Investigations on Eccentric Sleeve Grinding

An Intermittent-Progressive Machining Strategy for Fibre Reinforced Polymer Composites

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by

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ABSTRACT

Fibre Reinforced Polymer Composites (FRPs) find extensive applications in various industrial and research domains, exclusively in the aeronautical and space sectors. Advancements in moulding and lamination technologies, together with augmentations in matrix-resin fillers, made innovative developments in the near-net manufacturing of FRPs. However, the need for material removal/surface machining becomes inevitable while dealing with functional surfaces of FRPs that require high integrity, geometric, and assembly tolerances. Unfriendly machining behaviour of FRPs is always a concern, though their merits, such as strength-to-weight ratio, damping capacity, low thermal expansion, etc., are very attractive. Surface/sub-surface defects such as fibre-matrix debonding, delamination, fibre pull-out, etc., induced by the interaction of cutting edges on an anisotropic-heterogeneous fibre-matrix system are identified as the major bottleneck during traditional machining options. Such damages, driven by the cutting load and cutting temperature, are reported to be highly sensitive to the 'depth of engagement' of cutting edge. In this context, grinding is demonstrated to be a possible machining option due to the involvement of fine abrasive cutting edges. However, conventional surface grinding (CSG) couldn't resolve the concern of undesired fibre-matrix damages, which may be due to the continuous accumulation of cutting load and temperature by consecutive interaction of multiple abrasive grains present on the periphery of the grinding wheel. As adopted in metal grinding, the flood cooling strategy to handle cutting temperature is not thoroughly recommended in FRPs due to the hindrances caused by wet agglomerates of finely machined swarf and the anxieties of fluid entrapment in fibre-matrix systems. Though hybrid techniques such as Minimum Quantity Lubrication (MQL), Cryogenic cooling, etc., are also experimented, the barriers such as technical complexities, environmental/economic considerations, etc., may drag their wide acceptance in shop floor applications.

In this context, proposal of a new grinding strategy that can control the accumulation of cutting forces and cutting temperature, minimizing the surface/sub-surface defects on FRPs, became the topic of interest. The thought was further inspired by promising outcomes of ultrasonic vibration-assisted grinding (UVAG), raster fly cutting, and segmented grinding. All of these processes highlighted the merits of intermittent cutting cycles for force and thermal management during the machining of difficult-to-cut aerospace materials. As the focus shifted to FRPs, the goal was to devise a simple, cost-effective methodology that can provide the merits

of intermittent cutting action along with a progressive cutting scheme that can control the effect of depth of cut. The grinding strategy proposed in this thesis, named as *Eccentric Sleeve Grinding (ESG*), is such an innovation that facilitates a unique cutting scheme, combining the merits of intermittency and progressiveness to have in-situ control over the sensitivity of depth of cut. ESG is proposed as a methodology that can be adopted in a traditional grinding machine via a simple modification of grinding wheel mounting using a precisely machined eccentric sleeve. The controlled offset in the center of rotation of grinding wheel makes the cutting scheme unique while it interacts with fibre-matrix system of FRPs, with an *on-off* (intermittent) cutting cycle per revolution of wheel; along with a progressive (*step-by-step*) cutting action for successive grains in the cutting locus.

The present thesis provides a comprehensive investigation on eccentric sleeve grinding, covering the conceptual design, geometric/kinematic configurations, mechanics/force modelling, thermal modelling and related studies, surface generation and selection of process variables, micro-mechanics of material removal, defect analysis, assessment of surface integrity, comparison with CSG and practices such as segmented grinding, etc. A combination of theoretical models, simulations, and experimental investigations have been covered in each of these themes, as applicable, to illustrate the capabilities of ESG.