Significance of stainless steel wire reinforcement on the mechanical properties of GFRP composites

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Abstract - Investigations on flexural and tensile properties of GFRP laminates influenced by stainless steel wire reinforcement were carried out as a novel approach. Plain GFRP laminates and GFRP laminates reinforced with stainless steel wires at different depth with various pitch distances were fabricated by hand layup method. The composite specimens reinforced with steel wires were exposed to low frequency high amplitude cyclic load by using a cam arrangement. Three point bend test was carried out on those specimen to evaluate the flexural strength and flexural modulus. Also, tensile strength of the laminates was evaluated. It has been observed that the reinforcement of stainless steel wires has significantly improved the mechanical properties of the laminates.

Key words: Composite materials; Fatigue; GFRP; Flexural; Tensile strength.

I. INTRODUCTION

In recent years, composite materials have attracted the attention of many researchers due to their properties like high specific strength and stiffness, which facilitates potential applications in the area of aerospace, marine and automobile engineering. The composite materials can develop defects like fiber-breakage, fiber pull out, delamination, debonding and structural damages such as matrix crazing during processing and service [1]. These defects will reduce the residual properties of the materials [2, 3]. Hayato Nakatani et al., have investigated the low velocity impact-induced damage of Ti/GFRP laminates and explained the internal damage in the in-plane direction; also evaluated the effect of titanium face sheets on impact damage in the GFRP core [4]. Orientation of fiber and stacking sequence play a significant role on the performance of fiber reinforced composite [5]. Unidirectional fibres provide maximum strength and modulus when the load is applied along/parallel to the fiber orientation [6]. The effect of tuck stitching on the mechanical properties of knitted GFRP laminates were studied by Tuba Alpyildiz et al. [7]. Enhanced mechanical properties of composite materials after cyclic loading were observed and reported in many investigations [8-10]. Kelly A. Tsoi et al reported the influence of the wire pre-strain, the wire volume fraction and the wire position on the impact behavior of the stainless steel wire embedded and shape memory wire embedded GFRP composites.

In this paper, it is reported that stainless steel (SS) wire has been chosen as reinforcing material as a novel approach in order to increase the mechanical properties of the GFRP laminates. SS wires reinforced cross ply GFRP laminates have been fabricated. The influence of the wire position and pitch distances on fatigue flexural behavior and tensile behavior of the stainless steel wire embedded GFRP composites.

II. MATERIALS AND EXPERIMENTAL METHODS

Cross ply glass fiber mat of 0.5 mm thickness and austenitic stainless steel wire of diameter 250 μm were taken as the reinforcing materials to fabricate the Laminates. Epoxy resin LY-556 was used as the matrix and HT 917 was used as hardener in the ratio of 10:1. To embed the stainless steel wire, a wooden frame was designed and made in our laboratory with combs and slots of 1000 μm apart were situated at either end of the frame. A continuous stainless steel wire was then wound between these two combs which could be held constant during curing. The wires were then sandwiched between layers in the thickness direction based on the requirement. Plain and SS wires reinforced laminates were made by hand lay-up method and cured in room temperature for about 24 hours. Sufficient care was taken to ensure complete wet out of the fibers for effective bonding and to remove the entrapped air and excess resin. Laminates were properly cut in the dimension as per the ASTM standard for flexural test (80mm x 10mm) and tensile test (300mm x 25mm). Typical illustration of the test specimen is shown in Fig.1 (a). Four layers of cross ply glass fiber mat were used and SS wires were placed with different pitch distances at ¼th & ¾th depth (t) of the laminates along x-direction as shown in Fig.1 (b). In order to evaluate the strength of the material, six specimens were made with different pitch distance. The specimens were subjected to low frequency, high amplitude cyclic loads prior to the flexural tests. An offset cam (3mm) was used to impart the cyclic load. The frequency of loading was fixed as 100 cycles/min. The maximum deflection of the specimen during loading was fixed as 7 mm. The number of cycles was maintained by different times of exposure. The flexural response of cyclic loaded sample laminates was found by three point bending method and tensile strength of the unloaded specimen was found by INSTRON machine.

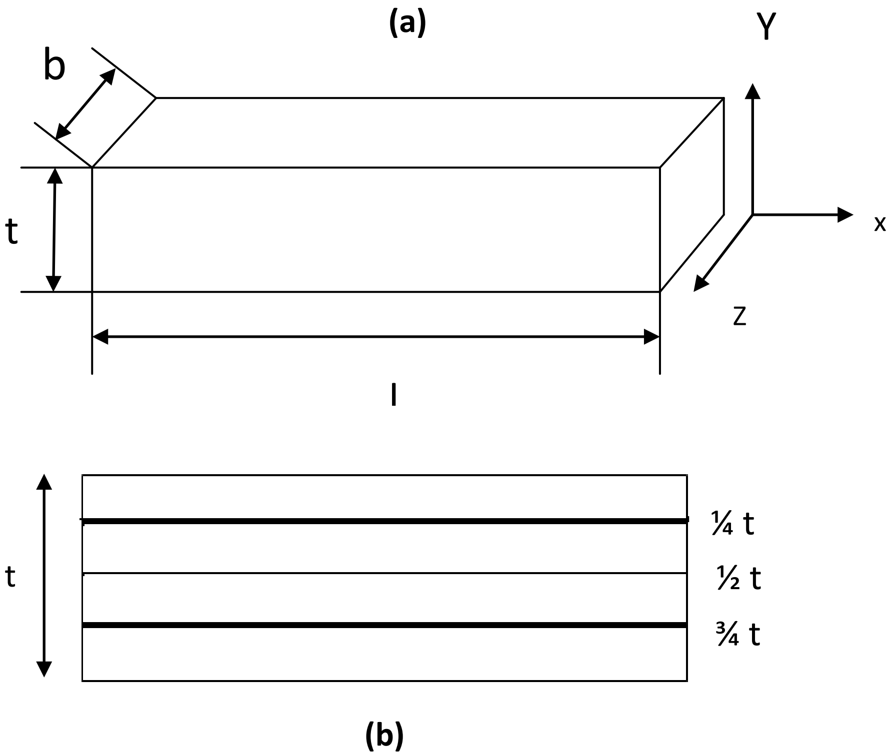

Fig.1. Illustration shows (a) the sample specimen and (b) position of SS wires in the laminates.

III. RESULTS AND DISCUSSION

i. Significance of SS wire reinforcement on flexure resistance

Typically observed flexural strength and flexural modulus of plain GFRP composites related to single SS wire embedded at ¾th depth (¾ t) composite is illustrated in Fig.2. It is seen that the reinforced composite laminate exhibits higher flexural strength due to initial cyclic loading up to 20000 cycles followed by a drop with higher cycles. While the increase in strength could be due to strain stiffening of the fiber and interface. The observed drop can be attributed to occurrence of possible structural defects such as debonding, matrix crazing and associated weakening. The introduction of cyclic load on the specimens increases the flexural strength initially, during which stiffening has taken place in the interface between fibers and matrix. With the continuation of cyclic loading, it has been observed that the flexural strength is decreased. Hence, exposure to cyclic loading up to certain duration has enhanced the flexural strength of polymeric composites due to the SS wire reinforcement. Typical variation of flexural modulus as influenced by low frequency cyclic loading is shown in Fig.2 (b). The observed drop beyond at 20000 cycles is due to occurrence of discrete/local defects such as debonding, fiber breakage and matrix crazing. It is seen that SS wire reinforced GFRP composite exhibits higher flexural resistance up to a critical exposure-duration. From the Fig. 2, it is also seen that by exposing a single SS wire reinforced GFRP laminate up to 25000 cycles results in reasonably good flexural strength. The observed dip in the flexure strength of plain GFRP composite after certain periodic exposure could be attributed to localized defects and subsequent annihilation.

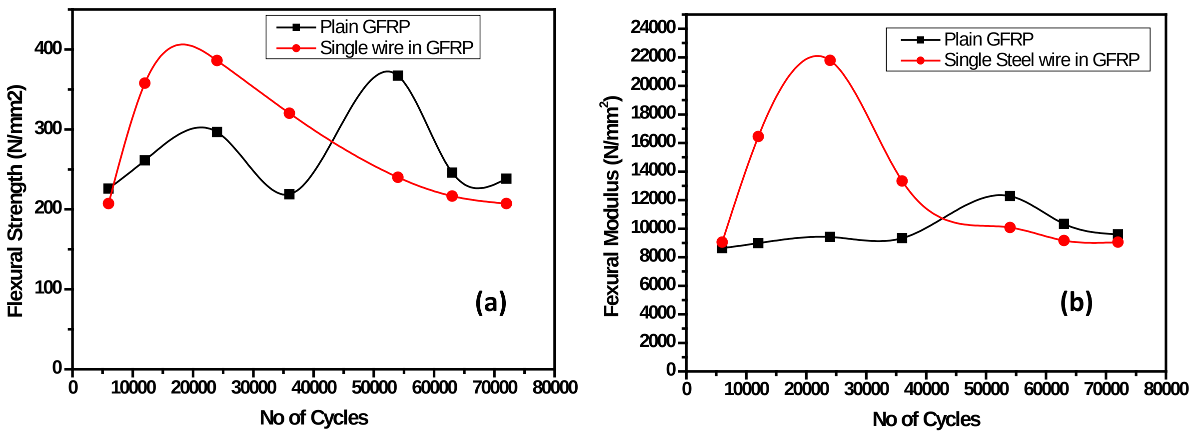

Fig. 2. Response of (a) Flexural strength and (b) flexural modulus versus number of cycles of the load for plain GFRP specimen and single SS wire reinforced GFRP.

ii. Significance of mode of SS wire reinforcement on flexure of GFRP composites

Three samples of SS wire reinforced GFRP laminates were prepared; one with SS wire at ¼th depth, second with ¾th depth and third in both the places through the thickness and as in the previous illustration (Fig.1). All the specimens were exposed to low frequency cyclic loading and subsequently tested for flexural response. Initially, after 10000 numbers of cyclic loading was given the specimens were tested for its leftover strength. The results showed that the specimen with wire at ¾th depth exhibited higher strength than other two specimens. Further studies for flexural response with respect to numbers of cycles of initial loading were carried out for the specimen with reinforcement wire at ¾th depth alone. Further, such tests were also carried out for the samples with reinforcement of SS wires embedded at different pitch distances. The SS wires were reinforced at ¾th depth with different pitch distances (i.e. 3mm, 4mm, 5mm, 6mm, 7mm and single wire at centre of the specimen) along z-axis.

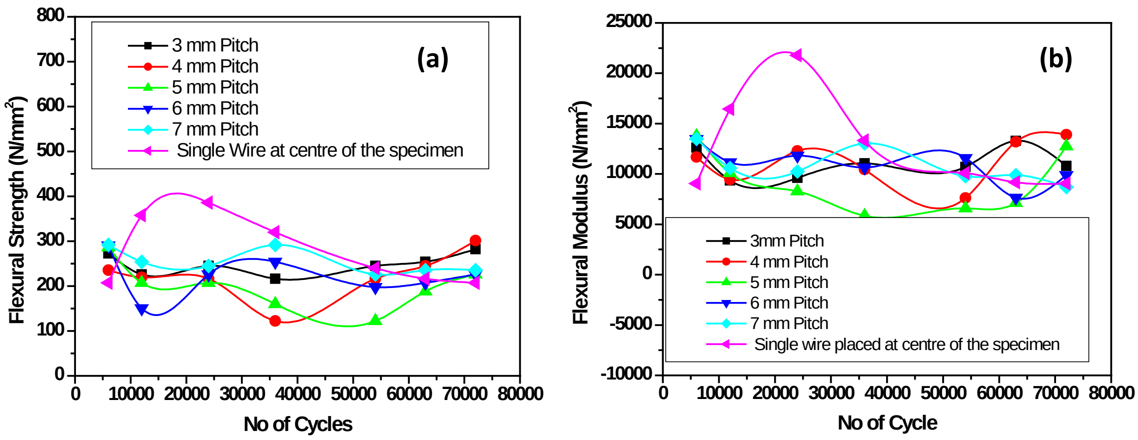

Fig. 3. Response of (a) flexural strength and (b) flexural Modulus with respect to Number of cycles of the load for SS wires reinforced GFRP laminates with various pitch distances

The flexural strength and flexural modulus were calculated for the samples with various pitch distances for different cyclic load. The experimental results of the GFRP laminates having the SS wire at ¾th depth were plotted as a graph in Fig. 3 (a). From these curves, it has been observed that the laminate having single wire at ¾th depth of the specimen exhibits more flexural strength than the other laminates. However, other reinforced composites have exhibited relatively lower order flexural resistance. This could be attributed to non favorable orientation of the reinforcement (z direction orientation) to the direction of low cyclic loading. Also among the reinforcements 3 mm pitch lay up has yielded more or less consistent (less cycle specific) flexure performance. The flexural modulus as influenced by the cycles of initial loading is shown in Fig. 3(b). The observations supplement the flexure characteristics. The drop in flexural strength of reinforced composite around a particular cycle is seen to be pitch specific.

Table 1. Tensile strength values of SS wires reinforced GFRP laminates with plain GFRP laminate.

Position of wire	**Pitch Distance (mm)**	**Tensile Strength (N/mm^2)**
Plain GFRP	Plain GFRP	120.37
¼ t	3	277.38
¼ t	5	123.68
¼ t	7	115.53
¾ t	3	278.65
¾ t	5	125.68
¾ t	7	116.87

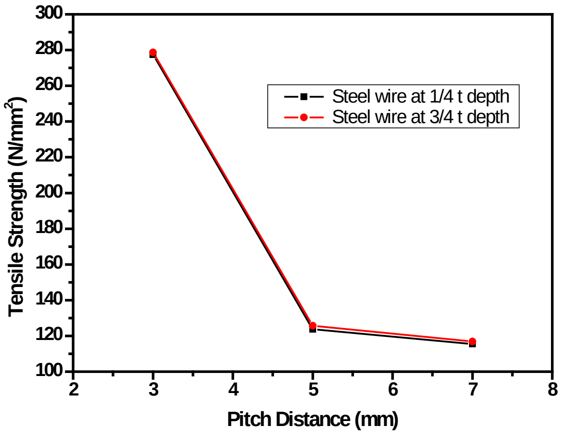

Fig.4. The variation of tensile strength with respect to pitch distances

iii. Tensile studies on plain and SS wires reinforced GFRP laminates

The tensile strength of the plain and SS wires reinforced GFRP laminates was determined to find the stress-strain behavior of the laminates. The breaking load and corresponding longitudinal expansion are recorded for five samples of each type of laminates. ASTM standard specimens were taken for testing and the average values of calculated tensile strength of different samples have been tabulated in Table 1. From the results it is observed that the SS wires reinforced GFRP specimen posses more tensile strength than that of plain GFRP specimen. It is also inferred that the specimen has the peak value of tensile strength for the least pitch distance. From the fig. 4, it is observed that the placement of SS wires either at ¼ t or ¾ t does not influence much on the tensile strength.

IV. CONCLUSIONS

In conclusion, plain and SS wires reinforced at two depths with different pitch distances of GFRP laminates were prepared by hand layup method successfully. The effect of number of SS wires on the flexural properties was studied after the laminates were subjected to various numbers of cyclic loads. It is observed that the laminates containing the single SS wire at centre of the specimen has more flexural strength and stiffness. The laminates of SS wires reinforced with 3 mm pitch has more tensile strength. From this study, it is concluded that the inclusion of stainless steel wires has increased its mechanical strength and depending on the nature of application one can vary the pitch distance to enhance the desired property of the laminates.

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