FINITE ELEMENT MODELING FOR MACHINING OF UNIDIRECTIONAL FIBER REINFORCED POLYMER COMPOSITES

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CERTIFICATE

This is to certify that the thesis entitled **'FINITE ELEMENT MODELING FOR MACHINING OF UNIDIRECTIONAL FIBER REINFORCED POLYMER COMPOSITES'** being submitted by **G. VENU GOPALA RAO** is the report of bonafide research work carried by him under our supervision. This thesis has been prepared in conformity with the rules and regulations of the Indian Institute of Technology Delhi, New Delhi. We further certify that the thesis has attained a standard required for a Ph.D degree of the institute. The research reported and the results presented in the thesis have not been submitted, in part or full to any other institute or university for the award of any other degree or diploma.

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ABSTRACT

Orthogonal machining of unidirectional carbon fiber reinforced polymer (UD-CFRP) and glass fiber reinforced polymer (UD-GFRP) composites are studied both experimentally as well as numerically. The orthogonal machining experiments are carried out on both the composites separately for a range of fiber orientations (θ), depths of cut (t) and tool rake angles (γ). The cutting (F_c) and thrust (F_t) forces are measured using piezoelectric dynamometer, chip formation process is observed and recorded using long distance optical microscope and video camera. The numerical study is done using finite element method (FEM) and it is carried out at two different scales namely macro-mechanical and micro-mechanical. First a macro-mechanical finite element (FE) model is used to simulate the machining process where the material is treated as an equivalent homogeneous material (EHM). The simulated cutting and thrust forces are correlated to the experimental observations. The cutting force from the macro-mechanical FE simulation agrees well with the experimental results. However, thrust force deviates from the experimental observations. In order to overcome this deviation of thrust force, a new two-phase micro-mechanical FE model is proposed in this research work. In the two-phase micro-mechanical FE model, fiber is assumed as elastic and matrix as elasto-plastic to estimate the cutting and thrust forces and chip formation mechanism during orthogonal machining. A bi-linear cohesive zone model (CZM) simulated the interface debonding between the fiber and the matrix. Fiber failure is based on Tsai-Wu stresses (or) in-plane maximum principal stresses reaching ultimate tensile strength of individual fiber. The damage initiation and evolution in the matrix material is implemented based on the yield strength and fracture energy respectively. The FE analysis is quasi static although explicit FE model with mass scaling is used for analysis to speed up the solution. During the FE

simulation, the induced contact pressures between the cutting tool and the fiber provided an estimate of the cutting and thrust forces. The simulated cutting and thrust forces matched well with the experimental data, thereby validating the new micro-mechanical FE model. The cutting forces vary with fiber orientation and depth of cut and the rake angle has a negligible effect on these forces. The chip formation mechanism in orthogonal machining of both UD-CFRP and UD-GFRP composites is also simulated in this study. The effect of fiber orientation, tool parameters and operating conditions on fiber and matrix failure is also highlighted. The degradation of the matrix adjacent to the fiber occurs first, followed by failure of the fiber at its rear side. The extent of sub-surface damage due to matrix cracking and interfacial debonding is also determined. The sub-surface damage is predominant due to matrix damage as compared to the interfacial debonding. The failure of fiber is found to be a combination of crushing and bending. It is concluded that the two-phase micro-mechanical FE model is more suitable in predicting the machining responses as compared to the single-phase macro-mechanical FE model.

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