AKADÉMIAI KIADÓ

The effect of vibrations on the mechanical properties of laminations

Fahad Mohanad Kadhim[1*], Muhammad Safa Al-Din Tahir[2] and Athmar Thamer Naiyf[2]

[1] Prosthetics and Orthotics Engineering Department, University of Al-Nahrain, Iraq

[2] Computer Engineering Technology, Faculty of Information Technology, Imam Ja'afar Al-sadiq University, Iraq

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ABSTRACT

This study aims to increase the mechanical properties of the composite material manufactured by the lamination process. In this study, the lamination process will be implemented in two ways, and mechanical properties are compared between the two methods. The first method covers the lamination process under the influence of vacuum pressure only, while in the second method lamination process is achieved by the influence of vacuum pressure and vibrate by shaker device. The results showed that the endurance stress of fatigue increased by 18.18% for the material manufactured by the lamination process under the influence of vibration, while the yield stress and ultimate stress values remained roughly constant for both methods.

KEYWORDS

lamination, composite material, epoxy, fiber carbon, prosthetic

1. INTRODUCTION

The lamination process is an important method for manufacturing composite materials [1, 2], as this process is widely used in the manufacture of prosthetics, orthotics, auto parts, water tanks, etc. But this process has some drawbacks, represented by the presence of air gaps between the layers of the material when pouring the epoxy, which prevents the penetration of the epoxy between the fibers, especially if the epoxy is of high density. This problem leads to a change in mechanical properties, especially in applications that are subjected to dynamic loads, as it directly affects fatigue properties. K. Yang et al. [3], study on the influence of change resin content on mechanical properties of composite laminates. The effect of fiberglass type and adding a very small amount of nano-filler in the resin on mechanical and thermal properties of multilayers laminate composite has been studied by Amal Nassar et al. [4]. The effects of fiber orientations, resin types, and several laminates on mechanical properties of laminated composites have been studied by Hossein Rahmani et al. [5] and Fahad Mohanad et al. [6]. Sabit Adanur developed research about the factors, which can affect the mechanical properties of laminated composites [7]. Fuzhong Wang, et al. [8] searches for how the improvement of mechanical properties and thermal conductivity of carbon fiber laminated composites through depositing graphene nanoplatelets on fibers. Luo Liang [9] studied the effects of inter-laminar contaminants on the mechanical properties of composite laminates.

*Corresponding author.
E-mail: fahad.mohanad@nahrainuniv.edu.iq, Fahadmohanad@gmail.com

2. EXPERIMENTAL PART

To manufacture samples of composite material with the same thickness material consisting of six layers of carbon fiber, samples were manufactured using (two plastic bags, six layers of carbon fiber, epoxy with hardener with a ratio of 80:30, a vacuum device, shaker, Arduino panels with power supply, and two iron sheets, each of which has dimensions of 15 × 30 cm) as it is shown in Fig. 1. Samples will be made in two ways. The first method is without the process of shaking the composite material during production. As for the second method, a vibrator is used to remove air bubbles from between layers of the composite material. Six layers of carbon fiber are placed between the two bags and using the vacuum system to empty the bag and the layers from the air and allow the epoxy material to enter and pull it between the carbon fiber layers, and then the cast layer is placed between the two iron sheets to compress it. As for the second method, the same steps are repeated in that production in the first method, but the shaker device is putting on the two iron sheets, which works to shake the layers and eliminate air gaps to replace them with epoxy material. The Arduino panels and power supply operate the shaker at different frequencies and each frequency during a specific period of time to ensure the elimination of air bubbles formed inside the layers of the composite material during the casting process. After hardened the material, samples of tensile and fatigue tests are cut by a Computerized Numerical Control (CNC) machine. The components of the composite material manufacturing system with the lamination process under the influence of vibration can be seen in Fig. 1.

2.1. Tensile test

The tensile test is used to determine the mechanical properties of composite materials cast using both processes. Samples were cut by a CNC machine. Three samples were cut for each method of composite materials. Samples were cut according to ASTM D638 Type 1 with a thickness of 4 mm [10] as it is shown in Fig. 2. The samples were tested at a strain rate equal to 2 mm min^{-1} by a Testometric device.

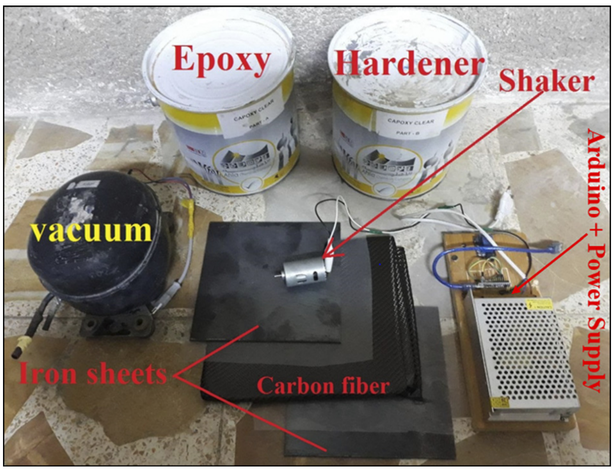

Fig. 1. The components of the system to composite material manufacturing by vibration method

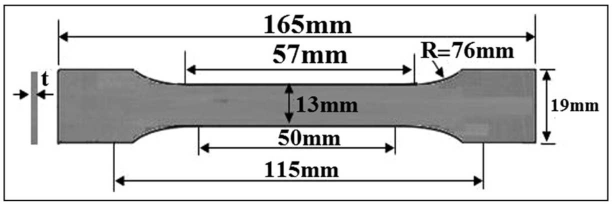

Fig. 2. The dimension of the specimen according to standard ASTM

2.2. Fatigue test

In this study, a fatigue test was performed twice to test the composite material resulting from the two methods mentioned. Seven samples were taken for casting under the influence of vibration and another seven samples for casting without the effect of vibration. Each test was repeated three times for each level of stress. Samples were cut according to the dimensions of the fatigue device HI-TEICH [11] as it is shown in Fig. 3.

3. FINITE ELEMENT ANALYSIS

The lamination process is an important method for manufacturing fiber-reinforced composites. One of the applications of the lamination process is the manufacture of feet in the field of prosthetics. Prosthetics are artificial devices that replace the amputee's missing parts of the body (limbs) [12]. Due to illness or accidents, a person may experience an amputation. In this study, a comparison was made in terms of the (stresses generated, deformations, and the safety factor) of a prosthetic foot made of composite materials poured under the influence of vibration and composite materials poured without the effect of vibration. The mechanical properties resulting from the (tensile and fatigue) tests for each of the casting methods were used as inputs to the ANSYS engineering analysis software to get the above comparison. For example, the boundary condition of analysis foot prosthetic is to fix the tip of the foot at the ankle joint region and applied the dynamic load at the heel and the toes of the foot where the foot will work as a leaf spring under the cyclic load. The load applied at the heel region is equal to 900 and 800 N at the toes region as it is shown in Fig. 4. These results can be measured from the gait cycle of humans.

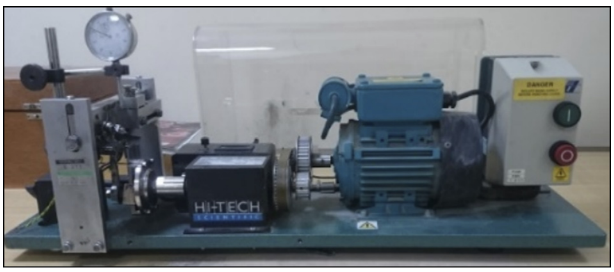

Fig. 3. The fatigue device, HI-TEICH

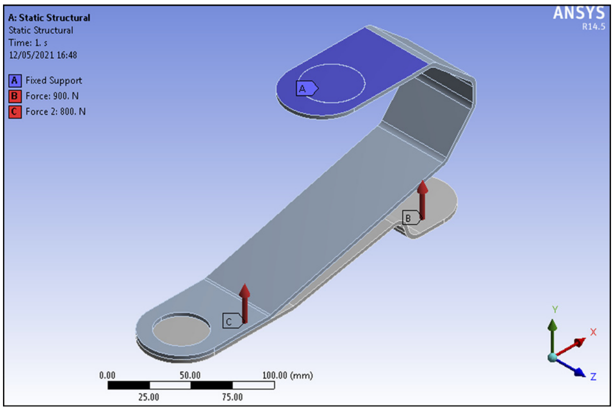

Fig. 4. The boundary condition applied on the prosthetic foot

4. RESULT AND DISCUSSION

By comparing the tensile test results of the composite material samples cast by the two methods, find that there is no difference in the tensile test values between the two cases. The values of both cases equal to 186 MPa for ultimate stress, 135 MPa for yield stress, and the modulus of elasticity 4.89 GPa as it is shown in Fig. 5.

As for the fatigue test results, it was noticed that there is a difference in the fatigue test results, as the value of the stress endurance was equal to 90 MPa in the samples that were cast without the effect of vibration as it is shown in Fig. 6, while

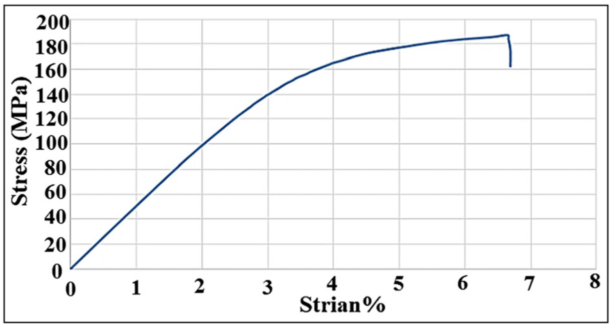

Fig. 5. The stress-strain curve of the composite material manufactured by two methods

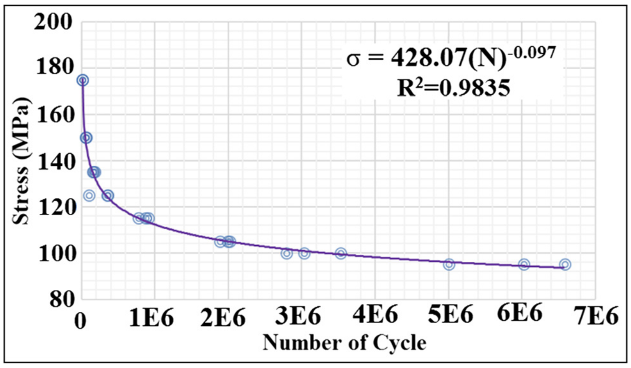

Fig. 6. The S-N curve of composite material manufactured without the effect of vibration

the value of the fatigue stress was equal to 110 MPa in the samples that were cast under the influence of vibration as it is shown in Fig. 7. By comparing the fatigue test results, it was found that the improvement in the stress endurance value is equal to 18.18%.

The results of numerical analysis of the foot shows (the maximum Von Misses stress is lightened with red color and equal to 31.97 MPa as it is shown in Fig. 8 and the maximum

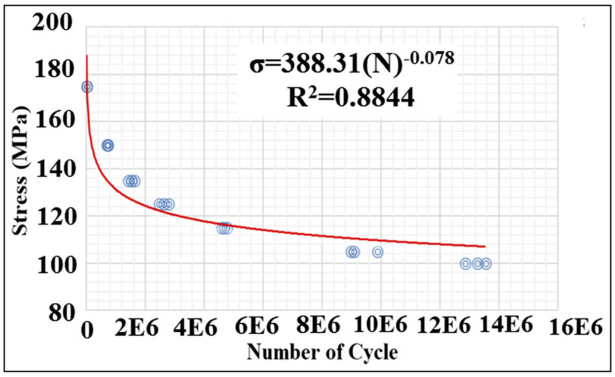

Fig. 7. The S-N curve of composite material manufactured under the effect of vibration

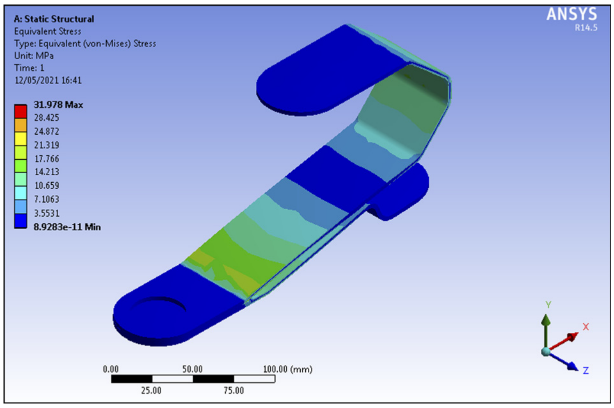

Fig. 8. The Von Misses stress of the prosthetic foot

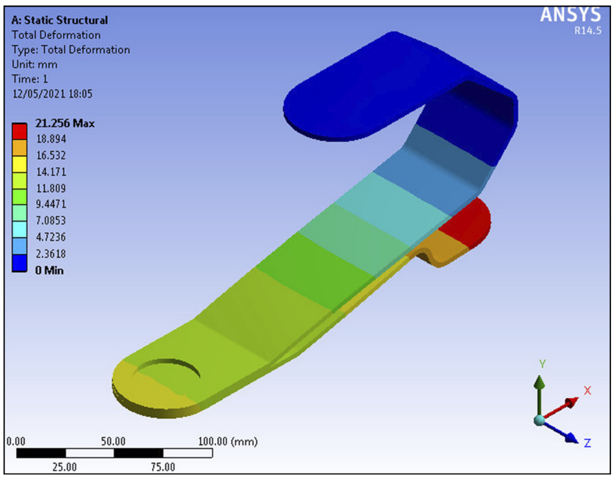

Fig. 9. The deformation of a prosthetic foot

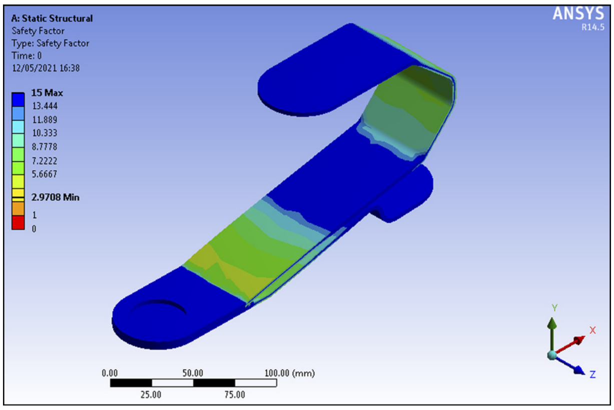

Fig. 10. The safety factor of the prosthetic foot made from vibrate composite material

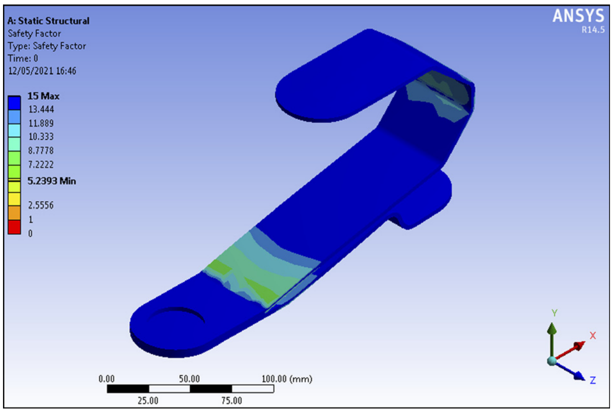

Fig. 11. The safety factor of the prosthetic foot made from non-vibrate composite material

deformation equal to 21.2 mm as it is shown in Fig. 9) for both casting ways of the composite material. The value of the safety factor of 2.97 is in the region that recorded the highest foot stress for the foot is made of composite materials cast under the influence of vibration as it is shown in Fig. 10, while the value of the safety factor is 2.5 at the same region when the foot is made of composite materials cast without the influence of vibration as it is shown in Fig. 11.

5. CONCLUSION

It can be concluded that the lamination process under the influence of vibration has a direct effect on increasing the fatigue life because it removes all air gaps generated between the layers of the composite material and also increases the saturation of the fibers with epoxy. The non-saturation of the layers with epoxy material and the presence of gaps between the layers help to accelerate the spread and flow of the crack in the stress area when a dynamic load is applied.

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