



## Abstract

The ever-increasing demand of carbon fibre reinforced polymers (CFRP) in aerospace, transportation sectors and other industries is seriously challenged by its low machinability, high tool wear rate, and susceptibility to delamination and thermal damage. This is attributed to the abrasiveness of the carbon fibre chips/debris, the material inhomogeneity, and anisotropic properties, and thus the high cutting force fluctuations. A practical approach to overcome these problems is to use the intermittent cutting process ‘orbital drilling’ (OD), to reduce forces and thermal damage, using a single layer superabrasive diamond (SAD) tool. This approach allows high speed machining while eliminating part thermal damage. Process optimization and tool design require a fundamental understanding of the behaviour of carbon fibres during machining CFRP of complex 3D architecture. This necessitates revealing the deformation mechanism and the failure modes. This presentation reports the results of numerical and experimental investigation of the material removal mechanism using a single diamond grain scratching on carbon/epoxy composites. The experiments were conducted using a geometrically well-defined diamond grain to determine the effects of fibre orientation on the material removal mechanism and to capture the effect of the grain geometry, a slant face versus an edge. Optical and SEM observations revealed that the primary chip formation mechanism consisted of initial epoxy crushing followed by fibre debonding. The debonded fibres were subjected to fibre bending or buckling, which created bending stresses inside fibres leading to fractures. Finite element modelling of the process based on the micro-mechanics approach was also conducted to reveal the composite failure modes, as well as to estimate the damage level outside the machining zone. It was found that fibres ahead of the cutting tool undergone significant fibre bending leading to tensile failure. The knowledge gained from this fundamental study provided the basis for modelling the cutting process, which involves the collective actions of numerous randomly distributed grains on the tool surface. This led to the development of a physics-based analytical cutting force model to predict cutting forces in machining CFRPs, taking into consideration the chip formation mechanisms, the material properties, the kinematics of a machining process, and the tool geometry. Inclusion of the chip formation mechanisms allows the model to predict forces for laminates with different fibre orientations and the variations of forces due to intra-ply and inter-ply fibre orientations. The main limitation of using superabrasive diamond tools to cut carbon fibre reinforced polymers is the high surface roughness of machined surfaces, which usually exceeds the aerospace industry specifications. To overcome this problem, while increasing tool life by an order of magnitude, a new hybrid oscillatory orbital process was developed using SAD tools. With proper selection of cutting conditions and process variables, the thrust force, tool temperature and surface roughness were reduced by ~ 35%, 25% and 80%, respectively, compared to conventional orbital drilling using carbide end mill, while increasing tool life by an order of magnitude. This is comparable to PCD tools, at a fraction of the cost.

**Keywords:** Carbon/Epoxy composite; Single layer diamond grains; Fibres failure modes; Analytical force model

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## Biography of Presenting Author



**Helmi Attia** is a Principal Research Officer, and former Manager of Advanced Material Removal Processes, Aerospace Manufacturing Technology Centre, National Research Council Canada (NRC). Before joining the NRC in 2002, he was a Principal Research Engineer at Ontario Hydro Research Division (1980-2002), and Manager of Fabrication Technology at Spar Aerospace Technology Ltd. (1979-80). He is an Adjunct Professor of Mechanical Engineering at McGill University since 2002. He held also Adjunct Professorship with Concordia University (1981-1990) and McMaster University (1991-2002). Helmi is professional engineer of Ontario since 1980. He is a Fellow of SME (Society of Manufacturing Engineers), Fellow of the College International pour la

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