This study focuses on devising analytical and numerical process models for simulating mechanical micro-machining of heterogeneous materials. These models are to assist in selecting process parameters for micro-machining of the advanced materials. The material studied is Magnesium Metal Matrix Composites (Mg-MMCs) reinforced with silicon carbide (SiC) particles.

This research is motivated by increasing demands of miniaturized components in various industries. Mg-MMCs become one of the best material candidates due to its light weight, high strength, and high creep/wear resistance. However, the improved mechanical properties bring great challenges for the subsequent micro-machining process.

Systematic experimental investigations on the machinability of Mg-MMCs reinforced with SiC nano-particles have been conducted by using the Design of Experiment (DOE) method on the nanocomposites containing 5 Vol.%, 10 Vol.% and 15 Vol.% reinforcements, and pure magnesium. Based on response surface methodology (RSM) design, experimental models and related contour plots are developed to predict cutting force, surface roughness, and optimize micro-machining conditions.

An analytical cutting force model has been developed to predict cutting forces of nano-reinforced Mg-MMCs in micro-milling process. This model is different from previous ones by encompassing the behaviors of nanoparticles in three cutting scenarios, i.e., shearing, ploughing and elastic recovery. By using the enhanced yield strength, three major strengthening factors are incorporated including load-bearing effect, enhanced dislocation density strengthening effect and Orowan strengthening effect. To validate the model, various cutting conditions using different size end mills (100 µm ~ 1 mm dia.) have been conducted. The simulated cutting forces show good agreements with the experimental data. The proposed model can predict major force amplitude variations and force profile changes with the nanoparticles' volume fraction.

Furthermore, a comprehensive evaluation of ductile fracture models has been conducted to identify the most suitable fracture criterion for FE micro-cutting simulation. The evaluated fracture models include constant fracture strain, Johnson-Cook (J-C), J-C coupling criterion, Wilkins, modified Cockcroft-Latham, and Bao-Wierzbicki (B-W) fracture criterion. Results indicate that by coupling with the damage evolution, the capability of J-C and B-W can be further extended to predict accurate chip morphology. B-W based coupling model provides the best simulation results in this study.

A 2-D FE micro-cutting model has been constructed to study the micro-cutting performance of Mg-MMCs materials. Firstly, homogenized material properties are employed to evaluate the effect of volume fraction. Secondly, micro-structures of the two-phase material are modeled in FE cutting models. The effects of SiC particles are evaluated in two case studies. By using homogenized material properties, the micro-cutting performance of nano-reinforced Mg-MMCs can be predicted. During micro-cutting, crack generation mechanism for Mg-MMCs is different from their homogeneous counterparts.

Through this research, a better understanding of the unique cutting mechanism for particle reinforced heterogeneous materials has been obtained and the effect of reinforcements on micro-cutting performance is revealed. The proposed analytical and numerical models can be used to optimize process parameters for preparing and micro-machining of the heterogeneous material. This will eventually facilitate the automation of MMCs' micro-machining process.
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The public is welcome to attend.