

# DEVELOPMENT OF COMPOSITE GRID TUBES FOR THE REINFORCEMENT OF CONCRETE COLUMNS

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**SUMMARY:** This paper introduces a new type of composite grid tubes for the reinforcement of concrete columns. The fibers were wound in the pre-cut grooves on the surface of a PVC tube to form a grid structure. The pattern could be either orthogonal or helical. Once the composite grid tube was fabricated, cement concrete was poured into the tube to form a hybrid column structure. Within the scope of the present study, the focus was placed on investigating the effect of confinement provided by the reinforcing composite grid tube on the compressive strength of concrete columns. The hybrid columns were subjected to uni-axial compression. The same test was performed on a pure concrete column as well for benchmarking. It was identified that the composite grid tube could substantially increase the compressive strength and toughness of concrete columns. With further investigation on durability, the present hybrid structure may have good potential to compete with the conventional steel rebar reinforced concrete columns.

**KEYWORDS:** composite grids, filament winding, concrete, hybrid system, infrastructure.

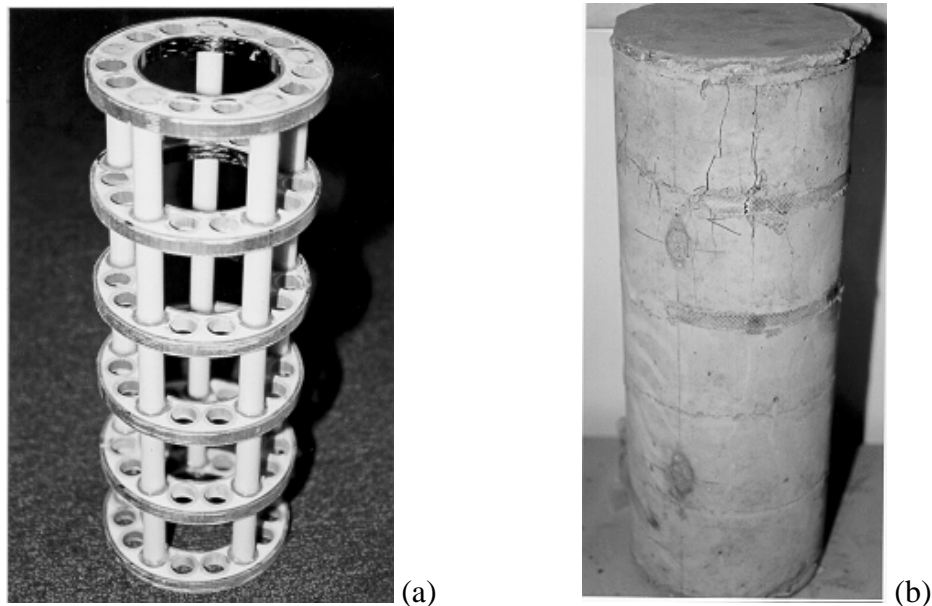
## INTRODUCTION

In the past thirty years of structural engineering, fiber reinforced polymer matrix composites (FRPMC) have been successfully used in aircraft, automotive vehicles, and sporting goods. The next promotion of applications for FRPMC will be the civil infrastructure [1]. Infrastructure systems consume a major portion of the wealth of our society. An estimated need for infrastructure construction and repairs in the Asian areas alone is almost US\$2 trillion by the year of 2000. Renewing the infrastructure in an intelligent manner by taking advantage of modern technology and by optimizing the performance of the structural system can achieve great savings and promote the economic growth of the society.

One technology that can be readily tapped for infrastructure construction and repairs is the application of composites. It is well known that composite materials have high specific strength, good fatigue life and corrosion resistance [2]. There are many processes for making composite structures. The most common ones for high-performance structures include:

pultrusion, filament winding, fiber placement, RTM, and various lay-up processes [3]. Each of these processes has its own advantages and disadvantages. In general, the major concern with composite structures lies in the cost of materials and the cost of processing composites into a finished product. In the past it has been identified that making the structure in a grid form is an effective way to save raw materials. The famous WWII English bomber, Wellington, was built with metallic grids of geodesic structures whose performance was well documented. Quite a few other successful applications of grid structures were reported in the literature. However, extensive usage of composite grids in civil infrastructure did not materialize because of the lack of cost-effective fabrication process and reliable engineering test data. Recently, Tsai & Chen demonstrated that grid structures interlaced with unidirectional fibers can combine the superior properties of composite materials with low cost manufacturing [4]. Lee *et al.* investigated concrete columns reinforced by composite grids with both experimental testing and computational modeling [5]. It has been shown that the compressive strength of concrete could be improved by the confinement provided by the composite grids.

In the present study, a new type of composite grid tubes for the reinforcement of concrete columns was developed. The fibers were wound in the pre-cut grooves on the surface of PVC tubes to form a grid structure. Hybrid columns were made by pouring cement concrete into the tubes. Within the scope of the present study, emphasis was placed on investigating the effect of confinement provided by the reinforcing composite grid tubes on the compressive strength of concrete columns. A uni-axial compression test was performed on hybrid columns and a pure concrete column for comparison. It was identified that the composite grid tube could substantially increase the compressive strength and the toughness of concrete columns. With further investigation on durability, the present hybrid structure may have good potential to compete with the conventional steel rebar reinforced concrete columns.

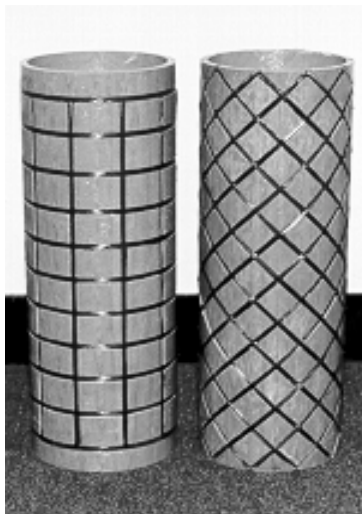


*Fig. 1: Previous design of composite grids-reinforced concrete column, (a) configuration of composite grids, (b) finished hybrid column after pouring concrete*

## DEVELOPMENT OF COMPOSITE GRID TUBES

In a previous study [5], a composite grid structure was developed as shown in Fig. 1(a). This structure consists of several graphite/epoxy “disks” and glass/polyester “stringers”. The former was fabricated by filament winding and the latter by pultrusion. The composite grids were placed in a mold and cement concrete was poured into the mold to make a hybrid column as shown in Fig. 1(b). A uni-axial compression test was conducted on such columns to evaluate their structural performance. It was found that the confinement provided by the composite grids could enhance the compressive strength of concrete. However, there are some disadvantages associated with the aforementioned design. First of all, the configuration of composite grids is too complicated. Secondly, a mold is required in order to pour the concrete. Furthermore, the foam filler between the inner and outer layers of the filament-wound “disk” is too compliant. As a result, the effective axial stiffness of the hybrid column is substantially reduced. Due to these drawbacks, a new design was proposed and investigated in the present study.

The newly developed composite grid tubes for the reinforcement of concrete columns are presented in Fig. 2. The fibers are wound in the grooves on the surface of a PVC tube to form a grid structure. The grooves are cut by a milling tool before filament winding. Both groove milling and filament winding can be performed on the same machine, which is modified from a conventional lathe machine. The cutting and the winding follow the same path, which is controlled by a microprocessor. The pattern of grids may be either orthogonal ( $0^\circ/90^\circ$ ) or helical ( $\theta^\circ/-\theta^\circ$ ). In the present study, the “wet winding” process (dry fiber filament fed through resin bath) was employed. For better quality and control, prepreg tows may be used. However, the material cost would be higher. It should be noted that the aforementioned fabrication process can be fully automated. Consequently, the production cost may be minimized and the quality may be assured. After filament winding, a curing process is required to treat the resin. Once the composite grid tube is completed, cement concrete is poured into the tube to form a hybrid column structure. The PVC jacket serves not only as a mold for concrete pouring, but also as a protection layer to prevent fibers from chemical attack (from the concrete). The concrete inside the tube takes twenty-eight days to cure and then the hybrid column is ready for testing.



*Fig. 2: Composite grid tubes with orthogonal and helical winding patterns*



*Fig. 3: Hybrid column subject to uni-axial compression test*

## UNI-AXIAL COMPRESSION TESTS

The objective of the present study is to characterize the structural performance of aforementioned hybrid columns under uni-axial compressive loading. The specimen was placed on an MTS-815 compression testing machine (capacity: 450 ton.) as shown in Fig. 3. At the top and the bottom faces of the column, two thick steel plates were used to cover the whole area. Strain gauges and extensometers were mounted on the lateral surface of the column to measure the axial deformation during testing. The uni-axial compression test was conducted at a stroke rate of 0.09 mm/min to ensure the static loading state. The same test was conducted on both composite grid reinforced columns and a pure concrete column for comparison. All column specimens had a length of 450 mm and an outer diameter of 165 mm. It should be noted that, within the scope of this paper, only orthogonal grids with 38-mm vertical pitch and 52-mm horizontal pitch were tested and compared. Specimens with various grid pitches and patterns are in production and the testing data will be released in the future.

Fig. 4 presents the experimental results in terms of stress-strain curves from the uni-axial compression tests. All specimens were loaded to failure. The testing data of three composite grid reinforced concrete columns were quite consistent. The averaged compressive strength of the hybrid columns was about 65 MPa while that of the pure concrete column was 40 MPa. From this comparison, it is observed that the strength of concrete column has been improved by 62.5% ( $65 \text{ MPa}/40 \text{ MPa}-100\%$ ). Also, the ductility has been increased from 0.55% to 0.68%. These improvements are attributed to the reinforcement of composite grids. In a previous study [5], it has been shown that the compressive strength and the ductility of concrete subjected to confinement can be substantially raised. In the present study, because the composite grid tubes provide the confinement (mainly in the hoop direction) to the concrete inside, the apparent compressive strength and the ductility of hybrid columns increase significantly. It is expected that the aforementioned structural performance could be further improved if the vertical pitch of the composite grids becomes smaller. However, the trade-off is the increase in material cost. With further analysis, an optimization between the cost and the performance may be reached.

*Fig. 4: Experimental results of uni-axial compression tests and comparison*

## CONCLUDING REMARKS

This paper introduces a new type of composite grid tubes for the reinforcement of concrete columns. A cylindrical PVC tube was used as a mandrel for the filament winding. A certain grid pattern was made on the surface of the PVC tube by a milling tool. The pattern could be either orthogonal or helical. The fibers were wound in the pre-cut grooves on the PVC tube to form a grid structure. A curing process is needed to consolidate the resin after filament winding. Once the composite grid tube was fabricated, cement concrete was poured into the tube to form a hybrid column structure.

The major objective of the present study was to investigate the effect of confinement provided by the reinforcing composite grid tube on the compressive strength of concrete columns. A number of uni-axial compression tests were performed on the newly developed hybrid columns and a pure concrete column for comparison. It was identified that the composite grid tube could substantially increase the compressive strength and toughness of concrete columns. The composite grid tubes introduced in the present study are aimed at replacing the conventional steel rebars for concrete column reinforcement. Since the fabrication of these grid structures can be fully automated for low-cost production and the composites have rather high corrosion resistance to the hostile environment, they have very good potential for infrastructure applications. Once the long-term durability is proven, the present hybrid structure may become a new option for building reinforced concrete columns.

## ACKNOWLEDGMENTS

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