ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) composite materials have been replacing the conventional materials such as steel, cast iron and aluminium alloys due to their specific properties such as high specific strength and specific modulus. CFRP materials have proven to be adaptable engineering materials in many applications including aerospace, automotive, construction, marine and sports. The increasing applications of CFRP parts have raised the need for large scale manufacturing and production of good quality of parts in terms of both surface integrity and dimensional accuracy. Surface finish and accuracy of the surface profile are two important machining characteristics which play a significant role in achieving overall product quality. The quality of the product is often directly related to the functional performance of the product.

Though composite parts are often made to near net shapes, some post-machining operations such as drilling and trimming after demoulding are inevitable. These operations must be performed to ensure that the composite parts meet dimensional tolerance, surface quality, and other functional requirements. The machining of CFRPs faces a lot of challenges due to its inhomogeneous and anisotropic material properties. After trimming, the finished edges of the CFRP parts might result in certain defects such as fiber pull-out, delamination, fuzzing, and resin degradation which results in deterioration of the surface quality and its performance. Further due to the high resistance to heat and abrasiveness of carbon fibers, the cutting tools undergo thermally-associated wear processes. Hence, it is essential to investigate the effect of fiber orientation of CFRP laminate, cutting parameters, tool geometry, and tool coating materials which influence cutting forces and cutting temperatures which affect surface quality of edges and tool wear. Obtaining defect free edges of CFRP parts and extended tool life for

cutting tools are possible by controlling or changing the various aspects such as process parameters, tool geometry and tool materials.

From the literature review, it observed that there is a vast scope in the area of controlling the edge trimming defects and improving tool life by controlling the process parameters, using new geometry cutting tools such as routers and tool coating materials. These have not been explored yet. Very limited research work have been carried out in the area of establishing on-line tool condition monitoring using acoustic emission (AE) technique for the router type tools which has complex tool geometry. This research work addresses this gap by carrying out the study in four phases to meet the desired objectives.

The first phase of experimental work involved in investigating the induced cutting force and thrust force during edge trimming of unidirectional CFRP (UD-CFRP) specimens of different fiber orientations namely 0°, 45°, and 90°. The UD-CFRP laminate was manufactured using unidirectional prepregs supplied by Hexcel Composite Company referenced under HEXPLY UD T700 268 M21 34% (T700-M21). Both orthogonal cutting and oblique cutting experiments were conducted using tungsten carbide single point cutting tools with different angles of inclinations (0°(orthogonal cutting) and 10°, 20°, and 30° (oblique cutting)) by varying the cutting parameters such as cutting speed and depth of cut. During orthogonal cutting, the cutting forces were found to be higher in 90° fiber orientation and lower in 0° fiber orientation. Cutting speed has a greater influence on cutting force, and chip formation of CFRP. During oblique cutting with different angle of inclination, the cutting forces seem to decrease with an increase in the angle of inclination. A significant decrease in cutting force during oblique cutting at 30° angle of inclination was also observed.

This research work was extended to investigate the edge trimming of UD-CFRP of 0°, 45°, and 90° fiber orientation specimens using tungsten carbide straight flute and helical flute end mills of 0°, 15° and 30° helix angle. The experiments were conducted by varying the spindle speed and feed rate while maintaining the depth of cut as constant. ANOVA was used to analyze and determine the significant parameter on cutting forces and surface roughness, which revealed that tool geometry (i.e. helix angle) followed by feed rate had the largest influence on feed force, normal force and surface roughness. Oblique cutting in all cases of fiber orientation, offer better surface finish with less surface damages when compared to orthogonal cutting. Surface roughness was found to decrease with an increase in helix angle and the cutting tool with 30° angle of helix, resulting in trimming of CFRP specimen with lower surface roughness. Microscopic studies revealed that during oblique cutting, the matrix covered the machined edges uniformly with no obvious broken fibers.

The second phase of this research work deals with an experimental investigation of edge trimming of both UD-CFRP and quasi-isotropic CFRP laminate which has a stacking sequence of $[90°/-45°/0°/+45°]_{2s.}$ Edge trimming operation was done under a set of cutting parameters using uncoated and TiN coated tungsten carbide flute tools in order to investigate the effect of coating on cuttting force and cutting temperatures on surface roughness and tool wear. Lesser surface defects and tool wear were observed while trimming of unidirectional and quasi-isotropic CFRP laminates using TiN coated flute tool. A microscopic study revealed that the defects such as fiber and resin disintegration and craters were not identified on the trimmed edges using TiN coated tool.

The third phase of the research presented an experimental analysis on high-speed edge trimming of CFRP with various cutting conditions and different geometry of tools such as helical flute, and router type tools. The investigation involved the measurement of cutting forces under the different machining conditions and its effect on the surface quality of the trimmed edges. It was found that the trapezoidal shape tooth router tool generated lower cutting force and moderate surface roughness with no delamination while edge trimming of CFRP materials. An acoustic emission sensing was employed on-line monitoring of the performance of tools and to determine the relationship between AE signal and length of machining for different kinds of tools. The performance of trapezoidal shape tooth router tool was identified to be the best when compared to other tools. Microscopic examinations on the trimmed edges were carried out and the observations further revealed that those edges trimmed with trapezoidal tooth shape router, have a smoother and finer surface with uncut fibers.

The fourth phase of the research work investigates high-speed edge trimming of CFRP materials using titanium aluminium nitride (TiAlN) and diamond like carbon (DLC) coated routers for analysing the effect of coatings on surface quality of trimmed edges and tool wear. DLC coated router tool, trimmed the edges with the lower surface roughness values without any thermal degradation when compared to the other two tools because of its salient characteristics such as low coefficient of friction and smooth coating surface. Moreover, the DLC coated router tool showed an extended tool life in terms of length of machining of around 6 meters with lower surface damages when compared to TiAlN and uncoated tools.