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EFFECTS OF CLAMPS IN COMPOSITE I-BEAMS STRENGTHENED WITH HM-CFRP

ABSTRACT

Corrosion of steel members and an increase in the traffic loads make the retrofit necessary for steel bridge beams. To strengthen composite steel bridge beams, either the existing damaged members are reinforced or they are replaced with the new ones. Both process demand a bridge to be closed to traffic for a long time. The bridge can shortly be opened to traffic after the damaged beams are rapidly strengthened by means of composite member reinforcements.

In this study, steel beams with I-cross section are reinforced using High Modulus Carbon Reinforced Polymer shortly named HM-CFRP. Also in this study, the effect of using steel clamps on the strengthening method is investigated. The clamps are used to avoid the slip of HM-CFRP material from epoxy.

Keywords: Steel Beam, Composite Beam, Reinforcing, HM-CFRP, Clamps

KOMPOZİT I KİRİŞİN HM-CFRP İLE GÜÇLENDİRİLMESİNDE KELEPÇE KULLANIMIN ETKİLERİ

ÖZET

Kompozit çelik köprü kirişleri artan trafik yüklerinden yada korozyondan dolayı güçlendirilme ihtiyacı doğabilir. Kompozit kirişlerin güçlendirilmesi için ya mevcut elemanlara takviye yapılır yada eleman yenisi ile değiştirilir. Bu işlemler için köprünün uzun süre trafiğe kapatılması gerekmektedir. Kompozit eleman takviyesi ile hasar görmüş kirişlere çok hızlı güçlendirme yapılarak köprü trafiği kısa sürede açılabilir. Bu çalışmada; I profiller çekme dayanımı oldukça yüksek olan Fiber Takviyeli Polimer olarak adlandırılan(HM-CFRP) malzemesi ile güçlendirilmiştir. Bu güçlendirme tekniğinde çelik kelepçelerin varlığının etkisi araştırılmıştır. Kelepçeler HM-CFRP'nin epoksiden sıyrılmasını engellemek amacıyla kullanılmıştır.

Anahtar Kelimeler: Çelik Kiriş, Kompozit Kiriş, Güçlendirme, HMCFRP, Kelepçe

1. INTRODUCTION (GİRİŞ)

For steel bridge beams, retrofit is required due to corrosion of the members and an increase in the traffic loads. Among common solutions are the replacement of the beam with a new one, and welding or bolting steel plates to the damaged section for the systems which undergo a reduction in cross-sectional area due to corrosion or the existing cross-sectional area becomes insufficient as a result of increased traffic loads. However, it is observed that these recommended solutions are time-consuming, not economical and disrupt the traffic for a long time [1]. Furthermore, an increase in the weight and a decrease in the fatigue performance may add up to other drawbacks [1, 2 and 3]. Instead of replacing the damaged members with a new one through welding or bolting, the idea that the retrofitting a member with carbon fiber polymer (CFRP) and adhesive is more applicable has become widespread [4].

The use of adhesives in conjunction with newly popular fiber composite materials has been considered by industry for special applications such as marine structures and in the repair of steel pipelines [5]. Using fiber materials for strengthening purposes has opened a new page for civil engineering. CFRP has been widely used to strengthen reinforced concrete members. The state of the art technology product, High Modulus Fiber Reinforced Polymer (HM-CFRP) with higher elasticity compared to the CFRP, has been started to be used in structural steel elements [6]. HMCFRP material may have elastic modulus up to three times than that of steel. High modulus carbon fibers are placed into pultruded laminates. HMCFRP plates can be used to increase the stiffness strength of steel bridges [3, 4, 7, 8 and 9].

CFRP materials are particularly preferred due to their corrosion resistance and the fact that the steel bridge beams especially their tension flange mostly undergo corrosion. CFRP materials are advantageous for being thin and light, and do not increase the weight of system. Moreover, FRP materials prevent cracks caused by fatigue [10]. In recent studies, CFRP is applied in welded connections, where fractures are expected the most, and very positive results are observed [11 and 12]. Also; CFRP sheets are used to strengthen in fill walls to increase their strength against lateral loads. Along with this; infill walls with structural opening are reinforced with CFRP [12, 13 and 14]. Adding a new section to an existing one through welding or its replacement reduces its strength. Steel is a heavy material and adding extra steel members also increases the weight of the system, thus FRP material has another advantage over steel materials due to its lightweight. It is also known from the previous studies that welding causes damage to the section. However, CFRP material also prevents beam cracks taking place during fatigue tests in addition to strengthening effect [6]. Therefore, use of CFRP material in reinforcement method provides another advantage.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Different brands of epoxy are tested in order to determine which type of epoxy is to be used. Made up I-cross section beam having a similar bending behavior were tested in place of reinforced concrete composite steel beams and the reinforcement methods are subsequently applied on the made up I-cross section steel beams.

In emergency cases such as earthquakes, it is crucial to maintain traffic flow for delivering the urgent needs. In addition, it is possible to quickly strengthen a steel member, which underwent a reduction in cross-sectional area due to corrosion resulting from ambient conditions by applying composite material to its tension flange.

3. TEST SETUP (DENEY DÜZENEĞİ)

3.1. Materials (Malzemeler)

HM-CFRP; HM-CFRP is a polymeric material consisting of one-dimensional fibers. Strip HM-CFRP material is made by laying fibrous material into high strength epoxy under appropriate conditions achieved in the workplace and impregnating carbon-based fiber with the high strength epoxy. For steel structures, HM-CFRP material is mainly used in increasing the strength of steel bridge beams. Due to its high flexural rigidity, it increases the rigidity of steel beam and moves the neutral axis to the lower part of the section. Table 1 represents values provided by the company by which HM-CFRP was supplied. Some bridges in the world at which HM-CFRP was used are Acton Bridge London England 2000, King Street Bridge Flintshire England 2000, Takiguchi Bridge Tokyo Japan 2008, and KY32 Bridge over Lytles Creek Kentucky USA, etc.

Table 1. General properties of HM-CFRP
(Tablo 1. HM-CFRP'nin genel özellikleri)

Property	HM-CFRP5/1.4
Elasticity modulus (MPa)	≥210.000
Thickness (mm)	1.4
Width (mm)	50
Cross-section area (mm^2)	70
Theoretical Tensile Strength (KN) Deformation ε= %0.4	59
ε= %0.6	87
ε= %0.8	115

Epoxy; Smaller scaled coupon tests were carried out to select the adhesive that is to be used in the full-scale test [3]. In order to ensure bonding between HM-CFRP and steel, epoxy selection is crucial. Thus, it was decided that it will be proper to perform tests on available epoxy brands in the market and to use the epoxy type delivering the best results in the full-scale test. As shown in Figure 1, six specimens were prepared for each brand of epoxy and subjected to tensile test. Test results are presented in Table 2.

Table 2. Failure loads for each epoxy brands
(Tablo 2. Epoksi kayma kuvveti)

Epoxy Brand	Manufacturer	Failure Load
MBT-Mbrace Lamin	YKS-BASF Company	42.62KN
Sika 30	Sika Company	36.42KN
Spabond 345	SP Systems North	51.78KN

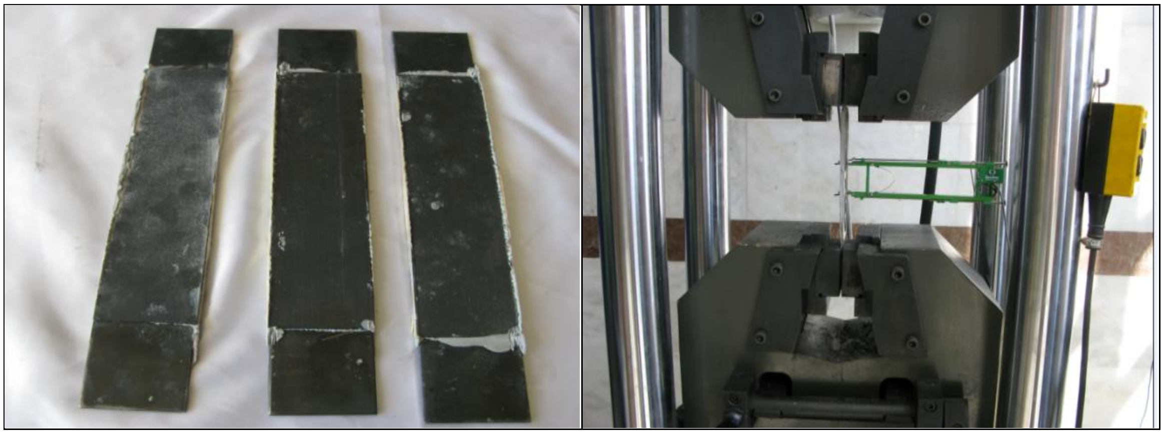


Figure 1. Test specimens and test set-up for epoxy selection
(Şekil 1. Epoksi seçimi için test düzeneği ve test numuneleri)

Steel; To quantify the tension strength of a steel beam, coupon specimens are prepared in accordance with the requirements of ASTM 638-08. Three specimens are cut from the flange and web of the steel beam. Results of the tension tests are given in Figure 2 and Table 3.

Figure 2. Steel specimens prepared for tensile testing
(Şekil 2. Çekme testi için hazırlanmış çelik numuneler)

Table 3. Steel tensile strength
(Tablo 3. Çelik çekme gerilmesi)

Location of Steel Specimen	Elasticity Modulus (MPa)	Yield Strength (MPa)
Upper flange of beam	179962	275
Web of beam	161657	265
Lower flange of beam	212967	300
I beam (average)	184862	280

3.2. Test Layout and Test Specimens (Deney Düzeneği ve Deney Numuneleri)

Since the load- displacement plot obtained from the bending test of a section consisting of reinforced concrete slab and steel beam and the load-displacement graphics for I- profile made only of steel indicate similar characteristics [15], made up steel I-Section was used in this study. Neutral axes of both the reinforced concrete section and the made up I-section profile were designed to be on the upper flange. For the upper flange of the section, testing on the sections that have steel plates in place of reinforced concrete slab was both easier and economical.

A 3 cm thick steel plate was welded onto the test specimens to represent the concrete composite I-beam. This steel plate is made of ST

37 grade steel while the I beam is made of ST44 grade steel. Three test specimens were constructed. These were prepared by welding a 3 cm thick steel plate onto IPE160 steel profile. In order to observe bending behavior of the strengthened beam, a four-point load test layout that provides a fixed moment area. The beam spans 2900 mm and reinforcing plates were used at the web on both supports and 1050 mm ahead. The distance between load points is 800 mm and the load is applied by means of a 40-ton Enerpac piston. In order to apply equal loads at loading points of the beam, a 200x200x1000 mm sized spreader beam was used. Two 20x30x900 mm sized steel bars were utilized to ensure the load transfer from the spreader to the beam. Rubber pads were used to prevent the bars from causing damage to the specimen. Displacement meters of Opkon and Diyotoyo brands were employed in order to measure displacements. These were located on the mid-span and on the bottom flange where loads are applied. Test layout is graphically presented in Figure 4.

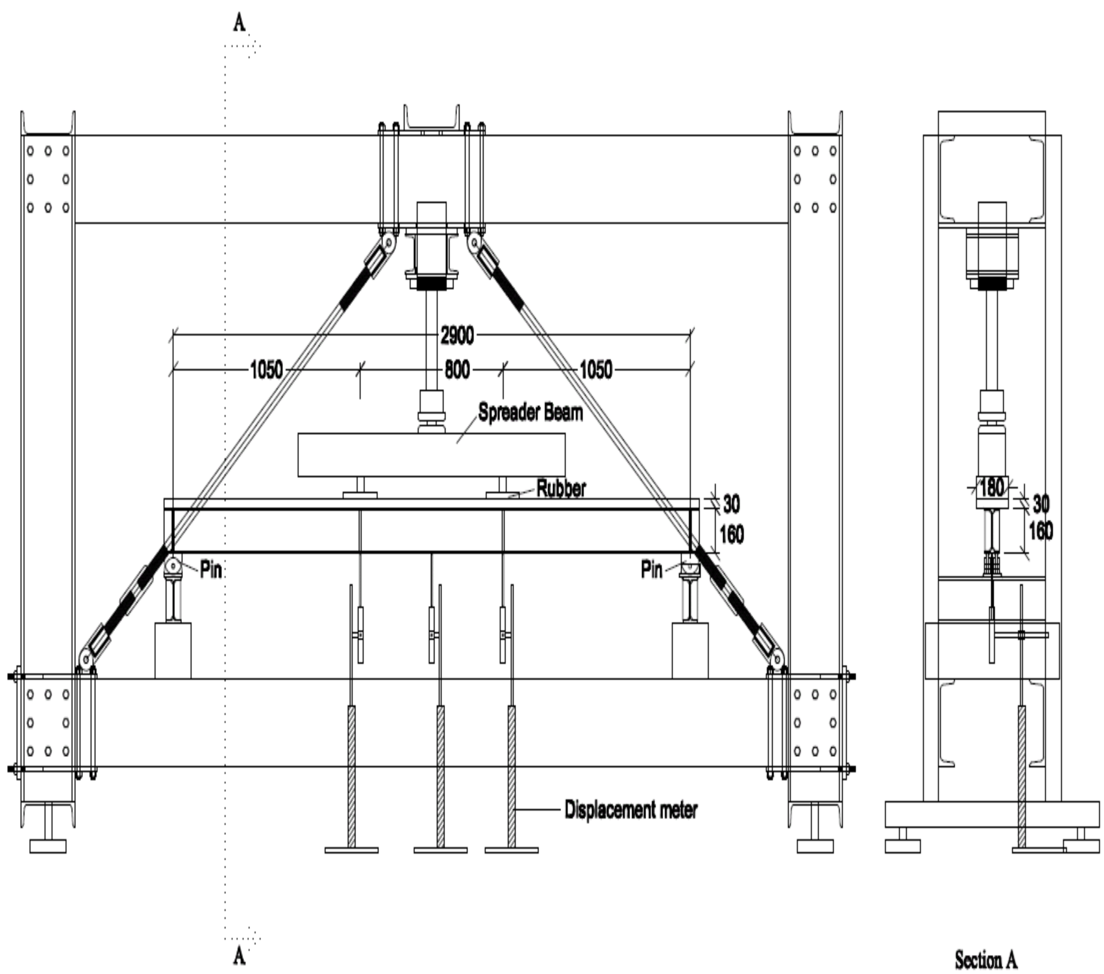
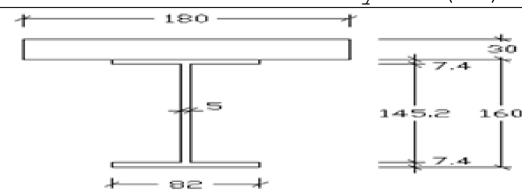
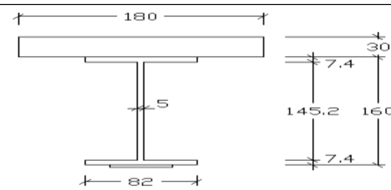
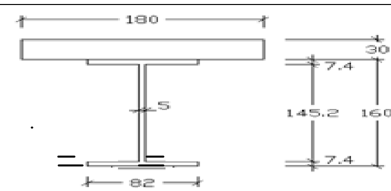


Figure 4. Test layout
(Şekil 4. Deney düzeneği)

A total of three test specimens were prepared so as to have 1 reference beam, 1 beam strengthened with HM-CFRP material and 1 beam strengthened with HM-CFRP material and equipped with steel clamps over the tension flange Table 4. Epoxy was prepared according to the mixture ratio given by the epoxy producing firm and was applied under the bottom flange so as to form a very thin layer. Before the application of epoxy, surfaces were cleaned both chemically and mechanically. At the final stage, HM-CFRP was placed on epoxy and compressed with clamps. At the end of the duration stated by the epoxy producer it was thought that the strength is enabled and test was done.

Table 4. Test specimens
(Tablo 4. Deney numuneleri)

Definition	Name	Cross Section and Layout (mm)
Steel only	Reference	
Steel and HM-CFRP	ST1	
Steel, HM-CFRP and 8 clamps	ST2	

Bending tests were carried out after a 28-day period, which is set by the epoxy manufacturer. Clamps were installed on the bottom flanges of the specimens during the tests Figure 3.

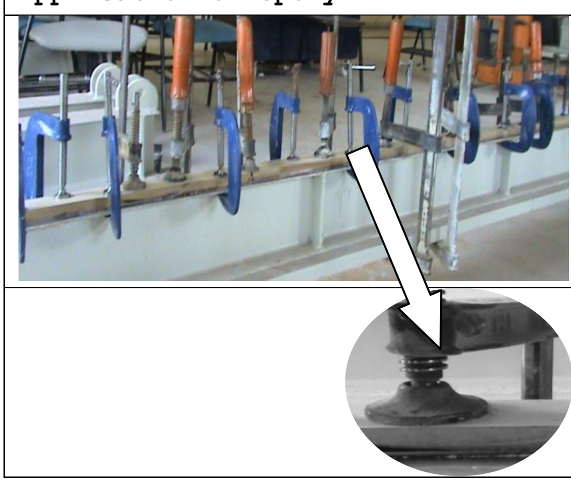
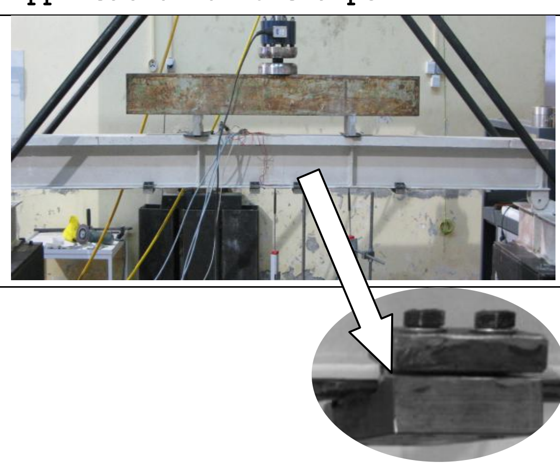
Application of epoxy	**Application of 8 clamps**
	

Figure 3. Application of epoxy and clamps
(Şekil 3. Epoksi ve kelepçe uygulaması)

4. TEST RESULTS (DENEY SONUÇLARI)

The specimens given in the table were tested for bending behavior. The damaged specimens obtained from tests are presented in Figure 5a, b, c. The applied loads versus mid-point displacement graphics obtained from tests are given in Figure 6.

Name	Deformed Forms
a-)Reference	
b-)ST1	
c-)ST2	

Figure 5. Deformed forms at the end of the tests
(Şekil 5. Numunelerin deney sonunda şekil değiştirmiş durumları)

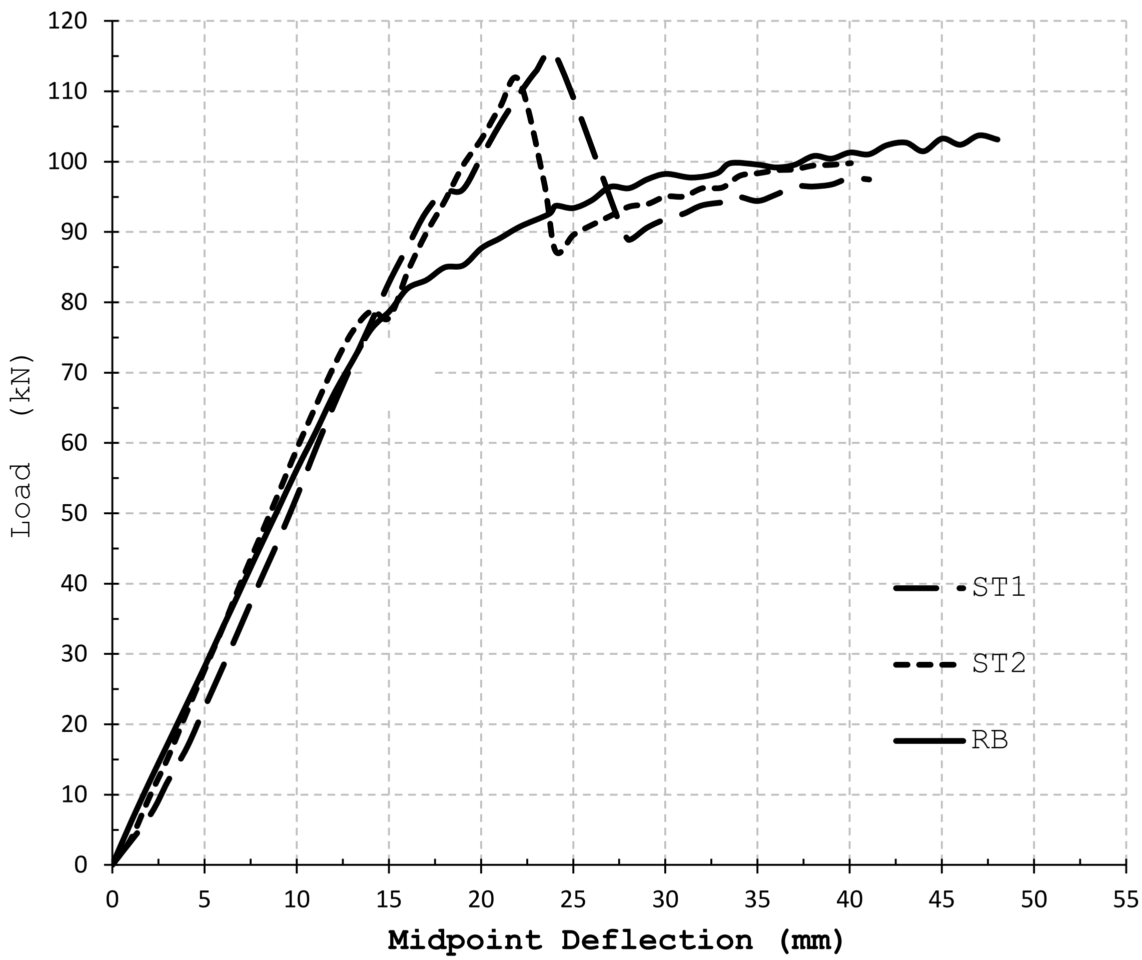


Figure 6. Test results
(Şekil 6. Deney sonuçları)

As the case is so in the test, a linear behavior is observed until HM-CFRP breaks and with the breaking of HM-CFRP it is observed that steel hardens and continues to take on load. The effect of strengthening is 39% in terms of maximum load. After the ultimate load is reached, HM-CFRP abruptly break and a dramatic decrease occurs in the strength. There is no much difference between the arrangement with clamps and the arrangement without clamps. The reason for this result is because perfect bond was achieved between HM-CFRP and steel by just using epoxy.

5. CONCLUSION (SONUÇLAR)

The difference between the strength characteristics of the steel I beam ST1, strengthened with HM-CFRP material, and the non-strengthened beam called the reference beam are presented in Figure 6. With HM-CFRP bonded to the tension flange by means of powerful epoxy, strength increases abruptly. When steel beams are strengthened with HM-CFRP, also an increase is obtained in the moment capacities of the beams. The effect of the area of added HM-CFRP on the strength increase level should be studied.

Since HM-CFRP broke in tension the use of clamps did not increase the beam's strength. It is believed that if the bonding strength of the epoxy had been less than the one used in the experiments, there would be a slip between HM-CFRP and steel. Then the clamps would have helped functioning of the system by increasing the strength of the retrofitted steel beam.

REFERENCES (KAYNAKLAR)

1. Schnerch, D. and Rizkalla, S., (2004).Strengthening of scaled steel-concrete composite girders and steel monopole towers with CFRP. FRP Composites in Civil Engineering, ISBN 90 5809 638 6, United Kingdom.
2. Rizkalla, S., Dawood, M., and Schnerch, D., (2008). Development of carbon fiber reinforced polymer system for strengthening steel structures. Composites Part A: Applied Science and Manufacturing, pp:388-397, United States.
3. Schnerch, D., Stanford, K., Sumner, E.A., and Rizkalla, S., (2005). Bond behavior of CFRP strengthened steel bridges and structures. Proceeding of International Symposium on Bond Behavior of FRP in structures, China.
4. Rizkalla, S., Sumner, E.A., Stanford, K., and Schnerch, D., (2004). Strengthening steel structure and bridge with high modulus carbon fiber reinforced polymers. Resin Selection and Monopole Behavior.
5. Glen, S., Tarek, H., and Rizkalla, S., (2005). Bond characteristics and quantifications of adhesive form marine applications and steel pipe repair. Third International Conference on Construction Materials, Performance, Innovations and Structural Implications (ConMAT'05), North Carolina State University, USA.
6. Dawood, M., Schnerch, D., Sumner, E.A., and Rizkalla, S., (2006). Strengthening steel bridges with new high modulus CFRP materials. International Conference on Bridge Maintenance Safety and Management, Portugal.
7. Dawood, M., Sumner, E.A., and Rizkalla, S., (2006). Fundamental characteristics of new high modulus CFRP materials for strengthening steel bridges and structures, USA.
8. Schnerch, D., Dawood, M., Emmet, A., and Rizkalla, S., (2005). Strengthening steel-concrete composite bridges with high modulus carbon fiber reinforced polymer (CFRP) laminates. Composite in Construction Third International Conference, USA.
9. Aiello, M.A. and Sciolti, S.M., (2006). Bond analysis of masonry structures strengthened with CFRP sheets. Construction and Building Materials, Volume:20, Number:1-2, pp:90-100.
10. Dawood, M., Rizkalla, S., and Sumner, E.A., (2007). Fatigue and overloading behavior of steel-concrete composite flexural member strengthened with high modulus materials. J Compos Construct, Volume:11, Number:6, pp:659-69.
11. Chen, T., Gu, X., and Zhao, X., (2010). Fatigue behavior of CFRP repair non-load carrying cruciform welded joint. The 5th International conference on FRP composites in civil engineering.
12. Lunn, D.S., Rizkalla, S., and Ueda, T., (2012). New FRP and adhesive materials for strengthening infill masonry structure. 6th International conference on advanced composite materials in bridges and structures.

13. Lunn, D., Maeda, S., Rizkalla, S., and Ueda, T., (2012). Anchorage systems for FRP strengthening of Infill masionry structures. The International journal of sustainable materials and structural systems.

14. Xiao, Z.G. and Zhao, X.L., (2012). CFRP repaired welded thin-walled cross-beam connections subject to in-plane fatigue loading. International journal of structural stability and dynamics Volume:12, Number:1, pp:195-211.

15. Aktas, M. and Agcakoca, E., (2011). Finite Element Analysises of Composite Steel Beams. 2nd International Symposium on Computing in Science and Engineering. pp:1370-1374.