ID-1023

REINFORCEMENT OF DAMAGED CONCRETE COLUMNS BY FILAMENT WINDING OF THERMOPLASTIC COMPOSITES

K. Friedrich[1], N. Glienke[1], J. Flöck[1], F. Haupert[1], S. A. Paipetis[2]

[1] *Institute for Composite Materials (IVW), 67663 Kaiserslautern, Germany*
[2] *Applied Mechanics Laboratory, University of Patras, Greece*

SUMMARY: An experimental study was conducted to investigate the effects of various composite systems with different fibres (E-glass and carbon) in two different thermoplastic matrices (PPS, PEEK) on strengthening efficiency for wrapped concrete columns. The results indicated that the use of E-glass fibres within a polyphenylenesulfide matrix to externally reinforce concrete columns is quite effective. The carbon fiber PEEK based system does not show much improvement in the load carrying capacity. The thickness of wrap/radius of concrete column-ratio has also an influence on the strengthening efficiency. E. g. ten layers of glass fibre/PPS-tapes resulted in a five fold improvement of the compressive strength of the non-reinforced concrete. Predamaged samples with the same amount of reinforcement were still 4.5 times stronger that the undamaged, non-reinforced concrete.

KEYWORDS: Concrete columns, thermoplastic filament winding technique, polymer composites, strengthening efficiency, infrastructure.

INTRODUCTION

The successful use of polymer composite materials in many technical fields such as the aerospace, automotive and sporting good industries has been demonstrated now over many years. In addition to being very light in weight and having a high strength-to-weight ratio, advanced composite materials have the beneficial characteristic of being resistant to corrosion and to the effects of chemicals generally. These advantages have also led to the fact that polymer composites have been utilized in small quantities in the building and construction industry for decades. However, because of the need to repair or retrofit rapidly deteriorating infrastructure in recent years, the potential market for using fiber reinforced composites for repair (and for a wider range of applications) is now being realized to a much greater extent. In fact, composites can be used either to strengthen existing structures or to build new, more durable infrastructural units. Numerous successful applications using fiber reinforced polymer-matrix composites in the construction industry, such as bridges, piers, building panels, walkways pipelines and offshore structures have been reported. Many of these were summarized in a recent review by Liao et. al. in a comprehensive paper on “Long-term Durability of Fiber-Reinforced Polymer Matrix Composite Materials for Infrastructure Application” [1]. And also other composite journals have prepared special issues that highlight the use of polymer composites in infrastructure [2]. In fact, the use of polymer composites in this important field was predicted by specialists of Scientific American as one of the most important fields for composite materials in the 21st century [3].

Another review journal, guest-edited by K. Friedrich [4], presents several articles that are especially focused on the problem of composite materials use in the repair of damaged infrastructures. In the paper “Composite Materials in Bridge Repair” [5] Urs Meier from the Swiss Federal Laboratories for Materials Testing and Research (EMPA) seeks do demonstrate how advanced polymer matrix composites can offer major advantages for repairing civil engineering structures, with special examples of this kind in Switzerland. Karbhari and Seible (University of California, San Diego, USA) concentrate in their paper "Fiber Reinforced Composites – Advance Materials for the Renewal of Civil Infrastructure" [6] on the use of composites in the renewal of civil structures with special emphasis on bridges and pipelines. Examples of large scale testing for the validation of structural effectiveness are given along with future design and research advances. "A Study on Polymer Composite Strengthening Systems for Concrete Columns", by Zhang, Ye and Mai (University of Sydney, Australia) [7], investigated the effect of various composite wrapping systems with different fibers, resins and architectures on the strengthening potential for wrapped concrete columns. Raw material costs were evaluated to identify the cost efficiency of each individual system.

Further studies focussing in the direction of the paper presented her, were published by Lin et. al. quite recently [8]. It was found that the compression strength of concrete columns reinforced by non-adhesive filament wound hybrid composites is higher that the one achieved by traditional glass/epoxy winding technologies.

The special objective of the present study was to demonstrate, that with the more recent thermoplastic filament winding technique even better values of compressive strength improvement can be achieved (than with the traditional wet winding, thermosetting composites), and this at much faster processing times.

EXPERIMENTAL

Cylindrical concrete specimens with a diameter of 103 mm were prepared with a demanded strength category B35 of the concrete group B II (Table 1).

CONCRETE GROUP	CONCRETE STRENGTH CLASSIFICATION	NOMINAL STRENGTH σ_N [N/mm^2]	SERIAL STRENGTH σ_S [N/mm^2]	DESIRED SAFETY MARGIN $\Delta\sigma$ [N/mm^2]	APPLICATION
Concrete B II	B 5	5	10	10	Only for Unreinforced Concrete
	B 10	10	20		
	B 15	15	25		
	B 25	20	30		
Concrete B I	B 35	35	45	10	Unreinforced and Reinforced Concrete
	B 45	45	55		
	B 55	55	65		

Table 1: Concrete classification by compression testing

After a standard storing time, some specimens were subjected to a tensile splitting strength test in order to simulate a damaged structure. The artificial crack was produced in the middle of the diameter along the longitudinal axis of the column (Figures 1 and 2). The average compressive strength of the concrete columns was 50 MPa.

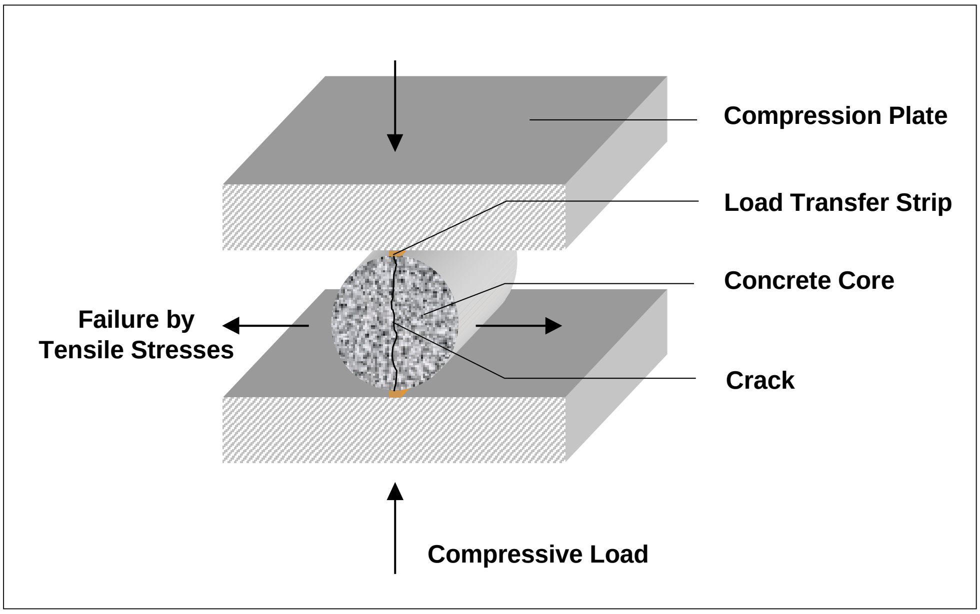

Figure 1: Schematic principle of the concrete core pre-damaging

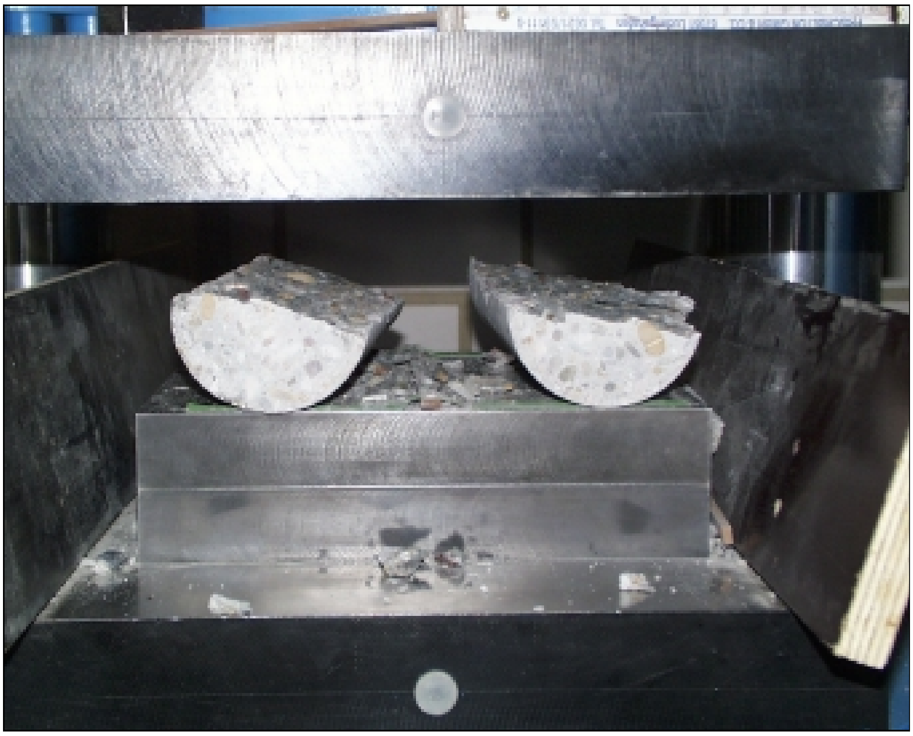

Figure 2: Simulating a pre-damage by artificial concrete core splitting

Two kinds of thermoplastic matrices were used for the composite wraps (Figure 3). Both were rather high temperature resistant polymers (polyphenylenesulfide PPS, polyetheretherketone PEEK), since these were simply available during the time of this study. The PPS was reinforced with continuous glass fibers, whereas the PEEK had a carbon fiber reinforcement. Testing of the tensile properties led to strength values of 828 MPa for the CF/PEEK system (E = 79 800 MPa) and of 666 MPa for the GF/PPS composite tape (E = 44 870 MPa) respectively.

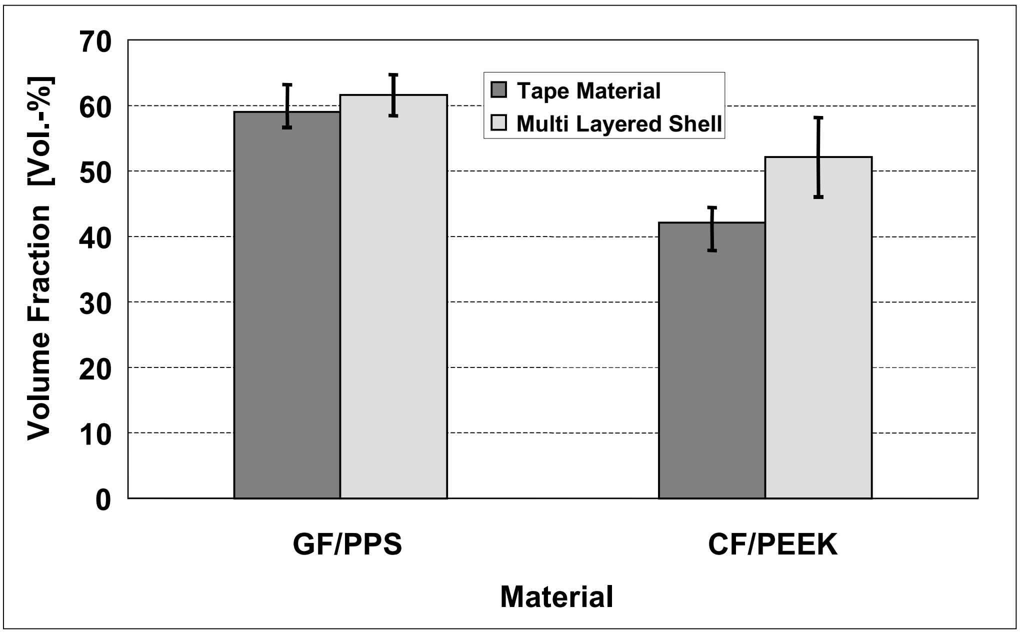

Figure 3: Fiber volume fraction of the fiber reinforced polymer composite tapes

The thermoplastic filament winding technique for wrapping the tapes around the undamaged and the pre-cracked concrete columns (that were temporarily fixed at the ends for the winding process) is schematically illustrated in Figure 4.

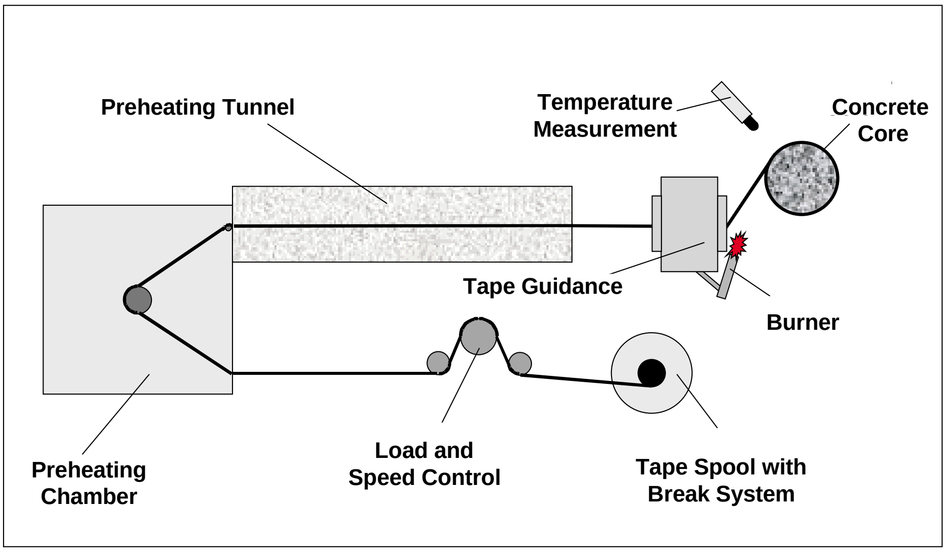

Figure 4: Schematic principle of the utilized winding technology

RESULTS

The values of the elastic moduli, as measured by a compression test, with strain gages attached to the outside of the unwrapped and wrapped concrete samples, are presented in Figure 5.

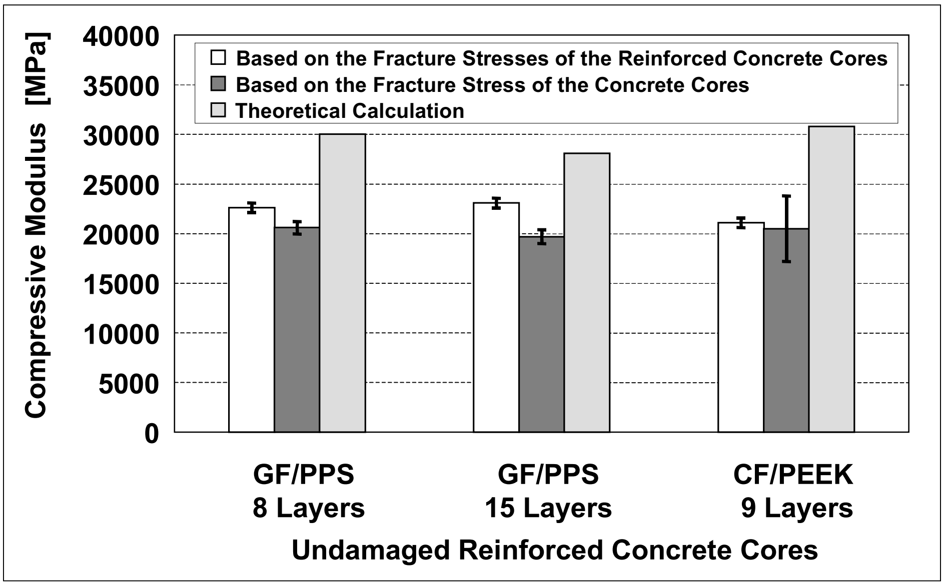

Figure 5: Comparison of the measured and the theoretical compressive moduli

It is obvious that the measured values are lower that the rule of mixtures – calculated, theoretical values, which, in turn, are slightly lower than the compression modulus of the neat concrete column (E_{compr} = 32 000 MPa).

With enhanced loading of the samples, the final breakdown of the wrapped samples occurred in a quasi-controlled manner, opposite to the catastrophic shear and splitting fracture of the neat concrete columns into many separate pieces (Figure 6).

Figure 6: Failure of a GF/PPS shell reinforced concrete specimen

This was especially true for the glass fiber/PPS-samples. The corresponding strength values gave evidence, that the wrapped samples were stronger, by a factor of about 3 to 5, than the undamaged , neat concrete columns. The actual improvement was a function of the fiber type and content as well as the number of layers wrapped around the original concrete sample (Figure 7).

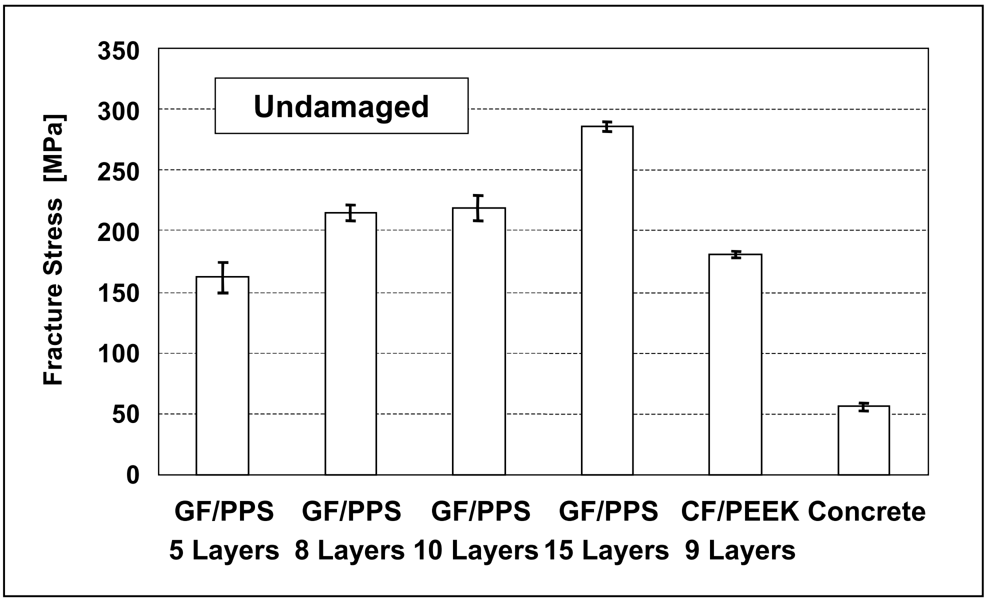

Figure 7: Compressive fracture stress of reinforced undamaged concrete cores

This situation did not dramatically change when the reinforced concrete cores were pre-damaged by a crack all the way through their center lengths (Figure 8). The function between the compressive fracture strength and the number of layers followed almost a linear relationship.

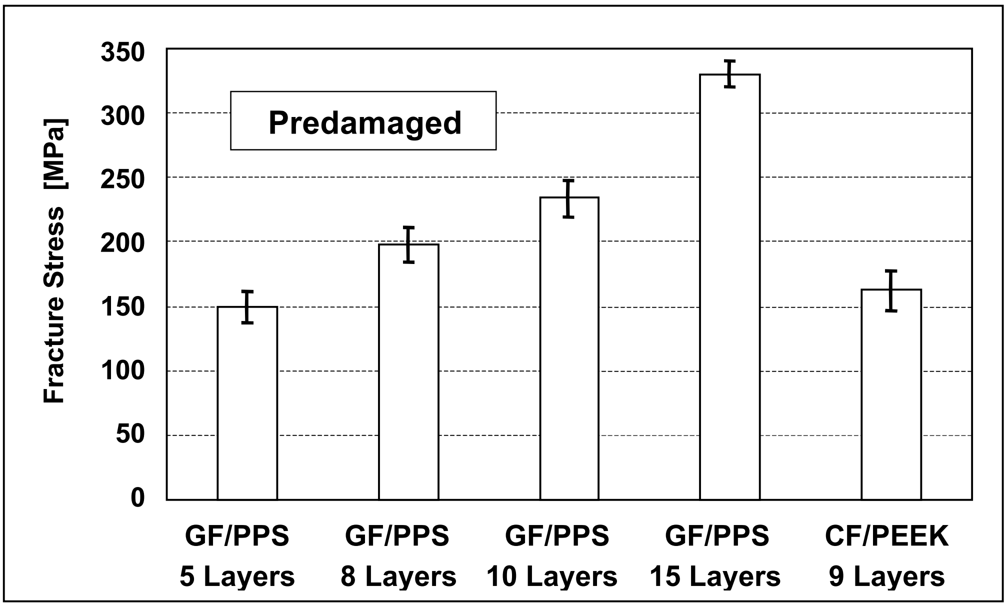

Figure 8: Compressive fracture stress as a function of layer thickness for GF/PPS-reinforced, undamaged and pre-damaged concrete cores

With regard to the failure modes and the stresses in an unreinforced and a glass fiber/PPS 3.2 mm thick shell reinforced concrete column one can state, that the composite reinforcement suppresses the shear failure tendency of the concrete. This leads to the fact that the concrete can sustain stresses which are clearly higher that the compressive strength values measured for the neat concrete columns (Figure 9). Additional finite element studies confirmed these statements [9].

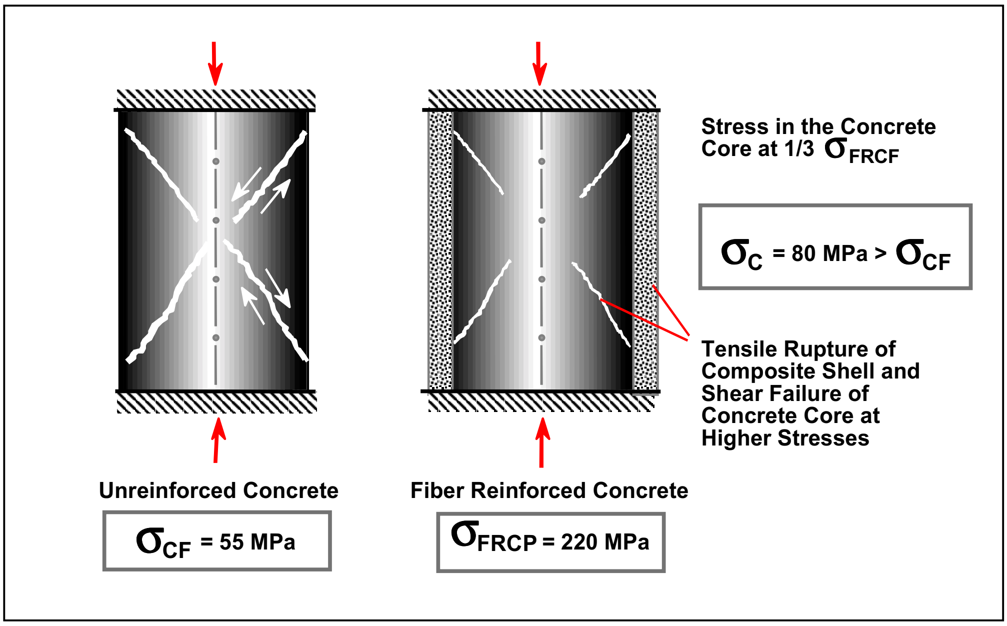

Figure 9: Schematic illustration of a failure prevention and strength enhancement of concrete columns by composite material wrapping.

CONCLUSIONS

This papers describes the failure of composite reinforced concrete columns, using the thermoplastic filament winding technique. The following statements can be drawn:

a) Thermoplastic tape winding is a useful method for strengthening undamaged and predamaged concrete columns.
b) E. g. ten layers of GF/PPS could enhance the compressive strength of a B 35 concrete column (Ø 100 mm) by a factor of 5.
c) Cracked-through columns could be rehabilitated by this method to a 4.5 times higher strength value than that of the undamaged concrete.

ACKNOWLEDGEMENTS

The authors like to acknowledge the Civil Engineering Department of the University of Kaiserslautern for their cooperation.

They are also grateful to the NATO Sci. Aff. Div. for support of this project through a research cooperation with Bulgaria and Greece (CRG 972 225).

Included are also thanks to the Research Technology Agency of NATO under the program of support to Greece, project G 97.

REFERENCES

1. Liao, K., Schultheisz, C. R., Hunston, D.L., Brinson L. C: *J. Advanced Mat*.,1998, Vol. 30, 3-40

2. Zureick, A. H., Chajes, M. J.: *Composite Sci. Technol*., 1998, Vol. 58, 1257-1258.

3. N. N.: Special Issue on Key Technologies for the 21st Century, *Scientific Amercian,* 1995, 126-127

4. Friedrich, K. (ed.): Composite Materials in Infrastructure, *Appl. Comp. Mat., 2000,* Vol. 7, 73-74

5. Meier, U.: Composite Materials in Bridge Design, *Appl. Comp. Mat*., 2000, Vol. 7, 75-94

6. Karbhari, V. M., Seible, F.: Fiber Reinforced Composites – Advanced Materials for the Renewal of Civil Infrastructure, *Appl. Comp. Mat.,* 2000, Vol. 7, 95-124

7. Zhang, S., Ye, L., Mai, J. W.: A Study on Polymer Composite Strengthening Systems for Concrete Columns, *Appl. Comp. Mat.,* 2000, Vol.7, 125-138.

8. Lin, H. K., Tai, N. H., Chen, C. C.: Compression Strength of Concrete Columns Reinforced by Non-Adhesive Filament Wound Hybrid Composites, *Composites A, 2000,* Vol. 31, 221-233.

9. Glienke, N.: Reinforcement of Concrete Structures by Fiber Reinforced Thermoplastic Composites (in German), *IVW-Report,* University of Kaiserslautern, Germany, 2000, No. 00-030,