STEEL REINFORCED POLYMER: AN INNOVATIVE AND PROMISING MATERIAL FOR STRENGTHENING THE INFRASTRUCTURES

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INTRODUCTION

The use of advanced composite materials in the construction industry is nowadays a mainstream technology(1), supported by design guidelines such as the ACI 440.2R-02 (ACI 440)(2) in the United States, the Fib-Bulletin 14 (2001)(3) in Europe and the recently published TR55 (2004)(4) in the United Kingdom. Fiber reinforced polymer (FRP) composite materials, even though very attractive, may be hindered by lack of ductility(5) and fire resistance(6). Both issues are currently under study by the research community, in order to provide on one hand, better knowledge in terms of overall structural performance and, on the other, remedies such as coatings that could prolong fire resistance.

A new family of composite materials based on unidirectional high strength twisted steel wires (about 7 times stronger than typical common reinforcing bars) of fine diameter (0.20–0.35 mm (0.0079–0.0138 in) see Figure 1), that can be impregnated with thermo-set (referred to as steel reinforced polymer, SRP) or cementitious (referred to as steel reinforced grout, SRG) resin systems is presented in this work (Hardwire 2002)(7). SRP/G has the potential to address the two shortcomings mentioned for FRP, in fact: a) steel cords have some inherent ductility; and b) impregnation with cementitious paste may overcome the problems of fire endurance and lowering down the application cost considerably.

The steel cords used in SRP are identical to those used for making the reinforcement of automotive tires, and manufactured to obtain the shape of the fabric tape prior to impregnation (Hardwire, 2002). The twisting of the wires allows some mechanical interlock between the cords and the matrix, and may also induce an overall ductile behavior upon stretching. The cords are also coated with either brass or zinc making the material potentially free of any corrosion and suitable for different

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kind of environmental exposure. Characterization work, including durability studies, is currently in progress as necessary for implementation in future design guidelines. Recent test results\(^8\) showed that the material does not experience a substantial yielding, but rather a similar behavior to the one experienced by high-strength steel used in prestressed concrete (PC) construction, with a slight non-linear range prior to rupture of the cords.

In this paper the authors introduce two case studies where steel reinforced polymers materials have been applied: a parking garage and a bridge. The first reports on tests performed up to failure in real size prestress concrete (PC) double-T beams. The second one reports on the application of such materials to strengthen a bridge in Missouri, USA, part of a research development project.

CASE STUDIES

*Performance of Double-T Prestressed Concrete Beams Strengthened with Steel Reinforced Polymer*

The first opportunity for experimenting this new material in the field, became available in the winter of 2003 when the City of Bloomington, Indiana, USA, decommissioned an existing parking garage near the downtown area. The parking garage was a two storey structure consisting of a reinforced concrete (RC) frame, cast in place columns and precast reversed-T PC beams, supporting double-T PC beams, of span length varying from 4.66 m to 13.41 m.

A total of three double-T PC beams were strengthened in flexure with with epoxy-based SRP and tested to failure: beam DT-C is the control beam, beam DT-1 represents the beam strengthened with one ply of SRP and DT-2U the one strengthened with 2 plies of SRP anchored with SRP U-wraps.

The epoxy resin for both strengthened beams was SikaDur Resin 330\(^9\). The choice of the resin was based on constructability so that it could be rolled onto the surface for overhead applications, while having enough consistency, even before curing, to be able to hold the weight of the steel tape during cure. The tape was medium density consisting of 6.3 cords per cm (12 WPI). The mechanical properties, based on steel net area, for an impregnated medium density tape, tested following the ASTM D 3039\(^{10}\) recommendations, are reported in Table 1.
SRP was installed following the recommendations of ACI 440 provisions for FRP materials, and Figure 2 documents some phases of installation.

The beams were tested under simply supported conditions and subject to a single concentrated load spread over both stems at mid-span. An electronic data acquisition system recorded data from four linear variable differential transducers (LVDTs) and two electrical strain-gages applied to the SRP in beams DT-1 and DT-2U.

Figure 3 illustrates the mid-span deflection plots for all three beams. SRP composite materials have shown to be effective in increasing the flexural capacity of the PC beams, 12% for beam DT-1 and 26% for beam DT-2U. End anchors in the form of SRP U-wraps have shown to be effective by preventing a complete detachment of the SRP laminate, once debonding has occurred throughout the concrete-SRP interface. Further investigation indicated that the increase in ductility showed by beam DT-1 and DT-2U, was also related to the slowly debonding that occurred prior complete detachment of the laminate.

Analytical validation\(^{(12)}\), using ACI 440 provisions, proved to be effective in anticipating the ultimate capacity, although further investigation in a controlled laboratory environment is recommended to properly calibrate the design related factors to anticipate the proper mode of failure and validate these findings.

*Preservation of Missouri Transportation Infrastructure: Validation of FRP Composite Technology Through Field Testing*

Five existing concrete bridges, geographically spread over three Missouri Department of Transportation (MODOT) districts, were strengthened using five different Fiber Reinforced Polymer (FRP) technologies as part of a joint MODOT – University of Missouri-Rolla (UMR) initiative. This project was intended to validate the use of FRP materials to strengthen existing concrete bridges considered structurally deficient. The bridges were selected in consultation with the respective District Offices, in order to allow a wide geographical spread of the project. None of the bridges were chosen on the same route.

Five different technologies were used for this validation, namely: FRP sheets and Steel Reinforced Polymer (SRP) applied by manual lay-up; pre-cured FRP laminates; near surface mounted (NSM) FRP bars; and, Mechanically Fastened (MF) FRP laminates. More than one strengthening technique was used for each bridge.
Bridge P-0692 located in Dallas County, MO, (see Figure 4) was chosen as the candidate bridge for strengthening a span employing steel reinforced polymer SRP as strengthening material. The structure has three spans and each of them consists of three RC girders monolithically cast with the slab. Each span is provided with one transversal beam. All spans are 12.9 m long. The total bridge length is 38.9 m and the total width of the deck is 7.2 m.

The design of the strengthening was conducted considering load configurations and analysis consistent with the AASHTO\textsuperscript{(12)} specifications and computing the strengthening system in compliance with ACI 440\textsuperscript{(2)} guidelines, accounting for larger safety coefficients to account for the novelty of the application. The strengthening included both improvement of the flexure and shear capacities of the RC girders as well as the flexural capacity of the RC deck (Figure 5).

To determine the global structural performance, in-situ load tests\textsuperscript{(13)} were performed before and immediately after strengthening of the five bridges. Deflections were measured at several locations, transversely at mid-span and longitudinally along an exterior and its adjacent interior girder, using a novel non-contact deflection monitoring technique based on high performance surveying equipment or Total Station\textsuperscript{(14)}. The static load tests were performed using standard trucks (Figure 6a). Typical results of load tests, before and immediately after strengthening, are shown in Figure 6b. It can be seen that after the application of the SRP reinforcement, a marginal decrease in deflection is obtained. Subsequent tests over a period of five years will be compared to these two baselines.

**FUTURE WORK**

Studies\textsuperscript{(15)} at the University of Missouri-Rolla are underway to characterize the material and to properly calibrate the design factors.

The test results of the work in the parking garage have been submitted for publication, while the progress of the bridge project and other studies on the application of steel reinforced polymers to buildings and bridges may be found at the following websites: http://www.rb2c.umr.edu and http://www.utc.umr.edu.
ACKNOWLEDGMENTS

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REFERENCES

(1) Rizkalla, S. and Nanni, A. (2003) “Field Applications of FRP Reinforcement: Case Studies” ACI Special Publication 215, Published by the American Concrete Institute, Farmington Hills, MI.

(2) ACI 440.2R-02, 2002: “Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures,” Published by the American Concrete Institute, Farmington Hills, MI, pp. 45.


TABLES

Table 1 - Material Properties of the 12 WPI Steel Tape

<table>
<thead>
<tr>
<th>Cord Coating</th>
<th>Cord Area per 12 Wires, [mm$^2$]</th>
<th>Cords per [cm]</th>
<th>Nominal Thickness$^{(1)}$, $t_{SRP}$ [mm]</th>
<th>Tensile Strength, $f_{fu,SRP}$, [MPa]</th>
<th>Ultimate Rupture Strain $\varepsilon_{fu,SRP}$</th>
<th>Tensile Modulus of Elasticity, [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brass</td>
<td>0.396</td>
<td>3.7</td>
<td>0.148</td>
<td>3070</td>
<td>0.0167</td>
<td>184</td>
</tr>
</tbody>
</table>

$^{(1)}$ The nominal thickness has been computed assuming the area of each cord and counting the number of cords in each ply, reported in *cords per cm*.
**FIGURES**

(a) Steel Cord with Wires Wrapped by One Wire

(b) 12WPI Tape with Cords Held Together by a Polyester Scrim

Figure 1 – Example of Steel Cord and Tape

(a) Application of Longitudinal Ply

(b) Application of U-Wraps

Figure 2 – SRP Installation Procedure

Figure 3 – Mid-Span Deflection Plots
Figure 4 – Bridge P-0962 Dallas County, MO

a) Flexural Strengthening of the Deck

b) Flexural Strengthening of a Longitudinal Girder

Figure 5 – SRP Installation by Manual Lay-Up

a) Load Testing

b) Deflection Before and After Strengthening (1 in = 25.4 mm)

Figure 6 – Structural Assessment