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Evaluating the performance and effect of the number of FRP composite wrapping on strength and ductility for low strength concrete

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ABSTRACT

FRP composites wrapping is one of the current approaches for many retrofitting concrete. It is considered as a new generation of materials. The main reason for using FRP is their outstanding mechanical and chemical properties as well as quick installation which all these advantages compensate for their cost at starting used. The main anxiety about the use of FRP is the minimum strength of the base substrate and its number of wrapping effect on the strength and ductility of the concrete. For this purpose, in this investigation, we measure the effect of FRP wrapping on low strength concrete. Three samples with inadequate cement content (i.e. 75, 150, and 225 kg/m^3) were prepared then each sample arranged in two different shapes, cubic with dimensions of 15×15×15cm and cylindrical ones with a diameter of 15 cm and a height of 30 cm. Longitudinal compressive tests were performed over several samples. Total of four cases were considered: One, three, five wrapping of FRP layers and sample with no FRP. The result showed that the effect of FRP wrapping is much higher on those samples with the least cement content. Results include compressive strength, elasticity modulus, failure strain, ductility and energy absorption. We also realized that as the number of FRP wrapping increased from one to three layers, the compressive strength, failure strain and energy absorption were enhanced too but the growth rate dropped in the most properties as the wrappings increased from 3 to 5 layers.

Keywords: FRP Composite Wrapping; Strength; Ductility; Energy Absorption; Low Strength Concrete

1. INTRODUCTION

Currently, repairing and retrofitting of defective structures is considered as one of the important issues of civil engineering all over the world. Fiber Reinforced Polymer (FRP) systems can be used with the aim of rebuilding or maintaining strength of a worn out structural member, repairing or retrofitting of undamaged structural members in order to endure the increased load due to changing of the structure operation or compensating for design and implementation mistakes.

1.1 History of FRP

In Europe, FRP systems were developed as alternates to steel plate bonding. Bonding steel plates to the tension zones of concrete members with adhesive resins were shown to be viable techniques for

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increasing their flexural strengths. This technique has been used to strengthen many bridges and high rise buildings around the world. Because steel plates can corrode, leading to a deterioration of the bond between the steel and concrete, and because they are difficult to install, requiring the use of heavy equipment, researchers have looked to FRP materials as an alternative to steel. Experimental work using FRP materials for retrofitting concrete structures was reported as early as 1978 in Germany. Research in Switzerland led to the first applications of externally bonded FRP systems to reinforced concrete bridges for flexural strengthening. FRP systems were first applied to reinforced concrete columns for providing additional confinement in Japan in the 1980s. Previous research and field applications for FRP rehabilitation and strengthening are described in ACI 440.2R-17 (2017). In Europe, the International Federation for Structural Concrete (FIB. 2001) published a bulletin for design guidelines, entitled "externally bonded FRP reinforcement for reinforced concrete structures".

1.2 Confinement of FRP

Confinement is generally applied to members in compression, with the aim of enhancing their load carrying capacity or, in cases of seismic upgrading, to increase their ductility. Traditional confinement techniques rely on either steel hoops or steel jackets for upgrading. Indeed, it is well known that increasing the confinement action enhances the concrete strength and ductility and, in addition, prevents slippage and buckling of the longitudinal reinforcement. In seismic problems, existing upgrading (either strengthening or retrofitting) techniques are typically based on increasing the confinement pressure in either the potential plastic hinge region or over the entire member. This technique can also be useful in lap-splices zones. Several experimental studies on concrete confined with FRP have been carried out which confirm the viability of this solution. Current analytical and numerical research aims at defining appropriate constitutive laws for FRP-confined models. In the field of design of FRP jackets extensive experimental work has been conducted by Seible et al (1995), and numerical and analytical work by Monti et al (2001), with the task of identifying suitable design equations that optimize the FRP jacket thickness as a function of the desired upgrading level. In this research, the Carbon fiber reinforced polymer has been selected for strengthening the concrete samples. This kind of FRP has the greater tensile strength and lower strain in comparison with other types of fibers (i.e. GFRP and AFRP). These Mechanical properties for CFRP provide the better confinement respect to the other ones.

1.3 Stress-strain model of FRP-confined concrete

Several models that simulate the stress-strain behavior of FRP-confined compression sections are available in the literature, for example Lam and Teng (2003) and Mander (1988) models. The stress-strain model by Lam and Teng (2003a,b) for FRP-confined concrete has been adopted by the committee ACI440. 2R-17 (2017) and is illustrated in Figure 1.

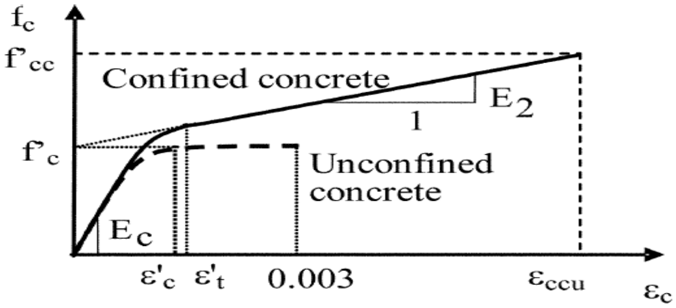

Figure 1. Lam and Teng’s stress-strain model for FRP confined concrete

In this study, regarding that concrete strength in Iran is low and concrete structures built in the past require repairing and retrofitting, the concrete samples were designed by a mix design that are of low strength and it was used from FRP for strengthening the samples. In the continuation of the study, the effects of using FRP on the strength and ductility of the concrete samples were investigated.

2. Experimental program

In this section, the material properties, mix design, preparation and curing are described respectively. In this study, the materials are selected so that it can provide the low strength concrete samples.

2.1. Material properties

The ordinary Portland type-II cement is used in the specimens. It was based on ASTM C150 (2007) and the gravel and sand aggregates are of river type in accordance with ASTM C33 (2003). The sand sizes ranged between 0 to 4.75 mm with apparent weight in SSD (Saturated Surface Dry) state of 2650 kg/m^3, and its 24-hour water absorption is 1.5% and also the super plasticizers are of type P10-3R based on ASTM C494 (2005). The FRP is of type C230 based on the properties presented in Table 1, and the used resin is of type epoxy DUR 300, in accordance with Table 2.

Table 1. Technical properties of FRP Fiber.

Name	WrapHex_230C
Fiber type	High Strength Carbon Fibers
Fiber direction	Unidirectional
Fiber tensile strength	4100 N/mm^2
Tensile elasticity modulus	231000 N/mm^2

Table 2. Technical properties of Resin.

Mixing ratio	A: B = 100:34.5 by weight.
Tensile strength	Curing 7 days, +23°C: 45 N/mm^2
Flexural modulus	Curing 7 days , +23°C: 3000 N/mm^2
Tensile modulus	Curing 7 days, +23°C: 3500 N/mm^2

2.2. Mix design

In this study, 12 mix designs were used and summarized in Table 3. Three samples were built for each mix design. Abbreviation in Table 3 designates the following:
C#: Value of cement content and L#: number of layers of FRP

Table 3. Mix designs used in different sample.

Mixture code	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	w/c	Water (lit)
C75L0	75	1066	1460	0.5	37.5
C75L1	75	1066	1460	0.5	37.5
C75L3	75	1066	1460	0.5	37.5
C75L5	75	1066	1460	0.5	37.5
C150L0	150	1006	1377	0.5	75
C150L1	150	1006	1377	0.5	75
C150L3	150	1006	1377	0.5	75
C150L5	150	1006	1377	0.5	75
C225L0	225	945	1294	0.5	112.5
C225L1	225	945	1294	0.5	112.5
C225L3	225	945	1294	0.5	112.5
C225L5	225	945	1294	0.5	112.5

2.3 Samples preparation

First the concrete was constructed and then it was inserted into pre-prepared molds and are kept in constant temperature and humidity for 24 hours in order to harden. Two different mold shapes were used, a cylindrical with dimensions of 15×30 cm and a cubic with a side length of 15 cm. After 24 hours, the specimens are removed from the molds and are placed into a water pond with temperature of 20 ± 2 °C for curing. Ertalon material was used to make a round cubic samples (see Figure 2). The ertalon material was manufactured in turnery in the form of a right triangle with two sides of 2.5 cm and a crescent chord of about 3.92 cm. The curing time of the samples was equal to 28 days in order to do compressive strength and elasticity modulus tests. After 28 days, the samples were taken out from the pond and placed in the laboratory for drying the surface of the samples. After two days, the samples were prepared in four modes including without FRP and with 1, 3, and 5 layers of FRP warps and after 7 days, they were subjected to compressive strength and elasticity modulus tests (Figure 3).

Figure 2. How to make rounded the cubic samples

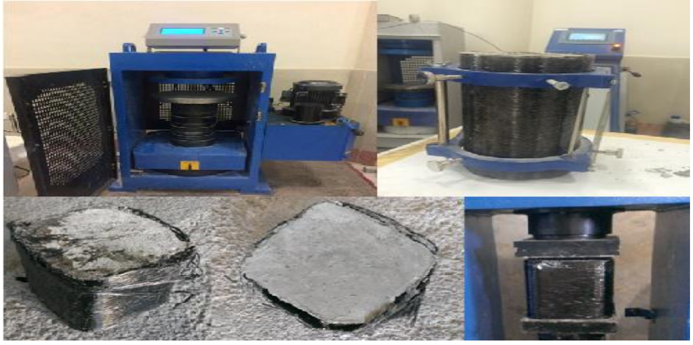

Figure 3. Samples manufactured for compressive strength and stress-strain tests

3. Results and discussion

This section deals with the investigation of the influence of using CFRP with different layers on the compressive strength, elasticity modulus, stress-strain curves, failure strain, energy absorption, and ductility of concrete samples.

3.1 Effect of Number of sheet CFRP fiber on compressive strength

The cubic specimens were prepared based on the standard ASTM C39 (2005) corresponding to each mix design for compressive strength testing. There were remained inside the molds for 28 days. After taking out from the molds, the cubic samples were warped by CFRP fibers with numbers of 0, 1, 3, and 5 layers. The effect of these layers on the compressive strength of the samples is shown in Figure 4.

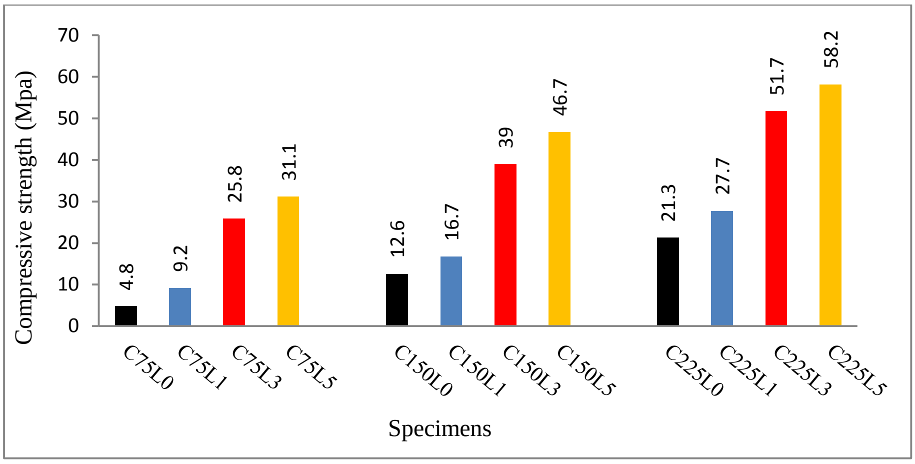

Figure 4. Compressive strength of cubic samples

As it can be seen in Figure 4, the compressive strength of the concrete samples increased with the increase of cement content and the number of FRP sheets due to the effect of bonding and confinement. Moreover, for instance, according to Figure 5, the samples of C75L3, C150L3, and C225L3 have compressive strength enhanced of 438, 210, and 143 percent as compared to the samples without FRP.

This obviously shows that the concrete has higher strength for those samples with more sufficient cement content but on the contrary, FRP has less impact on enhancing their strength and therefore influence of FRP in carrying the load in concrete with a higher strength is much less in contradiction with lower strength concrete and this is because of FRP has less contribution in sustaining the load in those type of materials. And this is mainly because that primarily concrete participates in carrying the load and then FRP interferes after the crack development in concrete.

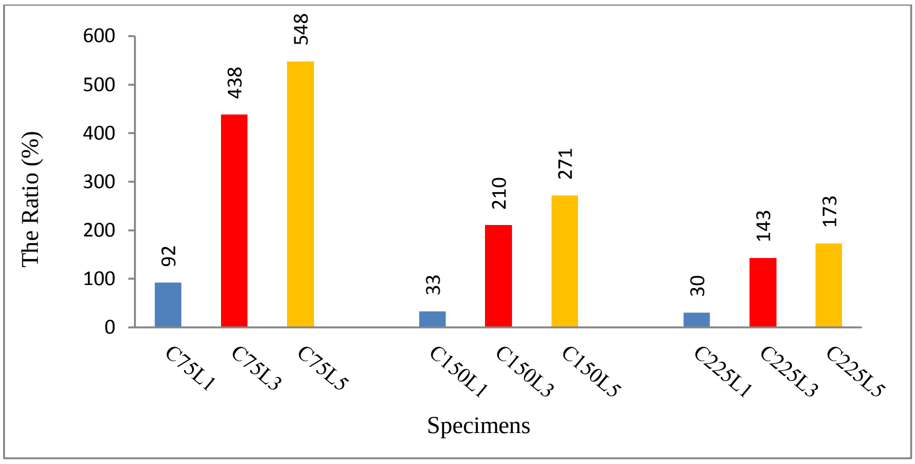

Figure 5. The ratio of the increase in the compressive strength of samples with increasing number of FRP layers relative to samples without FRP

3.2 Effect of Number of sheet CFRP fiber on Modulus of elasticity

The elasticity modulus testing was performed on the 15×30 cm cylindrical samples at the age of 28 days, in accordance with standard ASTM C469 (2014). The results for the testing samples are presented in Figure 6.

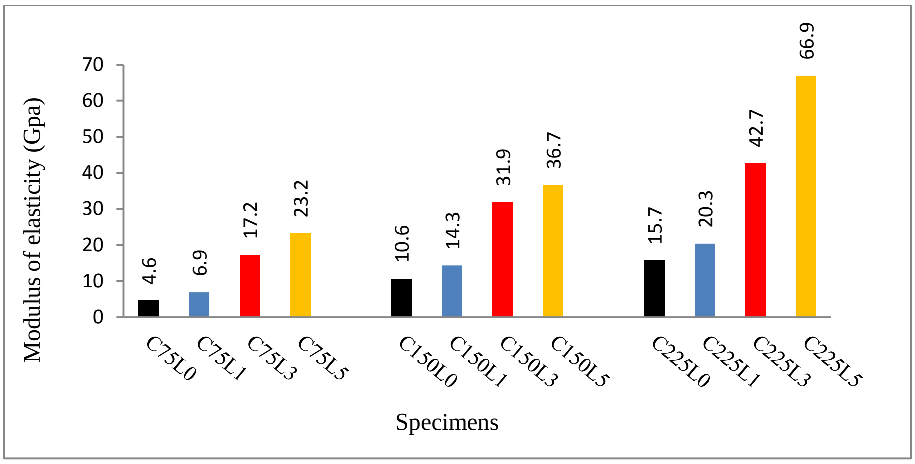

Figure 6. Elasticity modulus of cylindrical samples

Figure 6 shows that with addition of cement content and the number of FRP layers, the elasticity modulus of the concrete specimens are increased and this is due to the effect of bonding among the concrete aggregates and its confinement by FRP.

As a demonstration, Figure 7 exhibits the increase in elastic modulus of C75L3, C150L3, and C225L3 samples by 277, 200, and 172 percent compared with the one without FRP wrapping.

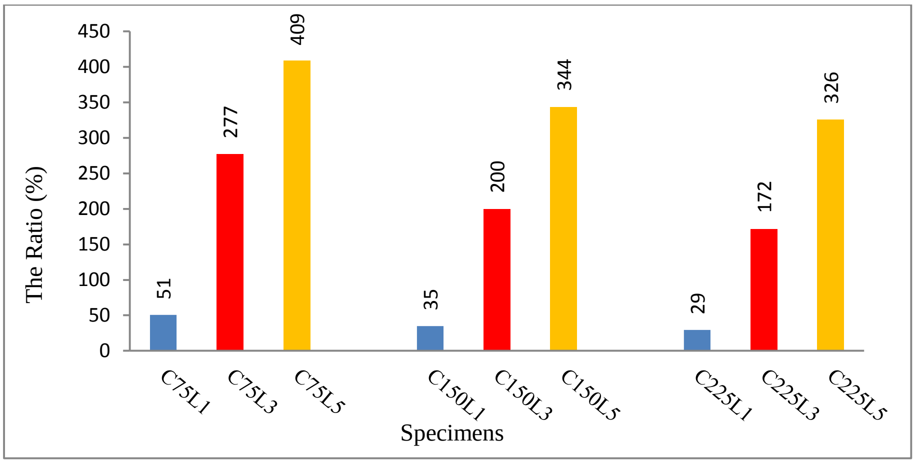

Figure 7. The ratio of increasing of elasticity modulus of samples with FRP layers relative to samples without FRP

3.3 Effect of Number of sheet CFRP fiber on curve stress-strain behavior

The stress-strain tests were performed on the 15×30 cm cylindrical samples at the age of 28 days and shown in Figures 8, 9 and 10.

The plots demonstrate two main obvious points: One is that the energy absorption (the area under the stress-strain curve) of samples increases not only by adding the cement content but also by increasing the number of FRP layers (i.e. from one to five) and the second one is how rising energy absorption and failure strain are affected by concrete compressive strength.

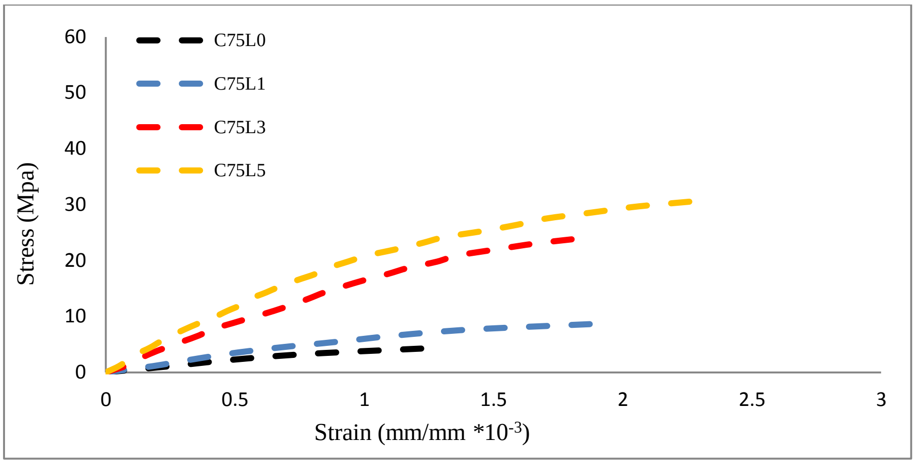

Figure 8. Stress-strain diagrams for samples with cement content of 75 kg/m^3

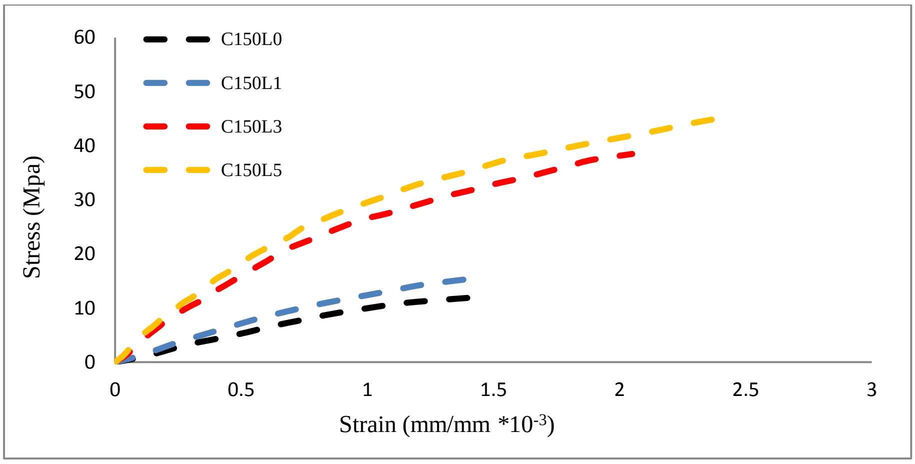

Figure 9. Stress-strain diagrams for samples with cement content of 150 kg/m^3

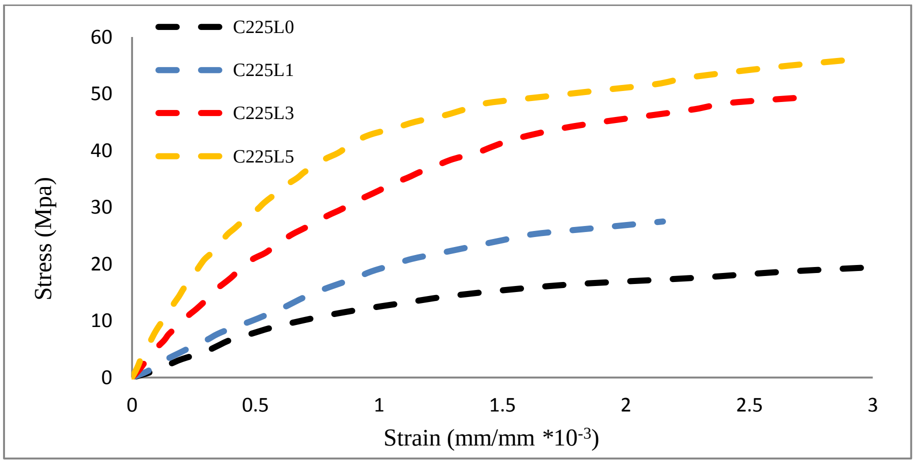

Figure 10. Stress-strain diagrams for samples with cement content of 225 kg/m^3

3.4 Comparison of the failure strain

The experimental performance on samples, Figure 11 shows that specimens with lesser part of cement content and higher number of FRP sheets have positive effect on increasing the limit of failure strain, nevertheless, there are some few exception to this result, one is sample with cement content of 75 kg/m^3 which has some disorderly results. In the other two cement content samples, the three layers of FRP sheets make the failure strain significantly increased but the five layers one do not show the same rate increase as the three layers one. So, we can suggest with caution that three FRP wrappings are the most optimized choice compared to others.

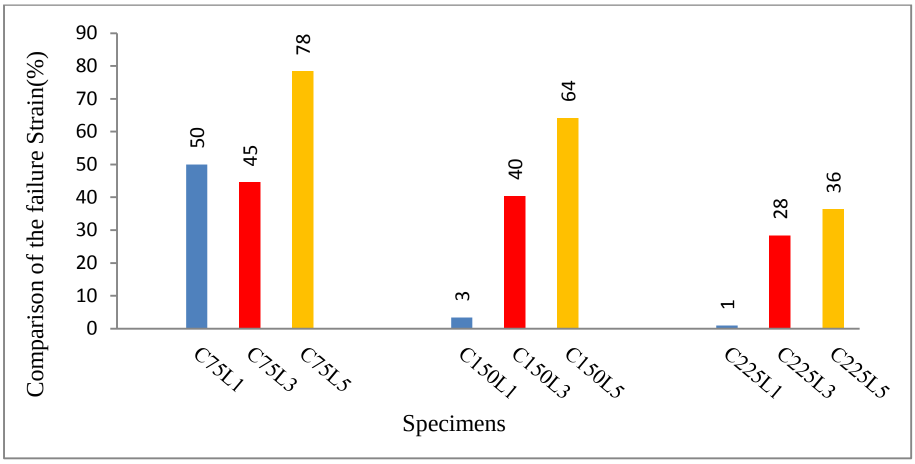

Figure 11. The ratio of the failure strain of FRP strengthened samples to non-strengthened samples (%)

3.5 Effect of CFRP fiber on energy absorption

In this study, MATLAB software (2010) has been used to estimate the area under the stress-strain curves for cylindrical 15×30cm specimens. This area illustrates the amount of energy absorption. The large-scale of area indicates the more energy is absorbed. In this process, we first compute the energy absorption of each mix design samples and then there were normalized. Considering all the three cement contents separately, the normalization was done by dividing the area under the curve of each sample to the minimum area of the sample without FRP (i.e. C75L0).

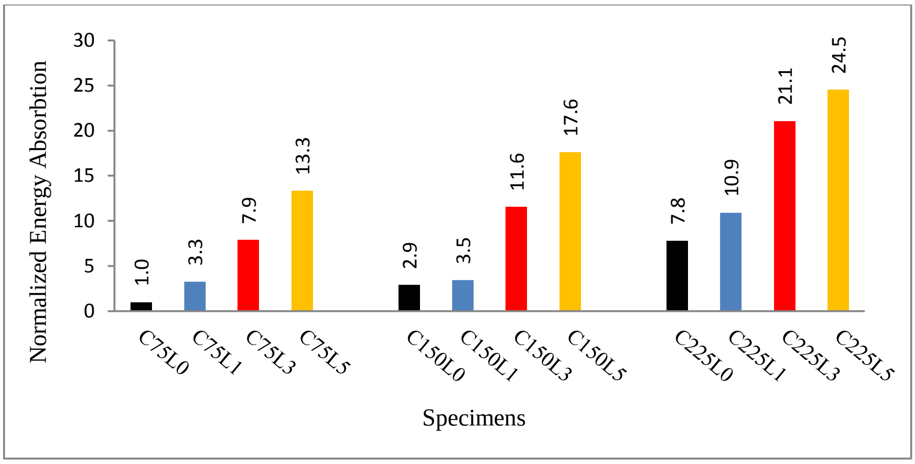

Figure 12. The normalized of energy absorption for each concrete sample to the minimum energy absorption

3.6 Effect of CFRP fiber on ductility

The ductility of the cylindrical 15×30cm samples is defined by dividing the failure strain over the yielding strain, this is in accordance to ASCE41-13 (2013). The yield strain was estimated by the following procedure:

Using MATLAB software (2010) to make the stress-strain curve of the sample an equivalent bilinear then the intersection of the lines is referred to yield strain (illustrated in Figure 13 for mix sample C150L5)

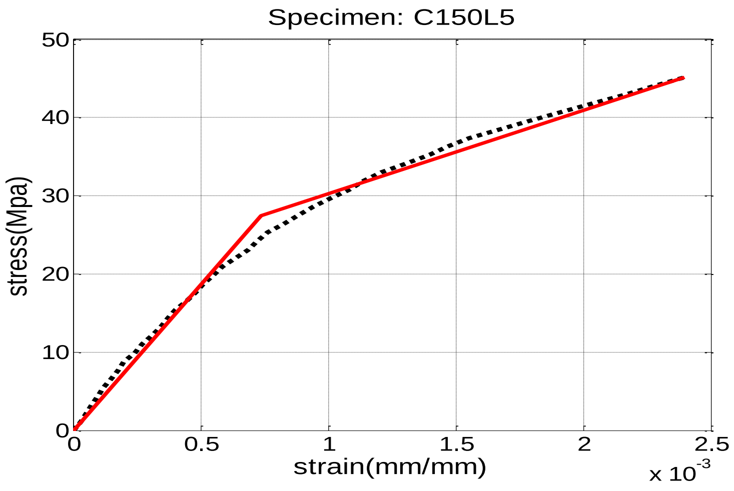

Figure 13. Ductility of concrete sample CL50L5 using MATLAB software

Figure 14 demonstrate that the ductility of concrete samples increases with increasing of the number of FRP layers in the most cases. However, in high strength concrete specimens among those without FRP has a higher ductility.

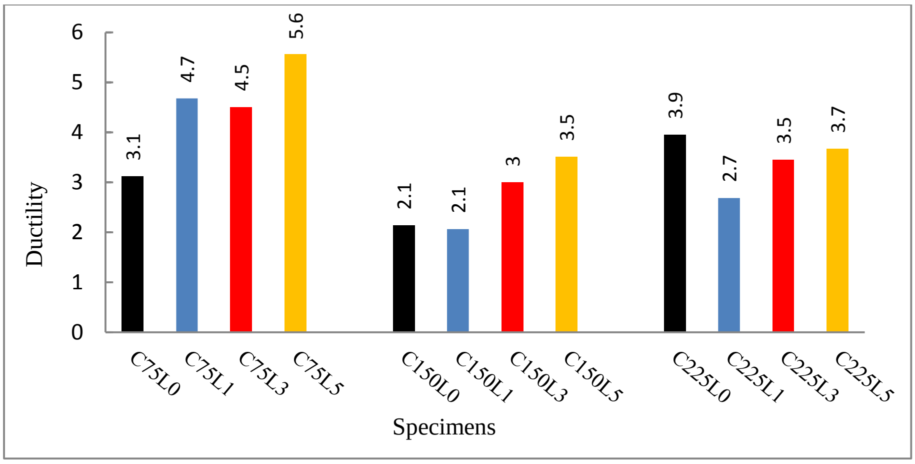

Figure 14. Ductility of testing samples with and without CFRP

4. Conclusions

1. In this study, in the most cases, mechanical properties of concrete such as the compressive strength, elasticity modulus, failure strain, energy absorption, and ductility are increased with piling up more layers of FRP. However, the FRP has more significant effect on these properties in the specimens having lesser part of cement content or in another words, concrete with lower strength.

2. We should emphasis (but not so strongly) that the growth of increasing of these mechanical properties is higher in samples with three layers of FRP compared to others.

Acknowledgments

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