Philippine Engineering Journal (1999) XX (1): 9 -24

BEHAVIOR OF CARBON FIBER REINFORCED CONCRETE BEAMS

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ABSTRACT

This test was undertaken for the purpose of demonstrating the increase in load carrying capacity of a plain reinforced concrete beam when reinforced with carbon fiber. A presentation was also made to show the ease with which the carbon fiber reinforcement is applied, something that cannot be said of steel jacketing. With regard to application, carbon fiber reinforcement is a more convenient alternative to the conventional steel jacketing technique for the rehabilitation of aging structures. It weighs substantially less than steel therefore it adds little, if any dead weight to the structure. It is five times stronger and it does not corrode. Deflections are also significantly reduced.

I. Introduction

The deterioration of concrete structures or damage due to earthquakes requires some method of strengthening or retrofitting. One such method is reinforcement with carbon fiber. In the construction of new structures, carbon fiber reinforcement serves just as well, allowing for smaller and more economical members.

II. Test Program

2.1 Description of Specimens

Three sets of 0.15 m x 0.15 m x 1.4 m reinforced concrete specimens are prepared for the study. Reinforcement is provided by 2 -12mm diameter bars at the top and bottom of the beam. Each set consists of one plain reinforced concrete beam, one reinforced concrete beam with one ply of carbon fiber and one reinforced with 2 layers of carbon fiber. The carbon fiber is applied longitudinally. Shear reinforcement consists of 10mm diameter closed stirrups. These are spaced at 0.50m on centers starting from the support up to the point of application of the load from both ends. The flexural reinforcement is also welded to steel plates at the ends of the member to preclude bond failure. Figures 1 and 2 show the dimensions of the specimens and the location of the strain gauges whose measurements form the basis for the graphs in Figures 17 to 25.

2.2 Materials

The average strength of concrete used for the specimens is 24 MPa (3500 psi). The yield and ultimate strength of the reinforcing bars are 345 MPa (50,000 psi) and 496 MPa (72,000 psi) respectively. REPLARK 30 (MRK-M2-30) carbon fiber is used. This type has a cross-sectional area of 1.67 cm^2/m, a tensile strength of 3,400 MPa (493,000 psi) and an elastic modulus of 230 GPa (33,400 ksi). The application of the carbon fiber reinforcement is shown step by step in Figures 3 to 8. Before the air holes are filled with putty, the concrete surface is ground and a coat of primer is applied. Note that another coat of resin is needed to cover the carbon fiber after impregnation is achieved. This allows continuity of the resin from the surface of the primer to the outer face. The fibers are therefore "sandwiched" by coats of resin.

2.3 Test Set-up

The specimens were tested under third point loading (ASTM C-78) with a span of 1.20 m. Strain gages were provided in the following locations: on top of the beam at mid-span, on the top and bottom of one of the tension bars, on the carbon fiber surface at mid-span and at 0.3 m from mid-span. Deflection transducers were also attached on both sides of the beam at mid-span. A load cell was attached to the loading jack for instantaneous measurements of the magnitude of the loading. All gages and transducers are connected to an automatic data-logger.

III. Discussion of Results

Plain reinforced concrete specimens reached an average ultimate load of 4.02 tons. Flexural cracks and subsequent yielding of the steel reinforcement initialized failure. Beams that were provided with one ply of carbon fiber reinforcement at the bottom in addition to usual steel reinforcement reached an average ultimate load of 6.99 tons. This represents a 74% increase in load capacity. Specimens that were provided with two-ply carbon fiber reinforcement reached an average ultimate load of 7.08 tons. This is roughly the same as the one-ply specimen average.

Deflections are also greatly reduced. If 60% of the average yield load for the ordinary reinforced concrete beam were taken to be the service load, the corresponding mid-span deflection would be about 3mm. At the same load level, the deflections for the single-ply and 2-ply specimens are 2 and 1.4mm respectively. This represents 67% and 47% of the deflection in the ordinary reinforced beam.

On a more specific note, it can be observed that the compression side for a plain reinforced specimen has an almost constant depth of about 50cm during the pre-failure loading stages. Sudden failure occurred at a load of 3.99tf. For the specimen reinforced with a single ply of carbon fiber, the depth of the compression face remained at approximately 53cm for a wider and higher range of values of the load compared to that of the plain reinforced concrete beam. Failure was also abrupt in nature. After the steel has yielded, it can be observed from the strain distribution diagrams that the slope of the load-strain curve for the carbon fiber flattens quickly so that the carbon fiber takes more stress for each increment of load than it used to. It therefore makes up for the loss of resistance of the steel, which by this time has already yielded. This behavior is also suggested in the strain diagram for a one-ply specimen. In the two-ply specimen, the depth of the compression face was approximately the same as that of the single-ply specimen except that the range of loads for which it was maintained is slightly higher. Similarly, the slope of the load-strain curve for the carbon fiber flattens just after the steel has already yielded but not as much as that of the single-ply specimen. The steeper slope (compared to that of the single-ply) can be attributed to the availability of a larger area of carbon fiber for resisting the moment and thus, the strains reach only about half as much (about 4000 microns for 2-ply and roughly 8000 microns for 1-ply).

In all the carbon fiber reinforced specimens, a sudden shear type of failure was observed. The carbon fiber reinforced beams behave like over-reinforced concrete beams. Diagonal tension cracks accompanied by local bond failure (between concrete and carbon fiber) were observed at the ultimate load near one of the supports. Consequently, a sharp increase in deflection and an even larger drop in load occur. Despite the large cracks, all the members were still able to carry loads that were greater than the ultimate load of their plain reinforced concrete counterparts.

IV. Conclusion and Recommendations

The use of carbon fiber reinforcement carries with it great advantage, ease of application and a significant increase in strength and decrease in deflection, but it is not totally free from disadvantage. The carbon fiber reinforced members tested behaved like over-reinforced concrete beams whose failure mode is one to be avoided. Since all of the carbon fiber reinforced specimens failed suddenly and without warning, additional precautions should be taken to avoid such type of failure. For beams, U-shaped carbon fiber reinforcement in the regions of large shear may reduce the possibility of such a failure. In this regard, it is recommended that future studies be dedicated to the prevention of the shear type of failure and the optimization of the carbon fiber for flexural reinforcement.

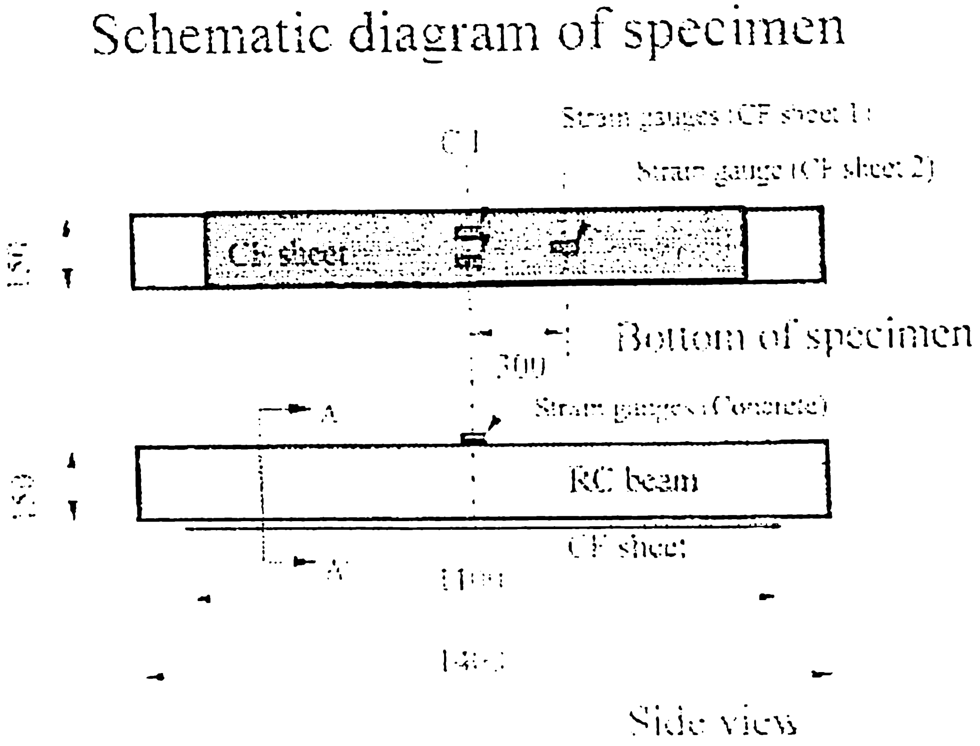

Figure 1. Specimen dimensions and strain gauge locations

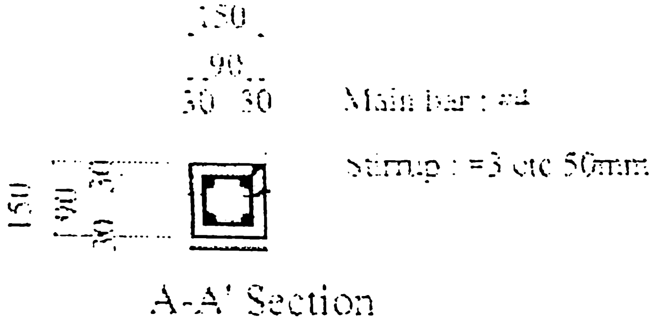

Figure 2. Beam cross-section

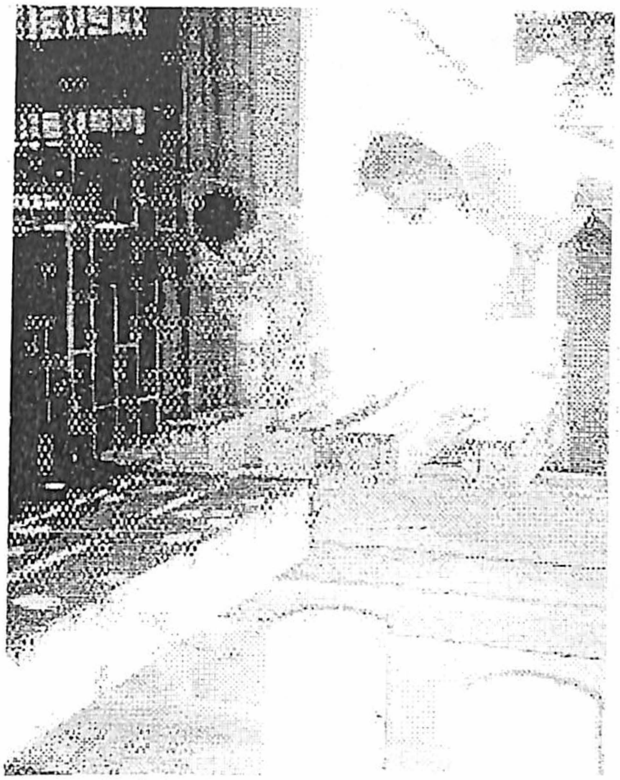

Figure 3. Putty application to air bubbles on the specimen surface

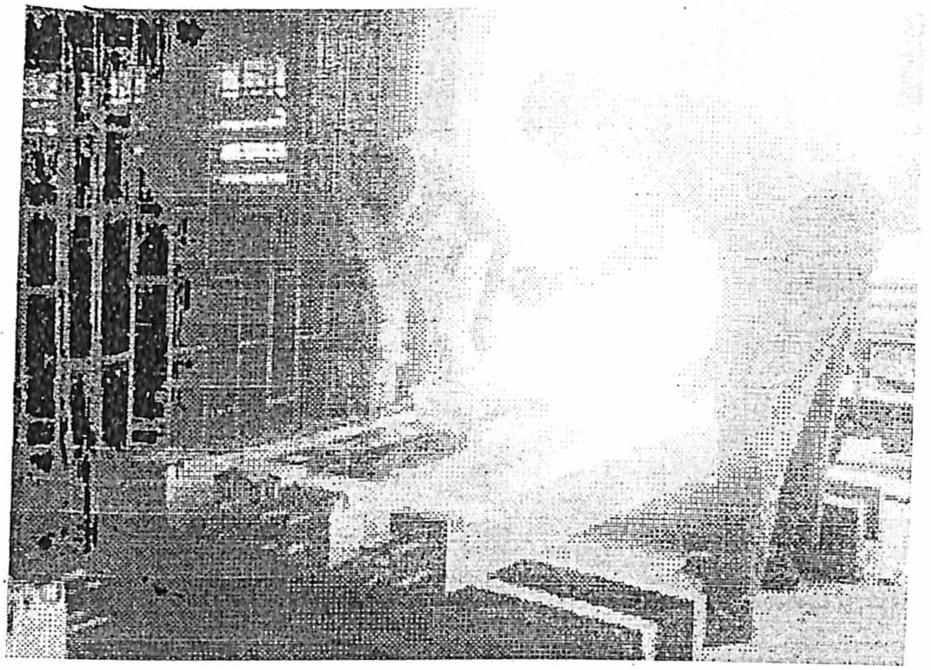

Figure 4. The resin undercoating is applied before the carbon fiber sheet is laid

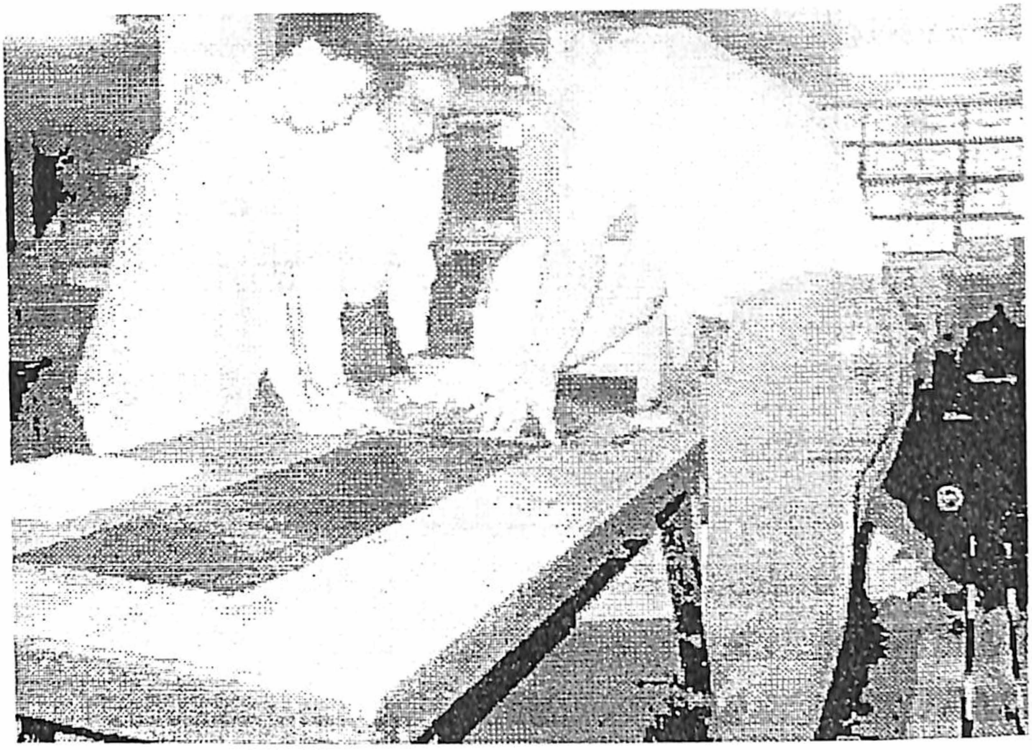

Figure 5. The sheet is cut into the appropriate size using a cutter

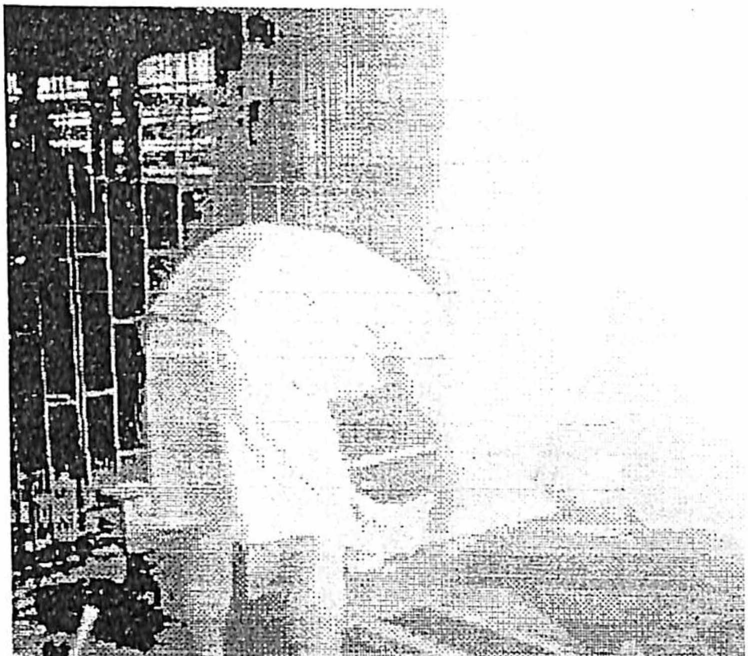

Figure 6. The sheet is laid on the specimen with the resin undercoating

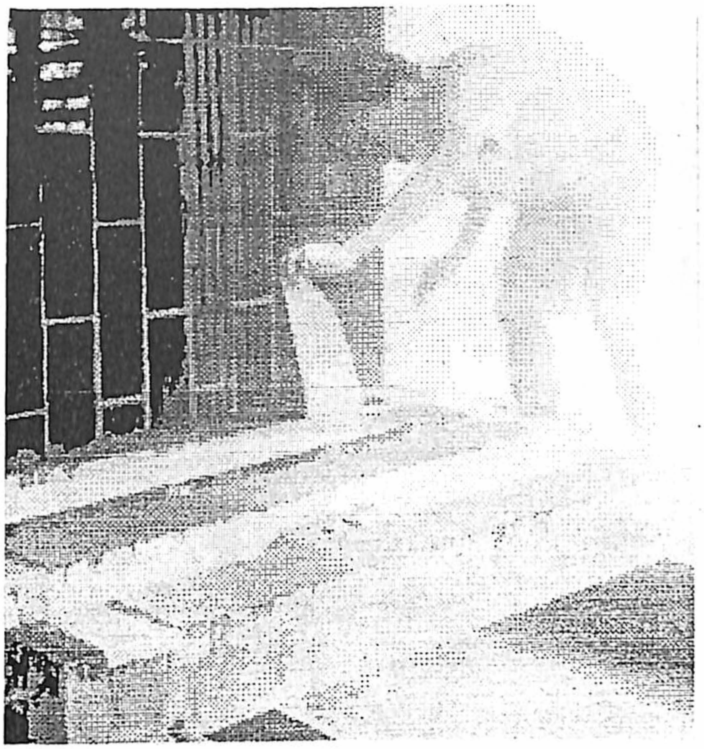

Figure 7. The paper cover is peeled off after the sheet is laid pat

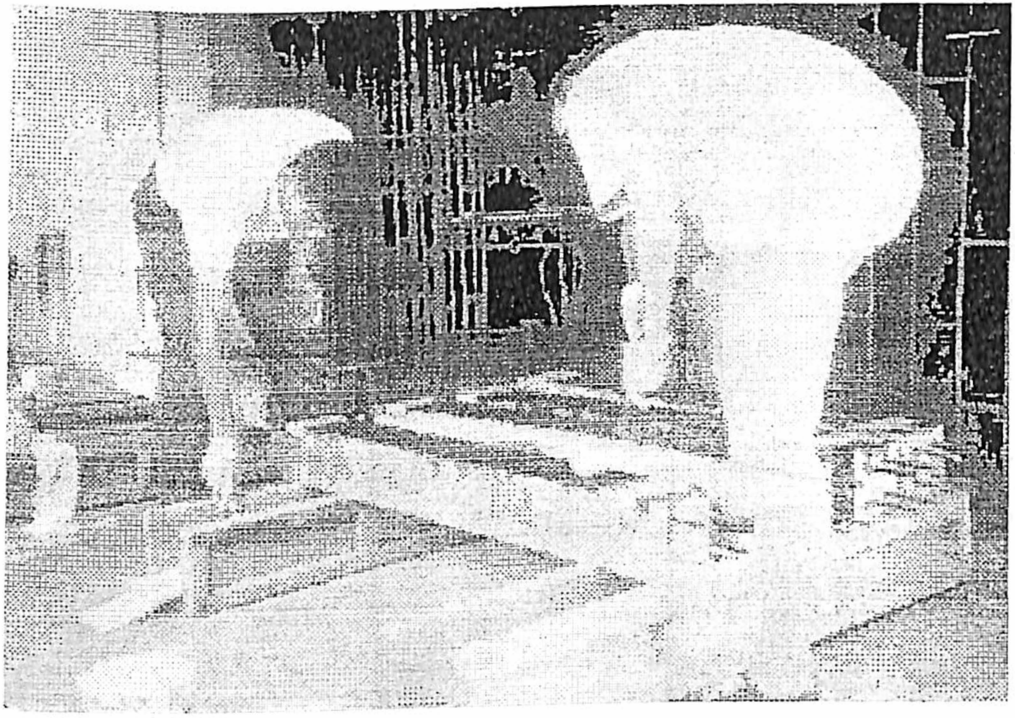

Figure 8. Plastic rollers are used to impregnate the fibers with resin

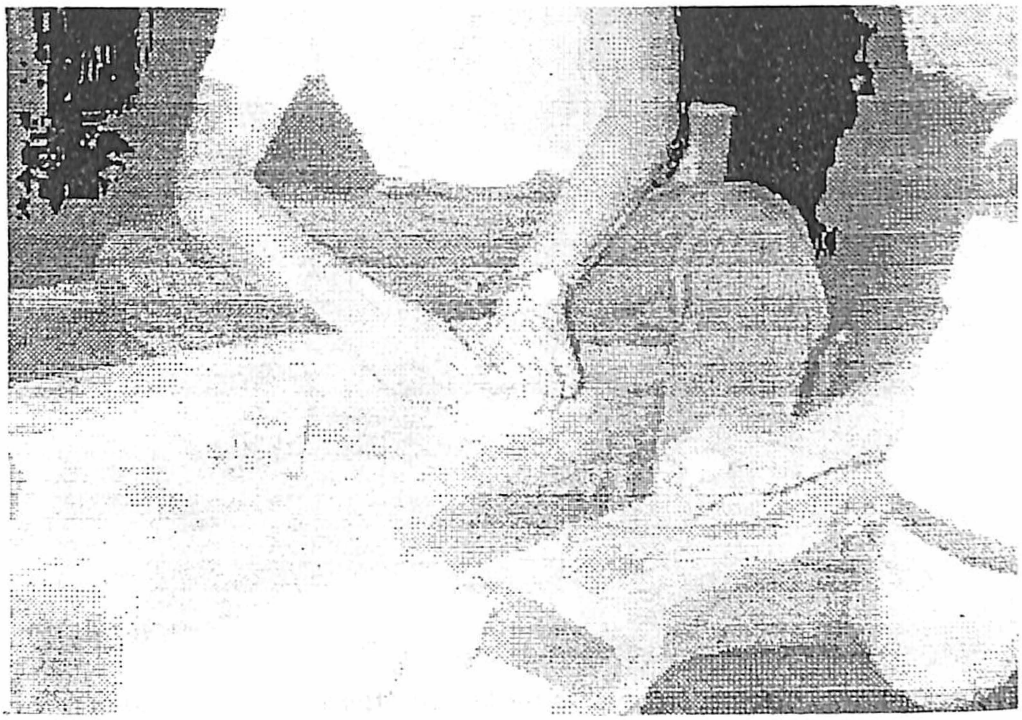

Figure 9. Strain gauges are attached to the points of measurement

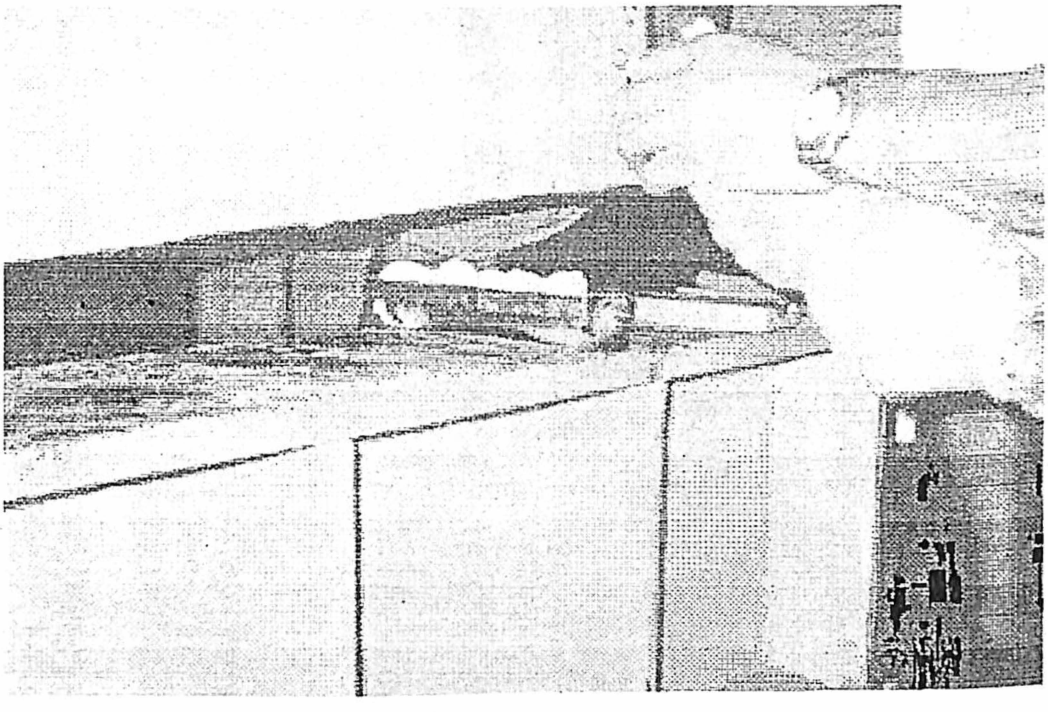

Figure 10. Plaster is poured on the supports to prevent movement of the specimen

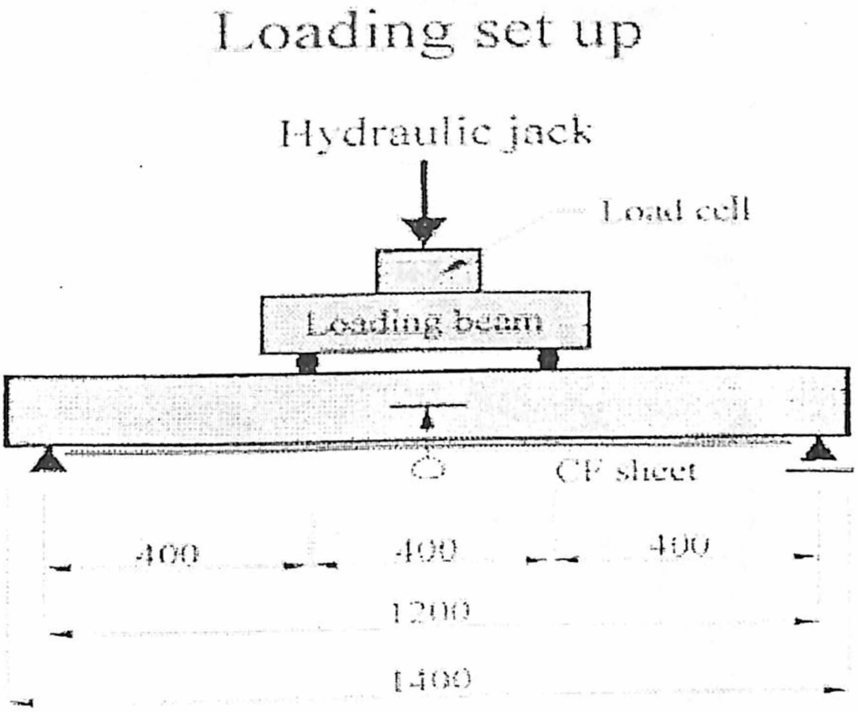

Figure 11. The loading set-up

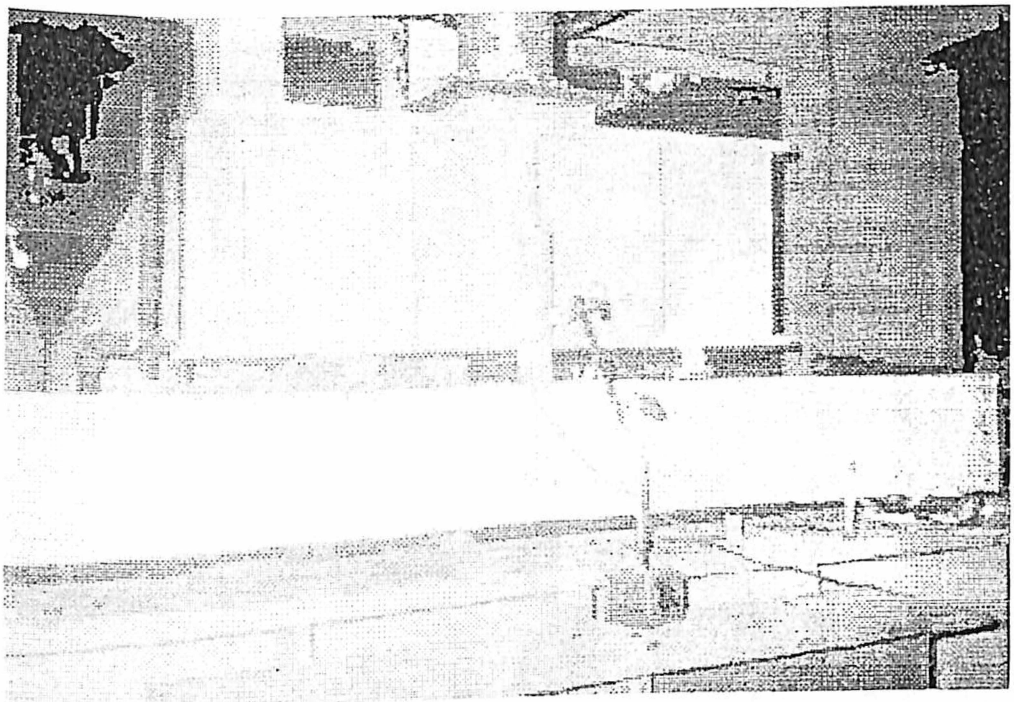

Figure 12. Loading set-up and midpoint deflection meter

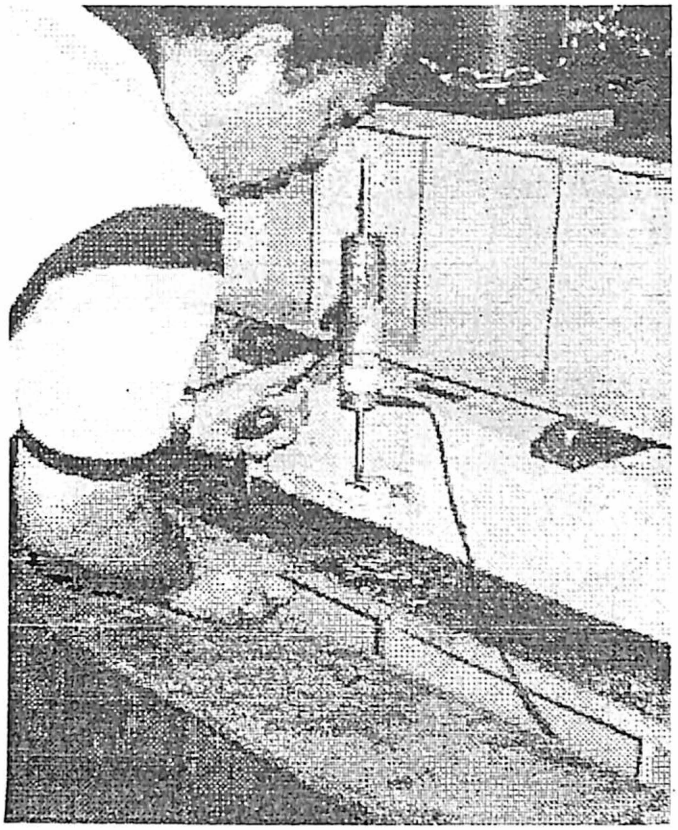

Figure 13. Installation of the deflection gauge

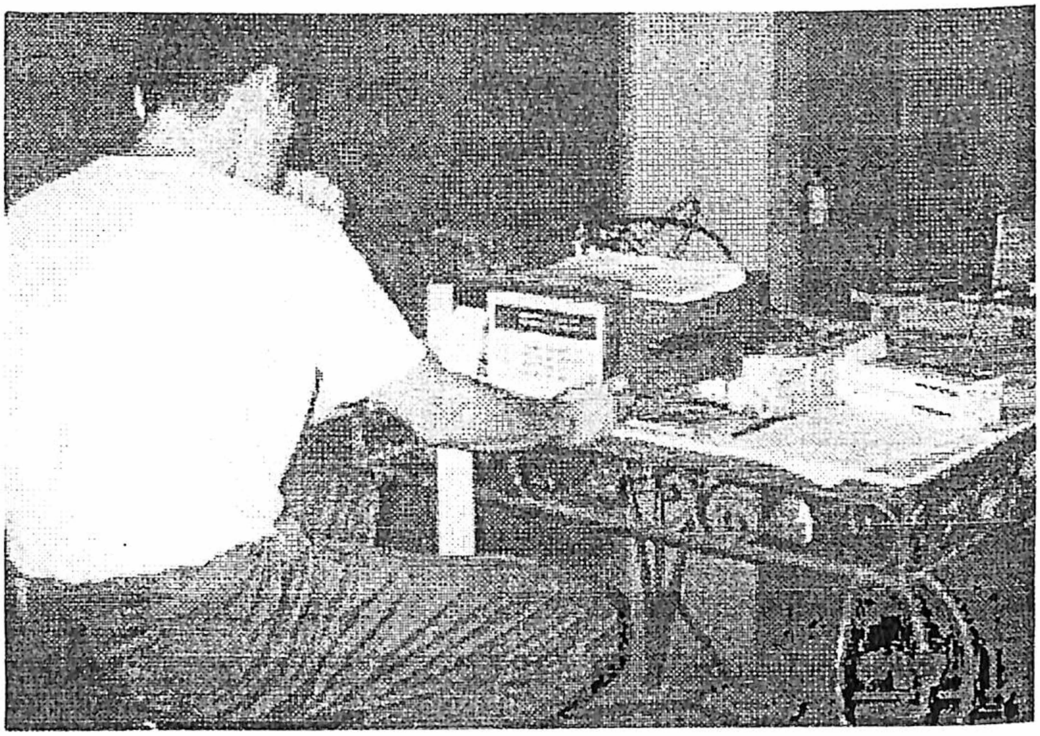

Figure 14. All measurements are recorded by the automatic data-logger

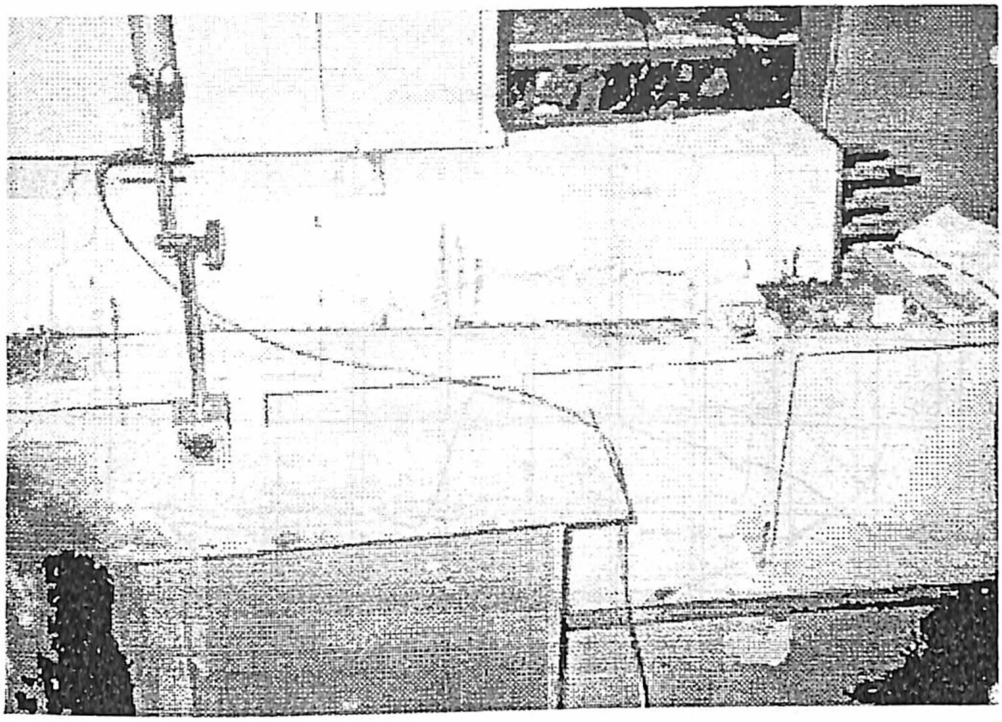

Figure 15. Diagonal tension crack at failure load, the specimen was reinforced with carbon fiber

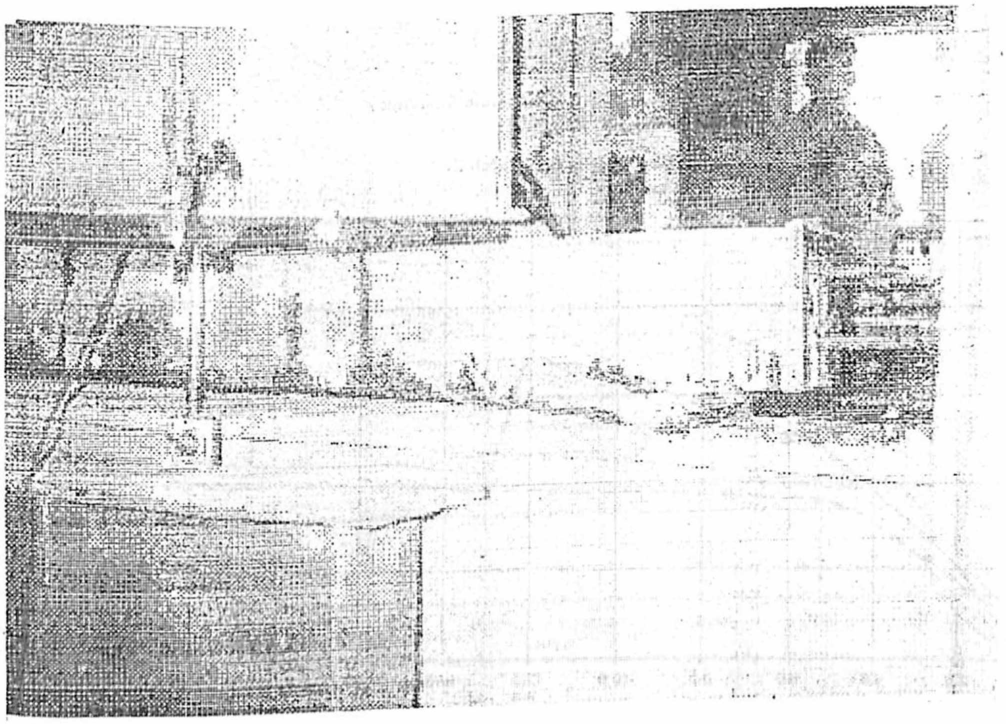

Figure 16. Another carbon fiber reinforced specimen at the failure stage

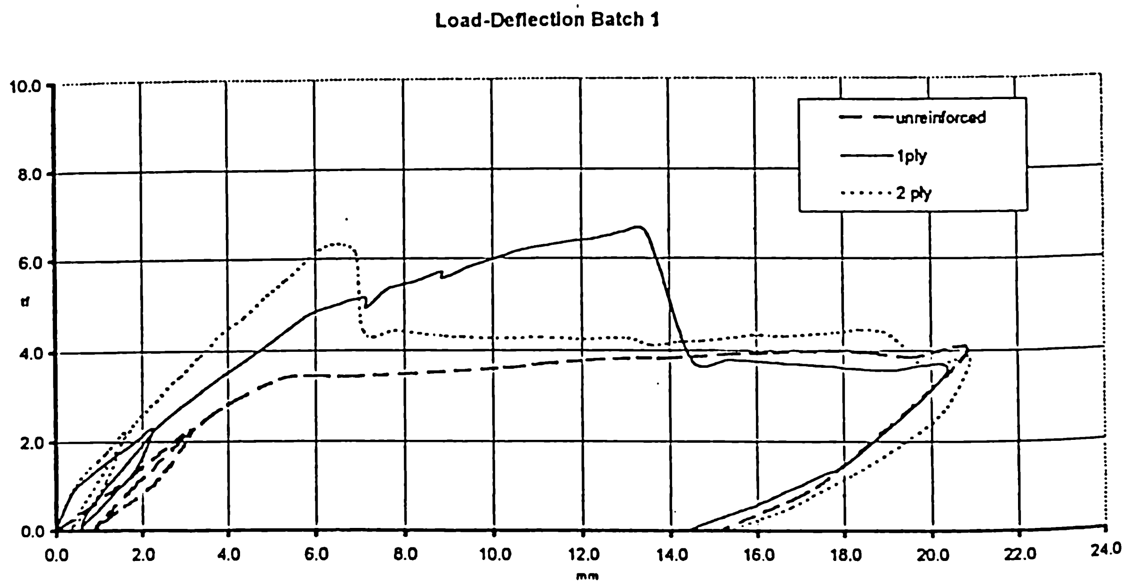

Figure 17. Load-Deflection curves for the first batch of specimens

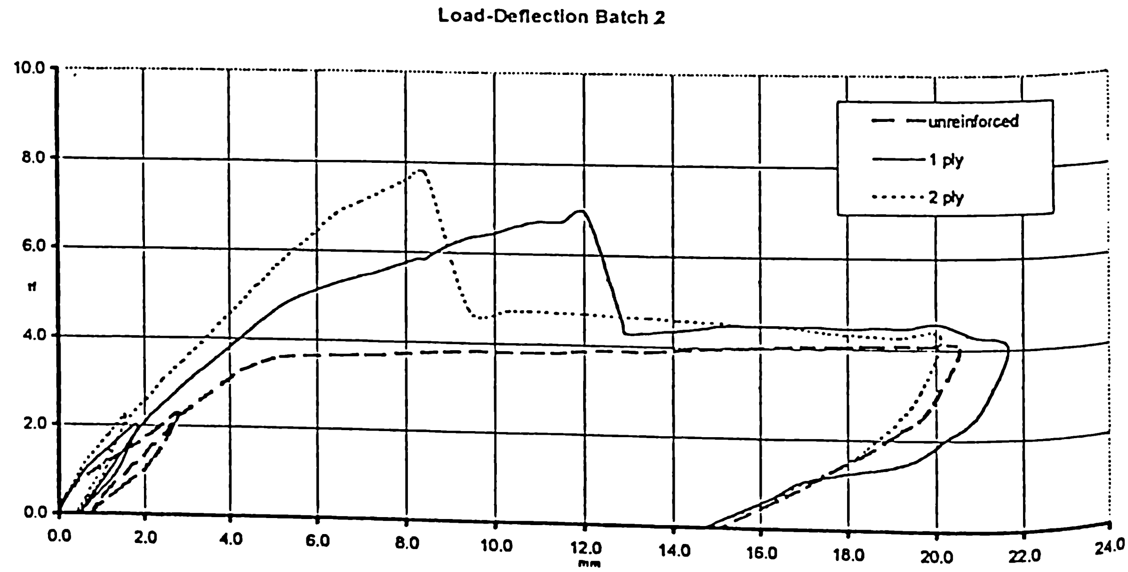

Figure 18. Load-Deflection curves for the second batch of specimens

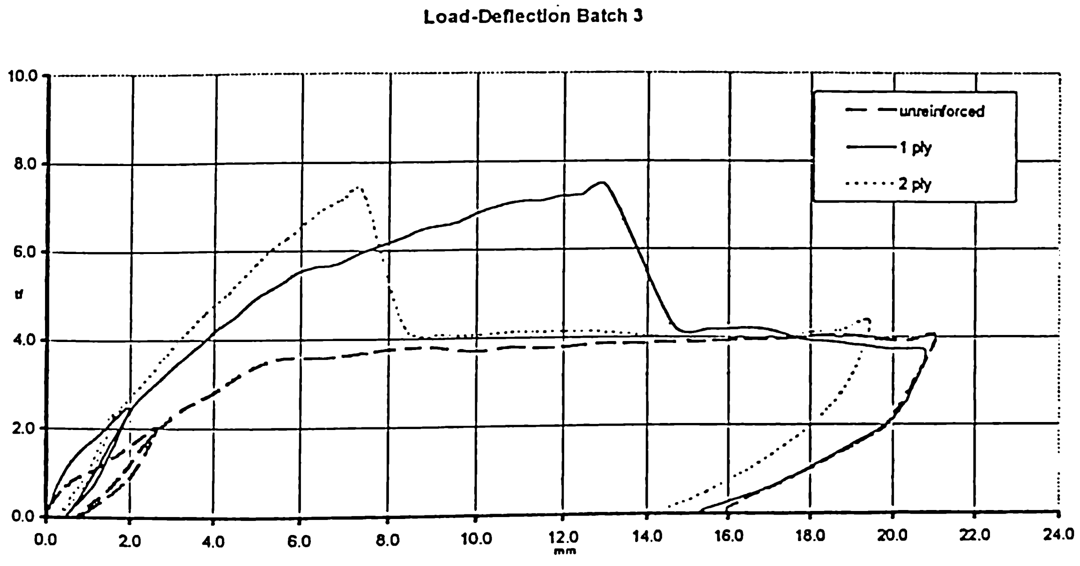

Figure 19. Load-Deflection curves for the third batch of specimens

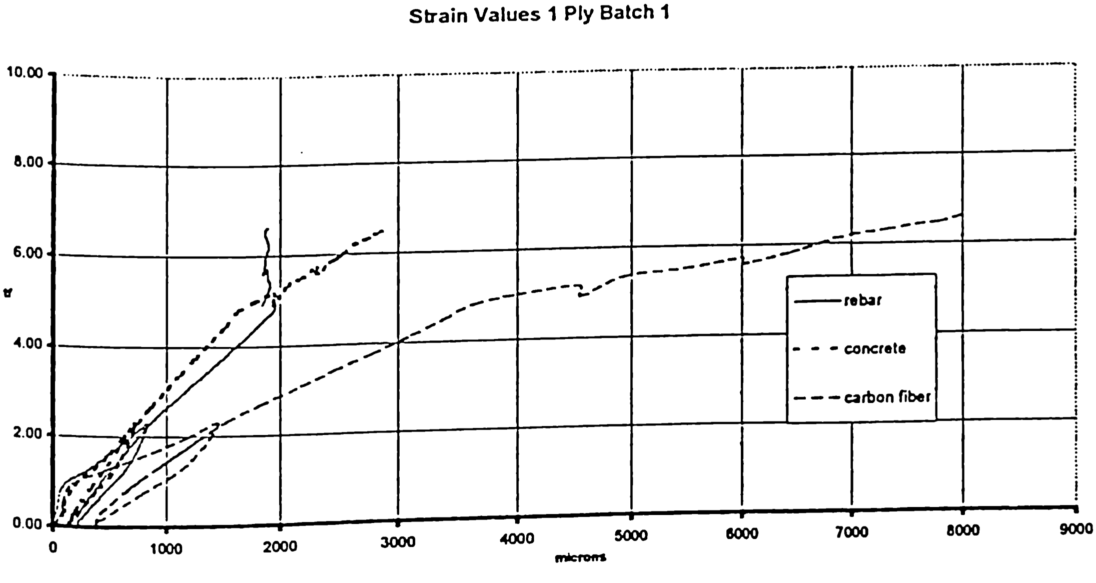

Figure 20. Load-Strain curves for the 1-ply specimen of the first batch

Strain Values 1 Ply Batch 2

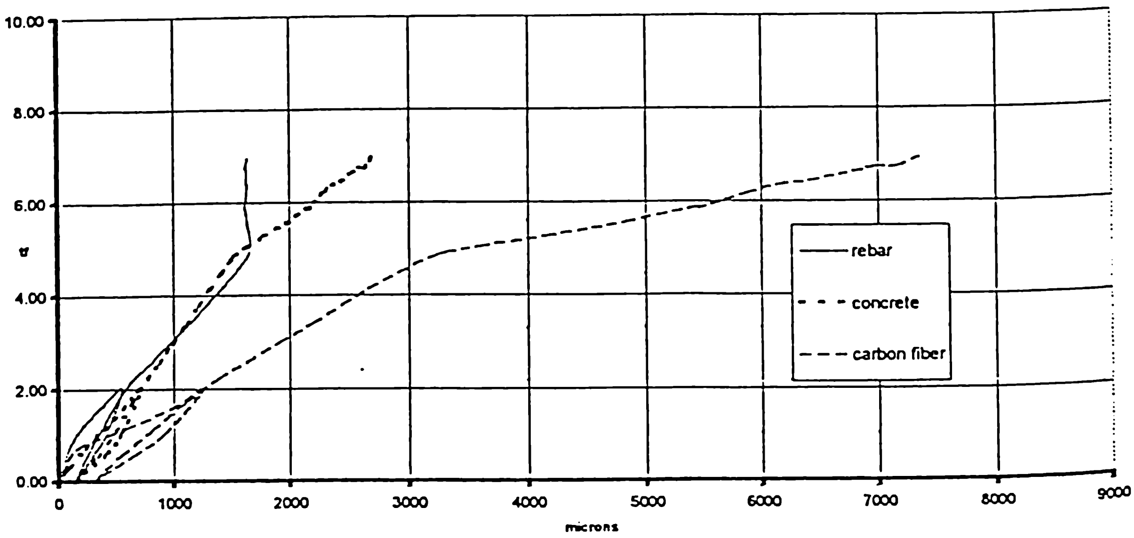

Figure 21. Load-Strain curves for the 1-ply specimen of the second batch

Strain Values 1 Ply Batch 3

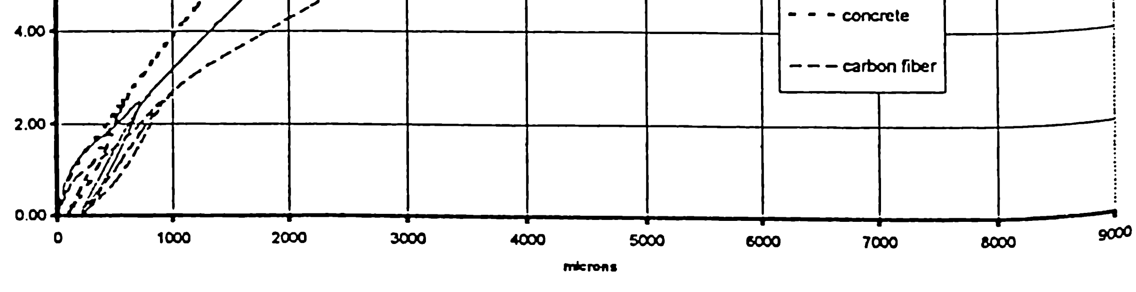

Figure 22. Load-Strain curves for the 1-ply specimen of the third batch

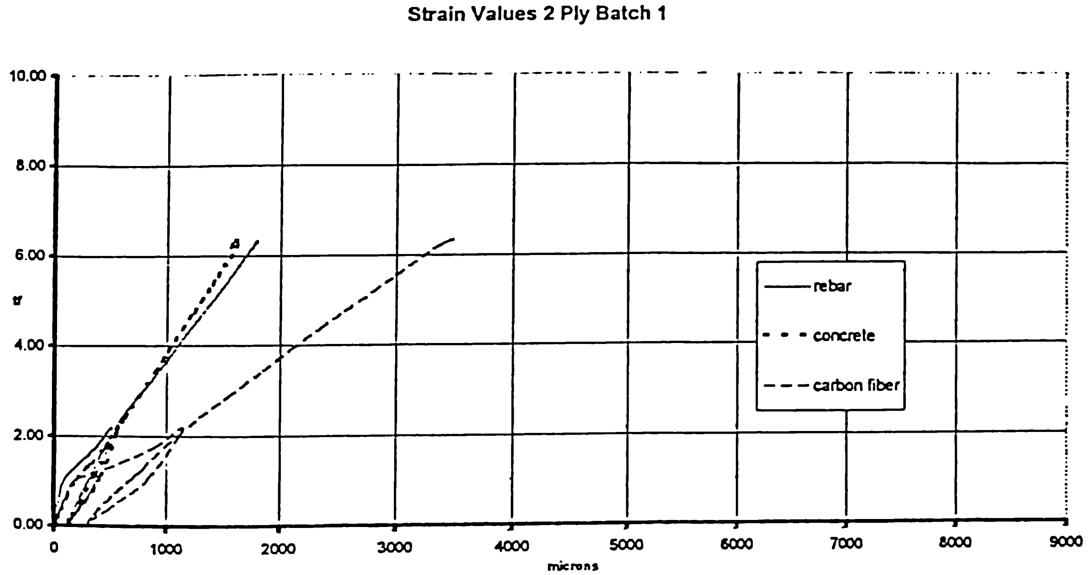

Figure 23. Load-Strain curves of the 2-ply specimen of the first batch

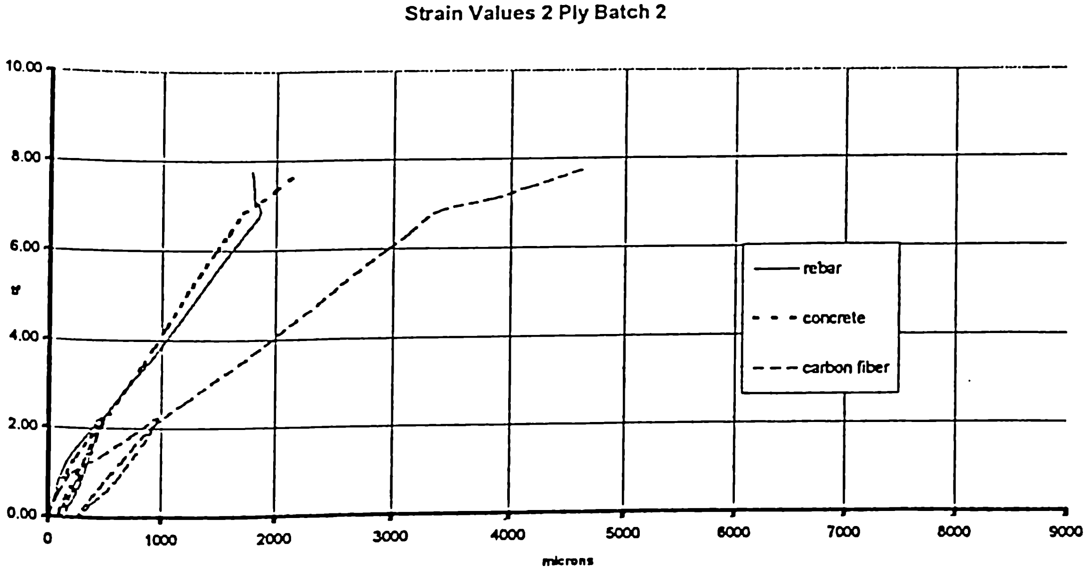

Figure 24. Load-Strain curves of the 2-ply specimen of the second batch

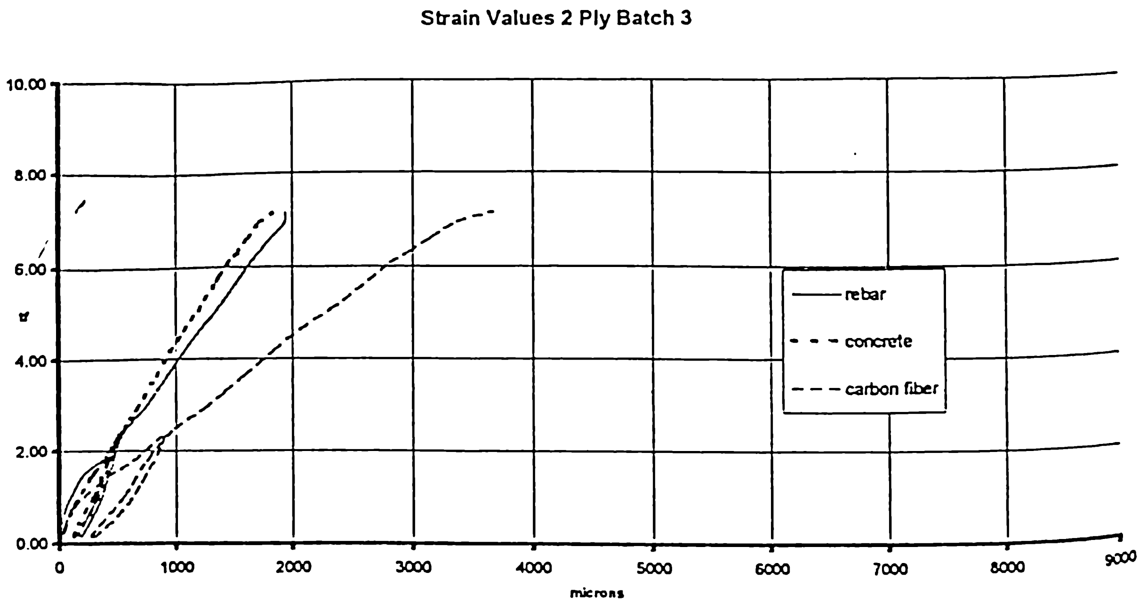

Figure 25. Load-Strain curves of the 2-ply specimen of the third batch

Reference

1. Mitsubishi Chemical Corporation, "REPLARK: Revitalizing Concrete Structures"

Acknowledgment

The authors would like to thank Mitsubishi Chemical Corporation for their guidance and invaluable technical assistance. They would also like to thank the staff of the UP Materials Testing Laboratory.