55	-
MgO	3.67	≤6.0%
SO_3	1.65	≤3.0%
Na_2O	0.41	-
K_2O	0.28	-
L.O.I	2.1	≤3.0%
I.R.	0.7	≤0.75%
Main Compounds (Bogue's equations)		
C_3S	55.13	-
C_2S	17.30	-
C_3A	6.05	-
C_4AF	10.80	-

Table 2

Physical Properties of cement		
Physical Properties	Ordinary Portland cement	Limits of ASTM C 150
Soundness by Autoclave %	0. 5	≤ 0.8
Fineness (air permeability test) cm2/gm	3130	≥2800
Setting Time (Vicat's method)		
Initial setting time, hrs:min	2:45	≥1 hr
Final sitting time, hrs: min	4:50	≤10 hrs
Compressive strength at		
3days, MPa	18.6	≥12
7days, MPa	25.5	≥19

Table 3

Sieve size (mm)	Passing by weight%	Limits of Iraq specification No.45/1984 Zone(3)
9.5	100	100
4.75	100	90-100
2.36	100	85-100
1.18	100	75-100
0.6	70	60-79
0.3	30	12-40
0.15	5	0-10
% Passing 0.075 mm	2.4	<5
Fineness modulus = 2.93		
Properties	**Test results**	**Limits of Iraq specification No.45/1984**
Specific gravity	2.65	-
Bulk density(kg/m3)	1680	-
Sulfate content %	0.45	≤ 0.5%
Absorption %	1	-

Table 4

Chemical Properties		
Oxides	Content %	Requirements of class N pozzolans according to ASTM C618
CaO	1.37	-
SiO_2	54.20	≥ 70
Al_2O_3	39.00	
Fe_2O_3	0.92	
MgO	0.15	-
SO_3	0.45	≤ 4
Na_2O	0.22	-
K_2O	0.27	-
L.O.I	0.71	≤ 10
Physical properties		
Fineness (air permeability test) cm2/gm		14300
Specific gravity		2.64
28 Days strength activity index (%)		92.3

Table 5

Type of hooked end steel fiber	Length, mm	Diameter mm	Aspect ratio l/d	Density kg/m3	Tensile strength MPa
Loosed , low carbon steel fiber	35 ±10%	0.6±10%	58	7800	>1000

Table 6

Technical properties at 25º C	
Based material	Polycarboxylic polymers with long chains
Color	Light yellow liquid
Freezing point	≈ -3º C
Specific gravity	1.05 ± 0.02
Air entrainment	Typically less than 2% additional air is entrained above control mix at normal dosages

Table 7

Designation	Cement kg/ m3	Fine Agg. kg/ m3	Metakaolin kg/ m3	Hyperplasticizer % by wt. of cement	Corrosion Inhibitor l/ m3	Steel fiber % vf
R	885	885	-	0.7%	-	0
F1.5	885	885	-	0.7%	-	1.5
F6	885	885	-	1%	-	6
F8	885	885	-	1%	-	8
F10	885	885	-	1%	-	10
M	799.5	885	85.5	1.2%	-	8

Table 8

Designation	Total absorption % at age of (days)		
	28	90	180
R	2.88	2.43	2.21
F1.5	2.69	2.13	1.83
F6	2.61	2.09	1.91
F8	2.55	2.11	2.00
F10	2.42	2.06	1.95
M	2.24	2.04	1.93

Table 9

Designation	Total Porosity % at age of (days)	
	28	180
R	3.46	3.2
F1.5	3.21	3.0
F6	2.92	2.6
F8	2.76	2.3
F10	2.54	2.15
M	2.42	1.81

Annex 2

Figure 1: Experimental program

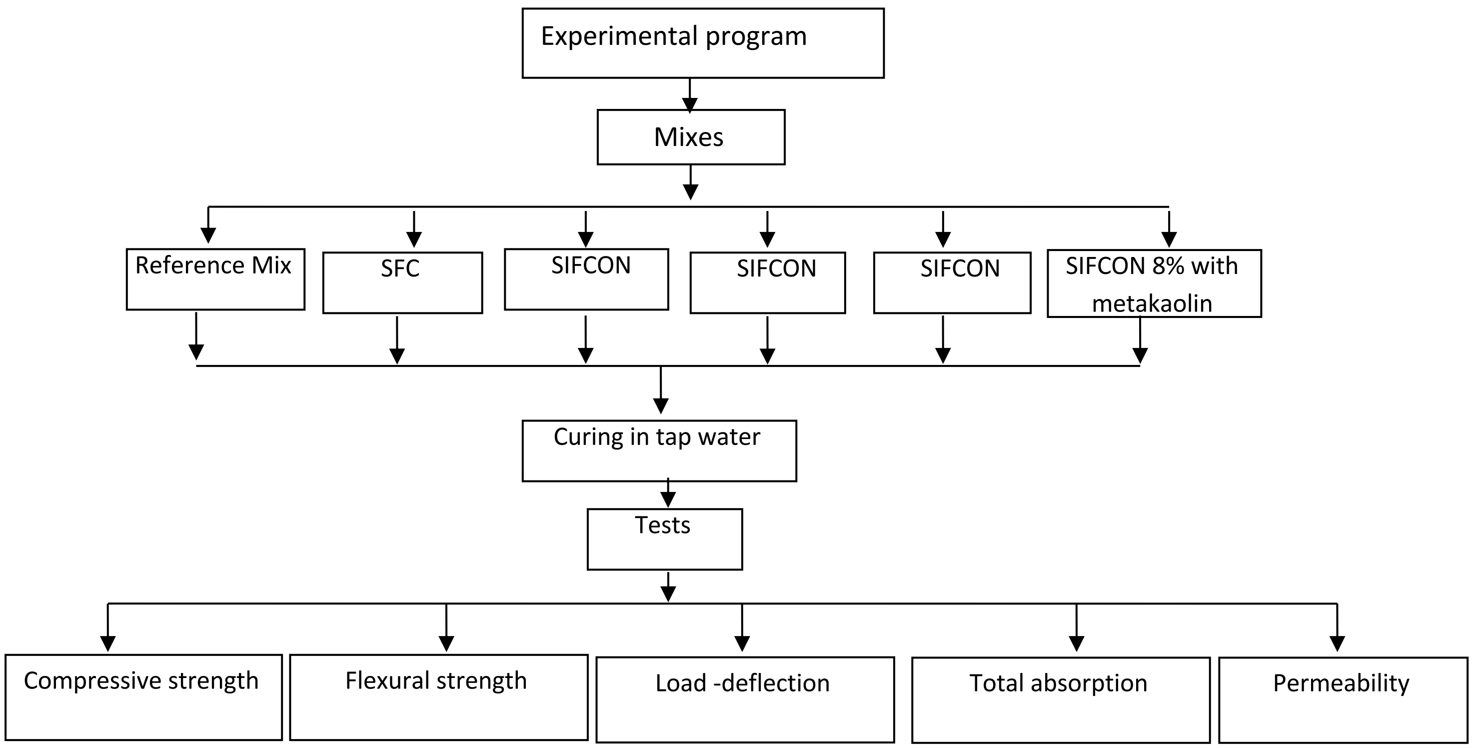
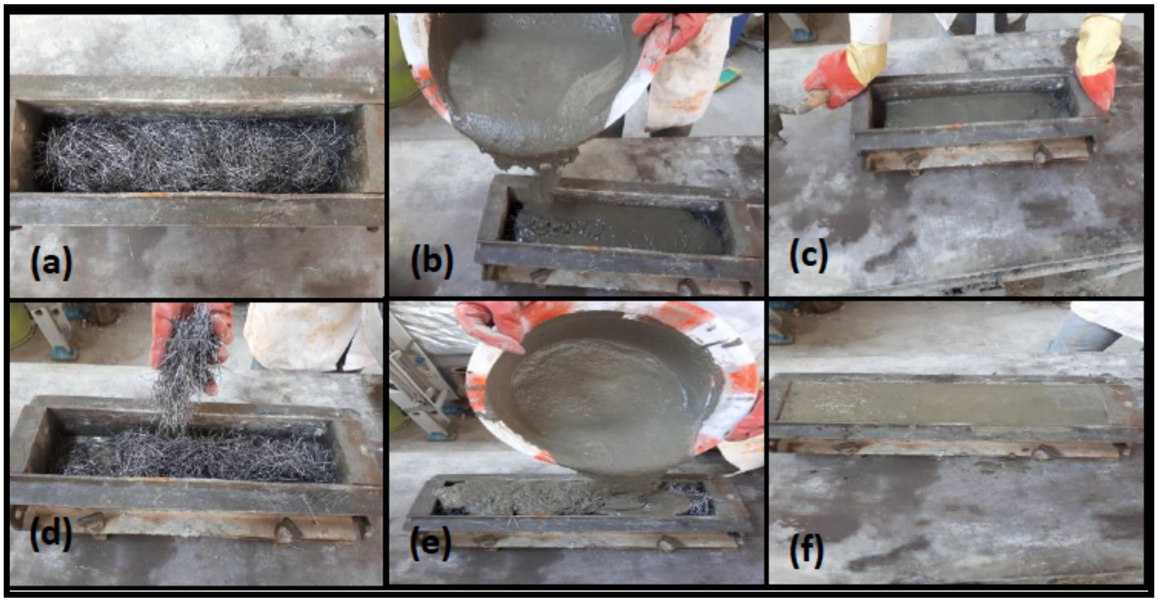


Figure 2

Figure 3



(a): placing 1st layer of steel fiber, (b): infiltration of slurry for 1st layer of SIFCON, (c): vibration, (d): placing the 2nd layer of steel fiber, (e): infiltration of slurry for 2nd layer of SIFCON and (f): vibration and leveling for 2nd layer

Figure 4

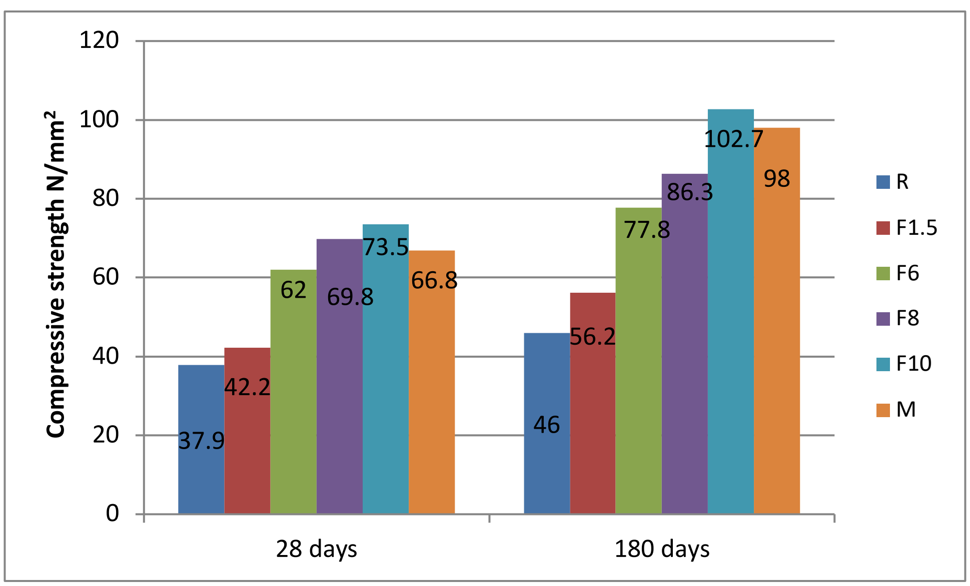


Figure 5

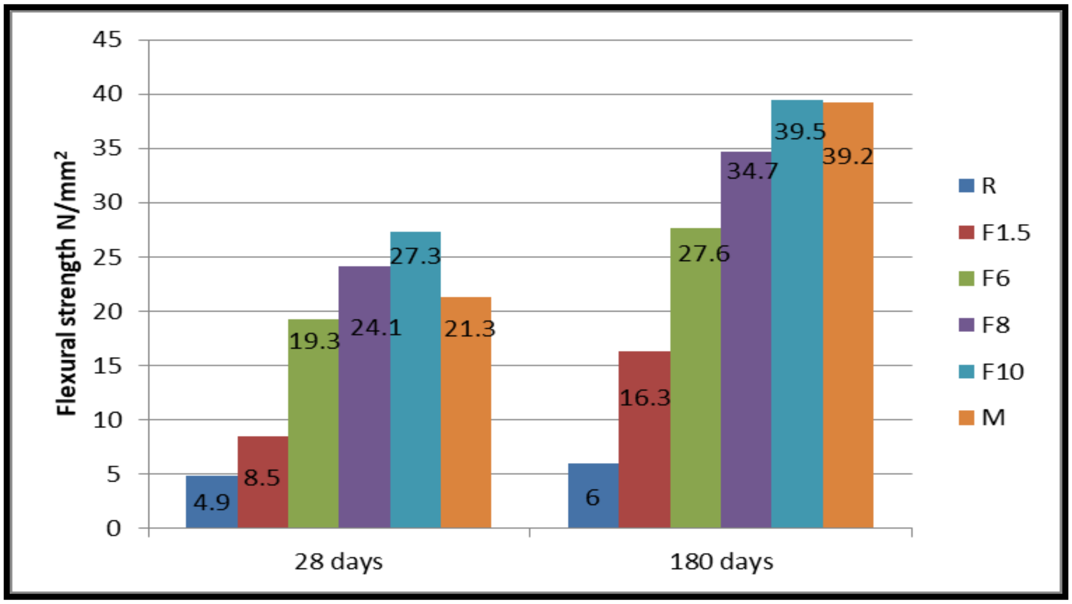


Figure 6

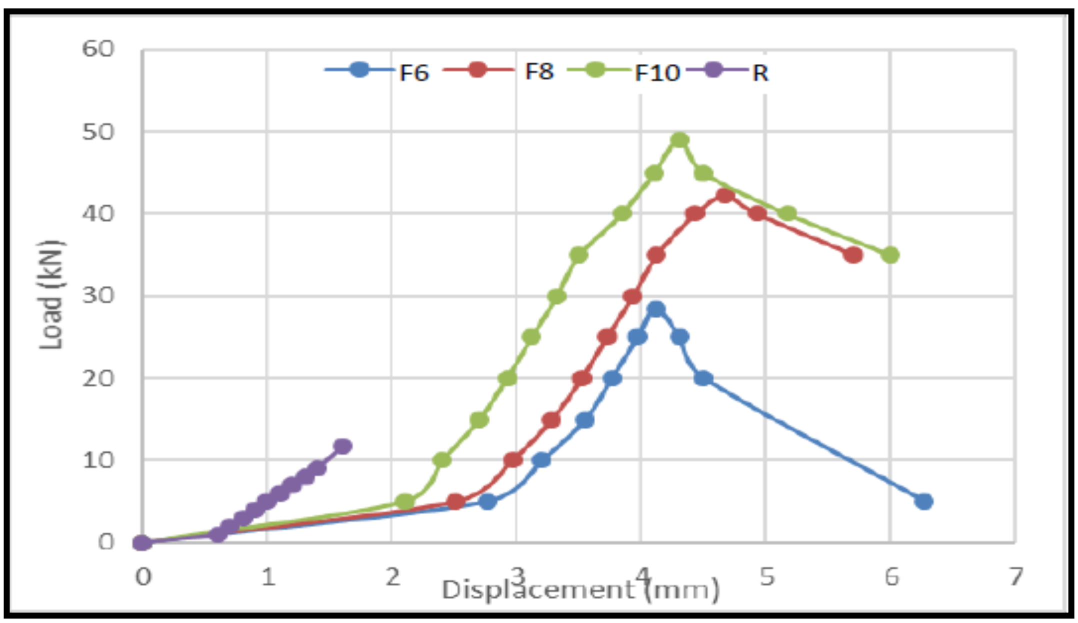


Figure 7

Figure 8