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Tool Wear and its Effect on Residual Tensile Strength in Drilling of Quartz Cyanate Ester Polymeric Composite

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ABSTRACT

Quartz-Fibre-Reinforced cyanate ester Plastics (QFRP) has superior performance in terms of mechanical, electromagnetic properties and are being widely used in military applications. Drilling is the general machining process for making hole to join the composite part to another sub-assembly. This study presents an influence of optimized drilling parameters on carbide tool wear and its impact on hole characteristics in QFRP composite. The aim is to achieve the optimum use of drill during the drilling process from application perspective without compromising the quality. In addition, the effect of tool wear and its impact on residual tensile strength of quartz composite are studied. The dominant wear mechanism observed is flank wear caused by the abrasive nature of the quartz fibre. The tool wear and delamination factor after drilling 200 holes are 186 µm and 1.40 respectively. The residual strength is affected by the tool wear due to relatively poor interlaminar property between fiber and resin in this quartz composite. The residual strength of quartz specimen drilled with the tool after drilling 200 holes is 14 % lower than the property of specimen drilled with fresh drill. The highlight of the present work is a combined analysis of wear in the tool, delamination induced and residual strength of quartz specimen. The results of this study strengthen the understanding of the drilling process of quartz polymeric composite material in aerospace applications.

Keywords: Quartz composite; Flank wear; Delamination; Residual tensile strength

1. INTRODUCTION

Fiber Reinforced Plastics (FRP) composite parts are used in aerospace and military applications owing to their characteristics such as low specific weight, corrosion resistance, excellent mechanical and other properties. Though the composite parts are realized very close to the final shape, secondary machining process is required to assemble the part to other systems. Among various secondary operations, drilling is the widely sought operation for making holes. When drilling a polymeric composite part, delamination is common. In addition to that, other drilling induced damages like fuzzing, internal cracks, fibre pull out are also observed. All these defects are due to significant difference in properties between the fibre and the matrix. Apart from Glass, Carbon, Kevlar fiber based reinforced plastics (CFRP, GFRP, KFRP), there are other fibers available which can be considered for specific applications. One of the fibers is Quartz Fiber Reinforced Plastics (QFRP) which possess excellent combination of structural and electromagnetic properties. This fiber finds potential use primarily in military applications.

The FRP are materials whose machinability is low and these materials induce abrasive wear on tool caused by the abrasive nature of the fibers. The wear caused in the tool during machining operations is seen to have a considerable effect[1] on the quality of drilled hole. Therefore the tool life of the material is important and need a conservative approach to avert undesirable defects on the component due to machining. Davim, *et al.*[2] performed experiments in drilling of CFRP composites and concluded that cemented carbide drill performs better with less wear and delamination. Most of the earlier studies indicated that the drill material used will have prominent impact on the drilled hole quality. Durao, *et al.*[3] performed drilling experiments on uni-directional carbon composite and concluded that higher bearing strength is achieved when drilling operation is carried out using carbide twist drill in combination with lower feed rate.

Khanna, *et al.*[4] used carbide drills with and without coating for tool wear analysis in drilling of GFRP. Delamination and flank wear observed were higher in coated drill bit than un-coated one. Also there is an increase in delamination with increase in wear on the tool for both the drill bits against the number of holes drilled. Ashrafi, *et al.*[5] carried out experimental drilling study with coated and uncoated twist drills on CFRP -Al stacks to analyse the machining parameters effect on the quality of hole. It was observed that coated tools produced more thrust than uncoated tools and less delamination on composite laminate was attained with low point angle.

Feito, *et al.*[6] studied the drill point angle influence and worn geometry on the hole quality in drilling of woven CFRP

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composite. It was concluded that delamination obtained were within the favourable limit with the low values of drill point angle. Also the delamination at hole exit deteriorated with the increase in wear of the tool. Ahmet, *et al.*[7] investigated the cutting parameters effect on delamination in drilling of CFRP composites. They concluded that the minimum thrust force, delamination was achieved with low feed rate, low point angle drill bit. Velayudham, *et al.*[8] studied the cutting parameters performance and number of holes drilled in drilling of high volume fraction GFRP with carbide drill having low point angle. It was concluded that the increase in number of drilled holes produced the gradual increase in thrust and tool wear. In addition, shrinkage in the hole dimensions was not observed.The holes produced were slightly oversized with the new drill. Rubio, *et al.*[9] studied the drilling performance on GFRP laminate with different cemented carbide drils and demonstrated that twist drill with low point angle produces less delamination at low spindle speeds and feed rates.Vijayan, *et al.*[10] investigated the effect of drilling parameters using carbide twist drill on CFRP laminates. Also they have studied the hole quality characteristics. This work concluded that feed rate during the drilling process has major impact on various hole quality parameters.

Lee, *et al.*[11] analysed the drilling characteristics of CFRP and hybrid composite for delamination and tool wear with the carbide drill having low point angle. They summarized that low feed rate and proper tool geometry can minimize generation of thrust force. Davim, *et al.*[12] studied the drilling performance of CFRP laminate manufactured by autoclave and concluded that the increase in both feed and machining velocity increase the delamination induced. Tsao, *et al.*[13] presented the results of force and roughness values in drilling CFRP. They showed that the output characteristics are primarily affected by the feed. Abrao, *et al.*[14] studied the cutting parameters performance and drill geometry effect in drilling of GFRP composite laminate. It was shown that the higher feed induced more thrust force due to elevation in the shearing area. Also, the higher thrust force was observed with the drill having high point angle.

Rawat, *et al.*[15] investigated the wear mechanism in woven graphite epoxy composites machined by high speed drilling process and reported the wear mechanisms. It is also reported that wear caused by abrasion on the flank face was more dominant. Fernandez, *et al.*[16] analysed the cutting parameters in CFRP material and explained that proper selection of cutting parameters mitigates the wear in the tool.

The number of consecutive holes drilled lead to wear in tool resulting in delamination due to machining .This defect generated during machining can cause detrimental effect to the part with a drilled hole which will end up in early part failure than the life intended .Therefore the study of drilling tool wear effect on the mechanical behaviour of composite plate is of utmost importance. Xiao,[17] *et al.* focused on the experimental studies and studied the residual tensile strength of CFRP composite laminate with different interlaminar strengths. It was concluded that delamination induced around the hole affects the residual strength in the composite specimen mainly with less interlaminar strength.

From the above literature, it is clear that most of the study done so far have focused on the performance of different tooling materials, their wear characteristics, the wear effect on the hole quality attributes, optimising various cutting parameters in drilling of CFRP and GFRP composite materials. Very few studies focussed to understand the effect of delamination on residual tensile properties.There is no specific investigation on novel quartz polymeric composite drilling to understand the quantum of tool wear and its effect on the hole quality attributes, residual strength from industrial application perspective.

To address this gap, the current study aims to focus on the effect of the optimised cutting parameters on the behaviour of tool wear and its impact on hole characteristics. Additionally, residual tensile strength of quartz composite with induced delamination was studied. The objective is to accomplish the optimum use of drill bit for machining without undermining the quality aspects of the component. The results of this study would improve the current understanding of the drilling operations in this quartz polymeric composite material for aerospace applications by taking joint effects of tool wear, delamination and mechanical properties into consideration.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Fabrication Process

Raw materials used and details of the laminate are described in this section. Quartz Cyanate ester polymeric composite laminates used for the experimentation were manufactured at Composites Center, Advanced Systems Laboratory. Raw material fiber is Quartz yarn purchased from M/s Saint Gobain, France and the matrix material resin is cyanate ester purchased from M/s Toray Advanced Composites, USA. Quartz yarn was woven into fabric.The weave type used was 2x2 twill with threads per inch at both the warp and weft direction as 30. Specifications of Quartz fabric is given in Table 1. Vacuum assisted resin transfer moulding (VARTM) was used to manufacture the composite laminate in a customised mould. Two parts cyanate ester resin system were taken in equal proportion and mixed thoroughly to achieve a mixture free of void by constant stirring. The mixed resin was transferred to the resin tank in the injection equipment. Reinforcement mat of 13 layers were sliced into required size of 300 X 300 mm and positioned in the cavity of the mould as shown in Fig. 1. Resin is preheated upto 40 ^{0}C to achieve a

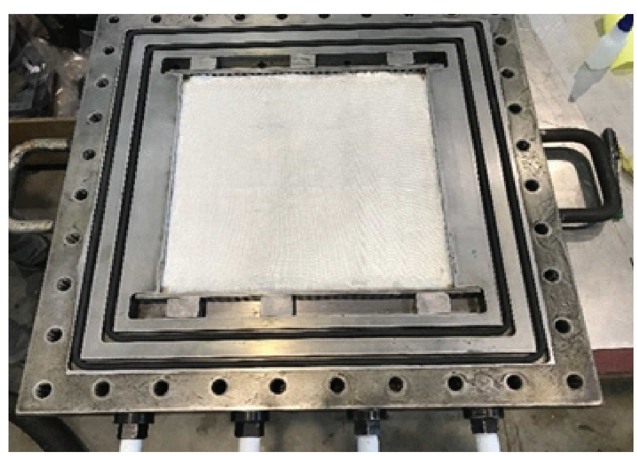


Figure 1. Quartz preform in the mould.

viscosity range of 100-150 cP .The heated resin was injected under 700 mm of Hg vacuum and the laminate was cured at 180 ^{0}C maximum temperature. The laminate thickness after curing as shown in Figure 2 was 4.0 mm and the fiber volume fraction of the laminate measured was 55 %. Degree of cure and Non- destructive evaluation (NDE) were performed to ensure the quality of the laminate. Mechanical properties of Quartz Cyanate Ester (QCE) composite is given in Table 2. For the present investigation, work specimens were cut from the fabricated laminate.

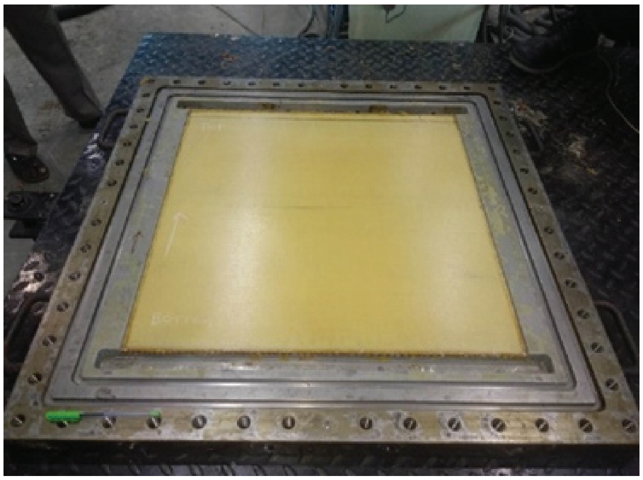


Figure 2. Finished quartz laminate.

Table 1. Specifications of quartz fabric

Parameter	Specified Value
Areal Density, GSM	310 ± 25
Count Warp, Threads/inch Weft, Threads/inch	 30±2 30±2
Weave type	2 X 2 Twill
Fabric Thickness,mm	0.3 ± 0.01

The optimized speed and feed considered in the current investigation were 500 rpm and 0.08 mm/rev respectively for all the tests. The diameter of the drill used for the experiments was 5mm with a helix angle of 30^{0} and image

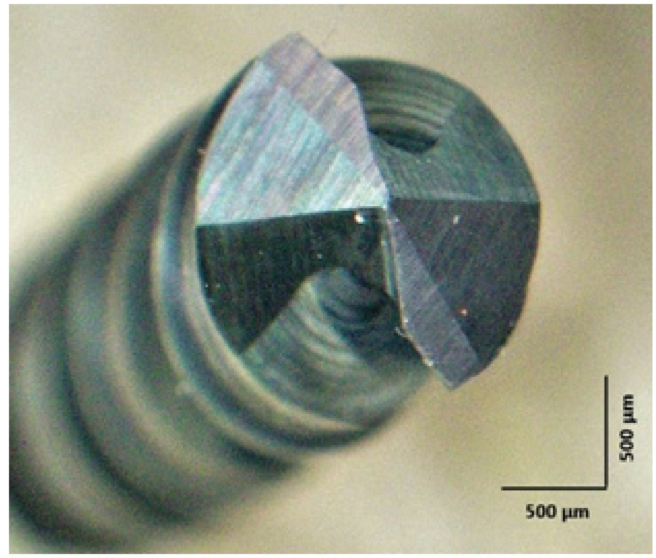


Figure 3. Image of fresh carbide drill bit showing flank surface.

of the fresh drill is shown in Fig. 3. The drilling experiments were carried out on BFW Gaurav BMV 35 TC 20 Vertical Machining Center (VMC) CNC machine held in a fixture as shown in Fig. 4. The tool life criterion was either 200µm average maximum flank wear or the delamination factor at the exit reaching 1.6 where the condition of the hole is deteriorated to the considerable extent. Delamination factor was evaluated using the equation:

$$F_d = \frac{D_{max}}{D_0} \quad (1)$$

Table 2. Mechanical properties of QCE composite

Quartz Cyanate ester Composite Properties	ASTM Standard	Average Tested Value	Coefficient of Variance (%)
Tensile Strength	D 3039	415 MPa	2.59
Tensile Modulus	D 3039	21 GPa	4.75
Poisson ratio	D 3039	0.18	1.79
Fibre volume fraction	D 3171	55%	-

2.2. Test Parameters and Procedure

Uncoated K20 grade carbide twist drill was selected for this study since this is a most common high wear resistant drill which produces less delamination[3-5]. Full factorial experiments with different levels of input parameters namely feed, speed and drill bit point angle were carried out. Delamination was the important factor considered in the present study. The tool having a point angle of 85^{0} induced less delamination. With the same drill, the other optimum parameters were derived for multi-objective characteristic attributes using genetic algorithm tool in Matlab R2018.

where, D_{max} is maximum diameter with delaminated zone and D_0 is nominal diameter of the drill. Further, the tensile property of Quartz composite specimen with open hole subjected to load testing was studied. These tensile testing experiments were performed on an Universal Testing Machine (UTM), Instron 1185 according to ASTM D5766 standard with a constant rate of 1mm/min.The rate of loading for testing of virgin quartz composite and quartz composite with drilled holes was maintained same. Five identical specimens for each set were tested at ambient temperature and the average value is reported.

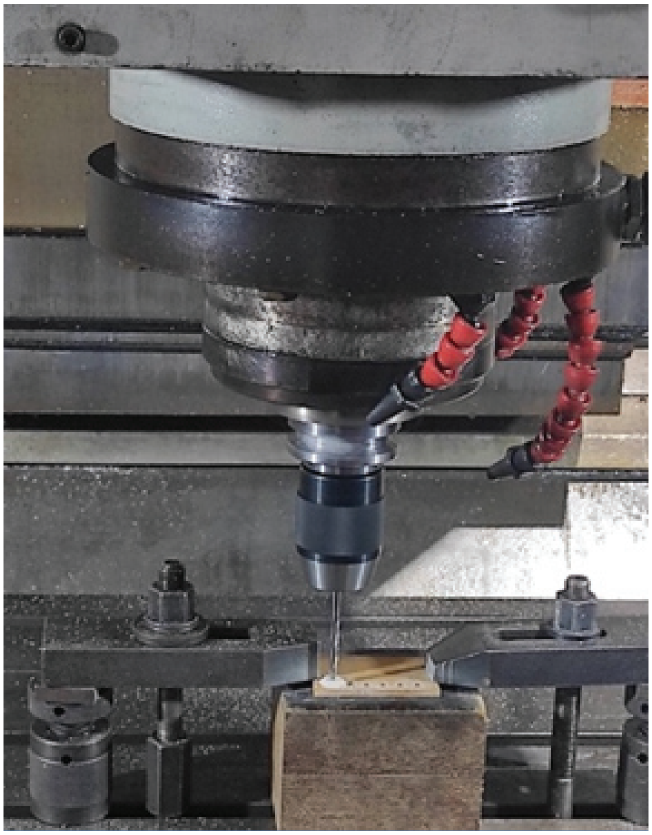


Figure 4. Drilling experiment on quartz composite held in fixture.

2.3. Measurement Methods

Drill flank wear quantification was done using Scanning Electron Microscope using SNE-4500 Plus and ImageJ software , once after every 25 number of holes are drilled. After the drilling experiments, SEM image at the flank portion of the drill was taken. This image was imported into ImageJ software and measured the average wear. During drilling, damage on the substrate is induced despite all the preventive considerations and these damages induced due to machining are measured in quantitative term after the test in the form of delamination factor. This delamination factor severity is high at exit based on the various previous studies. In this study also, delamination factor at exit was considered. In addition, other hole quality characteristics which get affected during the drilling process such as diameter, cylindricity and surface roughness were also measured. These were measured after every 25 number of holes. Delamination factor was evaluated with the hole surface image scanned using optical microscope "OGP Flash 200". The image was stored as bitmap format. Further the stored image was imported to "ImageJ" software for the evaluation of maximum diameter with the delaminated zone.

The delamination factor was evaluated using the Eqn. (1). Hole diameters and cylindricity were estimated using "DEA Global advantage Co-ordinate Measuring Machine (CMM)" with ruby probe of 1 mm diameter. Surface roughness (R_a) was measured with "Zeiss Surfcom-1900SD" surface measuring device at six different places on the hole surface along the direction of the drill and mean of six measured values was considered.

3. RESULTS AND DISCUSSIONS

3.1. Tool Wear Evolution

The tool drilling performance was quantified in terms of wear (in µm). The results of tool wear after drilling holes with the machining parameters of speed 500 rpm and feed 0.08 mm/rev are shown in Fig. 5.

The carbide twist drill was subjected to severe abrasion due to the nature of quartz fiber and the machined chips in powder form were produced during the drilling operation. Continuous impact of the tool cutting edge on the quartz fiber, and the abrasive nature of the quartz fiber produced flank wear. In woven composites drilling, severe abrasive wear was noticed on the flank face of the tool cutting edges[15]. No resin was observed on the surface of the tool. For the cutting conditions tested, the tool wear progressively evolved . As the cumulative duration of cutting process increases, material removed from the cutting edge on the drill bit in flank wear form increases. This wear lowers the cutting abilities of the tool and generates higher cutting forces leading to more delamination around the hole. Another important finding in this study is that the flank wear on the cutting edge is not uniform and progressive along the length. The wear is minimum near to the apex portion of

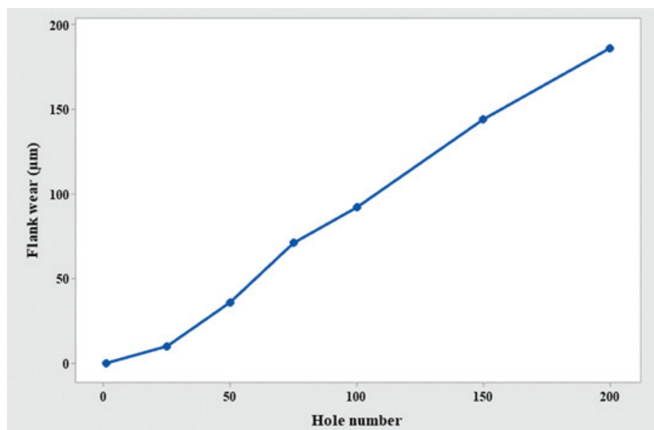


Figure 5. Effect of number of holes drilled on flank wear in tool.

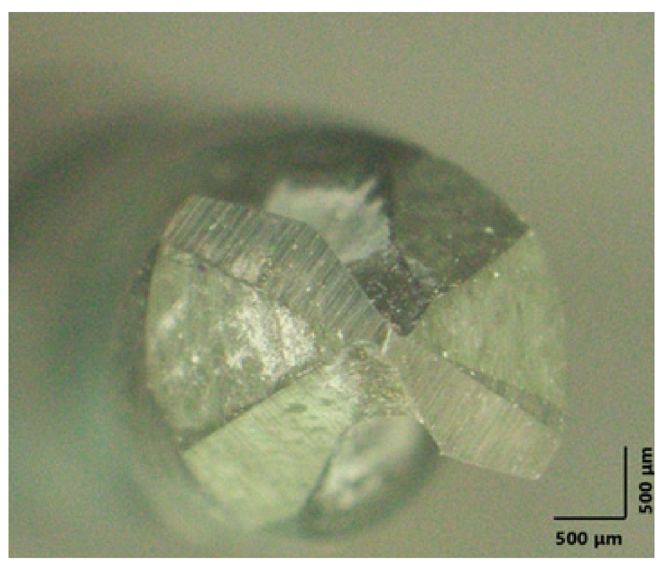


Figure 6. Image of carbide drill after drilling 200 holes showing flank wear.

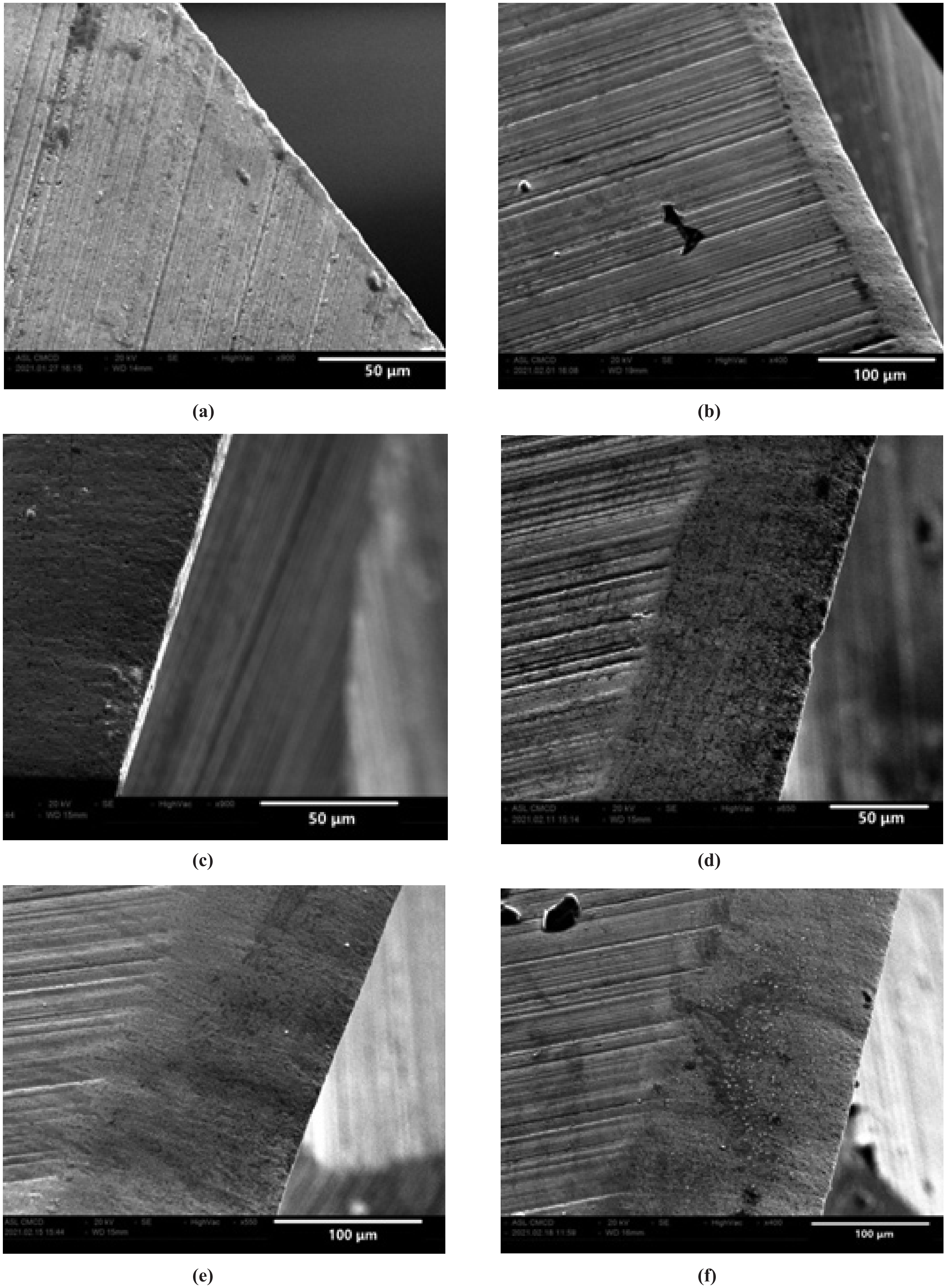


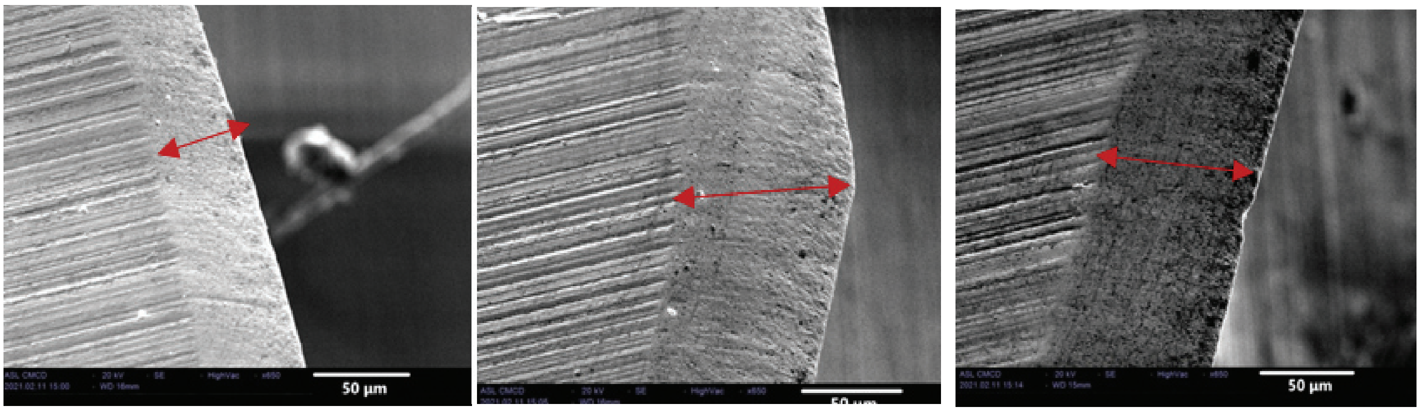
Figure 7. (a) – (f) Flank wear on tool after drilling 25, 50, 75, 100, 150 & 200 holes.

the drill bit and it gradually increases in the opposite direction away from the tool tip. The reason is due to large area of contact between the drill and workpiece at the region away from the tip than the apex part in combination with the thermal softening effect of tool, workpiece exhibiting higher wear in the tool[15]. Figure 6 shows the image of carbide drill after drilling 200 holes showing flank wear. Figure 7 shows the magnitude of flank wear on the tool after every 25 number of holes drilled up to 200 holes. Figure 8 shows the variation at three different points of the cutting edge for the drill bit that has drilled 100 holes in this quartz polymeric composite material.

3.2 Tribological Effects in Drilling Process

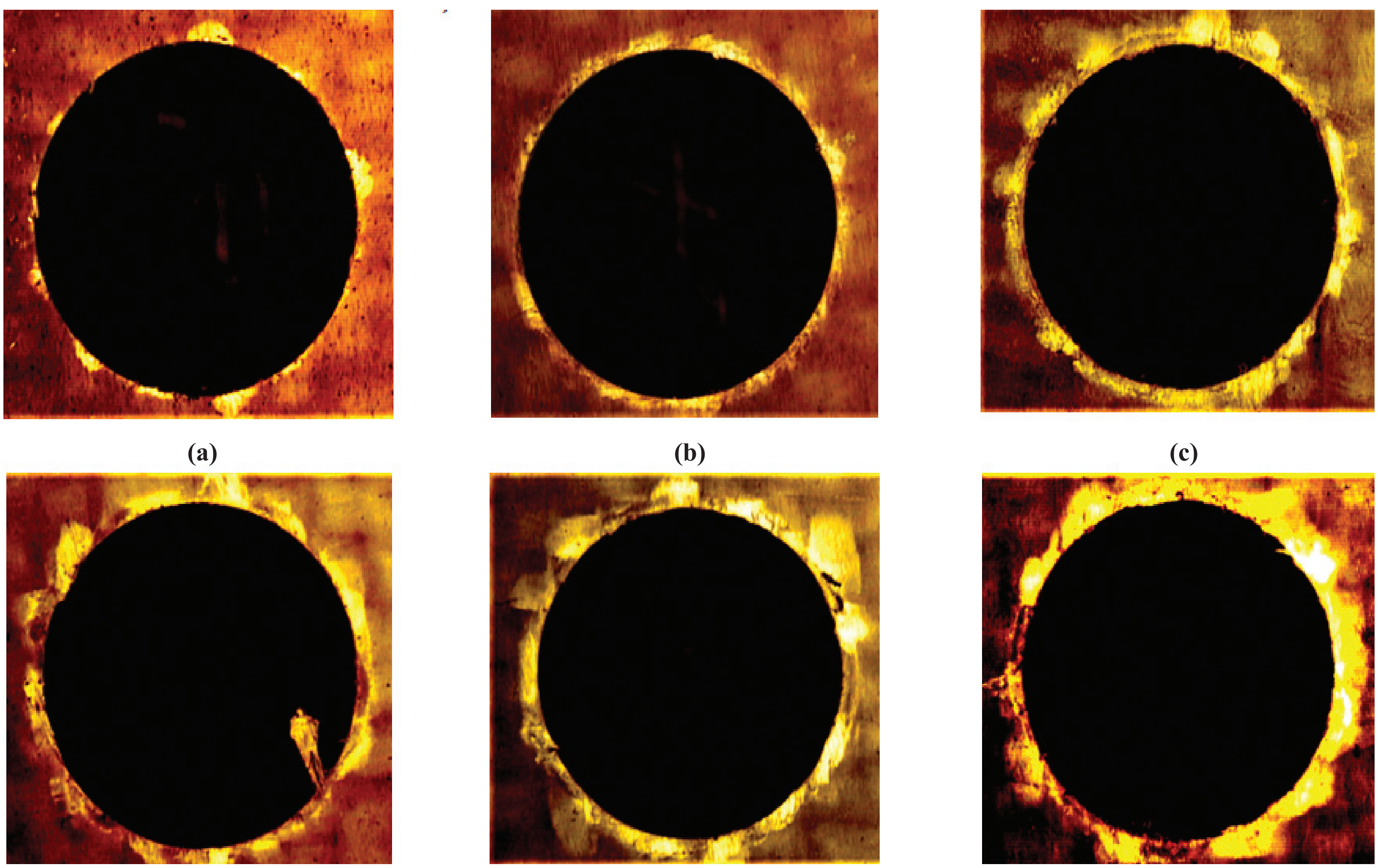
3.2.1 Effect of Wear on Delamination at Exit of Hole

Delamination at the exit of hole is the main criteria for tool replacement. Figure 9 shows the progression of delamination factor with respect to the number of holes drilled. Figure 10 shows the effect of number of drilled holes and tool wear on delamination factor. Delamination is primarily correlated to the thrust force .Initially, the induced damage is very less when the tool is fresh. After drilling 100 number of holes, rapid increase in delamination is observed till delamination factor of 1.4 after drilling 200 holes is reached.



(a) (b) (c)

Figure 8. (a) – (c) Flank wear variation on the cutting edge after drilling 100 holes.



(a) (b) (c)

(d) (e) (f)

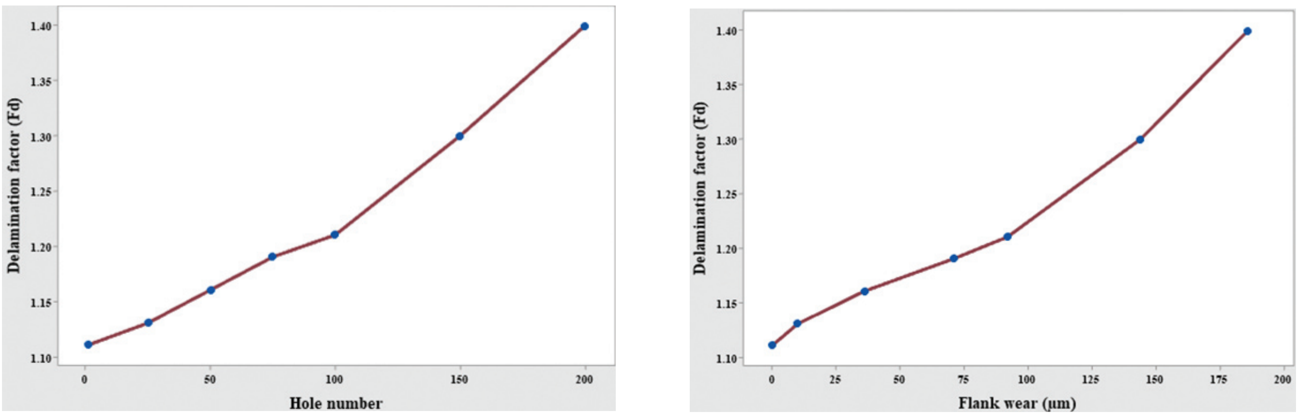
Figure 9. (a) – (f) Delamination progression on the 1st , 50th, 75th ,100th , 150th and 200th holes.

It is noticed that the level of delamination observed in the GFRP and CFRP composite after drilling similar number of holes is considerably low when compared to quartz composite[4,15]. This could be due to high abrasive nature of quartz fiber. The rate of increase in delamination is directly linked to the flank wear progression. Due to this progressive wear ,the cutting abilities of the tool continue to reduce resulting in uncut fibres around the hole surfaces. The tool cutting edge loses the sharpness and becomes blunt after initiation of the flank wear. Further the tool ploughs through the workpiece instead of cutting it after the wear is onset on the cutting edge. This phenomenon increases the thrust force and in addition to that there will be increase in matrix softening due to the relatively high temperature near to the exit of hole thereby increasing the delamination on the hole exit.

3.2.3 Effect of Tool Wear on the Diameter of Hole

Flank wear on the tool was observed to have substantial influence on the diameter of the drilled holes.

Figure 12 shows the variation of hole diameter with respect to the number of drilled holes and tool flank wear. At the beginning of the machining process , the drill bit is new and the cutting edge is not blunt. Due to this , the diameter of initial holes drilled was larger than the drill diameter. As the flank wear on the tool increases, there is reduction in the hole oversize magnitude due to progressive wear in the tool. Beyond the 75th hole only undersized holes were produced. Similar observations were reported in references 15,18-20 in which the hole diameter decreases because of the progressive flank wear in the tool.



(a) (b)

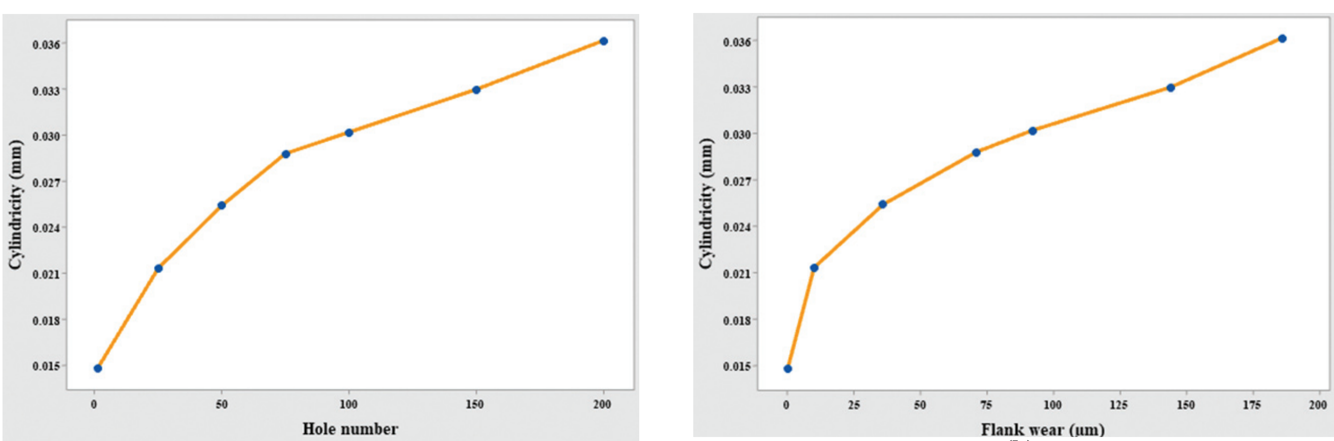
Figure 10. (a) & (b) Effect of number of holes and tool wear on the delamination factor.

3.2.2 Effect of Tool Wear on the Cylindricity of Hole

Cylindricity is defined by two concentric cylinders within which entire surface of the hole or the hole diameter along the length lies. It was found that the cylindricity of the hole increases when the flank wear on the tool increases. Figure 11 shows the effect of number of holes drilled with the tool and tool flank wear observed in the tool on the cylindricity of hole. It is apparent that the cylindricity of the hole deteriorated progressively with the increase in tool wear. As the wear progressed on the tool, the drill became blunt and ploughed the wall surfaces instead of cutting. This caused the form deviation causing cylindricity error.

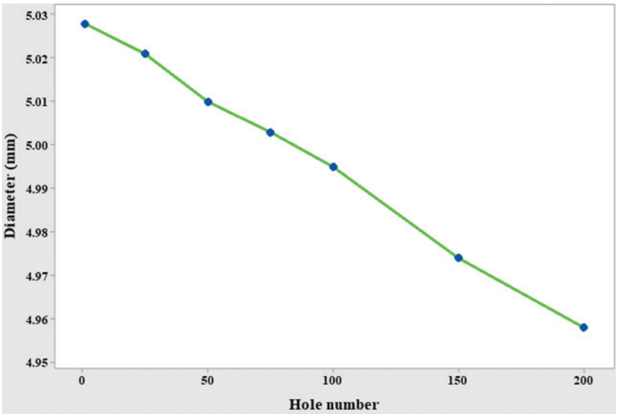
3.2.4. Effect of Wear on Surface Roughness of Hole

Figure 13 outlines the effect of number of drilled holes and tool wear on the surface roughness of hole. The roughness value of the drilled hole increases as number of drilled holes increases. These observations are similar to the results reported in[15,21]. As discussed earlier when the wear is progressed on the cutting edge of the drill, the drill becomes blunt and ploughed the wall surfaces instead of cutting. This flank wear progression resulted in generation of more thrust and cutting forces during drilling operation. The increased thrust and cutting forces induce micro - cracks between plies and more fiber pull - out, thereby affecting the finish of the hole.[15]

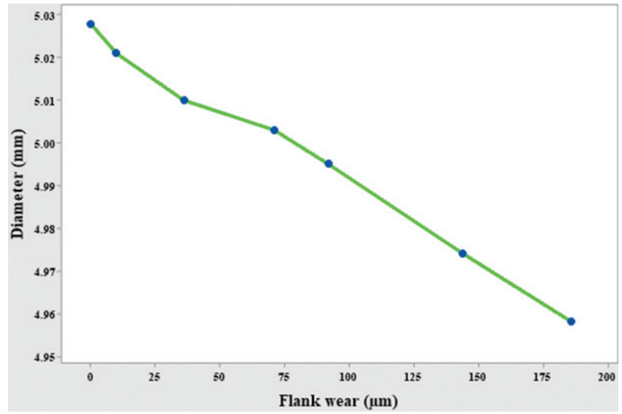


(a) (b)

Figure 11. (a) & (b) Effect of number of holes and tool wear on the cylindricity.

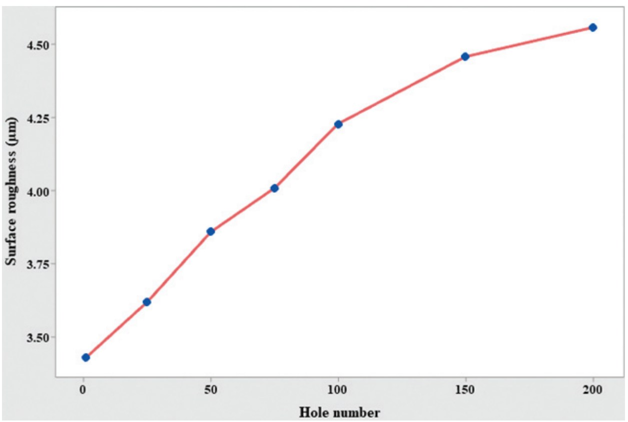


(a)

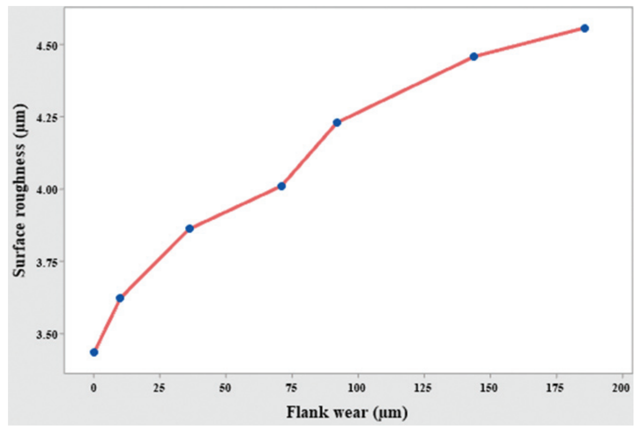


(b)

Figure 12. (a) & (b) Effect of number of holes and tool wear on the diameter.



(a)



(b)

Figure 13. (a) & (b) Effect of number of holes and tool wear on the surface roughness.

3.3 Effect of Delamination on Residual Tensile Strength

In this section, the effect of delamination induced during the drilling process of Quartz polymeric composite specimen on the tensile strength has been studied and reported.

The tensile property of Quartz composite specimen with open hole subjected to load testing was analysed. Hole on the specimens was drilled with varying flank wear on the drill bit. Varying flank wear on the drill was considered as a variable to introduce different level of delamination in the specimen. Specimens with dimensions 220 X 20 X 4 mm were cut from the large QFRP laminate. Holes of diameter 5 mm were made at the centre of specimen using new drill and drill bits with flank wear after drilling 75,150 and 200 holes respectively. Figure 14 shows the schematic image of specimen. Varying levels of delamination in the tensile specimen were noticed on the exit side of each hole due to the flank wear in the respective drill bits. Further the images of the drilled hole were taken and ascertained the same extent of delamination in the specimens as obtained in the tool wear studies before testing.

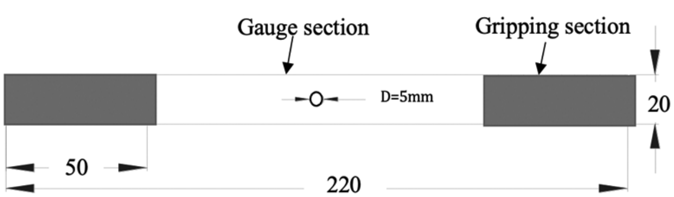


Figure 14. Schematic image of the open hole tensile specimen.

Detailed results of tensile testing of the specimens is given in Table 3. The value of modulus is not reported since the reduction is marginal or insignificant with respect to the virgin quartz composite. In that,QS denotes the quartz specimen, numerical subscript denotes the specimen set drilled with corresponding flank wear drill, F denotes the average failure

Table 3. Detailed experimental data of tensile testing

Specimen	F (kN)	σ_{mod} (MPa)	Coefficient of Variance (%)	Corresponding Delamination factor
QS_{new}	17.18	212	3.02	1.11
QS_{75}	16.70	207	2.63	1.19
QS_{150}	16.44	204	3.84	1.30
QS_{200}	14.65	181	4.28	1.40

load and σ_{mod} denotes the mean modified tensile strength from the actual specimen sizes.

From the results ,it was observed that there is a reduction in mean failure load in the composite with an increase in the number of drilled holes and delamination due to flank wear on the drill. The reduction is marginal or insignificant for the specimen drilled with flank wear after drilling 75 and 150 holes while compared to the specimen drilled using new drill. However tensile strength of the specimen with delamination drilled with flank wear after drilling 200 holes was about 14 % lower with respect to the specimen drilled using fresh drill .The testing data (load vs displacement) of one specimen from each set was considered and shown in Fig. 15. The reason for reduction in property could be due to relatively poor interlaminar property between fiber and resin in the composite[17]. During testing, initiation of damage started at the hole edges as these are the stress concentration points and the presence of delamination accentuates the stress concentration causing the delamination to aggravate further between the layers and finally specimen failed near the hole.

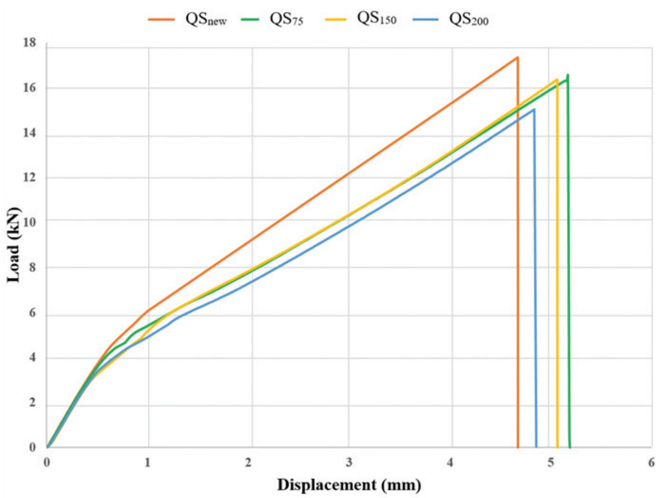


Figure 15. Load vs. displacement performance of specimens in tensile testing.

As the flank wear increases with the drilling time, the degradation on the exit side of the component increases which led to the layers being detached on the exit side of the hole. This demonstrated a decrease in the load transferring capacity between the layers. Further, the specimen with the highest delamination/degradation failed first and the same phenomenon was observed based on the test data. These results will help the designers and manufacturers to understand the effect of delamination, wear in tool on the tensile property of the material.In all, the delamination due to drilled hole affects the residual strength of the quartz cyanate ester composite considerably after drilling 200 holes.

3.4 Comparative Analysis

The results of tool wear after drilling 200 number of holes and tribological effects due to tool wear are analysed and compared in this section with the similar literature in the field of CFRP and GFRP materials. It is observed that the tool wear in drilling of holes in this Quartz polymeric composite is considerably higher when compared to the wear pattern in the CFRP and GFRP composites. The flank wear obtained in Quartz polymeric composite after drilling 200 holes was found to be 186 µm whereas in the case of GFRP and CFRP it was reported to be 92 µm and 138 µm for similar number of holes drilled.[4,15] This is possibly due to the high abrasive nature of the quartz fiber. The delamination factor obtained in Quartz polymeric composite after drilling 200 holes was found to be 1.4 whereas in the case of GFRP and CFRP it was reported to be 1.12 and 1.23 µm for similar number of holes drilled[4,8,15]. The increase in delamination is directly related to the flank wear progression. The diameter of the hole has considerable effect of the tool flank wear. Hole diameter variation in Quartz composite was found to be from 0.56 % oversized to 0.84 % undersized after drilling 200 holes.

Rawat, *et al.*[15] have observed a similar trend of lesser magnitude in CFRP. The surface roughness of hole increases with the number of drilled holes.The value obtained after drilling 200 holes in quartz composite was 4.56 µm.A similar trend with slightly lesser magnitude was observed for the CFRP by Rawat, *et al.*[15] The residual strength of quartz specimen with induced delamination due to drill wear is 14 % lower than than the property of specimen drilled with fresh drill whereas in CFRP, similar magnitude of delamination in the specimen produced residual property of 10 % less than the ideal specimen[17]. It is noted that these differences explain the importance of this study and this data will be useful for consideration during the drilling process of the quartz composite.

4. CONCLUSIONS

This study focused on drilling QFRP composite with carbide drill bit and analysed the effect of tool wear on various hole characteristics namely delamination, cylindricity , hole diameter surface roughness. Also the relation between number of drilled holes, delamination at the exit of the hole, tool wear, and residual tensile strength were investigated. The following are the main findings from the analysis.

- The main wear in drilling of quartz composite is flank wear and it is owing to abrasive behaviour of the quartz fibre. The tool wear in this Quartz polymeric composite is considerably higher when compared to wear pattern in CFRP and GFRP composites. The wear in Quartz composite was found to be 186 µm after drilling 200 number of holes.
- The occurrence of the exit delamination is primarily correlated to start of the flank wear and it increases with the number of holes drilled. The level of delamination occurred in quartz composite is considerably higher than the GFRP and CFRP composite after drilling similar number of holes. The delamination factor obtained in Quartz polymeric composite after drilling 200 holes was found to be 1.4
- The evolution of cylindricity and diameter had opposite trends with respect to flank wear. Cylindricity of the hole distorted progressively with increase in tool wear and the maximum value was found to be 0.0362 mm after drilling 200 holes. Diameter of the holes gradually decreased due to reduction in the drill diameter because of the flank wear and the value range is from 5.028 mm to

4.958 mm for drilling 200 holes. Surface roughness of the hole deteriorated due to increasing thrust force generated because of flank wear and the maximum value was found to be 4.56 µm after drilling 200 holes..

- Influence of delamination in the drilled hole affects the residual tensile strength of the quartz cyanate ester composite to a considerable extent. Residual tensile strength of the Quartz composite specimen with delamination drilled with the tool having flank wear after drilling 200 holes was about 14% lower with respect to the property of the specimens drilled using fresh drill.

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