

## Investigation of Mid-Layer Effects on Reinforced-Concrete Column Confinements Strengthened with Composite (CFRP) Sheets

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### 1-Introduction

Nowadays, the use of Polymer Composite Material (FRP) has extended widely as a reinforcing material to repair and strengthen important elements of concrete structures, especially columns. Despite extensive research on increasing the rate of ductility and strength of concrete columns confined with FRP composites, there are scarce comprehensive studies concerning the failure strain of wrapping sheets. Some experimental studies showed that FRP failure strain, achieved in standard experiments of determining strain in flat sample was unattainable and the failure strain of wrapping strengthened plates would be less than the above-mentioned amount at column failure. Therefore, most tensile capacity of the composite would remain useless.

### 2-The Aim of the Study

In the present study, we try to prevent stress concentration's transfer due to concrete cracking in reinforcing sheet as much as possible by placing a mid-layer between the concrete surface and the FRP sheet. This is done in order to increase load-bearing capacity, improve ductility behavior of cylindrical columns, and make optimal use of FRP's tensile capacity. The material used for the mid-layer is a thin galvanized sheet layer cut approximately equal in size to the sheets and located under the reinforcing sheet. The presence of this layer causes the cracks due to concrete failure to be absorbed by the additional mid-layer instead of FRP jacket. In addition, this mid-layer inhibits the adherence of the jacket to the concrete which in turn causes the reduction of shear force transfer from the concrete to the jacket (leading to the creation of biaxial stress in the jacket as well as the reduction of its performance compared with a flat sample).

### 3-Equipment and Material Testing

In this paper, 14 RC columns with circular sections that are 150 mm in diameter and 500 mm in height, are created and used in experiments. In order to reinforce the columns internally, six longitude reinforcements of 8 mm diameter ( $\approx 1.7\%$ ) and six simple stirrups that are 6 mm in diameter have been used in column length with distances of 85 mm. All the specimens have been removed from the mold a day after casting and cured

in water bath up to 28 days under standard conditions. After the curing stage, the probable anlagen are removed from the samples by a grinder since the concrete sap permeates through the cracks of the cast. The dusts produced in the holes are then removed by an air compressor. After that, the area for locating FRP strips on the samples' height is marked and finally, the end surfaces of the samples are capped to prevent the exertion of external loads from the center.

The strength of the experimented columns for each group is obtained from the mean of final strength of four standard cylindrical samples that are 150 mm in diameter and 300 mm in height. This is done based on the obtained mixture plan 28 Mpa. The cement that is used in the mixture is Portland cement Type 1 and the maximum aggregate size is 12 mm. Commercial Carbon fibers called Sika Wrap Hex 230C have been used to reinforce the samples externally. The features of these carbon fibers are presented in Table 3. In addition, the resin used is called Sika Dur-330. Its mechanical features are included in Table 2.

By means of displacement control method, samples undergo axial pressures via a hydraulic press device with 200 KN capacity and loading rate of 1 mm/min. Once the maximum load-bearing capacity is obtained, the samples' loading continues to reach 50% of the maximum load in the softening region. Results of the load and lateral and axial displacements in corresponding loading points have been registered by a data logger device. To achieve the axial displacement based on Figure 3-a, two LVDTs have been used and installed in the middle and the two sides of the samples in a distance of 240 mm. The average results obtained from these two LVDTs have been used in order to calculate the axial strain. Furthermore, a horizontal LVDT has been used in the middle of the samples to obtain lateral strains of the samples as illustrated by Figure 3-b. The accuracy of the displacement recording equipment used is 0.005 mm and their maximum measurable displacement is 25mm.

Table 1. Steel Properties

Steel	Yield Strength (MPa)	Ultimate Strength (MPa)
#6	354	398
#8	550	775

Table 2. Resin Properties

Resin	Tensile Strength (MPa)	Elastic Modulus (GPa)	Ultimate Tensile Strain (%)
Sikadur-330	30	4.5	0.9

Table 3. Fiber Properties

Fiber	Tensile Strength (MPa)	Elastic Modulus (GPa)	Ultimate Tensile Strain (%)	Thickness (mm)
Sika Wrap-230 C	4300	238	1.8	0.131

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### 3-Test Result

#### A. The influence of the mid-layer

According to the results obtained as shown in Table 4, in samples in which galvanized sheets are used as the mid-layer, the load and final deformation as well as energy absorption increase more than samples without galvanized sheets. Samples of group one that are used for evaluating the performance of galvanized sheets, indicate a 12% increase for load and 79% for energy absorption than samples without the mid-layer. In addition, the final strain of this sample also shows a significant increase. Overall, the influence of the galvanized sheet with primer on load is 9% to 24 % for different reinforcing methods. The samples with galvanized sheets also indicate an increase of 53-226% in their rate of energy absorption. In order to be sure about the discontinuity between the FRP and the galvanized sheet as well as non-confining columns by the mid-layer, a plastic thin layer being 0.02 mm thick has been used in C4<sup>\*</sup>-S.P-50.I, which is located between the FRP and the galvanized sheet. This thin layer dismisses any adhesion between the FRP and the galvanized sheet. Comparing the load-bearing capacity of C4<sup>\*</sup>-S.P-50.I and C2-S.P-50.I columns in Table 4 shows that these samples are similar in strength, even though energy absorption of C4<sup>\*</sup>-S.P-50.I is more than C2-S.P-50.I owing to greater decrease of shear stresses transferring to the reinforcing sheet. In other words, it seems that the methods which minimize the reduction of transferring stresses from the concrete to reinforcing confining sheets have more influence on increase of ductility. It must be noted that suitable confinement entails no free distance between concrete and the confining agent. Since the dilatation in compressive samples is usually about 80% of the final load, it seems that the performance of primer as a filling material is limited to this region. Before dilatation, a filling material in free distance between concrete and mid-layer sheet can transfer low radial stresses created in the loading sample, to the reinforcing sheet as a cylinder stress. Considering the lack of any structural role of the primer when increasing the load-bearing capacity, it can be stated that the effect of the primer is just filling the free distance between the mid-layer and the concrete. Hence, when there is no free space, the primer does not play any role to improve the column's behavioral performance. On the other hand, the presence of a free space can lead to weak performance of the reinforcing sheet. Since it is impossible to predict the presence or absence of this free space between the mid-layer and the concrete when reinforcing the practical columns, it seems that it is necessary to make use of the primer under the mid-layer as a filling material in all modes in order to make sure of the validity of reinforcing

system's performance as well as decreasing the level of risk level.

#### B. The influence of reinforcing strip width

In order to investigate the effect of the strip's width, one can refer to groups two and four for samples, reinforced with carbon fibers, along with groups five and seven for those reinforced with glass fibers in Table 4. In groups two and five the width of the reinforcing strips are 50 mm, while in groups four and seven similar FRPs, 25 mm wide strips have been used. As it can be seen in this Table, the rate of increased strength in confined columns with 50 mm one-layer strips are 44% for C2-S.P-50.I., whereas for confined strip with 25 mm one-layer strips this rate is 52% for sample C4-S.P-25. Therefore, the performance of galvanized sheet in samples with lower sheet widths can somehow justify that more strips with lower widths cause more monotonous energy distribution in the whole column's height, causing a better confining situation due to their better extensiveness. Also, lower sheet width provides an opportunity for central regions of the column (strips rupture zone) to undergo greater confinement, leading to more load-bearing capacity. For bilayer samples, by comparing the C4-S.P-25.II and C3-S.P-50.II columns, it can be observed that the strip's width has no significant influence on energy absorption and strength. Therefore, it could be claimed that in order to achieve more monotonous energy distribution in their height, columns with higher confinement (bilayer) need strips with a width below 25 mm because of their axial rigidity

### 4- Conclusions

The most important results achieved from experiments on samples are the following:

- Using galvanized sheet as the mid-layer inhibits stress concentration transfer as well as multi-axial stress to reinforcement sheet. This will increase the maximum load by 16% and energy absorption by 53% in the samples reinforced with carbon fiber.
- Using a mid-layer changes the columns' behavior from strain-softening to strain-hardening. In fact, when we use this innovative technique, it can be said that the weak confinement of the column changes into effective confinement.
- The presence of a free distance between the concrete and mid-layer affects the mid-layer's performance significantly.
- Reducing the width of the reinforcing strips from 50 mm to 25 mm, leads to an 8% increase in maximum load-bearing as well as 140% energy absorption in samples reinforced with carbon fiber due to more monotonous energy distribution in column's height.