Chapter 4
Effects of Drill Points While Drilling at High Spindle Speed

4.1 Introduction

High speed machining is now recognized as one of the key manufacturing technologies for higher productivity and throughput [2, 10, 14]. It is well known that the most effective way of achieving good quality holes while drilling fibre reinforced plastics is by reducing the thrust and torque [3–11, 14, 15, 17, 19]. High spindle speed reduces the cutting force requirements. So, drilling experiments were conducted with drill geometries, namely standard twist drill, Zhirov-point drill, and multifacet drill, using wide range of spindle speed, and feed rate to analyse thrust force, delamination and surface roughness.

4.2 Experimental Setup

Experiments were conducted using Acumac high-speed spindle (5 kW) mounted on a vertical CNC machine. Figure 4.1 shows the experimental set-up. Due to the high abrasive nature of fiber-reinforced materials, micro-grain carbide (Ø 10 mm-K10) was used in this investigation. Drilling of laminates was carried out for the following conditions using full factorial design. Cutting speed values were selected between 15.7 to 62.8 m/min and 440 to 600 m/min to study the effect of normal and high spindle speed respectively on drill geometries, surface finish and delamination.

$$\text{Spindle speed: } 500,\ 1{,}000,\ 1{,}500,\ 2{,}000 \text{ and } 14{,}000,\ 16{,}500,\ 19{,}000\,\text{rpm}$$

$$\text{Feed rate: } 0.02,\ 0.03,\ 0.04,\ 0.05\,\text{mm/rev}$$

V. Krishnaraj et al., *Drilling of Polymer-Matrix Composites*,
SpringerBriefs in Manufacturing and Surface Engineering,
DOI: 10.1007/978-3-642-38345-8_4,

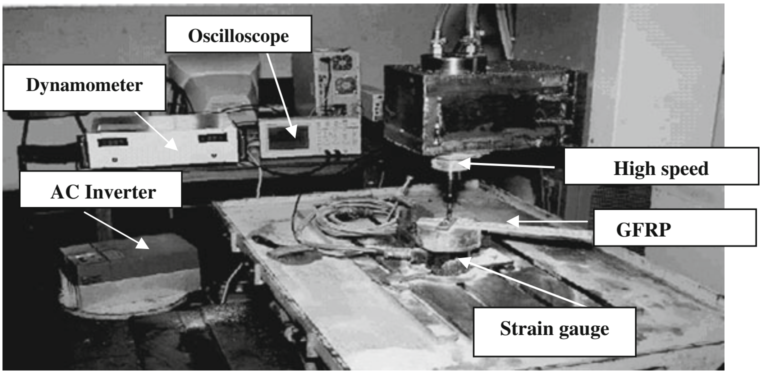

Fig. 4.1 High speed spindle experimental setup

4.3 Influence of Cutting Parameters on Thrust Force

Drilling parameters cause change in cutting forces, which influence the quality of the holes in terms of surface finish, circularity, delamination, fiber pull out, matrix cratering, etc. [3–5, 7–9, 11, 15, 19]. From the experiments it was found that high spindle speed decreases the thrust force [12, 14]. As seen in Fig. 4.2 Zhirov point drill experiences lower thrust force for the same operating conditions when compared to other geometries. This is because in the Zhirov drill the chisel edge has been replaced by cutting edges, therefore extrusion action is replaced by cutting action [1]. The Zhirov-point drill also produces more dimensionally accurate holes because of less deflection in the spindle through a reduction of the thrust force. At lower feed rate (0.02 mm/rev) Zhirov point drill and multifacet generated more or less same thrust force (around 20 N). This value is very less when compared to

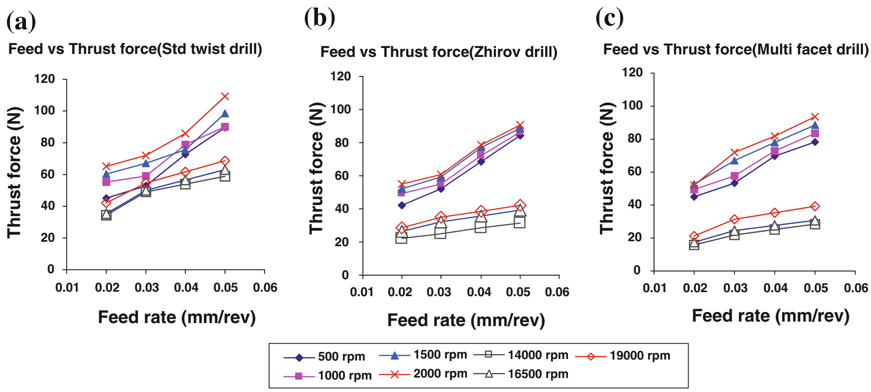

Fig. 4.2 Effect of feed rate and spindle speed on thrust force **a** Standard twist drill **b** Zhirov-point drill **c** Multifacet drill

drilling at normal spindle speed which is around 50 N. For all the drill geometries at high spindle speed the torque values are between 0.1 and 0.2 N-m. Not much variation in the torque values is recorded within the range examined.

4.4 Influence of Cutting Parameters on Delamination Factor

Delamination near the exit side is introduced as the tool acts like a punch, separating the thin uncut layer from the remainder of the laminate. The entry hole produced was neat for all the geometries. However, the fiber pull out at exit was more in the case of twist drill and Zhirov point drill. Multifacet drill produced clean cut holes at the exit side of the laminate. This is because the cutting mechanism of a multifacet at the last ply is like a trepanning with knife-edge. Therefore, exit hole was neat and fuzzy free. A button like chip was ejected at the exit side of the laminate while drilling using multifacet drill. The delamination was evaluated in terms of delamination factor. The delamination factor is the ratio of maximum diameter (Dmax) of the damaged zone to the actual hole diameter (D).

Figure 4.3 shows the relationship between the delamination factor and drilling parameters. It is concluded that delamination factor increases with feed rate and spindle speed [10]. The effect of high spindle speed is significant on standard twist drill, whereas the effect of high spindle speed on delamination factor during drilling using Zhirov point and multifacet is less significant.

Figure 4.4 shows the hole machined in the drilling process for standard twist drill, Zhirov point, and multifacet drill respectively. Multifacet drill presents a better performance than other drill geometries. The special characteristic of the drill is the extreme sickle-form design of the cutting edges. This pre-stresses the fibers in the direction of pull and separates them in the direction of thrust. This results in a clean cut with a smooth surface. The delamination is less compared to other drill geometries.

4.5 Influence of Cutting Parameters on Surface Roughness

After the drilling test, the quality of hole at entry and exit has been examined. The surface roughness (Ra) was evaluated as per ISO 4287/1 [4]. For each test 3 measurements over drilling surfaces were made. Figure 4.5 shows the effect of drill geometry on surface finish. The value of surface roughness increases with the feed rate, and decreases with the cutting speed. Zhirov drill produced better surface finish (4–5 μm) at lower feed rate. The outer most lip produced thin chip which improved the finish of the hole. Multifacet drill also generated better surface finish at lower feed rate when compared to standard twist drill. The effect of spindle speed on surface finish is less compared to feed rate for Zhirov point and

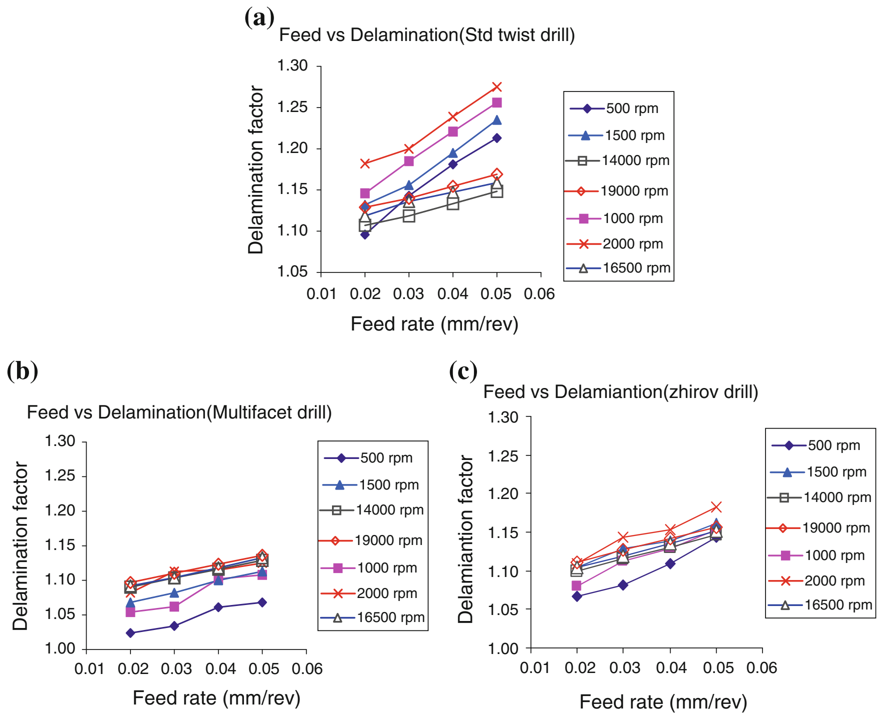

Fig. 4.3 Effect of feed rate and spindle speed on delamination: **a** Standard twist drill; **b** Zhirov point drill; **c** Multifacet drill

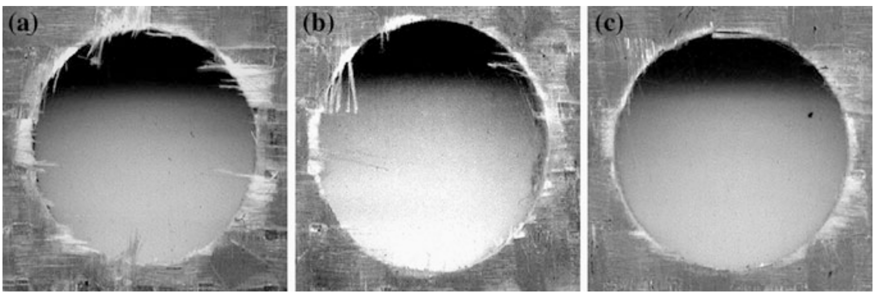

Fig. 4.4 Effect of drill points on delamination (φ 10 mm hole: magnification: 3X) **a** Standard twist drill; **b** Zhirov point drill; **c** Multifacet drill

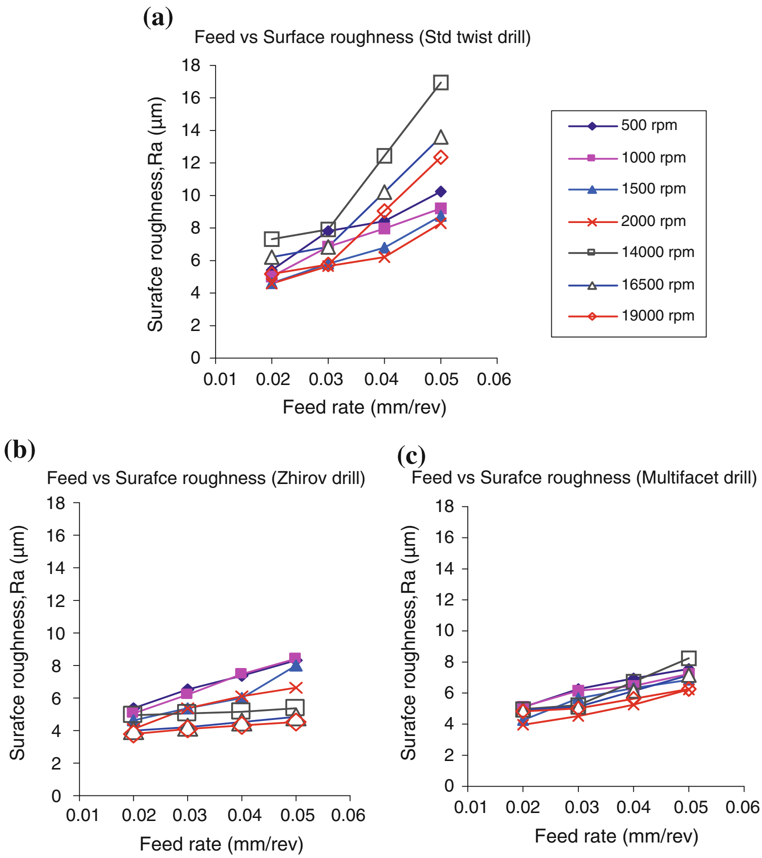

Fig. 4.5 Effect of feed rate and spindle speed on surface roughness **a** Standard twist drill; **b** Zhirov point drill; **c** Multifacet drill

multifacet drill [6, 8, 17]. With high speed drilling a considerable reduction in thrust force can be seen; however the drilled hole exhibits higher order surface roughness and only a marginal difference in delamination factor (Possibly due to higher order drilling temperature). It is seen that for standard twist drill and mulitifacet drill beyond 0.03 mm/rev steeper rise in surface roughness.

4.6 Influence of the Cutting Parameter on Hole Quality

The diameter of the holes drilled by carbide drill (φ 10 mm) is measured with the Co-ordinate Measuring Machine (CMM-MITUTOYA) using φ 3 mm Ruby crystal probe. The dimensions of the holes are measured at the middle of the laminate thickness.

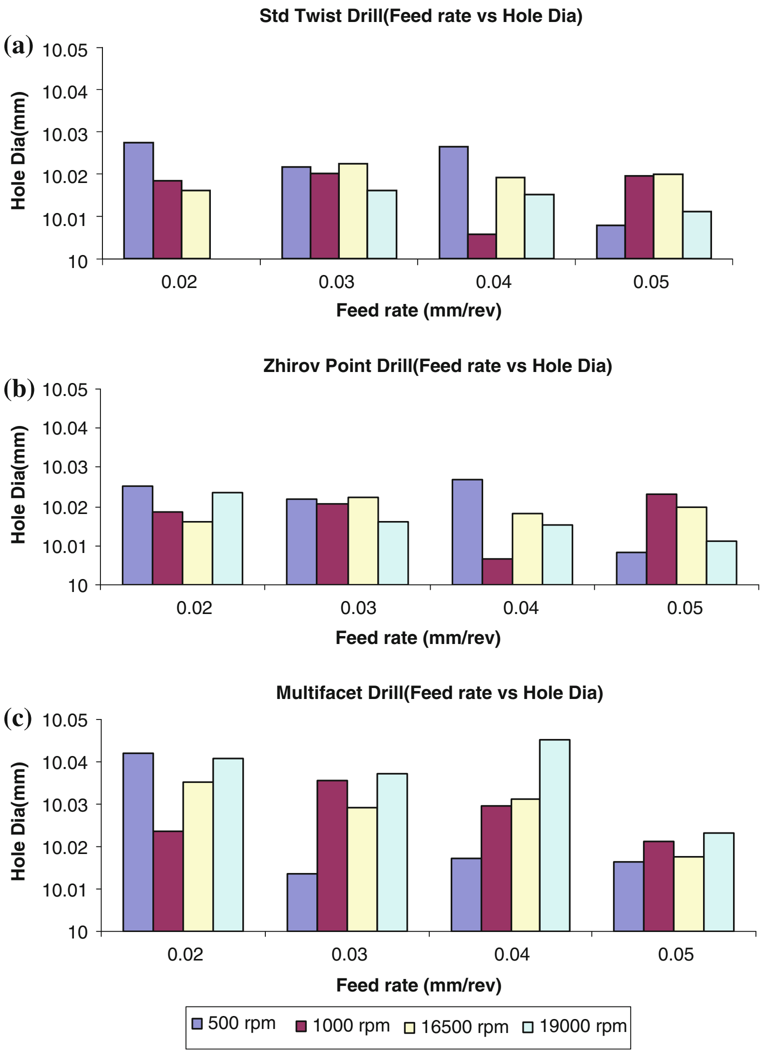

Fig. 4.6 Hole diameter for **a** Standard twist drill **b** Zhirov point drill **c** Multifacet drill

Lower order thrust force, i.e. better cutting action of carbides, higher order material stability, lower order wear, possible lower order cutting temperature on workpiece, all will induce less stress and consequently less relaxing, so mostly over sized holes are seen (Fig. 4.6). Better condition over circularity error unlike the case of HSS. Better circularity values are found when holes are drilled using Zhirov point and multifacet drills (Fig. 4.7). 6–8 μm circularity error in drilling of composite can be treated as negligible.

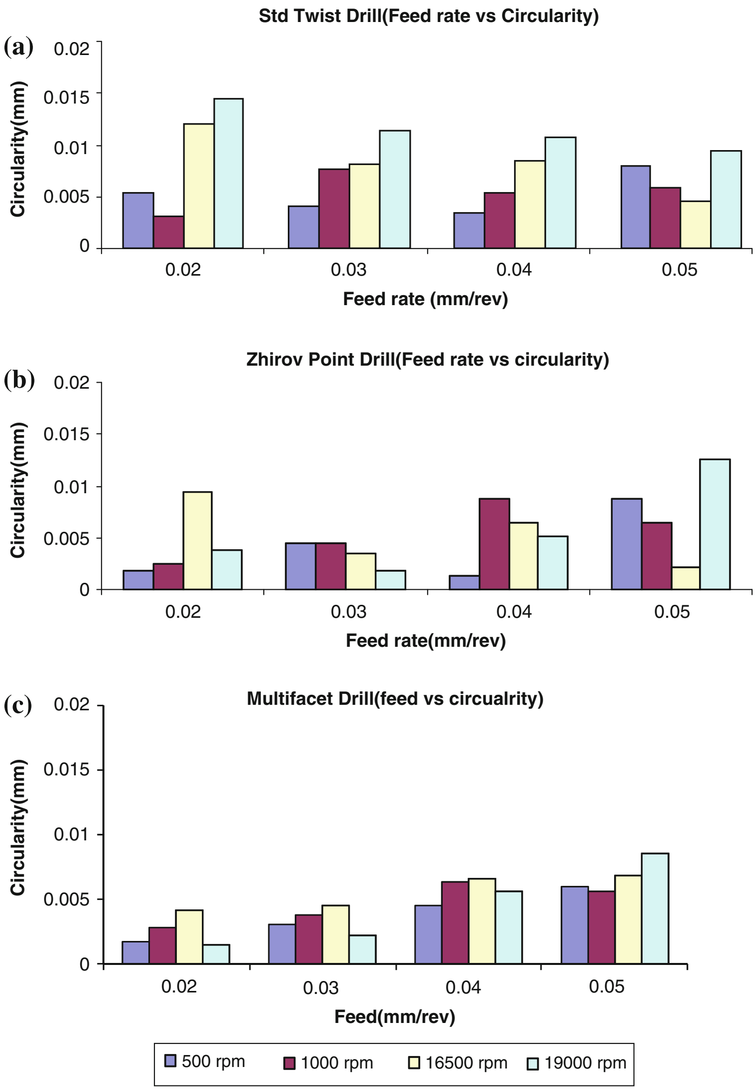

Fig. 4.7 Circularity for **a** Standard twist drill **b** Zhirov point drill **c** Multifacet drill

4.7 Tool Wear Study

In high speed drilling, the major reason for tool wear is the thermal softening of the tool material, and the abrasive nature of the chip. Because of tool wear, thrust force will increase [13, 16, 18, 20]. So, tool life can be predicted by measuring the thrust force with respect to the number of holes. In this tool wear study, carbide drill

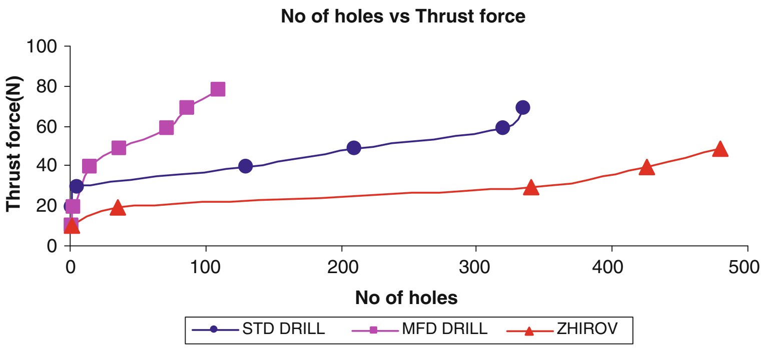

Fig. 4.8 Number of hole versus thrust force for carbide drill geometries

geometries are used at 16,500 rpm (518 m/min) spindle speed and 0.02 mm/rev (330 mm/min) to study the extent of tool geometry at high spindle speeds.

In standard twist drill, the thrust force at the beginning of the cut increased sharply because of initial wear (Figs. 4.8 and 4.9a). Initial wear was up to 10th hole and after that gradual wear took place. Beyond 325 holes the thrust force started increasing steeply. This could be because of rapid wear. Thrust force at the end of 325th hole is 60 N. In Zhirov point drill (Figs. 4.8 and 4.9b), thrust force increased sharply because of initial wear. Initial wear was up to 25 holes and after that gradual wear took place. Beyond 340 holes thrust force started increasing steeply. Thrust force at the end of 340th hole is 30 N. In multifacet drill (Figs. 4.8 and 4.9c) within 10 holes thrust force increased rapidly from 10 N to 40 N after that gradual wear took place. Thrust force at the end of 60th hole is 60 N. After that the force raised steeply because of rapid wear.

Figure 4.10 shows the worn out regions of the drill points. When the tool wear was observed using Tool maker’s microscope, uniform wear on the flank region was observed in standard twist drill. After the end of its tool life, a wear land of 0.15 mm was measured on its flank with minute chipping along the lips. In the Zhirov point drill, cutting edge near the groove (Cutting edges ground to replace chisel edge) may worn out rapidly that could have led to rapid increase in thrust force. Flank wear at the extreme end was 0.1 mm. Higher tool wear in multifacet drill at the end of cutting edge was observed, because of its sharp edge at the periphery. In all the drills along the cutting edges minute chipping was observed because of cutting hard glass fibers. Zhirov point could drill with lower thrust force and more number of holes, whereas multifacet drill cuts the hole without any fibre pull out.

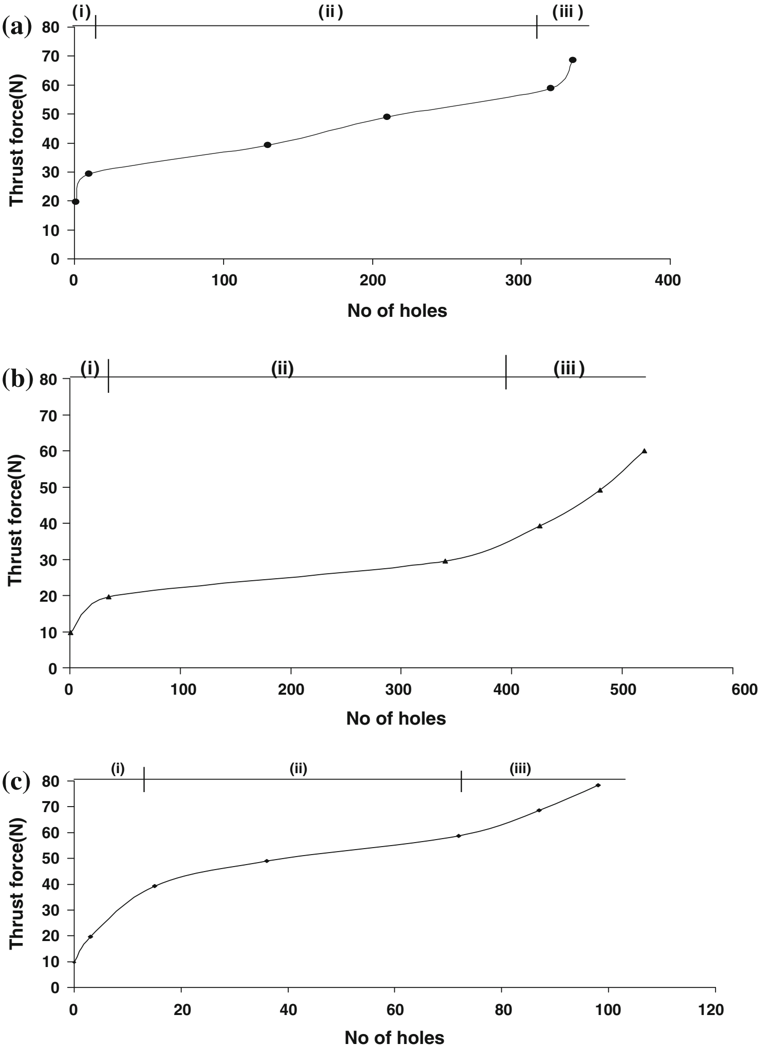

Fig. 4.9 Thrust force versus No of holes (at 16,500 rpm and 0.02 mm/rev). **a** Standard twist drill, **b** Zhirov point drill, **c** Multifacet drill. (*i*)-Intial wear (*ii*)-Normal wear (*iii*)-Rapid wear

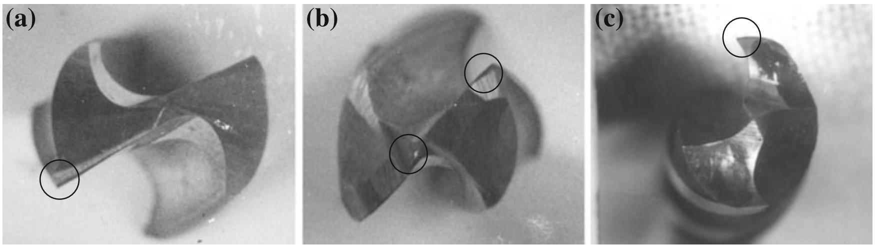

Fig. 4.10 Worn out regions of **a** Twist drill **b** Zhirov point drill **c** Multifacet drill

4.8 Summary

In drilling of composites, high spindle speed and low feed rate improve the machinability aspects within the range examined. The cutting force is less (thrust force and torque both recorded a very low value). The special geometry improves the quality of the hole further, especially Zhirov point drill [8]. From the experimental results (Ref. Fig. 4.8), Standard twist drill and Zhirov point drill were found suitable for producing more number of holes at high spindle speed with low feed rate.

Multifacet drill cuts the hole better than other drill geometries. The special characteristic of the drill is the extreme sickle-form design of the cutting edges. This pre-stresses the fibers in the direction of pull and separates them in the direction of thrust. This results in a clean cut with a smooth surface. The delamination is less compared to other drill geometries.

Zhirov drill produces better surface finish (3–5 μm) at lower feed rate. The outer most lip produces thin chips which improve the finish of the hole. Multifacet drill also generates better surface finish at lower feed rate when compared to standard twist drill. With high speed drilling a considerable reduction in thrust force can be seen, however the drilled hole exhibits higher order surface roughness and only a marginal difference in delamination factor possibly due to higher order drilling temperature.

In standard twist drill, thrust force at the beginning of the cut increases sharply because of initial wear. Initial wear is up to 10 holes and after that gradual wear has takes place. Thrust force at the end of 325th hole is around 60 N. In Zhirov point drill, thrust force increases sharply because of initial wear. Initial wear is up to 25 holes and after that gradual wear has taken place. Thrust force at the end of 340th hole is 30 N. In multifacet drill within 10 holes thrust force increases rapidly from 10 N to 40 N after that gradual wear takes place. Thrust force at the end of 60th hole is 60 N. After that the force rises steeply because of rapid wear.

When the tool wear is observed using Tool maker's microscope, uniform wear on the flank region is observed in standard twist drill. After the end of its tool life a wear land of 0.15 mm is measured on its flank. In the Zhirov point drill, cutting edge near the groove may be worn out rapidly that could have led to rapid increase in thrust force. Flank wear at the extreme end is 0.1 mm. Higher tool wear in multifacet drill at the end of cutting edge is observed, because of its sharp edge at the periphery. In all the drills along the cutting edges minute chipping is observed because of cutting hard glass fibers. From this high speed drilling study, it is concluded that Zhirov point could be used to drill holes with lower thrust force. The life of the Zhirov point is also higher.

References

1. Arshinov V, Alekseev G (1976) Metal cutting theory and cutting tool design. MIR Publishers, Moscow
2. Campos Rubio J, Abrao AM, Faria PE, Esteves Correia A, Davim JP (2008) Effects of high speed in the drilling of GFRP: evaluation of the delamination factor. Int J Mach Tools Manuf 48:715–720
3. Chen WC (1997) Some experimental investigations in the drilling of carbon fibre reinforced composite laminations. Int J Mach Tools Manuf 37(8):1097–1108
4. Davim JP, Reis P (2003) Study of delamination in drilling carbon fiber-reinforced plastics (CFRP) using design experiments. Compos Struct 59:481–487
5. El-Sonbaty I, Khashaba UA, Machaly T (2004) Factors affecting the machinability of GFR/epoxy composites. Compos Struct 63:313–327
6. Enemuoh UE, EI Gizawy SA, Chukwujekwu Okafor A (2001) An approach for development of damage free drilling of carbon fiber reinforced thermosets. Int J Mach Tools Manuf 41:1795–1814
7. Ho-Cheng H, Dharan CKH (1990) Delamination during drilling of composite laminates. J Eng Ind ASME 112:236–239
8. Hocheng H, Tsao CC (2005) The path towards delamination-free drilling of composite materials. J Mater Process Technol 167:251–264
9. Ho-Cheng H, Pwu HY, Yao KC (1993) Machinability of some fiber reinforced thermoset and thermoplastics in drilling. Mater Manuf Proc 8(6):653–682
10. Karnik SR, Gaitonde VN, Rubio JC, Correia AE, Abrao AM, Davim JP (2008) Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model. Mater Des 29:1768–1776
11. Khashaba UA (2004) Delamination in drilling GFR-thermoset composites. Compos Struct 63:313–327
12. Krishnaraj V, Prabukarthi A, Arun R, Elanghovan N, Senthilkumar M, Zitoune R, Davim JP (2012) Optimisation of machining parameters at high speed drilling of Carbon Fibre Reinforced Plastic (CFRP) laminates. Composite Part B 43(4):1791–1799
13. Kim D, Ramulu M (2004) Drilling process optimization for graphite/bismaleimide–titanium alloy stacks. Compos Struct 63:101–114
14. Lin SC, Chen IK (1996) Drilling of carbon fiber-reinforced composite material at high speed. J Compos Mater 194:156–162
15. Mohan NS, Kulkarni SN, Ramachandra A (2007) Delamination analysis in drilling process of glass fiber reinforced plastic (GFRP) composite materials. J Mater Proc Technol 186:265–271
16. Shaw MC (2003) The size effect in metal cutting. Sadhana 28(5):875–896
17. Velayudham A, Krishnamurthy R (2007) Effect of point geometry and their influence on thrust and delamination in drilling of polymeric composites. J Mater Process Technol 185:204–209
18. Velayudham A, Krishnamurthy R, Soundarapandian T (2005) Evaluation of drilling characteristics of high volume fraction fibre glass reinforced polymeric composite. Int J Mach Tools Manuf 45:399–406
19. Wong TL, Wu SM, Groy GM (1982) An analysis of delamination in drilling of composite materials. In: Proceedings of the 14th SAMPE technology conference, Atlanta, (GA), USA, pp 471–483
20. Zitoune R, Krishnaraj V, Collombet F (2010) Study of drilling of composite material and aluminium stack. Compos Struct 92:1246–1255