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Fatigue studies for glass fiber reinforced polymer matrix composites-A Review

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Abstract-Fiber reinforced polymer (FRP) composite is a new construction material, which is gradually gaining importance for engineering applications. Their use as structural materials in recent years has proved many advantages. The advantages over traditional construction materials are its high tensile strength to weight ratio, ability to be molded into various shapes, and potential resistance to environmental conditions which results in potentially low maintenance cost. These properties make FRP composite a good alternative for innovative construction. This paper reviews the different process of preparation of the GFRP composites and the fatigue behavior of fiber-reinforced polymer composites. To determine the fatigue life of fiber - reinforced polymer composites, input variables such as maximum stress, fiber orientation, and stress ratio and effects of a load were considered.

Keywords—GFRP Polymer composite; Woven glass fiber; Fiber orientation; Fatigue test; Fatigue behaviour.

1. INTRODUCTION

The main objective of this Review paper is to gain a better understanding of fatigue properties of epoxy resin composites reinforced with 2D woven glass fiber. The effect of fiber orientation & thickness of laminates has been investigated .The popularity and the usage of 2D woven composites has abruptly increased in the recent years in the field of aerospace, automobile and defense industries due to their light weight, lower production costs, higher fracture toughness, low thermal expansion, corrosion resistance and better control over the fatigue strength. The rotor hubs of the bearing less helicopter which are designed using fiber reinforced laminated composite materials experience bending as well as centrifugal loads in the flapping flexure region. Due to this the high demand for improved mechanical performance of these structural materials makes it even more necessary to evaluate these materials under different types of loading and at different fiber orientations. Fiber-reinforced polymer composites show strong anisotropic mechanical behavior due to their fiber orientations which leads to various failure mechanism. The anisotropic mechanical behavior of different fiber orientation creates more complexity in the multiaxial loading condition. So in order to avoid that an effort has been made to make quasi-isotropic composite materials with controlled parameters such as the stacking sequence of the plies and the orientations of the adjacent plies.

2. PROPERTIES, STRUCTURE, AND APPLICATION OF PMC

As reported by C.Elanchezhian et al. [1] in his studies composite is a material which made by the combination of two or more dissimilar materials so that it can gain the material properties superior to its parental ones. Owing to the superior properties gained by the fiber reinforced composite material the composite materials are used in different field of engineering such as defense, sports, aerospace etc. The FRP composite material is also gaining its interest day by day due to its eco-friendly material properties. Number of work has already been carried out by the researchers in the field of FRP composites.

It has been studied that the fibers such as carbon and glass fibers are abundant in nature which is also renewable and can be used as an alternative to the traditional reinforcement material in the composites which can gain the mechanical properties of high strength to weight ratio and also gain further weight reduction. The interfacial bond between the matrix and the reinforcement should be sufficient enough to transfer the load from the matrix to the reinforcements. While looking into the toughness of the composite, the interface should not be so strong that allow toughening mechanisms such as delamination of the fiber pullout to take place. The volume friction of the matrix and the fibers and the orientation (0/90/-45/45) of the reinforced fibers in the composites plays an important role in determining the properties.

The composite materials used now a days in the industries are made up of glass fibers. In case of fiber glass products there are two phases. The matrix phase which works on the transformation of the shear and the glass fiber which is the reinforcement phase is used to resist the tensile and the compressive load. It has been studied that the fiber glass composite material shows significant reduction of the weight, extremely strong, and robust material than the composites made of steel or timber with increased strength to weight ratio. The material is typically less brittle than the other type of fibers and the raw material are abundantly available in nature. The bulk strength and weight properties are superior as compared to the metal composites. Different types of complex intricate shapes can also be formed by the molding process very easily.

The epoxy material resin is used to provide the better binding properties between the reinforced phase and thee matrix phase. Normally the epoxy material which is used at the room temperature is Araldite LY556 which is based on Bisphenol-A and it is suitable for high performance composite FRP applications like Pultrusion, Filament Winding and Pressure Moulding. The hardener HY951 which is easily curable at room temperature is used to improve the interfacial adhesion and impart strength to the composite material. The mixture of the resin and the hardener in the ratio of 10:1 can be used to obtain the optimum matrix compositions as studied by B.Vijaya Ramnath et al.[2]

3. FATIGUE TEST

It has been observed that during the fatigue testing the temperature in the specimen is increased to the significant level. As studied by A.Vahid Movahedi-Rad et al. [3], the quasi-static experiments under standardized rates and at the rates similar to those which are achieved under the fatigue loading conditions were performed in order to obtain the fatigue strength of the examined material and investigate the rate effects. A wide range of cyclic load was applied on the specimen so that wide range of fatigue lives can be covered from 500 to around **10**^6 cycles in order to determine the number of cycles of failure. The effect of the fiber orientation on fatigue strength was significant at all stress ratios and temperatures as studied by **Mortazavian** et al. [4]

4. FATIGUE BEHAVIOR

Fatigue behavior is the design parameter for the repeatedly loaded structure within its endurance limit. Some of the design parameters are discussed below:

A. Fatigue life and the effect of stress ratio

It was studied by **Thomas** Kelle et al. [5] in his paper that a classical power law relationship can be used for the simulation of the fatigue behavior which is given by the bellow mentioned formula:

$$\sigma_{\max} = \sigma_0 N_f^{-\frac{1}{k}}$$

Where σmax is the fatigue maximum stress level, Nf is fatigue life σ0, 1/k are model parameters derived by linear regression analysis. P.N.B. Reis et al studied that the fatigue behavior of the composite is highly dependent on stress ratio 'R'. Mandell and Meier et al. [6] and El-Kadi and Ellyin et al. [7] have discussed the effect of stress ratio on the fatigue life of the composite material. They found that for a given maximum stress of a specimen in tension- tension loading there is increases in the fatigue life with increasing R. Where as in compression-compression loading the fatigue life of the composites decreases with the increase of R. Rosenfeld et al. [8] and Huang et al.[9] has studied the effect of the compressive loading on the fatigue behavior of graphite/epoxy laminates for the stress ratio R = 0; - 1 and 1.They have concluded that there is a significant reduction of the fatigue life at R= - 1 and the same is higher for R = 1.

B. Self-generated temperature evolution daring fatigue loading

It has been studied that the temperature of the specimen subjected to fatigue loading increases due to the internal friction. Anastasios P. Vassilopoulos et al.[10] investigated the self-generation of heat during fatigue loading and stated that when the specimen approaches to the failure point, the formation of the hot spots takes place and the distribution of the temperature remains non uniform throughout the life time. In majority of the cases the failure occurs at, or close to the location of the hotspot of the specimen. The self-generated temperature pattern remains more uniform for the for lower stress levels. Generally more hotspot areas are detected in higher stress levels on the specimen.

C. Fatigue damage growth.

A. Muc et al. [11] investigated the fatigue damage growth of the composite structures with circular and elliptical holes. He stated that the experimental result that he obtained from the damage growth consists of three stages. During the first stage, the growth of the damages very rapidly due to the occurrence of multiple splits along fibers within the material of the panels. During the second stage the growth of the damage is slow and steady because of the appearance of the "X" pattern of splitting cracks which is tangent to the hole edge and is parallel to fiber direction. In the third and the final stage, the damage grows very rapidly until fracture occurs due to delamination.

5. PROCESS OF PREPARING THE COMPOSITES FOR FATIGUE TESTING.

The preparation of the polymer matrix composite can be adopted using various technique. Some of the preparation using random and woven glass fiber mat are discussed below:

A. Hand lay-up method followed by hydraulic press

Suresha et al. [12] has prepared the composite of epoxy matrix reinforced with woven GF using the hand layup process. Here the epoxy is mixed with the hardener in the weight ratio of 100:12.The matrix epoxy resin and the reinforced GF were mixed to maintain the thickness of 3 mm and then the hydraulic press of 0.5 MPa is used. The specimen is allowed to cure at room temperature for a day. Then the specimen is de-moulded and again post curing is done at a temperature of 120°C for 2 hour in an electrical oven. The prepared laminate size was 250 mm 250 mm 3 mm.

B. Silicone rubber mould.

Aramide et al. [13] has prepared the composite of unsaturated polyester reinforced with GF using the silicon rubber mould. At first the mould was cleaned properly using the releasing agent (hard wax) for the ease of the removal of the composite after curing. A brush is used to apply the unsaturated polyester resin with the curing agent on the mould. The GF is then placed over the resin. A steel rod is used to roll over the GF and make it completely weight in the resin also to get the equal distribution of the resin. This process is repeated time and again until the desired thickness is attained. The composite is cured over a period of time and get fully hardened. The composite is then de-moulded and the edges were trimmed using hand file. The content of the fiber used is 3% to 30% in the preparation of the composite plates.

C. Hand lay-up method followed by compression moulding.

Erden et al.[14] prepared the composite using the hand layup method with polyester matrix reinforced with woven roving mat E-GF which is followed by the compression at a pressure of 120 bar and cured at room temperature for about 120 minute fiber volume fraction used in the composite preparation is 37% and the thickness attained is 3.5 mm.

D. Hot press technique.

Atas et al. [15] prepared the composite using epoxy as matrix and GF as the reinforcement followed by the hot press technique. The composite laminate prepared is of the dimension 305 mm × 305 mm. The shearing process is applied to transform the orthogonal fabric to non-orthogonal fabric and is weaved between fill and wrap. The weight of the epoxy resin and the hardener used in the ratio of 10:3.The composite is then cured at 60 ° for two hour and 93 ° for three hour. The pressure of 0.35 MPa was applied on the laminate during the curing process.

6. CONCLUSIONS

The literature review concerning the fatigue test, fatigue behavior and the process of preparation of the GFRP composite have been discussed in this paper. Some of the Key observation that are evolved from the literature review are mentioned bellow:

- The temperature in the specimen subjected to the fatigue loading increases to a significant level due to applied stress, geometry of the specimen and the cyclic frequency.
- The temperature generated due to the fatigue loading reduces the fatigue strength of the material.
- Fatigue life of the composite is dependent on the stress ratio 'R'
- Depending on various environmental conditions various technology can be used to prepare GFRP.
- The fatigue strength, flexural strength and the ultimate tensile strength increases with the increase of the volume of the fiber glass 'Vf' of the composite.
- With the increase of the fiber glass volume 'Vf' the Young's modulas of elasticity of the composite material increases.

REFERENCES

[1] P.N.B. Reis, J.A.M. Ferreira, J.D.M. Costa, M.O.W. Richardson. Fatigue life evaluation for carbon/epoxy laminate composites under constant and variable block loading. Composites Science and Technology 69 (2009) 154–160.
[2] TP Sathishkumar, S Satheeshkumar and J Naveen. Glass fiber-reinforced polymer composites - a review. *Journal of Reinforced Plastics and Composites* 2014 33: 1258 originally published online 8 April 2014.
[3] A R A Syayuthi , M S Abdul Majid, M J M Ridzuan, K S Basaruddin, Peng, T L. Effect of stress ratio on the fatigue behaviour of glass/epoxy composite. *Phys.: Conf. Ser.* 908 012030.
[4] P.N.B. Reisa, J.A.M.Ferreirab, F. V. Antunesb, J.D.M.Costa. Fatigue behaviour of hybrid composite laminates subjected to bending

loading. Faculdade de Ciências e Tecnologia da Universidade do Coimbra Pólo II, 3030 Coimbra, Portugal.

[5] E. K. GAMSTEDT, R. TALREJA. Fatigue damage mechanisms in unidirectional carbon-fibre-reinforced plastics. Journal of materials science 34 (1999) 2535 – 2546.

[6] Shimokawa T, Hamaguchi Y. Distribution of fatigue life and fatigue strength in notched specimens of a carbon eight-harness-satin laminate. J Compos Mater 1983; 17:64–76.

[7] Abd Allah MH, Abdin EM, Selmy AI, Khasshaba UA. Effect of mean stress on fatigue behaviour of GFRP pultruded rod composites. Compos: Part A 1997; 28A:87–91.

[8] Kawai M.A Phenomenological model for off-axis fatigue behavior of unidirectional polymer matrix composites under different stress ratios. Compos: Part A 2004; 35:955–63.

[9] Mandell JF, Meier Urs. Effect of stress ratio, frequency and loading time on the tensile fatigue of glass–reinforced epoxy. ASTM STP 1982; 813:55–77.

[10] El-Kadi H, Ellyin F. Effect of stress ratio on the fatigue of unidirectional glass fibre/epoxy composite laminates. Composites 1994; 25(10):917–24.

[11] Rosenfeld MS, Huang SL. Fatigue characteristics of graphite/epoxy laminates under compressive loading. J Aircraft 1978; 15:264–8.

[12] Rotem A, Nelson HG. Failure of a laminated composite under tension compression fatigue loading. Compos Sci Technol 1989; 36:45–62.

[13] Petermann J, Schulte K. The effects of creep and fatigue stress ratio on the long-term behaviour of angle-ply CFRP. Compos Struct 2002; 57:205–10.

[14] Epaarachchi JA, Clausen PD. An empirical model for fatigue behavior prediction of glass fibre–reinforced plastic composites for various stress ratios and test frequencies. Compos: Part A 2003; 34:313–26.

[15] American Society for Testing and Materials. Standard test method for compressive properties of polymer matrix composite materials with unsupported gage section by shear loading. Annual book of ASTM standards, vol. 15.03, 1999 [D 3410/D 3410M-95].

[16] Aramide FO, Atanda PO and Olorunniwo OO. Mechanical properties of a polyester fiber glass composite. Int J Compos Mater 2012; 2: 147–151.

[17] Mathew MT, Naveen Padaki V, Rocha LA, et al. Tribological properties of the directionally oriented warp knit GFRP composites. Wear 2007; 263: 930–938.

[18] Lopez FA, Martin MA, Alguacil FJ, et al. Thermolysis of fibreglass polyester composite and reutilisation of the glass fibre residue to obtain a glass ceramic material.

[19] Erden S, Sever K, Seki Y, et al. Enhancement of the mechanical properties of glass/polyester composites via matrix modification glass/polyester composite siloxane matrix modification. Fibers Polym 2010; 11:732–737.

[20] Awan GH, Ali L, Ghauri KM, et al. Effect of various forms of glass fiber reinforcements on tensile properties of polyester matrix composite. J Faculty Eng techno 2009; 16: 33–39.

[21] Alam S, Habib F, Irfan M, et al. Effect of orientation of glass fiber on mechanical properties of GRP composites. J Chem Soc Pak 2010; 32: 265–269.

[22] Gupta N, Balrajsinghbrar and Eyassuwoldesenbet. Effect of filler addition on the compressive and impact properties of glass fibre reinforced epoxy. Bull Mater Sci 2001; 24: 219–223.

[23] Faizal MA, Beng YK and Dalimin MN. Tensile property of hand lay-up plain-weave woven e glass/polyester composite: curing pressure and ply arrangement effect. Borneo Sci 2006; 19: 27–34.

[24] Leonard LWH, Wong KJ, Low KO, et al. Fracture behavior of glass fiber reinforced polyester composite. J Mater Design App Part L 2009; 223: 83–89.

[25] Visco AM, Calabrese L and Cianciafara P. Modification of polyester resin based composites induced by seawater absorption. Compos Part A 2008; 39: 805–814.

[26] Hameed N, Sreekumar PA, Francis B, et al. Morphology, dynamic mechanical and thermal studies on poly (styrene-co-acrylonitrile) modified epoxyresin/glass fibre composites. Compos Part A 2007; 38: 2422–2432.

[27] Colakoglu M. Damping and vibration analysis of polyethylene fiber composite under varied temperature. Turkish J Eng Env Sci 2006; 30: 351–357.

[28] Adam, T. J., & Horst, P. (2017). Fatigue damage and fatigue limits of a GFRP angle-ply laminate tested under very high cycle fatigue loading. *International Journal of Fatigue*, 99, 202-214.

[29] Akinyede, O., Mohan, R., Kelkar, A., & Sankar, J. (2009). Static and fatigue behavior of epoxy/fiberglass composites hybridized with alumina nanoparticles. *Journal of Composite Materials*, 43(7), 769-781.

[30] Botelho, E. C., Rezende, M. C., Mayer, S., & Voorwald, H. (2008). Evaluation of fatigue behavior on repaired carbon fiber/epoxy composites. *Journal of Materials Science,* 43(9), 3166-3172.