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ASSESSMENT OF OPEN CENTRAL HOLE ON THE STRESS CONCENTRATION FACTOR OF GLASS FIBRE-COCONUT COIR-HUMAN HAIR HYBRID COMPOSITE

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ABSTRACT

The recent research attempts in polymer composites are indicative of a shift of choice to synthetic fillers from natural fillers as the low eco-compatibility of the former is posing serious environmental hazards. Anyhow, the comparatively lower mechanical properties of the natural fibre reinforced polymer composites have restricted their entry into many sectors. A complementary measure by presenting a combination of natural and synthetic fibres in the polymer matrix can achieve a good balance between the degradability and performance of the material. In the recent past, a few research attempts were made on the feasibility of hybridization using selected natural and synthetic fillers.

Most of the assembling operations of fibre reinforced plastic sheets involve a number of riveted joints which require the presence of holes which naturally give rise to zones of stress concentration. This factor has made the analysis of open hole behaviour of these laminate composites, a crucial step in defining their suitability for applications.

The open hole mechanical properties of human hair-coconut coir-glass fibre-human hair hybrid composite (HCGHRP) are studied in this paper. The composite samples were prepared by hand lay-up. Eight sets of tensile and impact specimens with each set comprising of specimens with centrally drilled holes of a particular diameter were prepared and the experimental tensile and impact values were recorded. Additionally, Whitney Nusimer point stress model was validated for these values. The stress distribution in the open hole specimens were studied by Finite Element Method. In all these Increase in hole diameter was found to cause an increase in hole sensitivity. The finite element analysis of the loaded specimens indicated a much higher concentration of load in the regions surrounding the hole.

Keywords: Stress concentration factor, open central hole, glass fibre, human hair

INTRODUCTION

Green environment campaign has forced the researcher to change their approach in polymer composites reinforcement material from synthetic fillers to natural fillers to enhance polymer composites properties. The key is a low eco-compatibility of the synthetic fillers is posing serious environmental hazards. Since comparatively lower mechanical properties of the natural fibre reinforced polymer composites as restricted their entry into many sectors. A complementary measure has been taken by presenting a combination of natural and synthetic fibres in the polymer matrix can achieve a good balance between the degradability and performance of the material. In the recent past, a few research attempts were made on the feasibility of hybridization using natural and synthetic fillers. Raghavendra et al., studied an effect of hybrid combination of jute and glass fibres in epoxy matrix. They reported that composite with glass fiber showed tensile strength of 78MPa and this value was approximately equal to the average of the tensile strength of the composites reinforced by jute and glass fibres. Hazizan et al., investigated on the mechanical behavior of pultruded jute/glass fibre composites which shows much higher mechanical properties. Atiqah at al., have been investigated mechanical properties of kenaf and glass fibres reinforced in epoxy and unsaturated polyester. This combination has produced good mechanical properties in case of epoxy, but unsaturated polyester composite showed no significant results. Therefore, there is an ample evidence for the successful development and characterization of hybrid composites. Senthilnathan et al., fabricated a glass-coconut coir-human hair hybrid composite and natural fibers have significantly influenced the mechanical properties.

In fact polymer materials finding a place in structural application where requires many holes with different size for the assembling of these polymer laminates or sheets. These holes are a high prone to stress riser in the joining zone. This factor has made to attempt an analysis open holes behavior of fabricated laminate composites. This is a crucial step in defining their suitability for applications. Many researchers have been studied the effects of stress concentrations on laminate composites. Durao et al., studied tensile strength variation by introducing an open-hole in sisal reinforced epoxy composite. Luis Miguel et al., performed bearing test and delamination onset test on the polymer composite and validated by the damage assessment method using radiographic images. The results give a relative importance to the drilling tools and machining parameters to the life expectancy of these laminates. Salleh et al., fabricated a long kenaf/woven glass reinforced polyester resin composites and assess the damage area by open hole stress concentration. Open holed tensile strength of the composites continuously decreasing with increased size of the hole. Panneerdhass et al., studied effects of different size of central hole on the tensile variation of natural fiber reinforced composites. They claimed that tensile strength varied from 9.6-19.10 MPa.

The technique used for accurate prediction of the open hole tensile strength with stress concentrations is limited. Point stress model proposed by Whitney et al., is widely used for preliminary sizing and optimization of designing composite laminates with stress concentrations. Hence in this study Whitney point stress model have been used to assess the open tensile strength of composite. Additionally, Finite Element Approaches have been employed for faster and more accurate prediction of open tensile strength. Camanho et al., developed an accurate strength prediction method for composite laminates with circular holes subjected to tensile load, based on independently measured material properties. The underlying principle of this method was Leguillon’s concept of finite fracture mechanics. In another research attempt, a thorough investigation of open hole tensile tests with focus on scaling effects was carried out, followed by the proposal of a cohesive zone, which enabled the implementation of an interface element for an explicit FEM package. Green, Hallett, & Jiang et al., interface elements were used within FEM models of open hole specimens, not only model ply failure prediction but also inter-ply-delamination. Avani et al., Finite Element Static analysis is performed on the natural fibers and synthetic fibers reinforced hybrid composite using software ANSYS11.0 with design constraints as stress and deflection. Natural fiber reinforced composite showed reduction in stress and deflection without compromising stiffness when compared to synthetic fiber reinforced composite.

This research work focuses on evaluation of open hole tensile properties of human hair and glass fiber reinforced epoxy polymer composite by experimental and prediction methods. Whitney and Nusimer point stress model was used to predict the open holed tensile strength of composite and finite element method developed on the basis of anisotropic Hooke's law and tensorial presentation of the Kelvin Formulation and compared with the Whitney and Nusimer point stress model.

EXPERIMENTAL PROCEDURE

Materials and fabrication

Staring materials for fabrication of composites were epoxy resin and fibers such as human hair-coconut coir-glass-human hair (HCGH). Total fiber volume fraction was not exceeding 40%. Reinforcement fibers were treated with NaOH solution. These fibers were stacked consecutively by placing one another with inter epoxy resin. Compression molding was used press the stacked layer of fiber in order to penetrate the resin into the inter gap of fibers.

Open hole tensile and impact testing

Composite drilled with different size of hole from 3-10 mm with a step of 1 mm dia. HSS drill with point angle 118° was used. The drilling operation was carried out in a radial drilling machine without ancillary plate at the bottom of composite sample. The open hole specimens were prepared as shown in “Figure.1.and 2.” Typical open hole drilling before and after specimens for tensile and impact strength as shown in “Figure.3, 4, 5 and 6.”

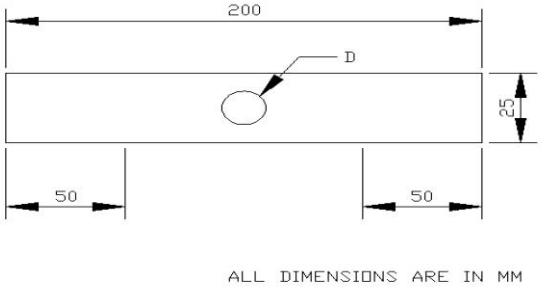

Figure.1.Open hole for tensile specimen

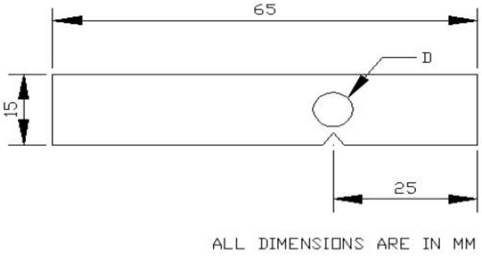

Figure.2.Open hole for impact specimen

Figure.3. Typical open hole before tensile specimen

Figure.4. Typical open hole before tensile specimen

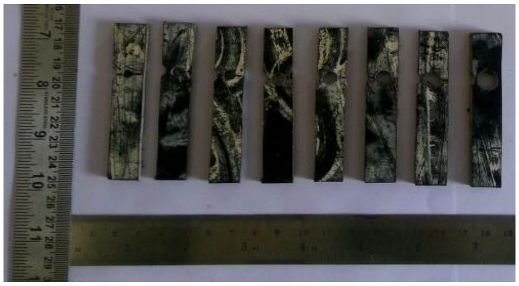

Figure.5. Typical open hole before impact specimen

Figure.6. Typical open hole after impact specimen

Universal Testing Machine (Instron 3369) was used to determine a tensile strength of the specimens of length 250 mm and width 25 mm. A crosshead speed of 5 mm/min was maintained throught the experiment. In each case, eight samples were tested and the average values were reported.

Charpy impact test was employed to determine the absorbed energy and sample size of 65mmx15mmx5mm.

Finite Element Modelling

3D modelling of the composite was carried out using a ABAQUS- Finite element tool and stress analysis were carried out.

RESULTS AND DISCUSSION

Tensile Strength

The open hole tensile strength of the HCGHRP composite are presented in “Figure.7.” The open hole tensile strength are lower for larger hole diameters. In case of samples with diameters of 3 mm, the open hole (notched) tensile values are very close to the unnotched tensile strengths, which are 8.86 MPa to 15.8 MPa. A probable reason for this trend could be the fact that the increase in hole diameter causes reduction in the cross sectional area in the proximity of the hole which promotes early failure.

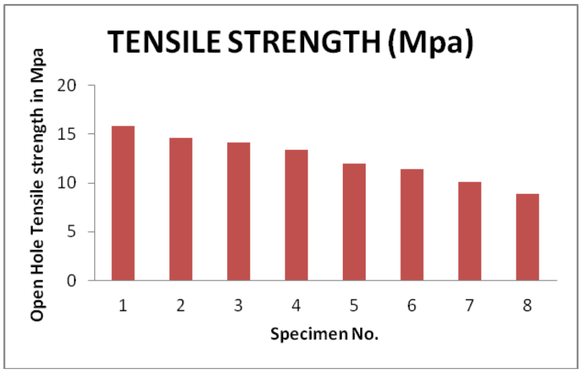

Figure. 7. Open hole tensile strength

Similar observations were reported from L.M. Durao et al., in a study of two different types of reinforced plates, glass fibre reinforced epoxy and sisal fibre reinforced epoxy composites.

Validation of Whitney-Nusimer point stress model

The mathematical relationship between notched (open hole) tensile strength and unnotched tensile strength values of a laminate composite is given by Whitney-Nusimer point stress model. The Whitney-Nusimer point stress model for an isotropic material is given by the expression ,

$$\sigma_{th.} = \left[\frac{2}{2+\lambda^2+3\lambda^4}\right]\frac{\sigma_o}{C_W}$$

$\sigma_{th.}$ -theoretical gross area notched tensile stress

σ_o - unnotched tensile stress

C_W - width correction factor

λ - r/(r+r_o) (where ‘r’ is hole radius and r_o is the distance from hole edge to the point where notched tensile stress equals unnotched tensile stress)

The width correction factor (C_w) is given by [Mallick et al.,]

$$C_w = 1-0.05\left[\frac{d}{w}\right]+1.5\left[\frac{d}{w}\right]^2$$

d- diameter of the hole
w- width of the tensile specimen

The HCGHRP composite is in the form of a rectangular plate consisting four staking layer. It is assumed to be isotropic material behavior. Therefore, the theoretical open hole tensile strength were calculated using the above mentioned expressions.

The theoretical open hole tensile strength was good agreement with the experimental values and the deviation increases with increasing hole diameter (Figure.8) due to increase in damage zone. Hence this equation only holds a minor drilling induced damage. Hole diameters beyond 5mm show a very low tensile strength which results practically undesirable in application (Refer Figure.10. S3, S4, S5).

Therefore, the HCGHRP composite shows a good adherence to the Whitney-Nusimer point stress model in the low diameter range.

Exp.-experimental notched tensile stress

Th.-theoretical notched tensile stress

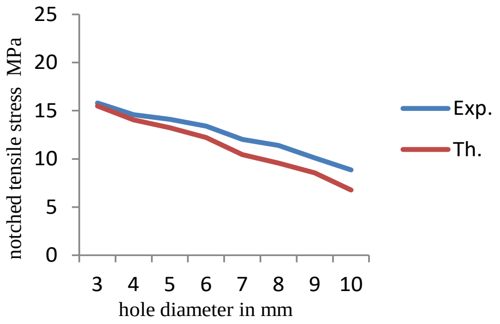

Figure.8. Deviation between theoretical and experimental values

Impact Strength

The variation of open hole impact strength is presented in “Figure. 9.” These figures clearly indicate the gradual decrease in (3mm to 10 mm diameter for drill) impact strength. Similar observations were made by Cao et al., and Isik et al.,

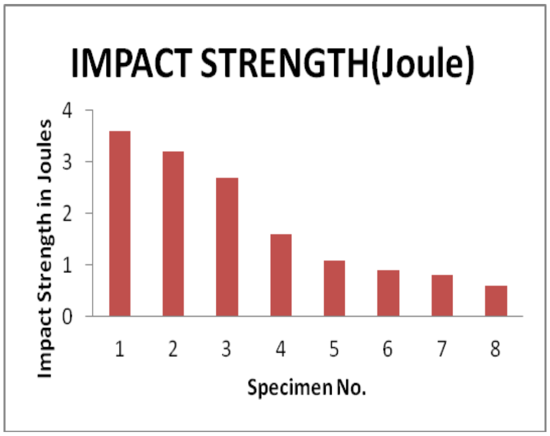

Figure.9. Open hole impact strength

ANALYTICAL ANALYSIS

Tensile property of fiber and composite

It is well known that fiber content and fibre matrix adhesion is mainly responsible for tensile properties of a fibre reinforced composite. The variation in the open hole tensile strength of the composites with 40% of volume fractions of fibres and the results show a decrease in open hole tensile strength value with an increase in hole diameter and the values corresponding to a hole diameter of 3mm are very close to the unnotched tensile strengths 40% fibre contents respectively.

Assumptions to be made in FEA Analysis

For 3D finite element analysis of the present work is done in ABAQUS- Finite element tool using a 3D element suitable for composite analysis known as “SOLID 42” and is an 8-Noded element useful for structural analysis of composite which facilitates near about 400 layers. The young’s moduls of used fiber and composite is presented in Table 1. young’s moduls H-C-G-H composite value as used in this model. Figure 9 and 10 show the meshing and tensile loading specimen.

The FEA results in “Figure.12.” as shows stress distribution of a human hair-coconut coir-glass fibre-human hair hybrid composite (HCGHRP).

Table 1 Young’s modulus of fiber and composite

S.NO	YOUNG’S MODULUS			
		E (GPa)		E (GPa)
1	Coconut coir	4-6	C-H-G-C	19.95
2	Glass fibre	80	G-H-C-H	19.95
3	Human hair	7.3	H-C-G-H	19.95

FINITE ELEMENT MODELLING

The part is meshed by partitioning the layers and assigning varying element types. Hex and Tet elements are used with the global size of 2mm and increased local seeds in the hole region which is 0.5mm for accuracy. The part is meshed using Abaqus tool itself. The respective boundary conditions were defined and loads are varied from 5Mpa to 25Mpa in steps of 5.

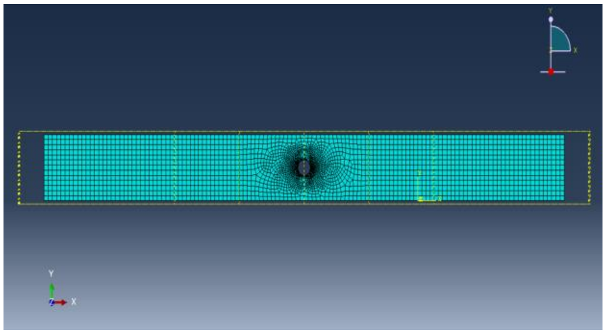

Figure.10. Meshing

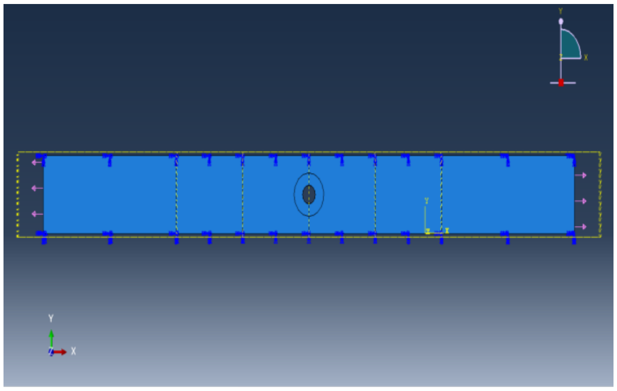

Figure.11. Loading

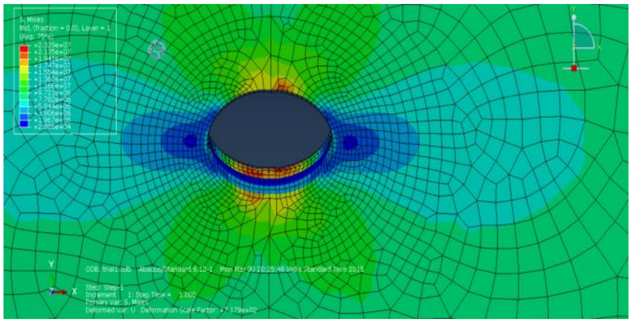

Figure.12. Stress distribution

When uniform load is applied to all plies in axial direction, it is conceived that the glass layers distort less under the influence of the pressure load than the coir and hair layers. The maximum stress in each case is observed in the regions surrounding the hole due to stress concentration.

This is many times greater than the actual stress that would have been developed in the specimen without the drilled hole. The graphic visualization of the deformed sample shows that the layers of coconut coir and human hair are deformed more than the layer of glass which serves as the synthetic reinforcement to improve the strength of the hybrid polymer. Stress concentration occurs in the open hole region and the stress induced in this region is much higher than the actual load applied. When the applied load increases beyond the ultimate strength of the polymer which has been determined from previous mechanical testing, fracture occurs in the region where maximum stress is induced ie. at the hole region.

Comparison of theoretical and FEA

The FEA results indicated that the stresses in human hair-coconut coir-glass fibre-human hair hybrid composite (HCGHRP) are much lower compared to analytical because of the variations in the literature repoted values of natural fiber strength.

CONCLUSION

The effect of stress concentration on tensile and impact properties of the HCGHRP-epoxy composite was analyzed. Central holed tensile values were varied from 8.86 MPa to 15.8 MPa. The hole sensitivity was found to increase with increasing hole diameter. The Whitney-Nusimer point stress model shows higher validity for lower hole diameters. The finite element model has given a clear visualization of the stress distribution in the specimen.

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