Investigation of the Machinability Behavior of %40 Glass Fiber Reinforced Polyphthalamide Matrix Composite

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Abstract

Glass fiber reinforced polymer composites (GFRP) are widely employed in aerospace, military and aviation applications due to their superior properties. Glass fiber reinforced Polyphthalamide (PPA) matrix composite is one of them. Compared to other polymer matrix composites, PPA is used relatively high temperature applications. However, drilling of GFRP is highly difficult due to inhomogeneous composite structure. In addition, due to abrasiveness of the reinforcement material, tool forces increases. Therefore, it reduces tool life and result in poor surface quality. For this reason, while cutting GFRP composites, cutting parameters should be correctly determined. In this study, machinability behavior of %40 glass fiber reinforced Polyphthalamide matrix composite is investigated by using drilling process which is the most utilized manufacturing operation. In addition, Machinability behavior is assessed in terms of delamination defect. Delamination measurement is based on three different feed rates and cutting speeds with three different tool materials.

Key words: GFRP, PPA, Machinability, Delamination

1. Introduction

In our day, Glass fiber reinforced polymer (GFRP) materials are increasingly used in specific areas such as aviation, military and aerospace due to superior properties [1]. Especially, in aviation area, GFRP composites are widely employed. Drilling operation is perhaps one of the most widely utilized operation. To illustrate, while in a single engine aircraft over 10000 holes are made, in a shipping aircraft millions of holes are made [2].However, machining of GFRP composites are not easy when compared to other homogenous materials. Because of inhomogeneous nature of reinforced composites, material removal processes is difficult [3]. During machining of fiber reinforced plastics, some defects were encountered such as fiber pullout, burr, swelling, microcracking, splintering and delamination [4].

Delamination defect is considered as major problem caused by drilling operation because this defect reduces bearing capacity and lower resistance of fatigue loads. In addition, it reduces long term performance of fiber reinforced composites and adversely affect tolerances of drill diameter [5]. It was stated that in aviation industry, Sometimes part rejections caused by delamination defect accounts for nearly %60 of all part rejections in final assembly. There is two type of delamination in drilling fiber reinforced plastic composites. One of them occurs drill entrance known as peel up, the other occurs drill exit known as push out [6].

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Delamination damage is studied by various researchers [7-9] and concluded that delamination associated with drilling forces, drill tool geometry and machining parameters.

Bosco, Palanikumar, Prasad, Et al [7] carried out a study on delamination of GFRP-armor steel sandwich composites with different machining parameters and concluded that increase in feed rate causes more delamination damage which is attributed to rising of thrust force. Moreover, increase in drill diameter result in higher delamination damage, which is attributed to high contact area between drill tool and machined part.

Davim, Pedro and Antonio [8] studied delamination of GFRP composites under different cutting conditions by using “Brad & Spur”(K10) cemented carbide drill (R20719680 according to DIN 6539) and concluded that as cutting speed and feed rate increases, delamination damage rises. However, the feed rate has the highest influence on delamination.

E. Kılıckap [9] carried out a study on delamination of GFRP composites with different cutting parameters using different drill bit angles of 135° and 118°, stated that rise in feed rate and cutting speed increases, drilled hole is adversely effected by delamination damage. Moreover, delamination damage mainly arises from feed rate and 135° drill result in more delamination at entrance of hole than 118°.

Polyphthalamide (PPA, High Performance Polyamide) is member of polyamide (nylon) family, which is a thermoplastic synthetic resin. This material resistant to relatively high temperatures. PPA materials found in area of automotive applications as the housing for high temperature electrical connectors and a wide range of other uses. In addition, it may be employed in cutlery applications[10]

In this study, high speed steel (HSS), Titanium Nitride coated HSS and uncoated carbide twist drills are employed. Experiments carried out under 15, 20, 25 m/min. cutting velocities and 0.05, 0.1, 0.15 mm/rev. feed rates. The main objective of this study is investigate effect of delamination on %40 fiber glass reinforced Polyphthalamide under different cutting conditions and diverse drill materials.

2. Materials and Method

2.1. Manufacturing of Material

%40 glass fiber reinforced Polyphtalamide (PPA) was manufactured by injection molding method. Fibers with short length were used. Parts thickness was adjusted to 4 mm. Additional information about Polyphtalamide is presented in Table 1.

Table 1. The properties of composite material

Properties	Standard	PPA+40%GFR
Density , g/cm^3	ISO 1183	1.4
Water Absorption, %	ISO 62	1.25
Tensile Strength at Break, MPa	ISO 527	215
Tensile Modulus, MPa	ISO 527	12500
Elongation at Break, %	ISO 527	2.2
Flexural Strength, MPa	ISO 178	300
Flexural Modulus, MPa	ISO 178	11000
Ball Indentation Hardness , MPa	ISO 2039	290

2.2. Drilling Operation

Drilling operation was executed in CNC machine. Haas TM1 with 4000 maximum RPM and 5,6 Kw power was used as CNC machine. This CNC machine is shown in Figure 1. In drilling operations, cutting fluids was not employed. All drilling test conditions were summarized, and are given in Table 2.

Table 2. The experimental parameters and their values

Parameters	Values	Units
Drill type	HSS, HSS+TiN, Carbide	-
Feed rate	0.05, 0.10, 0.15	(mm/rev)
Cutting velocity	15, 20, 25	(m/min)

Figure 1. Experimental set-up

2.3. Delamination Factors

Delamination damage was measured by proportion of maximum diameter to drill diameter. Delamination Factor was presented in formula shown above.

$$F_{Del} = \frac{D_{\max}}{D_{Drill}} \quad (1)$$

In this work, delamination was measured by Nikon Eclipse L150 Microscope. Zoom setting was adjusted 20 x and resolution is 1 mm.

Figure 2. Optical microscope

3. Results and Discussions

3.1. Effect of feed rate on delamination factor

Figure 3a-c show the effect of feed rate on delamination factor in drilling of glass fiber reinforced polymers. The figures show that the delamination factor increases with the increase of feed rate in drilling of GFRP composites. Observing Figure 3 (drill carbide), it can be noticed that delamination is most affected by feed rate and best results are obtained at lower feed rates. Rajamurugan et al. [11] was under the opinion that the feed rate was determined to be the most significant parameter affecting the delamination factor and cutting forces, while increasing the feed rate increases cutting force significantly. Khashaba, Seif, and Elhamid [12] presented a story which describe the influence of drilling parameters (cutting speed and feed rate) on the required cutting forces, torques and delamination. Clear effect of cutting speed on the delamination size was not observed, while the delamination size decreased with decreasing the feed rate.

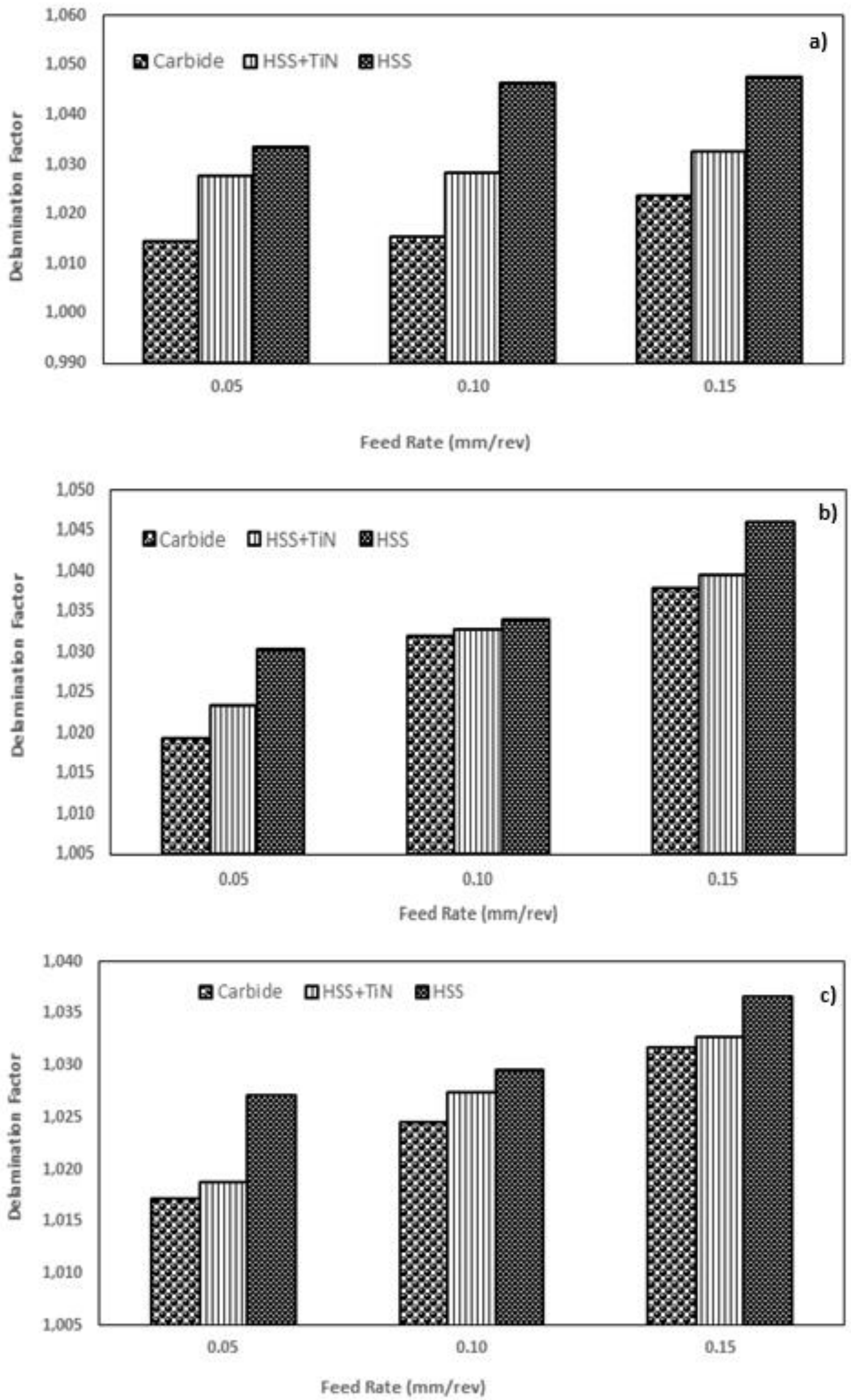

Figure 3. Effect of feed rate on delamination factor cutting speed: a) 15 b) 20 c) 25 m/min

3.2. Effect of cutting velocity on delamination factor

Figure 4a-c show the influence of cutting speed on delamination factor while drilling glass fiber reinforced composite using the three different tool materials. The delamination factor decreased with an increase in the cutting velocity for the three cutting tools, as seen in Figure 4a-c. The reason is, the increase of cutting speed increase the temperature produced in drilling of composites, which softens the matrix material and shearing, in turn the delamination is reduced [11]. The figure indicates almost the same trend as discussed earlier [13] [14]. Mohan, Kulkarni, and Ramachandra [14] have performed and analyzed delamination in drilling process of GFRP composite material, in order to understand the effects of process parameters on the delamination. Rao, Rudramoorthy, Srinivas, and Rao [13] presented a comprehensive study of delamination in use of various drill types, three different feed rate and spindle speeds. In these studies, cutting velocity was found to be the second factor affecting the delamination factor of composite material.

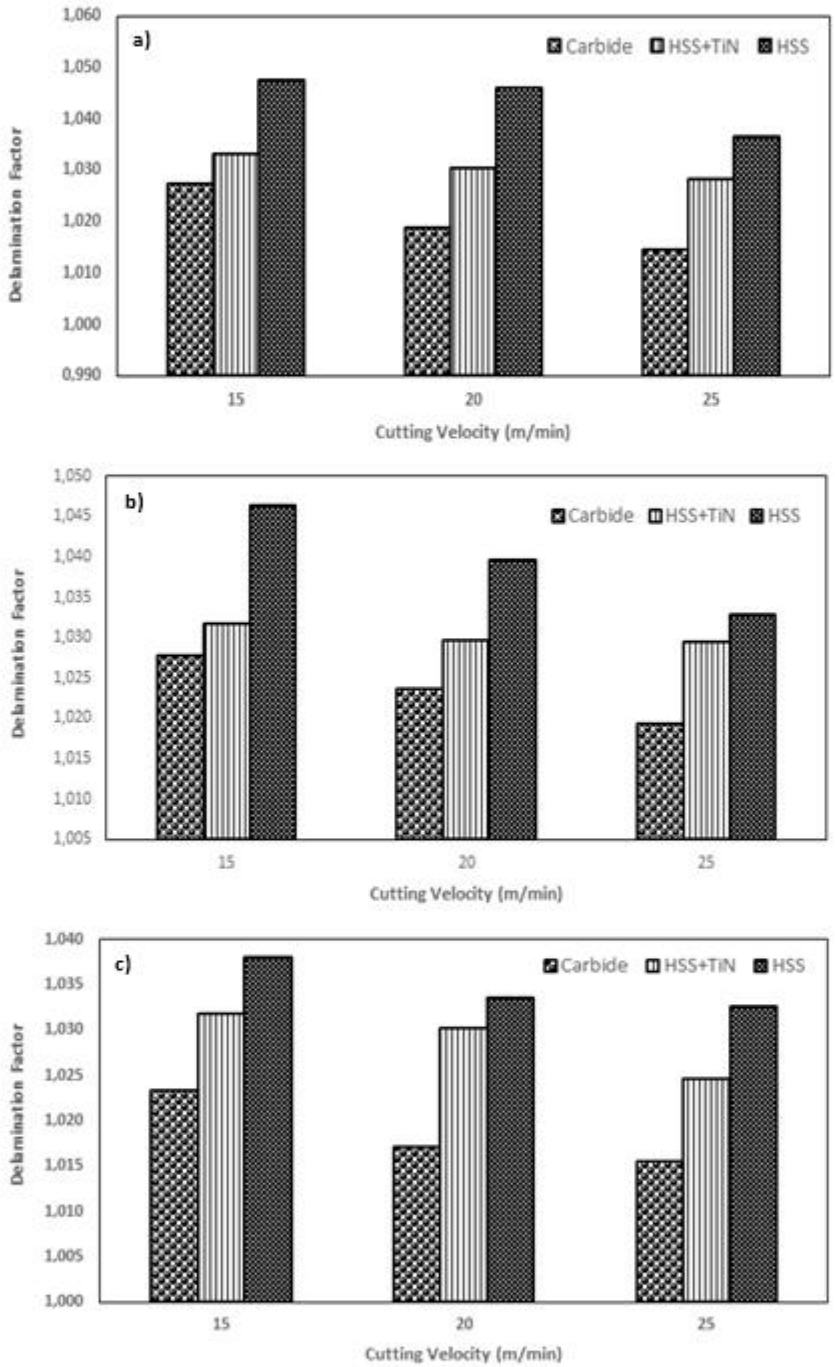

Figure 4. Effect of cutting velocityon delamination factor feed rate: a) 15 b) 20 c) 25 m/min

Conclusions

In this study, effects of drilling parameters and different cutting tools on %40 fiber glass reinforced Polyphthalamide matrix material is investigated under dry cutting conditions in terms of delamination damage. The results can be drawn as follows:

1) The experimental results show that the delamination factor increases with increases in the feed rate.
2) The delamination factor decreases with increases in the cutting velocity.
3) The best delamination results are given by Carbide drill.
4) Feed rate is the factor, which has greater influence on delamination factor, followed by cutting speed.

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