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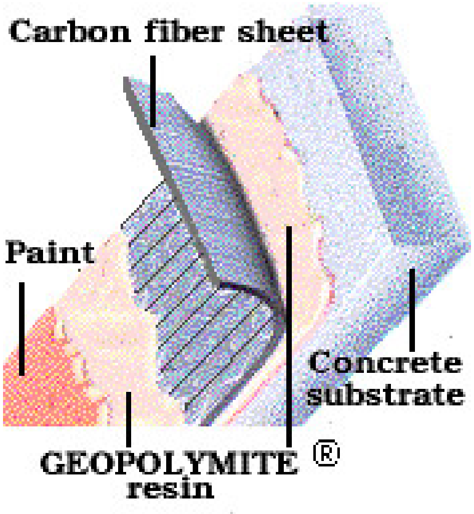
GEOPOLYMER FOR REPAIR AND REHABILITATION OF REINFORCED CONCRETE BEAMS



Project
GEO-STRUCTURE
Fire-Proof
External repair and structural retrofit
for aging infrastructure,
aging buildings,
earthquake
and
hurricane prone areas.

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Geopolymer for Repair and Rehabilitation of Reinforced Concrete Beams

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ABSTRACT

This report presents the results of an experimental investigation of the behavior of reinforced concrete beams strengthened with carbon fiber fabrics and geopolymer. The primary objective of the investigation was to determine whether geopolymer can be used instead of organic polymers for fastening the carbon fabrics to concrete. Four reinforced concrete beams that were similar to the ones reinforced with carbon fabrics and organic adhesives were tested. The beams had 0, 2, 3 and 5 layers of unidirectional carbon fabrics attached at the tension face of the beams.

The results indicate that geopolymer provides excellent adhesion both to concrete surface and in the interlaminar planes of fabrics. All three beams failed by tearing of fabrics. This is very significant because very few researchers report failure of beams with tearing of fabrics. The most common failure pattern reported in the literature is the failure by delamination of fabrics at the interface of concrete and fabrics. Hence it can be stated that geopolymer provides as good or better adhesion in comparison with organic polymers. In addition, geopolymer is fire resistant, does not degrade under UV light, and is chemically compatible with concrete. Therefore, the product can be successfully developed for use in the repair and retrofitting of concrete structures.

INTRODUCTION

It is well known that the national infrastructure is in need of major repairs and rehabilitation. A number of repair and strengthening techniques are being promoted. Strengthening of reinforced concrete structures with externally bonded steel plates is one of the techniques developed in the 1960's. Recently, high strength carbon, glass, and aramid composite plates are being promoted as a better alternative to steel plates [1]. The major advantages in using the composite plates are: lightweight, corrosion resistance, and ease of application. The lightweight is a major advantage during construction because heavy equipment is not needed. The composites can also be applied layer by layer resulting in almost a homogeneous final structure.

The major disadvantage of composites is their lack of fire resistance and degradation under UV light leading to long-term durability problems. The carbon and glass fabrics can withstand normal fire exposure and are durable under UV light. But the weak link is the organic polymers that are used to attach these fabrics to concrete. Hence, an investigation was undertaken to evaluate the use of an inorganic polymer which was developed recently. This inorganic polymer, known as geopolymer, is an alumino silicate which can sustain up to 1000˚C (2000˚F). The polymer is durable and does not degrade under UV light.

EXPERIMENTAL PROGRAM

A number of investigators have evaluated beams strengthened with carbon fibers and organic polymers. The current experimental program was designed to simulate the research conducted at the Universite de Sherbrooke [2]. This strategy was used to reduce the number of beams to be tested for comparing organic and geopolymers. Four singly reinforced concrete beams that were similar to Sherbrooke beams were cast and cured for 28 days. Then three of the beams were strengthened using carbon fabrics and geopolymer. All the four beams were tested as simply supported beams under four point loading. The details of the beams and experimental procedures are presented in the following sections.

DETAILS OF THE BEAMS

Four reinforced concrete beams that were 10 ft. 6 in. (3200 mm) long, 7.875in. (200 mm) wide and 11.813 in. (300 mm) deep were constructed. These beams were tested over a simply supported span of 9 ft 10 in. (3000 mm). The reinforcement details of the beams are shown in Fig 1. The tension reinforcement consisted of 2# 4 bars. The tension reinforcement was kept to a minimum, in order to avoid the shear failure of strengthened beams. The compressive strength of concrete was about 6800 psi. The control cylinders made with all four beams provided consistent compressive strength results.

Strengthening of Beams

Three beams were strengthened using 2, 3, and 5 layers of unidirectional carbon fabric. The fabric made of T300 carbon fibers had a density of 5 oz/yd^2. After curing, the bottom surface of the beams were roughened, first by dry grinding followed by sand blasting. These operations removed the weak mortar layer, exposing some aggregates.

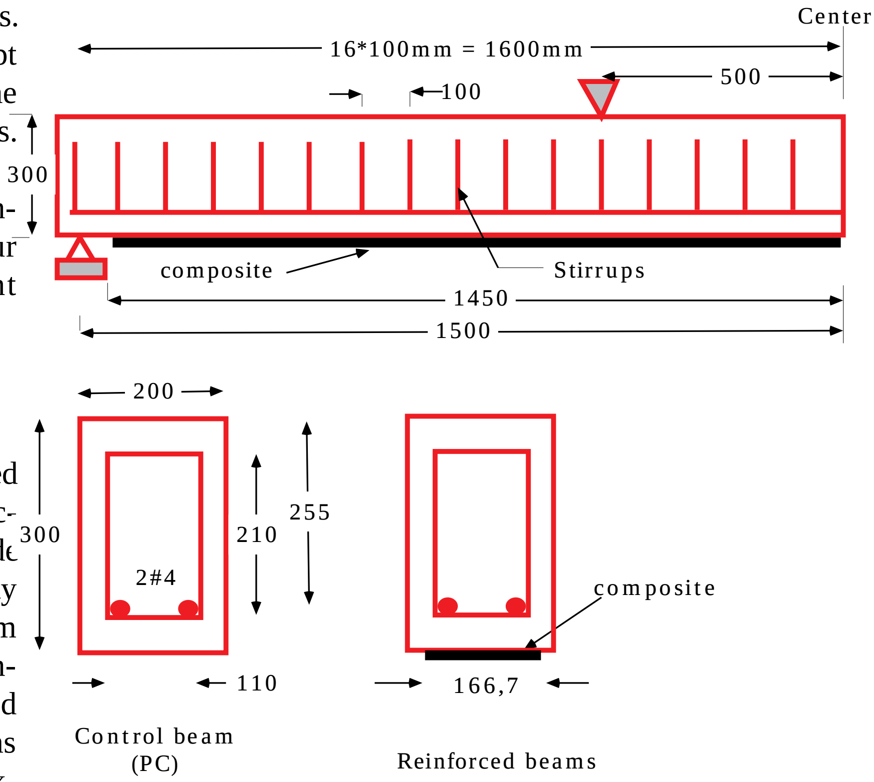

Figure 1: Beam Cross Sections

The rough surface was primed with a mixture of geopolymer to avoid the loss of geopolymer from fabrics to voids in concrete. The fabrics themselves were pregged using hand pre-pregging and placed at the bottom surface of the beam. The beam with two layers was allowed to dry for 24 hours and heated to 80˚C to cure the geopolymer. For beams with 3 and 5 layers, after placing the fabrics, they were covered with bleeding cloth and a vacuum of about 28 in. of mercury was applied for better adhesion. These beams were also heated to 80˚C to facilitate curing.

Instrumentation and Test Set-up

The beams were instrumented to measure strains in concrete, tension steel, and the composite; and the deflections. The strain values in the composite can be considered only as average values because the gages were glued to both the fibers and the matrix. The beams were simply supported over a span of 9 ft 10 in (3000 mm) and two concentrated loads were applied at 3 ft. 3.3 in. (1000 mm) from the supports. The loads were measured using MTS data logging systems. The beam set-up, ready for testing is shown in Fig 2.

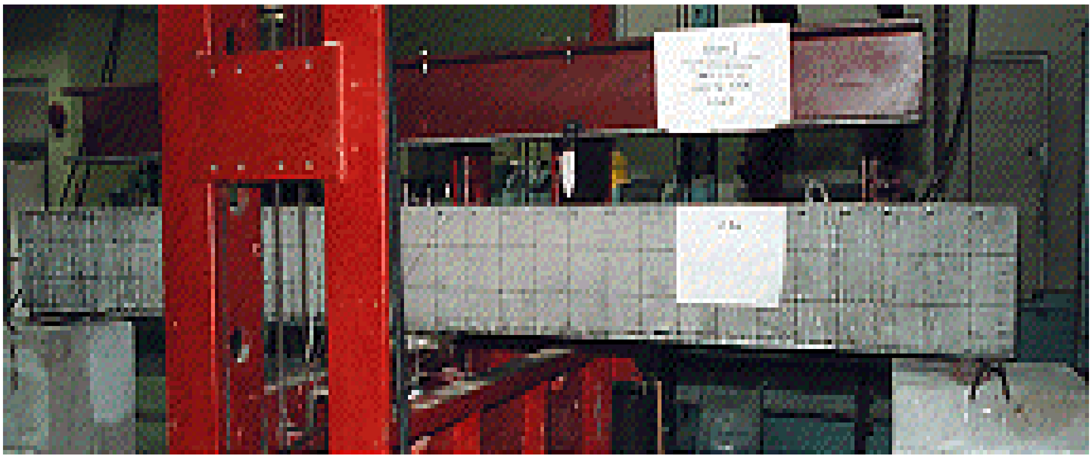

Figure 2: Beam Prior to Start of Testing

The loads were applied in 1000 or 500 lb. increments. For each increment of loading, strains, deflections and crack pattern were recorded.

RESULTS AND DISCUSSION

A summary of results is presented in Table 1, which shows loads corresponding to yield and final failure, and mid-span deflections at failure.

Table 1. Summary of Test Results

Beam Design.	Load at Yielding of Steel, k	Failure Load, k	Deflection at at Failure, in.	Mode of Failure
Control	12.5	16.0	3.5	Yielding of steel
With 2 layers	14.0	18.1	0.76	Rupture of Composite
With 3 layers	15.8	20.5	0.90	Rupture of Composite
With 5 layers	16.5	24.7	0.92	Rupture of Composite

Mode of failure

As mentioned earlier, all the strengthened beams failed by rupturing of the composite. This shows that geopolymer provides effective adhesion even when five layers of fabric were used. In practice, the number of fabric layers have to be limited to 3 or 4 for economical reasons. Hence, if the repair system is properly carried out, failure by delamination of composite can essentially be eliminated. Since the beams were purposely underreinforced with sufficient shear reinforcement, shear failure did not occur even when the moment capacity was increased by 50 percent over the control beam. As the number of layers increased, the length of composite that ruptures also increased.

Load-deflection behavior and crack patterns

As expected, the stiffness of the beam increased with the number of layers of fabric as indicated by the decrease in deflection, shown in Fig. 3. The depth of neutral axis seem to increase with the number of layers. This should also be expected because increased tension force for a given curvature requires increased compression force. Since the strength of concrete is the same, the increased compression force capacity has to come from increased compression force provided by a larger depth of neutral axis.

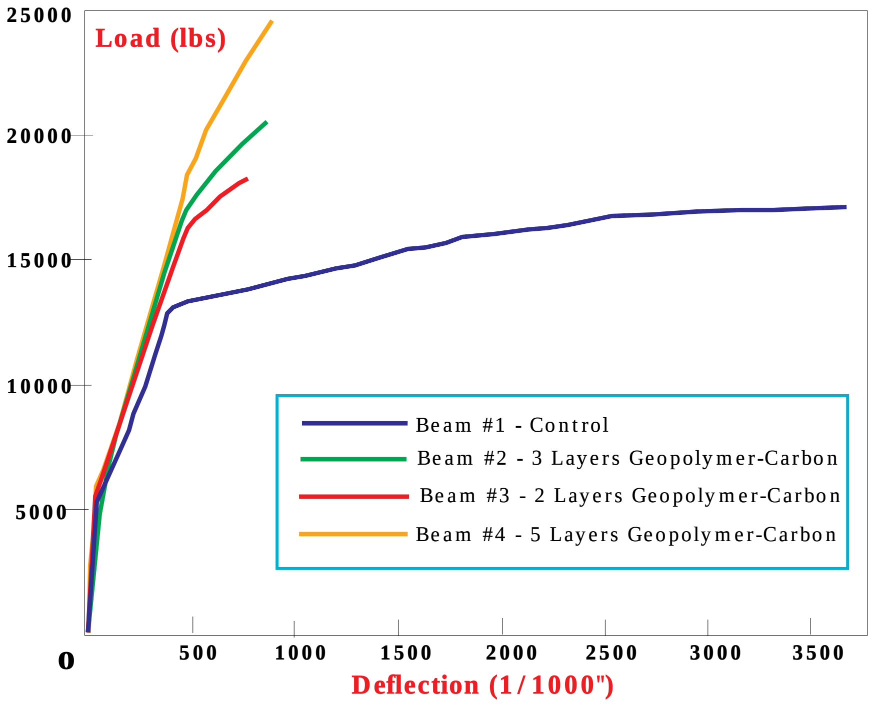

Figure 3: Load vs Deflection. All Beams

The crack patterns of strengthened beams are different from the control beam. Strengthened beams had more cracks and were more closely spaced. As the number of layers increased, the length of the beam over which extensive cracking occurred also increased. Maximum crack widths were smaller for the strengthened beams. Typical crack patterns are shown in Fig. 4.

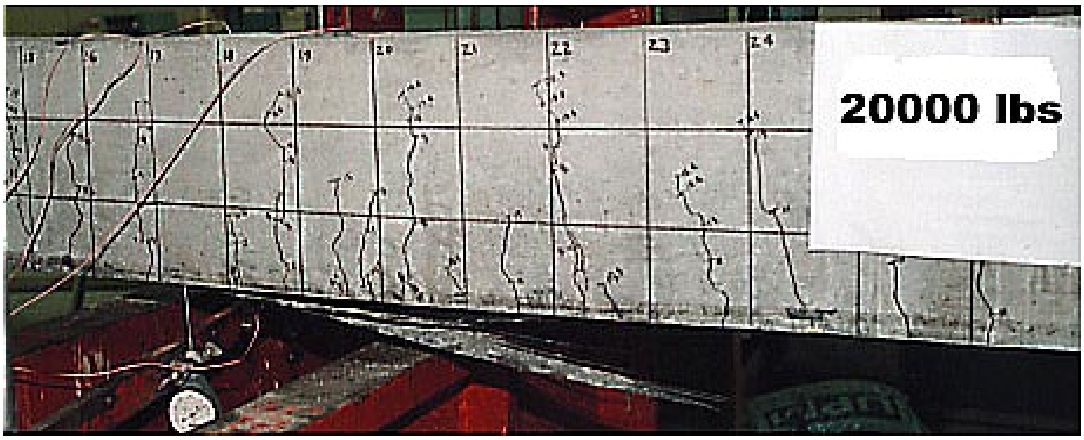

Figure 4: Cracking Pattern for Beam # 2 at 20000 lbs Load, after Rupture of Composite (bottom)

Comparison of organic and geopolymer

As mentioned earlier, the beams were designed so as to allow direct comparison of results obtained by Labossiere et al. at the Universite de Sherbrooke. Their control beam had a capacity of 14.3 kips, and their strengthened beam had a capacity of 22.4 kips. Hence the strengthening provided an increase of about 50 percent. They used 3 layers of Tonen Unidirectional fabric. The amount of reinforcement in 3 layers of Tonen fabric is slightly higher than 5 layers of fabric used in the current study. The beam with 5 layers also sustained 50 percent more load than the control beam, Table 1.

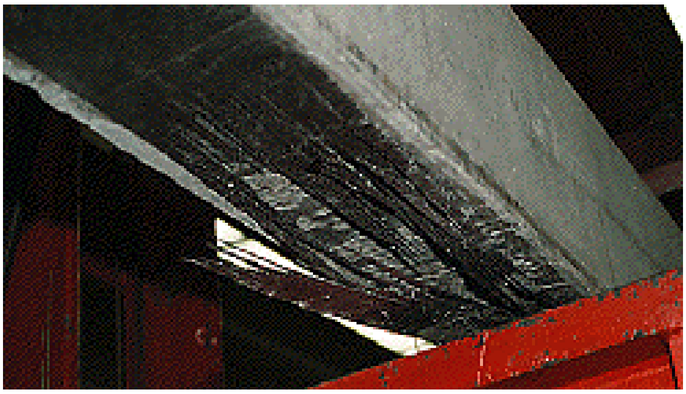

Figure 5:Rupture of Geopolymer-Carbon composite

The primary difference between the organic polymer and the geopolymer is the failure pattern. In the Sherbrooke study, the composite peeled off, whereas the composite ruptured in the current study (see Fig 5). Delamination failure not only underutilizes the composite strength, but is also extremely brittle. This type of failure must be avoided at all costs, in order to provide warning of the impending failure.

The deflections and crack patterns of beams with organic and geopolymers are comparable. The composite in the current study recorded larger strains than the strains reported in the Sherbrooke study.

In summary, it can be stated that geopolymer provides a better structural performance than the organic polymer.

CONCLUSIONS

Based on the experimental results obtained in the current study, and the results reported by other researchers [1-3], the following conclusions can be drawn.

- Geopolymer can be successfully used to bond carbon fabrics to reinforced concrete beams.

- With proper design and construction process, failure by delamination of composite can be eliminated.

- The performance of geopolymer is better than organic polymer in terms of adhesion. In addition, geopolymer is fire resistant, durable under UV light and does not involve any toxic substances. Geopolymer is water based and no special protective equipment other than gloves is needed. Excess material can be discarded as ordinary waste. This aspect is very important during the construction phase.

REFERENCES

1. ACI Committee 440, State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures, American Concrete Institute, Detroit, MI, 1996, 68 pages.

2. M'Ba Zaa, I., Missihoun, M., and Labossiere, «Strengthening of Reinforced Concrete Beams with CFRP Sheets,» Fiber Composites in Infrastructure, 1996, pp.746-759.

3. Nakamura, M., Sakal, H., Yagi, K., and Tanaka, T., «Experimental Studies on the Flexural Reinforcing Effect of Carbon Fiber Sheet Bonded to Reinforced ConcreteBeam,» Fiber Composites in Infrastructure, 1996, pp.760-773