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Drilling of TiO_2 and ZnS Filled GFRP Composites

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ABSTRACT

In the present work an attempt has been made in order to investigate the drilling behavior of the TiO_2 and ZnS filled glass fabric reinforced polymer matrix composites (GFRP). The volume fractions in the matrix were chosen as 1%, 2% and 3%. Drilling has been conducted on a radial drilling machine. Speed of drilling and drill tool diameter were considered as the varying parameters with three levels. Thrust force has been considered as the output parameter and is been measured in each combination of parameters chosen. Results reveal that, the addition of filler will increase the thrust force developed during drilling, also results indicate that, addition of filler will increase thrust force upto 2 vol% of filler thereafter increase in filler content result in almost constant thrust developed. Also it can be observed that, with the increase in drill tool diameter the thrust developed also increases.

Keywords: Fillers; Thrust Force; Drilling; GFRP; Speed

1. Introduction

Polymer matrix composites are increasingly being used because of their high stiffness, specific strength and wear resistance. On account of their good combinations of properties, fiber reinforced polymer composites are used particularly in the automotive, aircraft industries and the manufacture of spaceships and sea vehicles [1]. It is generally known that the epoxy resins with appropriate curing agents find use as products in protective coatings, adhesives, structural components because of their good mechanical properties, excellent chemical resistance, good wettability and electrical characteristics [2]. Their use is always indicated where fluids are ineffective or cannot be tolerated because of the possibility of contamination of the product or the environment, or the lack of opportunity for maintenance [3].

Many researchers [4-7] were reported that the wear behavior of polymers was improved by the incorporation solid particles. The filler materials include organic, inorganic and mechanical particulate materials. The addition of filler particles to polymer matrices can produce a number of desirable effects, and this has been widely been investigated in the past decades. Among polymers, epoxy resin is widely used in production of glass fiber composites due to their wetting power and adhesion to glass fiber, low setting shrinkage, considerable cohesion strength, adequate dielectric characteristics, and thermal properties. Epoxies commonly modified by the inclusion of inorganic-particulate fillers, such as silica, alumina, mica or talc. Fillers are added to improve fracture toughness and electrical or heat transfer properties, to increase resin stiffness, wear resistance, and to reduce the coefficient of thermal expansion [8].

Drilling of composite materials irrespective of the area of application can be considered as a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. With regard to the quality of machined component, the principal drawbacks are related to surface delamination, fibre/resin pullout and inadequate surface roughness of the hole wall. Among the defects caused by drilling, delamination appears to be the most critical. In order to overcome these difficulties it is necessary to develop procedures to select appropriate cutting parameters, due to the fact that an unsuitable choice could lead to unacceptable work material degradation.

The variation of cutting forces with or without onset damage during drilling was investigated [9] and concluded that a damage-free drilling process may be obtained by the proper selections of tool geometry and cutting parameters. The influence of trepanning tool on thrust force and torque when drilling GFRP has been investigated [10]. The investigation showed that the performance of the trepanning tool was superior to the conventional twist drill, resulting in 50 and 10% of thrust force and torque, respectively. In order to investigate the effect of the drill diameter on the thrust force and torque,

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researchers [11] employed conventional high speed twist drills with diameters of 8, 9, 10, 11, 12, and 13 mm to machine a glass fibre reinforced plastic using a constant rotational speed of 875 rpm and feed rates of 0.1 - 0.23 and 0.5 mm/rev. The results indicated that thrust force and torque increased with drill diameter and feed rate, due to the increase in the shear area. Increasing cutting speed also resulted in higher thrust force and torque, however, not to the same extent as when feed rate is elevated. Effect of drill size and feed on thrust force and torque has been investigated [12].

From the review of previous works carried out it is clear that, addition of filler material will improve the wear properties of the glass fabric reinforced composites (GFRP). Since large structures of composites cannot be made out of single mould, composites need to be fastened. Fastening of composites is done by either adhesive joining or mechanical fastening. To join composites by mechanical fastening, composites needs to be drilled. Also it is known that the speed of drilling and drill tool diameter effects the hole quality to large extent. The quality of hole generated and delamination is directly dependent on the Thrust force developed during the process of drilling. Hence the present work concentrates on the evaluation of Thrust force generated during drilling, while the speed of drilling and drill tool diameter are varied. Thrust force generated during drilling of unfilled, TiO_2 filled and ZnS filled composites has been recorded.

2. Materials and Experimentation

2.1. Materials

The matrix material used was a medium viscosity epoxy resin (LAPOX L-12) and a room temperature curing polyamine hardener (K-6). This matrix was chosen since it provides good resistance to alkalis and has good adhesive properties. The reinforcement material employed was 7-mil E-glass fabric. The Titanium dioxide (TiO_2) amorphous powder and Zinc Sulphide (ZnS) amorphous powder are used as filler materials.

2.2. Composite Combinations

Hand lay-up technique of laminating the composites has been employed for composite fabrication. Two material compositions of Glass/Epoxy (G-E) composites were chosen namely G-TiO_2-E and G-ZnS-E. Each material composition has been fabricated for three different volume fractions, the details of the percentage volume fractions of epoxy resign, glass fabric and fillers are shown in **Table 1**.

2.3. Experimentation

Large plates of composites are made in order to carryout drilling operation with 10mm thickness. Drilling has been carried-out in a radial Drilling Machine. The drilling machine is been connected to a Drill Tool Dynamometer which gives the digital reading. Speed of drilling and Drill tool diameters are chosen as input parameters and Thrust force is considered as the output parameter. During conducting tests the maximum Thrust recorded is considered as the resultant, and has been recorded. The summary of parameters considered for drilling is shown in **Table 2**.

3. Results and Discussion

Composites can be joined with the help of fasteners, preferably mechanical fastening, and to do so, it is necessary to drill holes on the composite plates. Hence in the present work drilling is considered as the machining operation and carried-out on filled and unfilled composites.

Drilling holes in composites can cause failures that are different from those encountered when drilling metals. Delamination, fracture, break-out and separation are some of the most common failures. Delamination (surface and internal) is the major concern during drilling composite laminates as it reduces the structural integrity, results in poor assembly tolerance, adds a potential for long term performance deterioration and may occur at both the entrance and exit plane. Delamination can be

Table 1. Composite combinations.

Sl. No.	Filler	Combination or volume fractions	Representation
01	-	Glass Fabric 60% + Epoxy 40%	GE
02	TiO_2	Glass Fabric 60% + TiO_2 1% + Epoxy 39%	GTE-I
03		Glass Fabric 60% + TiO_2 2% + Epoxy 38%	GTE-II
04		Glass Fabric 60% + TiO_2 3% + Epoxy 37%	GTE-III
05	ZnS	Glass Fabric 60% + ZnS 1% + Epoxy 39%	GZE-I
06		Glass Fabric 60% + ZnS 2% + Epoxy 38%	GZE-II
07		Glass Fabric 60% + ZnS 3% + Epoxy 37%	GZE-III

Table 2. Summary of parameters considered for drilling.

Sl. No.	Speed in rpm	Drill diameter in mm
01	525	3
02	951	6
03	1625	9

overcome by finding optimal thrust force (minimum force above which delamination is initiated). **Figure 1** shows push out delamination at exit because at a certain point loading exceeds the interlaminar bond strength and delamination occurs. **Figure 2** shows peel-up delamination at the entrance, because the drill first abraded the laminate and then pulled the abraded material away along the flute causing the material to spiral up before being machined completely. This type of delamination decreases as the drilling proceeds since the thickness resisting the lamina bending becomes greater.

In order to know the effect of filler volume on the drilling behavior and influence on thrust force the specimen are drilled for three different drill sizes and for three different spindle speeds.

3.1. Effect of Process Parameters on the Drilled Composite and the Drilling Performance

In order to know the effect of drill size and drilling speed on the drilling performance, each combination of the composites is drilled for different drill diameters and drilling speeds. When speed is varied drill size is kept constant and in the same way speed is kept constant when drill size has varied.

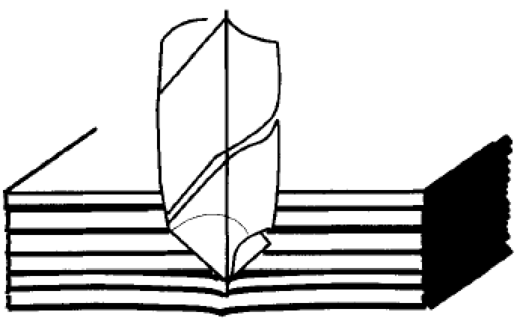

Figure 1. Push-out delamination at exit.

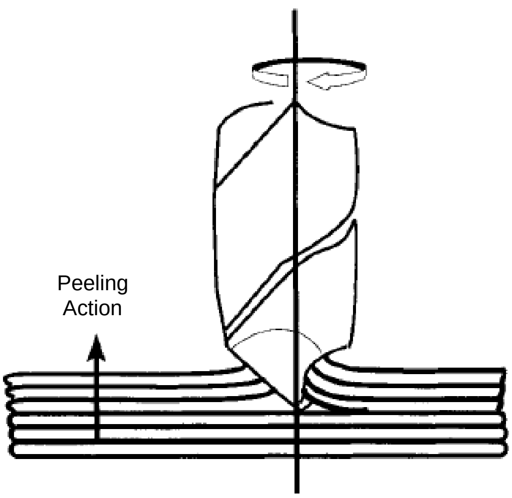

Figure 2. Peel-in delamination at entrance.

During drilling, a vertical force, that is, a thrust force, is generated. This thrust force can be considered as the sum of several components, each one rising either from the cutting process or from the friction between material and cutting tool. The cutting process occurs along the cutting lips and at the chisel edge. The cutting process along the lips generates a force on each lip that has a force component parallel to the axis of the drill, that is, the feed direction. Moreover, the chisel edge generates a vertical penetration force. The friction forces arise from two components. The first is related to the friction between the side surface of the tool and the generated hole surface, which leads to the vertical force. The second component is related to the friction between the chip flow along the helical grooves, which generates the vertical force. Sum-up of all this forces gives the total thrust force acting on the drill. The thrust force observed during drilling not only depends on the geometry of the drill and on the type of material and laminate being worked upon, but also on the relationship between the feed rate and the cutting speed, as well as on the degree of wear of the drill.

In the present work Thrust force is considered as the out-put or resultant of drilling. Thrust force is measured with the help of a calibrated drill-tool dynamometer. The thrust force generated is measured in each case and has been recorded, the results of which are shown in figures following.

Figures 3-5 show the thrust force against different drilling speeds with respect for 3 mm, 6 mm and 9 mm drill sizes respectively for TiO_2 filled composites. From the figures it can be observed that the Thrust generated increases with the increase in the speed of drilling. The common thing that can be observed in all the three cases is that, the drilling speed is more significant on the thrust force, as the spindle speed increases the thrust force generated also increases. This is because of the reason as the spindle speed increases the resisting force also increases, after certain limit the effect of speed becomes less significant, this can be observed from block for speed-2 and

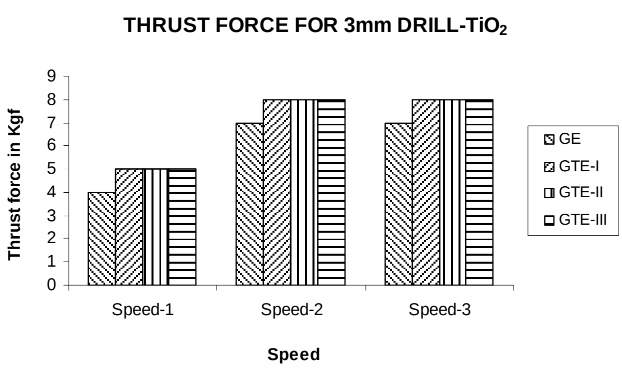

Figure 3. Comparison of thrust force against drilling speeds for TiO_2 filled composite (3 mm).

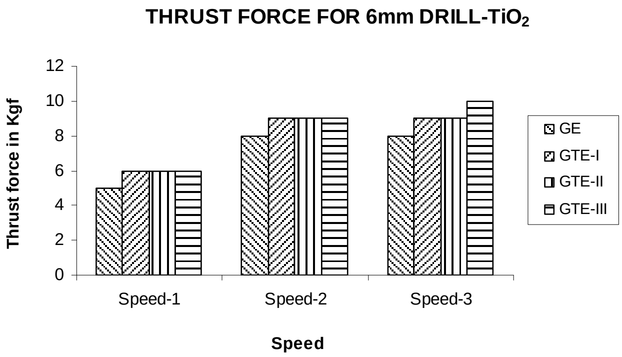

Figure 4. Comparison of thrust force against drilling speeds for TiO_2 filled composite (6 mm).

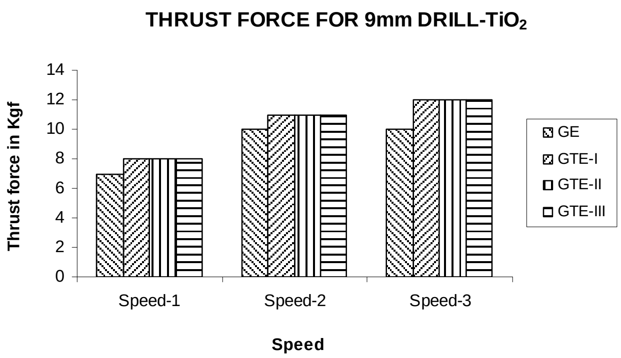

Figure 5. Comparison of thrust force against drilling speeds for TiO_2 filled composite (9 mm).

block for Speed-3 in each of the case. The peel-in kind of delamination can be observed in all the cases, and fiber pull out is observed at the exit side.

Compared to unfilled and filled composites, thrust developed during drilling of unfilled composites is comparatively lesser with that of filled composites, and when the filler content is under consideration, the effect of filler content on thrust force is not significant, this can be observed from the Figures, in each block the variation in thrust value is not much differed, this indicates that the effect of filler is less significant on the drilling performance. As the drill size varies the thrust force increases this is because, as the drill diameter increases the force required by the drill to penetrate the component also increases.

Observations also show that, the Thrust generated in all the combinations of composites increases with the increase in drill tool diameter. This is due to reason that, with the increase in drill tool diameter the shear area produced by drill tool also increases, this will leads to the increase in Thrust generated.

Figures 6-8 show the thrust force against different Drilling speeds with respect to 3 mm, 6 mm and 9 mm drill sizes respectively for ZnS filled composites. From the figures it is clear that, as the speed of drilling increases there is an increase in the thrust force also. Considering the effect of filler content, the effect of filler content on the drilling is less significant in case of this composites, this is because there is no much difference in thrust force as observed during drilling. As the drill size increases, the Thrust force required to drill the hole also increases. The peel-in kind of delamination can be observed in all the cases, and fiber pull out is observed at the exit side.

As the drilling speed exceeds a certain range, the Thrust generated remains somewhat constant in all the cases of composites, this is due to reason that at higher speeds the heat generated will be more and this heat will

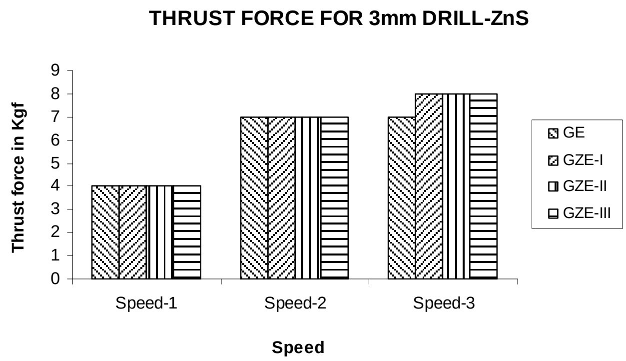

Figure 6. Comparison of thrust force against drilling speeds for ZnS filled composite (3 mm).

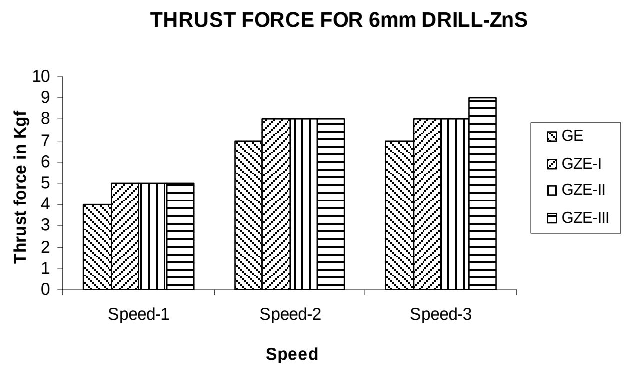

Figure 7. Comparison of thrust force against drilling speeds for ZnS filled composite (6 mm).

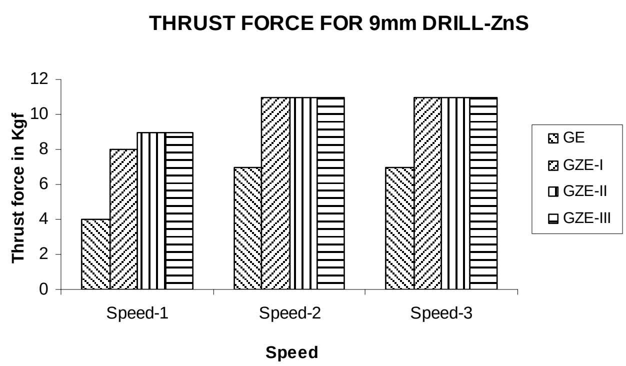

Figure 8. Comparison of thrust force against drilling speeds for ZnS filled composite (9 mm).

make the material behave softer that the usual case and hence the resistance offered for drilling becomes lesser, this will result in development of less Thrust. In comparison with TiO_2 and ZnS filled composites, TiO_2 filled composites will offer more resistance that ZnS filled composites. Since the ZnS filled composites are comparatively less brittle that TiO_2 filled composites, they behaves bit softer at early stages than TiO_2 filled composites, offering less opposition for drilling.

4. Conclusions

From the experimentation conducted and observations made during testing, following conclusion can be drawn:

- The thrust force generated during drilling of filled composites mainly depends upon drill diameter and the speed of drilling in the present case.
- Effect of filler volume on the Thrust generated is neglizable.
- Thrust force developed during drilling of TiO_2 filled composites is more in comparison with ZnS filled composites.

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