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RESEARCH ARTICLE

Flexural Behavior of self Compacting Concrete Beams Strengthened with Carbon Fiber Reinforced Polymer Sheets

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Abstract

The main objective of the work in this Paper is to study the Flexural Behavior of self Compacting Concrete Beams Strengthened With Carbon Fiber Reinforced Polymer Sheets.

The experimental work consists of fabrication and testing simply supported reinforced concrete self compacting concrete(SCC) beams , consists of five beams failed in flexure and each beam had 2100 mm length and (175x300)mm cross sectional dimensions, all SCC beams made from self-compacting concrete with concrete compressive strength of about 45.894 MPa were casted and tested at 28 days.

This research is devoted to investigate the behavior and load carrying capacity of reinforced concrete strengthened and repaired with carbon fiber reinforced polymer (CFRP) sheets in flexural .

For SCC beams designed to fail in flexure investigate how the number of layers and configuration of CFRP sheets affect the flexure behavior and the load carrying capacity. The results, show that the beams strengthened externally by CFRP sheets provided improvement in ultimate loads. The increase in ultimate loads reached (33.3 %) the behavior of strengthened and repaired SCC beams by CFRP sheets increasing the ultimate strength and reducing the ultimate central deflection for increasing the load at the cracking stage and also the load capacity and reducing flexural crack widths compared with the control beam.

INTRODUCTION

For several years, the problem of durability of concrete structures has been a major problem posed to engineers. The creation of durable concrete structures requires adequate compaction by vibrating. Over vibration can easily cause segregation. In conventional concrete, it is difficult to ensure uniform material quality and good density in heavily reinforced locations, If steel is not properly surrounded by concrete it leads to durability problems, One solution for the achievement of durable concrete structures is the employment of self-compacting concrete(SCC), SCC is one of the most important innovations in the concrete technology, It arrived as a revolution in the field of concrete technology, It is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. It is a highly workable concrete that can flow through densely reinforced or geometrically complex structural elements under its own weight and adequately fills voids without segregation or excessive bleeding without the need for vibration to consolidate it, SCC flows like "honey" and has nearly a horizontal concrete level after placing, When SCC is placed in a form, its motion may be a creeping movement or a rapid flow, Because of this style of flow, the surface finish between the form and the concrete can be exceptionally smooth, creating a much – improved form finish over conventional concrete, SCC technology was initially developed in Japan in the 1980 to address the lack of skilled workers and to provide a durable concrete with reduced need for labor during construction, SCC was first successfully used in Japan in 1988, In the 1990, development and use of SCC technology started in Sweden and then quickly expanded throughout Europe, Specifications and guidelines for SCC use have already been developed in Europe, SCC research and use has recently been making progress in North America and has been of particular interest to concrete producers and users, also Using carbon fiber reinforced polymer (CFRP) sheets has proved to be an effective means of upgrading and strengthening reinforced concrete beams, However, premature failures such as peeling failure and sheet separation can significantly limit the capacity enhancement and prevent the full ultimate and the effect of Flexural behavior clear on the SCC beams compared with control beam, Externally strengthening with advanced composite materials, namely, carbon fiber reinforced polymers (CFRP), represents the state-of-the-art in upgrading or rehabilitation techniques, Carbon fiber reinforced polymer (CFRP) sheets are becoming widely used in upgrading and rehabilitation of reinforced concrete members, CFRP offers the design engineer excellent properties not available in traditional materials, This strengthening composite corrosion resistant and possesses higher strength and stiffness compared to steel, The ease of handling and application gives CFRP an advantage over traditional materials for certain applications, Beam strengthening using externally bonded composite sheets/plates/strips, has been studied widely in the last two decades , Meier [6] reported the use of thin CFRP sheets as flexural strengthening reinforcement of concrete beams. He showed that CFRP can

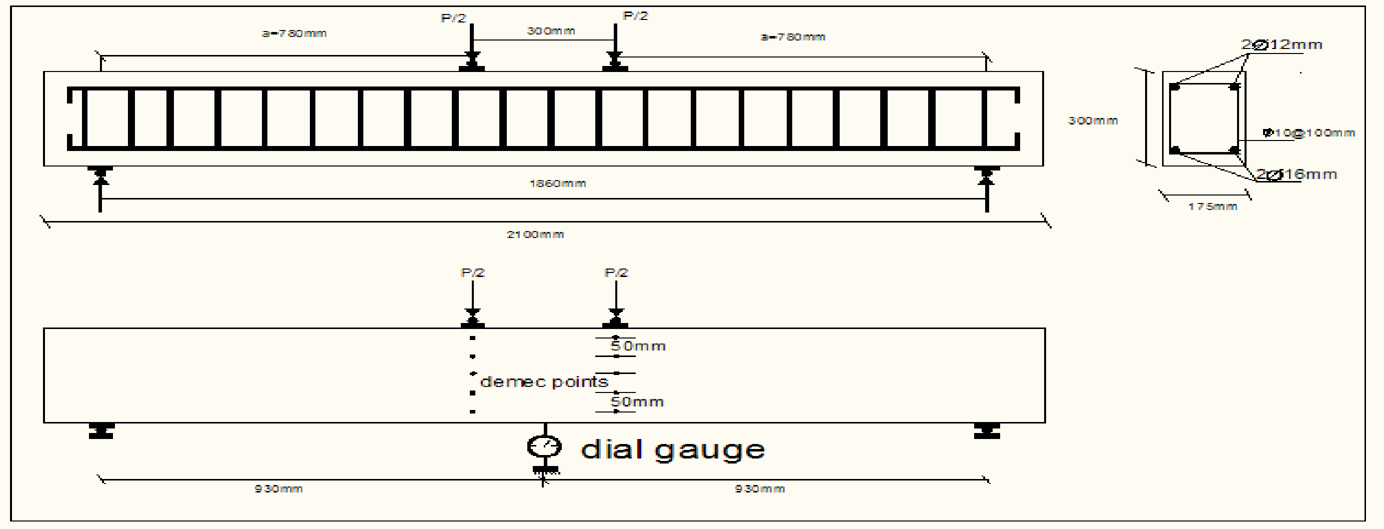
replace steel with overall cost savings in the order of 25%. Triantafillou [5] proposed a theoretical model to compute the shear strength capacity of a beam strengthened with externally applied FRP. Later on, this proposed model was calibrated using seventy- five published experimental test results which resulted in an experimental program to predict the effective strain in FRP laminates. In the year 2001, Matthys and Triantafillou made slight modification of Triantafillou and Antonopoulos [7] expression of effective strain and indicated that in addition to all other influential factors, effective strain in FRP is also a function of the beam shear span-to-effective depth ratio. However, Matthys and Triantafillou made this comment on the basis of the least square fitting of experimental results collected from past literatures . Collotti et al. [4] developed a theoretical model based on truss analogy method in conjunction with the theory of plasticity .They reported that the theoretical model provided good correlation with past experimental results. Zhangand Hsu [8] reported the result of an experimental study conducted on eleven beam specimens strengthened with both procured and wet layup composites systems. The recent edition of theACI 440 [1, 2] proposed a theoretical model to compute the enhancement of shear strength of RC beams using external FRP laminates. They focused on the developed effective strain in composites at failure which varies depending upon the variability of composites material properties, dimensions and the application techniques. The above review of literature illustrates that although substantial research has been conducted on FRP strengthening of RC beams, but still the behavior of FRP strengthened beams under different schemes of strengthening is not well established. In the present study, through an experimental program, efforts have been made to study the efficiency and effectiveness of two different but very practical FRP schemes for flexure and shear strengthening of RC beams. , but the problem of this studies using the normal reinforcement concrete and that's used a vibration machine to get a durable beam concrete and also used CFRP sheets with thickness 0.30 mm, so in this research will studying Flexural Behavior of self Compacting Concrete Beams Strengthened With Carbon Fiber Reinforced Polymer Sheets and with CFRP sheets 0.13 mm thickness.

Experimental Work

Several tests are conducted in order to view the differences in the behavior of SCC in its fresh and hardened states as well as the structural behavior. The slump flow and V-funnel tests for mortar and slump flow, T500, L-box, V-funnel, sieve segregation resistance and fresh density tests are conducted for concrete during its fresh state. The hardened concrete tests are compressive strength, flexural strength, splitting tensile strength, and static modulus of elasticity. Furthermore, the shrinkage, absorption and durability of SCC are investigated.

Table (1) Concrete mix materials

Material	Content
Cement kg/m^3	453
Lime Stone Powder kg/m^3	113
Coarse Aggregate kg/m^3	809
Fine Aggregate kg/m^3	906
Water/cement ratio (w/c)	0.35
SP (% of cement)	1.5



Figure(1):Details of the tested beam failing in flexure with (a/d=3)

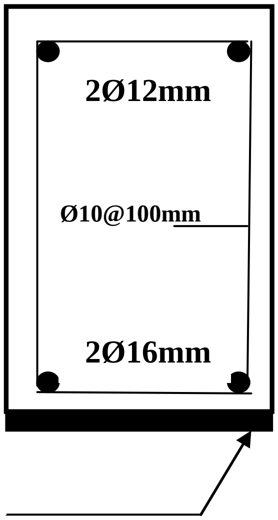
Before the testing day, the beams were painted with white paint on both sides, to achieve clear visibility of cracks during testing. Also, the locations of supports and the points which the load was applied were fixed as well as positions of the demec points were marked and the stainless steel locating discs were attached using an epoxy resin. The method of measurement and instrumentations used during the tests were as follows:

1- Deflection: The deflection at mid-span was measured by using dial gauges of 0.01 mm/div. sensitivity with magnetic base and 25 mm capacity .it was placed underneath the bottom face of the tested beam at mid span.

2- Concrete strain: The concrete strains were measured in the middle zone of the beam at five points (50, 100,150,200,250) mm from the top face . at the main reinforcement level, the middle of the depth, and midpoint between them . The strains on the surface of the concrete were measured by demec mechanical strain gauge of digital type (Mitutoyo Absolute) with a gauge length of 100 mm and accuracy of one micron .

3- Cracking: The appearance of first crack and crack developments were marked throughout the testing process. At the end of each step of testing process, cracks were sketched and crack-width measured using a hand microscope of accuracy 0.02 mm per division .

however the main objective of the current research work is to investigate the effect of CFRP Sheets on the behavior and load carrying capacity of strengthened and repaired reinforced concrete SCC beams. The experimental program variables include length and orientation of CFRP, effect of different configurations of CFRP Sheets (one layer with width 175mm , two layers with width175mm , three Strips with width 30mm and three strips the width of was 30mm and with fully warp CFRP sheets at anchorage zone) For Beams designed to fail In flexure Details of the tested beams shown in Table (2) .



Figure(2)

(layer of CFRP sheet bottom beam)

Table (2) (Details of the tested beams failing in Flexure)

Beam No.	Details of strengthening
SCCUF1-1	Reference beam (control beam) without strengthening
SCCSF1-2	strengthened with one layer of CFRP sheet on the bottom face of beam (the width of CFRP sheet was 175 mm)
SCCSF1-3	strengthened with two layer of CFRP sheet on the bottom face of beam (the width of CFRP sheet was 175 mm)
SCCSF1-4	strengthened with three CFRP strips (the width of CFRP strips was30mm)
SCCSF1-5	strengthened with three CFRP strips (the width of CFRP strips was30mm and with fully warp CFRP sheets at anchorage zone)

Experimental Results

To ensure the self-compacting concrete, two tests were carried out on the fresh concrete. They were the slump flow test and L-box test . It was found that for slump flow test, the average diameter of slump flow was 705 mm while T50 was 2.4 second and for the L-box test the ratio of H2/H1 was 0.85 and for The V-funnel test was8.65 sec. All of these values are accepted since they are within the ranges limited by ACI 237R-07 and EFNARC[3] however , The mix proportions used to cast the designed test specimens are presented in Table (1). Single batch was used to cast all the specimens. Six cylinders (150 × 300 mm) were cast to determine the 28-days compressive strength, $f'c$, from the batch. The mix was designed for 45.894MPa of compressive strength it was found all the beams in this study which was under-reinforced and failed by crashing of concrete after the tension reinforcement had yielded. The first visible flexural cracks noticed at 16.66 to 19.44 % of failure load. These cracks were vertical, started from the bottom side of the beam between the two point applied loads. As the load increased the cracks propagated diagonally towards the concentrated loads. crack pattern for the beams are presented in Figures (4)and Summary of test results are presented in figure (3).

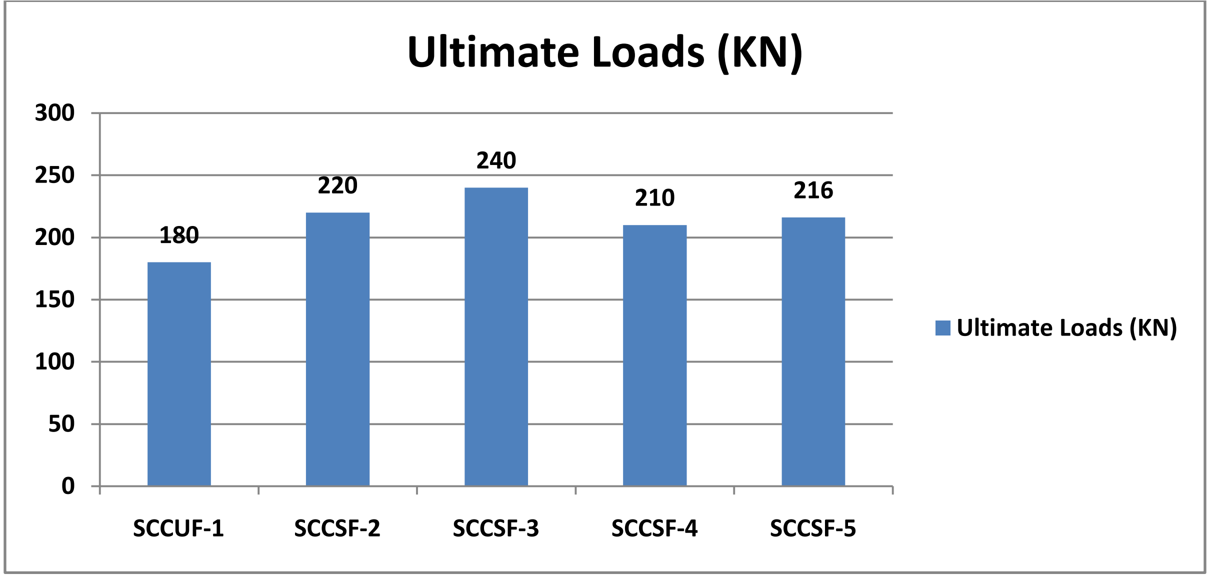
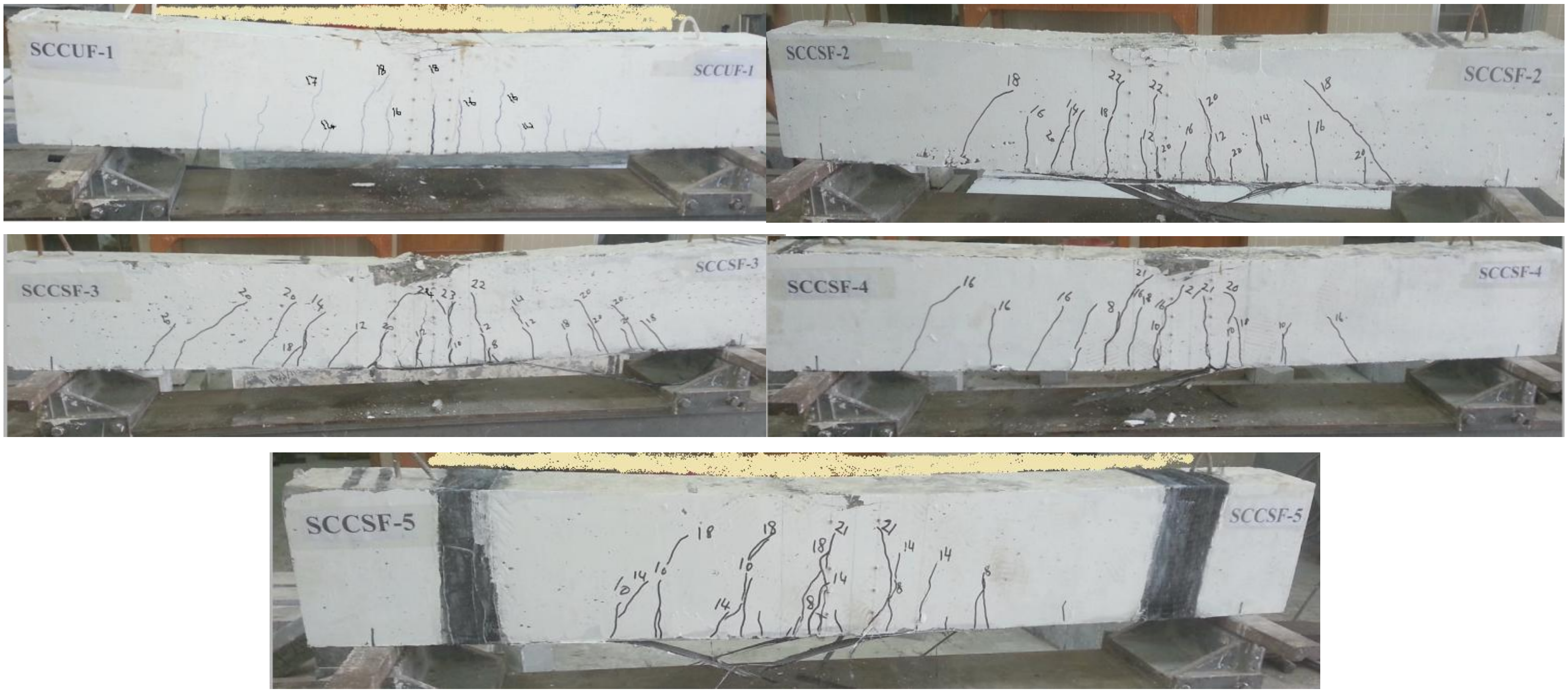


Figure (3): Ultimate loads



Figure(4)

Beam	Cracking load p_{cr},(kN)	Ultimate load p_u,(kN)	Pcr/pu %
SCCUF-1	30	180	16.66
SCCSF-2	40	220	18.18
SCCSF-3	43	240	17.91
SCCSF-4	37	210	17.61
SCCSF-5	38	216	17.59

Table (3): First crack and ultimate loads of SCC beams failed in flexure.

The cracking loads are presented in Table (3), and the crack patterns for all tested specimens are shown in Figures (4).For all beams, usual flexural and diagonal cracks are encountered, For all tested beams, comparison is performed with first cracking load for SCC beams. for the control beam(SCCUF-1),. As the load was increased further, several flexural cracks initiated in the compression face at intervals throughout the beam, gradually increased in number, became wider and moved upwards reaching the compression face of the beam, As the load was increased further, a loss of stiffness occurred and one mode of failure appeared which can be classified as flexural failure in tension by yielding of the steel reinforcement followed by crushing of concrete, The strengthened SCC beams with CFRP Sheets(SCCSF-2,SCCSF-3,SCCSF-4,SCCSF-5) also showed similar behavior, but when the load reached yielding of steel, the CFRP sheets contributed mainly in resisting the loads and increased the stiffness of the concrete beams up to failure. The failure was usually recorded due to debonding of CFRP sheets from bottom face of beams specimens which was very suddenly and the only indication of such failure was few popping sounds before debonding happened. In repaired beams, the failure was similar to strengthened beams, Deflection was measured at midspan of the beams at different loading stages. The decreased in deflection for beams (SCC) is attributed to the number and configurations of CFRP sheet layers of self compacting concrete used in making these beams.

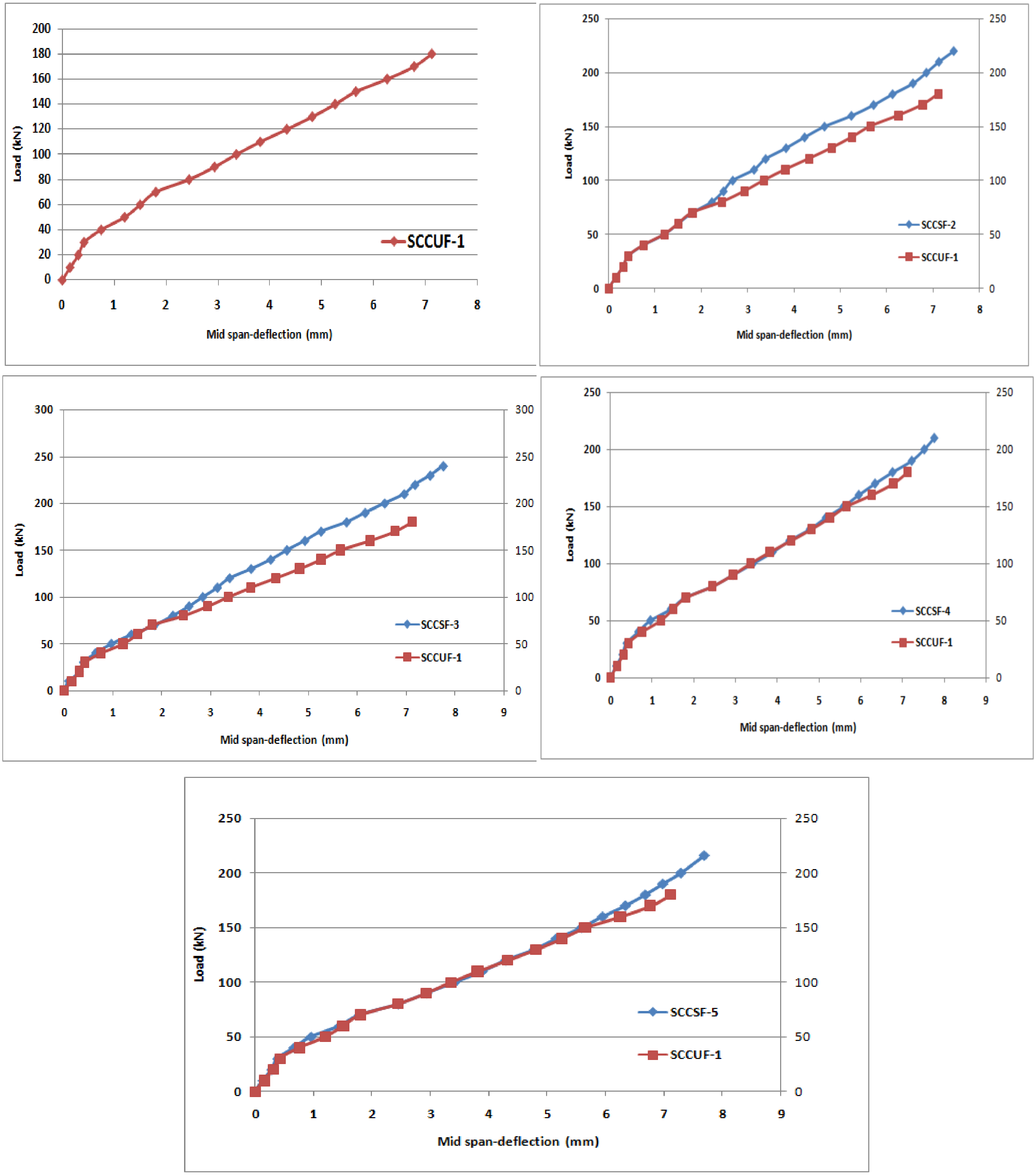


Figure (5): Comparison of load - midspan deflection curves for beams.

Conclusions for Experimental Work

Based on the overall results obtained from the experimental work for the externally strengthened or repaired reinforced concrete Self compacting beams by CFRP sheets failing in Flexure, the following conclusions can be drawn as follows**:**

1. In general higher ultimate loads were achieved for SCC beams strengthened with CFRP sheets as compared with unstrengthened control beam.
2. For beams designed to fail in Flexure, beams made with SCC beams strengthened with CFRP sheets compared with control beam the average increase in ultimate load of about 33.33%
3. The result of the experimental study indicates that externally bonded CFRP sheets can be used effectively to strengthen the reinforced concrete beams. Regarding the effect of number of layers, an increase in stiffness and flexural strength is achieved with the increase of CFRP layers.
4. Regarding the effect of transverse edge strip, significant improvement in flexural strength was noted and the de-bonding of sheets occurred just before the final failure. Never the less, the possible brittle failure of the strengthened beams still needs to be considered.
5. The CFRP anchors are more effective than increasing the length of CFRP sheets in increasing the ultimate load capacities. The CFRP improves the structural behavior of concrete section, improves the structural stiffness of the strengthened beams.
6. Presence of Flexure reinforcement in SCC beams failed in flexure decreases deflection at the same load level.
7. A stiffer load-deflection response is observed for reinforced concrete SCC beams strengthened with CFRP sheets as compared with response of control SCC beam.
8. The number of flexural cracks in all SCC beams was lower than the similar SCC beams strengthened with CFRP sheets.
9. A decrease in the width of cracks due to presence of CFRP sheets is occurred. The average decrease is about 45 % of the crack width of the control SCC beams at ultimate load levels.
10. The maximum strains developed in vertical CFRP sheets depend on the locations of these sheets. The maximum strains occur in sheets located at the middle of the flexural span and located at the middle of the shear span between support and point load.
11. The decreased in deflection for SCC beams is attributed to the numbers, configurations and orientation of CFRP sheet of self compacting concrete used in making these beams.
12. Different spacing of CFRP Sheets for SCC beams is attributed to decreased the deflection and width of cracks.
13. Different width of CFRP Sheets for SCC beams is attributed to decreased the deflection and width of cracks.
14. In all tested SCC beams considered in the present work, the failure mode of strengthened or repaired SCC beams is a diagonal flexural crack caused (by debonding failure) of all CFRP sheets located in the flexural zone at ultimate load level.
15. The inclined CFRP sheets give better enhancement than the vertical CFRP sheets in ultimate load, deflection and crack width because the resistance are directly rather than componentally.

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