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Effect of Process Parameters on Thrust Force in Drilling of Carbon-Glass Fibers Reinforced Epoxy hybrid Composites

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Abstract

In the present investigation, effect of process parameters on thrust force in drilling of carbon and glass fibers reinforced epoxy hybrid composite were studied. The vacuum bagging technique was adopted for the fabrication of hybrid composite materials. The effect of process parameters on thrust force in drilling operation was studied by varying the feed and speed to obtain the quality holes in the hybrid composites were determined. The study indicates that the effect of spindle speed on thrust force is not significant and lower feed rate has to be used for higher spindle speed in order to obtain the quality holes in the hybrid composites.

Keywords: Epoxy, Hybrid Composite, Carbon/Glass Fiber, Thrust force

1. INTRODUCTION

The fibers reinforced hybrid composite materials have grown in recent years in every field of engineering due to their inherent advantages over conventional materials. However, due to the presence of two or more dissimilar phases, hybrid composite materials expose challenges during machining as well as material characterization. Polymer based composites also provide good design, flexibility and high dielectric strength and usually require lower tooling costs. In machining processes, the quality of the component is greatly influenced by various process parameters such as cutting conditions, tool geometry, tool material, machining process, chip formation, work-piece material, tool wear and vibration during cutting, etc. Drilling which is a secondary machining process is per-formed on fiber reinforced hybrid polymer composites to know the effect of various factors during machining. Drilling is the most widely used for machining of composite materials, the effect of thrust force and torque that occurs during drilling to obtain a profile to fasten the composites in aerospace, automotive and machine tool industries. The main concern in the drilling of composite to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of holes drilled. Mathew et al. [1] studied that thrust is a major factor responsible for delamination and it mainly depends on tool geometry and feed rate. Trepanning tools, which were used in this study, were found to give reduced thrust while making holes in thin laminated carbon fiber reinforced polymer composites. In his work the peculiarities of trepanning over the drilling of unidirectional composites has been emphasized. Sonbaty et al. [2] studied the influence of some parameters on the thrust force, torque and surface roughness in drilling processes of FRP. These parameters include cutting speed, feed, drill size and fiber volume fraction. Zitoune et al. [3] studied the parametric influences on thrust force, torque as well as surface finish, on carbon fiber reinforced polymer composites. The experimental results showed that the quality of holes can be improved by proper selection of cutting parameters. This is substantiated by monitoring thrust force, torque, surface finish, circularity and hole diameter. Capello and Tagliaferri [4] studied to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out on glass-polyester composites using standard HSS tool, drilling was interrupted at preset depths to study damage development during drilling. Arul et al. [5] suggested that the drilling of polymeric composites which aimed to establish a technology that would ensure minimum defects and longer tool life using HSS drill. Using HSS drill, a series of vibratory drilling and conventional drilling experiments were conducted on glass fabric reinforced polymer composites to determine delamination factor. Hocheng and Tsao [6] studied the critical thrust force and delamination on carbon fiber reinforced polymer composites. and compared the effects of these on different drill bits. The advantage of these special drills were illustrated mathematically as well as experimentally, that their thrust force is distributed toward the drill periphery instead of being concentrated at the center. Lin and Chen [7] carried out a study on drilling composite materials at high speed and concluded that an increase in the cutting velocity leads to an increasing tool wear that in turn provokes it an increase in the thrust force [8]. Abrao et al. [9] conducted the review of drilling of fiber reinforced plastics. This review highlighted the various aspects of on drilling of glass and carbon fiber reinforced polymers. Further, aspects such as tool materials and geometry, machining parameters and their influence on the thrust force and torque are investigated. Additionally, the quality of the holes produced is also assessed, with special attention paid to the delamination damage. Drilling of composite materials is different than drilling of metals as drill has to pass alternatively through plastic (matrix) and fiber (reinforcement) which have different properties. The difference in the physical and chemical properties of the constituents makes the understanding of the mechanism of material removal quite complex. Material removal during drilling of composites involves series of fractures aided by diverse nature and uneven load sharing between matrix and fiber [10-12]. The present work is to study the influence of process parameters on thrust force in drilling of glass fiber and carbon fiber reinforced in epoxy polymer matrix hybrid composites. The hybrid composites were developed by varying the reinforcements from 15%, 30%, 45% and 60% of glass and carbon fibers in 40% epoxy matrix under vacuum bag process. The effect of different feed rate, spindle speed, type of cutting tool of 3 mm, 6 mm and 9 mm diameters on thrust force in drilling of hybrid composite were studied.

2. EXPERIMENTAL DETAILS

2.1 Material selection

The glass fibers and carbon fibers are selected as reinforcements and epoxy as matrix material. The epoxy resin and hardener Tri Ethylene Tetra Amine (TETA) were provided by Atul Ltd. Polymers division, Valsad, Gujarat, India. The glass fiber of bi-directional woven mat with 200 gsm and the density of 2.5 gm/cc are used. The carbon fiber of bi-directional woven mat with 200 gsm and the density of 1.78 gm/cc are used. The glass fiber and carbon fiber used in the fabrication of hybrid fiber reinforced composites are shown in figure 1.

Figure 1: The glass fiber and carbon fiber

2.2 Fabrication of Composites

The glass fiber and carbon fiber reinforced in epoxy polymer matrix hybrid composites were developed using vacuum bag process by varying the reinforcements in terms of weight percentage of 15%, 30%, 45% and 60% in 40% of epoxy matrix. The weight fraction of fibers and epoxy matrix materials were determined by considering the density, specific gravity and mass. Initially, the fabrication of the composite was done at room temperature by hand lay-up technique. The required ingredients of resin and hardener were mixed thoroughly in a basin and the mixture is subsequently stirred constantly. The required sizes of fiber mats were prepared and the glass fiber was positioned manually in the open mold and the mold surface must be smooth enough to prevent bonding to the laminate. The mixture so made is brushed uniformly over the glass and carbon plies alternatively. The entrapped air is removed manually with rollers to complete the laminates structure. Then the vacuum bagging is applied to the mold with a vacuum pressure of 0.1mbar for uniform distribution of resin and also to remove the entrapped air. The composite is cured at room temperature and the post curing was done at 50^{o}C for 30 min, 65^{o}C for 45 min and 75^{o}C for 1 hour. The fiber reinforced polymer matrix composites is mainly used due to easy availability of glass fibers and economic processing technique adopted for producing the fiber reinforced polymer matrix composites. The vacuum bagging process adopted for the development of hybrid composite is shown in figure 2.

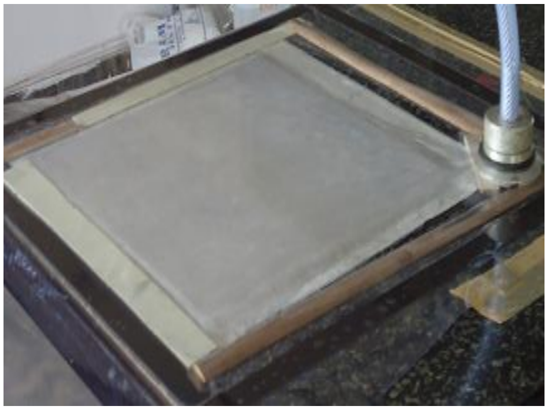


Figure 2: Vacuum bag process

2.3 Testing of FRP hybrid composites

The glass and carbon fibers reinforced epoxy composite slabs were taken out from the mold and then the specimens of suitable dimensions were prepared from the composite slabs for conducting tests according to the ASTM standards. The test specimens were prepared using diamond tipped cutter and different tools in the work shop. The 200 mm x 200 mm x 3 mm size specimens were prepared form the developed composites and edges of the specimen are finished by using file and emery paper. The drilling of hybrid composites was carried out on a vertical CNC machining centre (Model: AMC55 with FANUK control, Make: MAKINO Singapore) by using HSS, Titanium coated and carbide tipped drill bits with three different drill bit diameters of 3mm, 6mm and 9mm. The dynamic and quasi-static measurements of the thrust force and torque are recorded, by using an IEICOS drill tool multi-component piezoelectric dynamometer (Model: 601A: 100kgf thrust and 10kgm torque, Make: IEICOS). The experimental set up is shown in figure 3. The experiments have been carried out at three different spindle speeds of 800 rpm, 1200 rpm, 1600 rpm and 2000 rpm, with different feed rates of 10 mm/min, 15 mm/min, 20 mm/min and 25 mm/min. The thrust force and torque signals recorded during the drilling operation by using the IEICOS multi-component digital force indicator (Model: 651: 2 channel digital force indicator, Make: IEICOS).

Figure 3: Drilling of hybrid composite fixed on the IEICOS drill tool multi-component piezoelectric dynamometer

3. RESULTS AND DISCUSSIONS

3.1 Effect of drill bit type in drilling of hybrid composites

The variation of thrust force in drilling of hybrid composites by using 3 mm HSS, titanium coated and carbide tipped drill bits at spindle speed of 1200 rpm and feed rate of 15 mm/min is shown in the figure 4. The thrust force increases as the percentage of carbon fibers content increases in the matrix material and the thrust force decreases as the percentage of glass fibers content increases in the matrix material. The thrust force indicated in drilling of hybrid composite by using carbide tipped drill bit is minimum than titanium coated and HSS drill bit. The thrust force in drilling of 60% GF+0% CF reinforced hybrid composite by using 3 mm titanium coated drill bit decreases by 15.75% as compared to drilling of 60% GF+0% CF reinforced hybrid composite by HSS drill bit and the thrust force decreases by 31.66% in drilling of the 60% GF+0% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 60% GF+0% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 30% GF+30% CF reinforced hybrid composite by using 3 mm titanium coated drill bit decreases by 7.27% as compared to drilling of 30% GF+30% CF reinforced hybrid composite by HSS drill bit and the thrust force decreases by 28.15% in drilling of the 30% GF+30% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 30% GF+30% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 0% GF+60% CF reinforced hybrid composite by using 3 mm titanium coated drill bit decreases by 15.6% as compared to drilling of 0% GF+60% CF reinforced hybrid composite by HSS drill bit and the thrust force decreases by 33.38% in drilling of the 0% GF+60% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 0% GF+60% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 0% GF+60% CF reinforced hybrid composite by using 3 mm HSS drill bit increases by 58.11% as compared to drilling of 30% GF+30% CF reinforced hybrid composite and the thrust force decreases by 45.15% in drilling of the 0% GF+60% CF reinforced hybrid composite by using HSS drill bit as compared to drilling of 30% GF+30% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 0% GF+60% CF reinforced hybrid composite by using 3 mm carbide tipped drill bit increases by 60.29% as compared to drilling of 30% GF+30% CF reinforced hybrid composite and the thrust force decreases by 40.85% in drilling of the 0% GF+60% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 30% GF+30% CF reinforced hybrid composite by using carbide tipped drill bit.

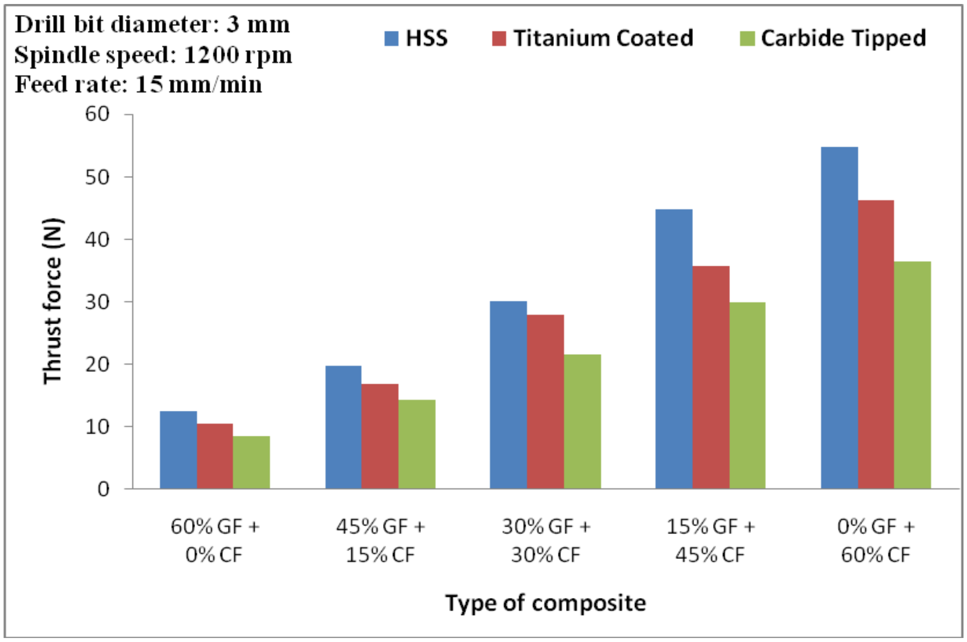


Figure 4: Variation of thrust force in drilling of hybrid composites by using 3 mm HSS, titanium coated and carbide tipped drill bits

The variation of thrust force in drilling of hybrid composites by using 6 mm HSS, titanium coated and carbide tipped drill bits at spindle speed of 1200 rpm and feed rate of 15 mm/min is shown in the figure 5. The thrust force increases as the percentage of carbon fibers content increases in the matrix material and the thrust force decreases as the percentage of glass fibers content increases in the matrix material. The thrust force in drilling of 60% GF+0% CF reinforced hybrid composite by using 6 mm titanium coated drill bit decreases by 21.64% as compared to drilling of 60% GF+0% CF reinforced hybrid composite by HSS drill bit and the thrust force decreases by 35.17% in drilling of the 60% GF+0% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 60% GF+0% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 30% GF+30% CF reinforced hybrid composite by using 6 mm titanium coated drill bit increases by 58.05% and increases by 27.84% while drilling with carbide coated drill bit as compared to drilling of 60% GF+0% CF reinforced hybrid composite by using HSS drill bit. The thrust force increases by 7.12% in drilling of the 0% GF+60% CF reinforced hybrid composite by using titanium coated drill bit and decreases by 18.05% while drilling with carbide tipped drill bit as compared to drilling of 30% GF+30% CF reinforced hybrid composite by using HSS drill bit.

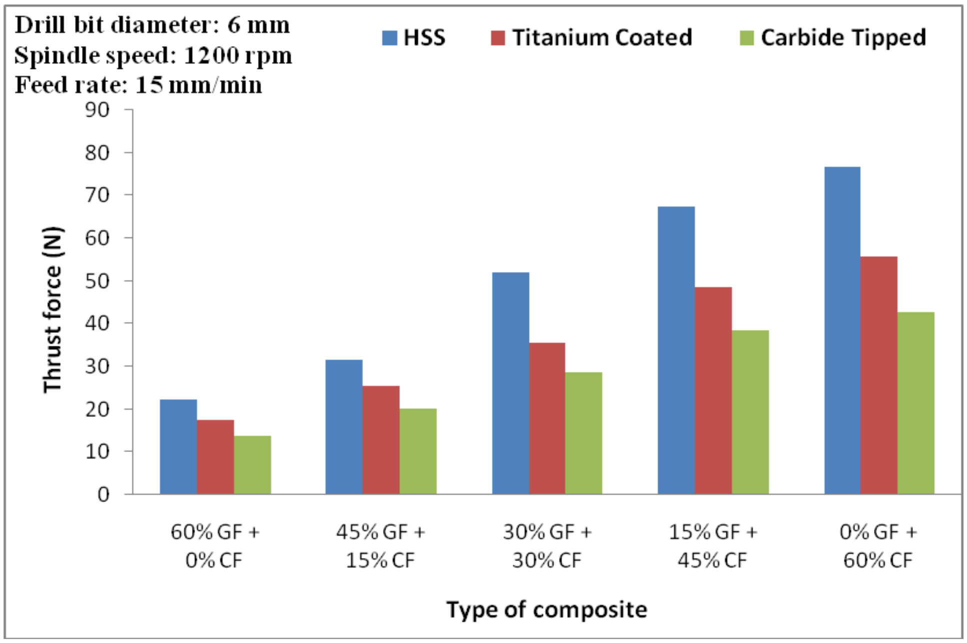


Figure 5: Variation of thrust force in drilling of hybrid composites by using 6 mm HSS, titanium coated and carbide tipped drill bits

The variation of thrust force in drilling of hybrid composites by using 6 mm HSS, titanium coated and carbide tipped drill bits at spindle speed of 1200 rpm and feed rate of 15 mm/min is shown in the figure 6. The thrust force increases as the percentage of carbon fibers content increases in the matrix material and the thrust force decreases as the percentage of glass fibres content increases in the matrix material. The thrust force in drilling of 60% GF+0% CF reinforced hybrid composite by using 6 mm titanium coated drill bit decreases by 17.16% as compared to drilling of 60% GF+0% CF reinforced hybrid composite by HSS drill bit and the thrust force decreases by 41.95% in drilling of the 60% GF+0% CF reinforced hybrid composite by using carbide tipped drill bit as compared to drilling of 60% GF+0% CF reinforced hybrid composite by using HSS drill bit. The thrust force in drilling of 30% GF+30% CF reinforced hybrid composite by using 6 mm titanium coated drill bit increases by 7.27% and increases by 34.49% while drilling with carbide coated drill bit as compared to drilling of 60% GF+0% CF reinforced hybrid composite by using HSS drill bit. The thrust force decreases by 10.61% in drilling of the 0% GF+60% CF reinforced hybrid composite by using titanium coated drill bit and decreases by 26.82% while drilling with carbide tipped drill bit as compared to drilling of 15% GF+45% CF reinforced hybrid composite by using HSS drill bit.

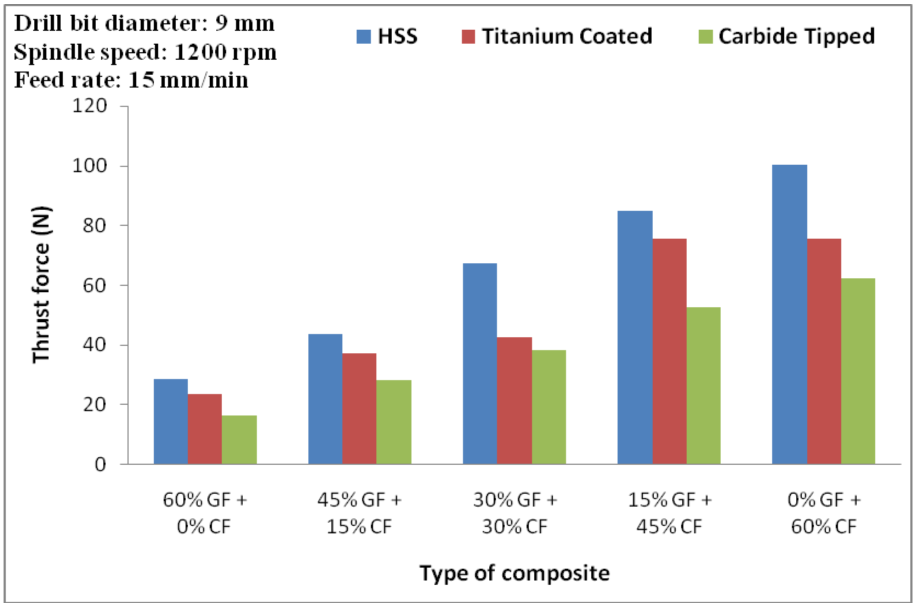


Figure 6: Variation of thrust force in drilling of hybrid composites by using 9 mm HSS, titanium coated and carbide tipped drill bits

The variation of thrust force in drilling of 30% GF+30% CF hybrid composite by using 3 mm diameter HSS drill bit for different spindle speeds at different feed rates is shown in the figure 7. The thrust force increases as feed rate increases and the thrust force decreases as spindle speed increases in drilling of 30% GF+30% CF hybrid composite for all spindle speeds. The thrust force in drilling of 30% GF+30% CF hybrid composite at 25 mm/min for 800 rpm increases by 48.75% and the thrust force increases by 16.2% in drilling of the hybrid composite at 15 mm/min as compared to drilling of hybrid composite at 10 mm/min for 800 rpm by using 3 mm HSS drill bit. The thrust force decreases by 28.17% in drilling of the 30% GF+30% CF reinforced hybrid composite at feed rate of 25 mm/min at 2000 rpm and decreases by 25.12% while drilling at 1600 rpm as compared to drilling of hybrid composite by using 3 mm HSS drill bit at 800 rpm.

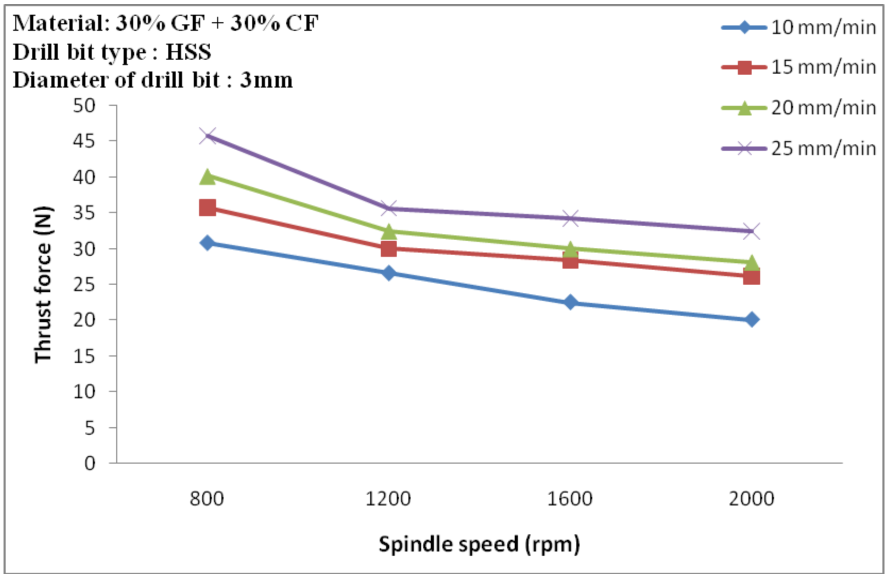
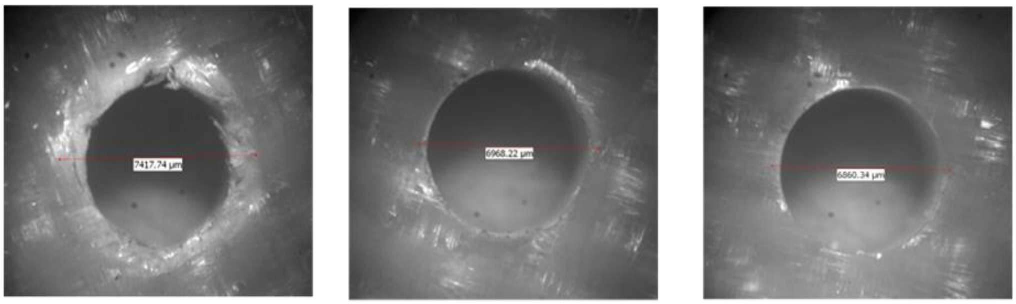


Figure 7: Variation of thrust force for different spindle speed in drilling of 30%GF+30%CF hybrid composites by 3 mm HSS drill bit

3.2 Delamination in hybrid composites

Delamination of the 30% GF + 30% CF hybrid composite drilled by 6 mm HSS, titanium coated and carbide tipped drill bits is shown in the figure 8. The delamination in the 30% GF + 30% CF hybrid composite drilled by 6 mm HSS is 7417.74 µm, by 6 mm titanium coated is 6968.22 µm and by 6 mm carbide tipped is 6860.34 µm. The minimum delamination was observed by drilling the 30% GF + 30% CF polymer hybrid composite by using carbide tipped drill bit compared to other drill bits. The carbide tipped drill bits provides accurate circular profiles with less delamination but cost of the carbide tipped drill bits are high. Similar observations were reported by many researchers. S. Jain and D.C.H. Yang [13] reported that the major damage is certainly the delamination that can occur both on the entrance and exit sides of the work piece. The delamination on the exit surface, generally referred to as push down delamination, is more extensive, and is considered more severe. Hocheng and Tsao [14] have beautifully explained the causes and mechanisms of formation of these push down delamination and they have also reasoned out the dependence of extent of delamination on the feed rate.



HSS Titanium coated Carbide tipped

Figure 8: Delamination of the 30% GF + 30% CF hybrid composite drilled by 6 mm HSS, titanium coated and carbide tipped drill bits

4. CONCLUSIONS

The carbon fiber and glass fiber reinforced hybrid composites have been fabricated by vacuum bag method. The drilling of hybrid composites was carried out on a vertical CNC machining centre by using HSS, titanium coated and carbide tipped drill bits with three different drill bit diameters of 3 mm, 6 mm and 9 mm. The thrust force increases as the percentage of carbon fibers content increases in the matrix material and the thrust force decreases as the percentage of glass fibers content increases in the matrix material. The thrust force indicated in drilling of hybrid composite by using carbide tipped drill bit is minimum than titanium coated and HSS drill bit. The thrust force increases as feed rate increases and the thrust force decreases as spindle speed increases in drilling of 30% GF+30% CF hybrid composite for all spindle speeds. The carbide tipped drill bits provides accurate circular profiles with less delamination but cost of the carbide tipped drill bits are high.

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