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Investigation of fatigue behavior of polymeric composites manufactured by hand lay-up and vacuum infusion process (VIP)

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Abstract- **In this paper the tension-tension fatigue behavior (R=0.1) of fiber reinforced polymer composites made by hand lay up and vacuum infusion process (VIP) were studied. According to the results of static tension test, tensile strength was higher in the VIP specimens than that of the hand lay up specimens, 387 MPa and 233 MPa respectively. At 76MPa stress amplitude, the VIP specimens survived for 151624 cycles; whereas the fatigue life of hand lay-up specimens was 44422 cycles at 65.57 MPa stress amplitude. Longer life of the VIP specimens can be related to the higher number of defects formed during manufacturing of the hand lay up specimens. Examining the fracture surfaces of the specimens after fatigue tests, revealed that fiber pull out and debonding in hand lay up specimens and matrix cracking and debonding in the VIP specimens were the main mechanisms for their fatigue failures.**

Keywords – fatigue, fiber reinforced polymer composite, hand lay up method, Vacuum infusion process (VIP)

I. INTRODUCTION

Nowadays more and more countries have paid more attention to wind energy which is renewable to sustain the increasing energy demand. In wind turbines, blades materials significantly affect the performance and properties of blades, such as blade weight, damage mechanism, and fatigue life. Wind turbine blades are made from anisotropic materials, polymer matrix composites materials, in a combination of monolithic (single skin) and sandwich composites. Blade designs are mainly based on glass fiber-reinforced composites (GFRP) [1]. These materials are mainly processed by vacuum infusion process (VIP) and hand lay-up [2].

Generally, wind blade materials must withstand severe fatigue loading under service environments. Various materials and different processes have significantly affected the service life of the blades under complexity of loadings [3].

In this study, we compare the fatigue behavior of glass fiber reinforced polymer matrix composites (GFRP) manufactured by hand lay-up and Vacuum Infusion Process (VIP). The dominant fatigue failure mechanism for each type of specimens will be explored by examining the fracture surfaces of fractured specimens by the means of scanning electron microscopy (SEM).

II. MATERIALS AND METHOD

Preparation of the specimens

For making GFRP specimens, epoxy resin and woven E-glass mat with different orientations (0°, 90° and $\pm45^\circ$) were used. The stacking sequence was selected similar to the real operational conditions of wind turbines blade (90/0/±45/0/±45/0/90). In hand lay-up method after placing each layer, resin is applied to the fibers by the aid of a brush. In VIP vacuum drives the resin flow throughout the layers. The dry glass fiber layers are placed inside the mold. The mold is packed in a vacuum bag. Resin is applied through tubes connected to vacuum bag as soon as vacuum reaches the required pressure. A 600mm by 600mm sheet was made by each process. After cutting the composite sheets to required dimensions the final dumbbell-shaped specimens were obtained by CNC milling.

Tensile and fatigue tests

According to ASTM D3039, 5 specimens were selected for static tension test. Tensile tests were performed on a Zwick250 universal testing machine. A universal fatigue testing machine was used for fatigue tests. Tension-tension fatigue tests with a stress ratio of 0.1 (R=0.1) were conducted using dumbbell-shaped flat specimens. For reducing the cracks on the surface of the machined specimens, these surfaces were polished by a soft emery cloth. To ensure that no fracture occurs at the grips, tabs were used.

III. RESULTS AND DISCUSSION

Tensile strengths of the materials are reported in table 1. The results of tension-tension fatigue tests are given in tables 2 and 3. The stress-cycles curve is presented in Fig. 1. The SEM images of the fatigued fracture surfaces are shown in Fig. 2 and 3. According to the results of static tension test, tensile strength of VIP specimens is 66% higher than that of hand lay-up specimens. Results of fatigue tests revealed superior fatigue properties of VIP specimens. As it can be concluded from Fig. 1, at the same fatigue life e.g. 100000 cycles, the applied stress amplitude on VIP specimens (84Mpa) is 38% higher than that of hand lay-up specimens (61Mpa). At higher stress amplitudes, e.g. 85Mpa, fatigue life of VIP specimens is about 100 times longer than that of hand lay-up ones. This significant difference is due to lower defects in VIP specimens and the different fatigue failure mechanisms of these two types of specimens. Fig. 2 and Fig. 3 show fiber pull-out and debonding failure for hand lay-up specimens and matrix cracking and debonding mechanisms on fracture surfaces of VIP specimens.

TABLE 1: TENSILE STRNGTH OF HAND LAY-UP AND VIP SPECIMENS

Manufacturing process	No. of specimens	Tensile strength (MPa)
VIP	5	387
Hand lay-up	5	233

TABLE 2: RESULTS OF HAND LAY-UP SPECIMENS TENSION-TENSION FATIGUE TEST

No. of specimens	Frequency (Hz)	σ_a (MPa)	σ_m (MPa)	N (the average of cycles to failure)
6	8	84	103.6	1161
6	8	65.57	80	44422
6	8	56.3	68.81	210412

TABLE 3: RESULTS OF VIP SPECIMENS TENSION-TENSION FATIGUE TEST

No. of specimens	Frequency (Hz)	σ_a (MPa)	σ_m (MPa)	N (the average of cycles to failure)
6	8	101.79	124.41	36848
6	8	76	92.9	151624
6	8	67.01	81.9	317035

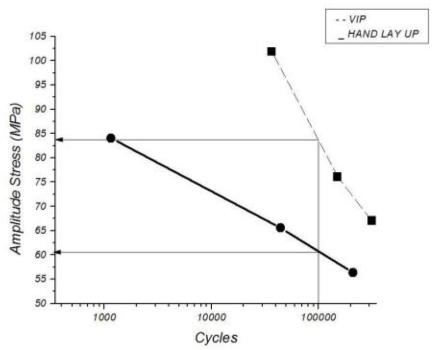
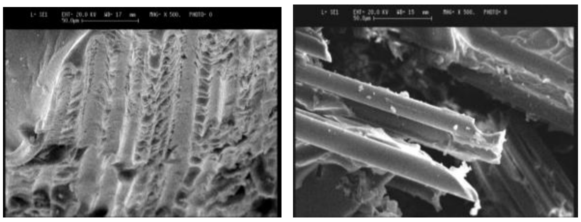
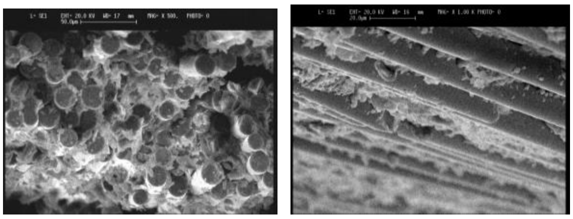


Fig 1: Amplitude stress-cycles for VIP and hand lay-up specimens



(a) (b)

Fig 2: SEM images of the hand lay-up specimens fracture surface. (a) debonding, (b) fiber pull-out



(a) (b)

Fig 3: SEM images of the VIP specimens fracture surface. (a) matrix cracking, (b) debonding

The presence of the localized pulled out fibers can be a representation of matrix cracking and its growth which leads to the final failure [4]. The observed remained matrix on the fibers in Fig. 3 (a) and the absence of that on the pulled-out fiber in Fig.2 (b) respectively shows the occurrence of cohesive and adhesive debonding in VIP and hand lay-up specimens [5, 6].

IV. CONCLUSION

Tensile strength in VIP specimens was 66% higher than that of hand lay-up specimens, which is due to the lower manufacturing defects, especially bubbles in specimens made by vacuum infusion process. The results if tension-tension fatigue tests (R=0.1) showed that at high stress amplitudes, fatigue life of VIP specimens is about two orders of magnitude longer than that of hand lay-up specimens. At lower stress amplitudes the difference in fatigue life of specimens made with the two methods was smaller though VIP specimens still showed superior fatigue life. This significant difference is due to the different fatigue failure mechanisms of the two types of specimens. Fiber pull-out and debonding mechanisms were observed in hand lay-up specimens and matrix cracking and debonding were detected in VIP specimens.

V. REFERENCES

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