INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: **Numerical and experimental studies on single point diamond turning of brittle and ductile materials**

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SHORT ABSTRACT

Silicon and silicon carbide materials are widely used materials in semiconductor industries, defence, aerospace and biomedical due to their excellent mechanical, chemical and thermal properties. However, mechanical processing of these materials is very much difficult because of their brittleness. Single point diamond turning (SPDT) successfully produces optical finish surfaces on these materials; however, it causes severe tool wear to the diamond tool. SPDT comprises of complex interaction of its process factors. Analytical modeling of these parameters is difficult. Numerical simulations are therefore becoming imperative to study the nanometric cutting processes. At present, molecular dynamic (MD) simulation is regarded as the high-end numerical simulator. However, MD simulation considers a very limited work-domain, i.e., a nano-portion of the cutting process. Moreover, it requires substantial computing time. An alternate way to this problem is to employ finite element method (FEM). FEM is capable of obtaining insight into the effects of the cutting process that are sometimes not possible to visualize through experiments.

After an extensive literature review on various aspects of SPDT process such as analytical, experimental and numerical studies on various process parameters, tool geometry, and material aspects, it was found that scant literature is available on numerical simulation of silicon and silicon carbide. Moreover, there is hardly any comprehensive and systematic study reported on the influence of critical machining parameters such as speed, feed, depth of cut, tool geometry parameters viz. rake angle, cutting

edge radius on the performance measures, i.e., cutting forces and surface roughness. Thus, a need was identified to understand the effects of various process parameters, tool geometry, workpiece material, working condition on process output and product quality. This motivated to carry out the present research work.

In this research work, a finite element method based two-dimensional numerical model of nanoindentation and plunge cutting process is developed to determine the ductile to brittle transition (DBT) thickness and to understand the ductile regime machining (DRM) of silicon and silicon carbide. This thesis aims to provide an understanding of the ductile regime machining by identifying the critical depth of transition and thereby predicting the machining force and surface roughness to optimize the process conditions for the improvement of process efficiency and product quality. Arbitrary Lagrangian Eulerian (ALE) formulation with an explicit solution scheme was employed to simulate the interaction between the diamond indenter and the workpiece. The diamond indenters and the silicon carbide in the model are defined as homogeneous and isotropic elastic materials. Drucker-Prager material model is used to model the material behavior of silicon carbide along with elastic material properties. Experimental validations of load-displacement (P-h) plots were carried out by using published experimental data and found that the calculated Young's modulus and hardness from the numerical simulations are in good agreement. It was observed that the maximum von-Mises stress reaches to 16 GPa and 38 GPa when the indenter's depth was around 91 nm and 375 nm just before the formation of crack/fracture for silicon and silicon carbide respectively. These pressures are higher than the hardness of the workpiece (12 GPa and 26 GPa) that felicitate to change the phase of silicon and silicon carbide. Thus, the critical depth of indentation, i.e., ductile to brittle transition was found to be 91 nm and 375 nm for silicon and SiC respectively.

Plunge cutting simulations were carried out by using a diamond tool having rake angles of 0º, −25º and −30º, the clearance angle of 10º. To achieve an inclined motion of the tool, i.e., continuously varying depth of cut from 0 to 600 nm, tool has given simultaneous speeds along *x* and *y*-axis directions. To identify the DBT depth or critical depth of cut (CDC), three methods were employed, i.e., visual inspection of surface profile, variation of machining force and specific cutting energy. A comparative analysis of performance of three methods has also been presented. The CDCs obtained from the force analysis were 78 nm, 84 nm and 108 nm for 0º, –25º and –30º rake angle tool respectively. The critical depths of cut for SiC were found to be around 65 nm. These values are found to be close to the experimental CDCs.

A two-dimensional numerical model of SPDT process of silicon and silicon carbide using FEM was developed to predict the machining force values. The results predicted by the numerical model and

developed integrated approach were validated with available published experimental results. Prediction using two different material models viz. Johnson-Cook (JC) and Drucker-Prager (DP) were compared. A study on the chip formation while performing the nanometric cutting simulation of SPDT of SiC was presented. Parametric studies were also carried out using full factorial and response surface methodology based set of numerical experiments and the behavior of SPDT of silicon and silicon carbide was studied. The confirmation simulations showed mean prediction error of below 8.5% for silicon carbide and 5% for silicon.

An integrated finite element method-image processing technique (FEM-IPT) based model for the prediction of surface roughness during SPDT of Al6061−T6 is presented. The present technique is found to be simple and economical. It very well predicts the surface roughness values before the actual machining runs. The comparison between experimental roughness and numerically predicted roughness shows that the prediction error during SPDT of Al601-T6 was varied between 2.19−20.41% and the overall mean prediction error was found to be 8.71%.

In view of limited availability of SPDT machine to carry out experimental studies, very limited numbers of experiments were carried out on available Al6061-T6. Results were used to validate the developed FEM-IPT model and to investigate the effect of process parameters such as speed, feed, and depth of cut on the surface roughness. Mixed level full factorial experiments were carried out. Experimental results showed that minimum surface roughness value of Ra = 6.5 nm was successfully obtained for a combination of speed of 1.309 m/s, feed of 3 μm/rev and depth of cut of 10 μm whereas maximum surface roughness value of Ra=13.03 nm was obtained for speed 2.356 m/s, feed 10 μm/rev and depth of cut 20 μm. The results of regression analysis reveal that the mathematical model developed using factorial analysis allows prediction of surface roughness within 7.3% prediction error. It is felt that the developed integrated approach will be useful to predict the surface roughness at shop floor before carrying out the actual machining runs. This will certainly help the process engineers to apply proper process parameters to obtain the desired process performance. The information and knowledge generated during numerical and the experimental studies presented in this thesis will be useful to the researchers and engineers as important guidelines. Overall, it is found that the numerical approach developed in this work can be thought to be simple, easy and economical alternatives to costly, tedious and time-consuming physical experiments.