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Deformation Processing

Strain-Gradient Plasticity: Applications to Materials Processing

Y. Huang, A. Chandra and M. Krishnamurthy
National Science Foundation

Experiments have shown that material behavior at the microscale is significantly different from that at the macroscale. For example, the conventional plasticity theory cannot explain the increased hardness in micro-indentation tests as compared to macro-indentation of the same material. The strain gradient plasticity recently proposed by Fleck and Hutchinson (1993) is potentially capable of effectively probing micron and sub-micron scale material behavior. However, a material length scale is introduced in the strain gradient plasticity, and needs to be determined from a set of independent microscale experiments. The proposed work first focuses on developing independent experiments to estimate the 'material length scale'. We will then utilize the strain gradient plasticity theory to probe different engineering applications where microscale phenomena play important roles, such as in machining, composites, and micro-mechanical sensors, actuators and transducers that commonly use thin film bi-layers (thin film on thin film).

Forming Advances for Aluminum Automotive Components and Applications: Active Drawbead Systems for Concurrent Preform and Process Optimization

K.J. Weinmann, A. Chandra, and M.L. Bohn
U.S. Department of Energy/ALCOA

The development of a specialized sheet metal stamping die incorporating the drawbead as a control element is proposed with the purpose of improving aluminum sheet stamping processes. The die will be outfitted with several custom transducers placed at strategic locations in the die shoulder. Each sensor will measure both local drawbead restraining force and local wall tension in the sheet. Based on this information, control signals (desired drawbead penetrations) will be computed and sent to the individually servo-controlled, hydraulically actuated drawbeads in the die. Additionally, the blank holder force (BHF) will be controllable in the sense that a desired BHF can be selected and applied through the draw. A parametric FE model will be developed. FE modeling, as a time-saving and cost-effective numerical tool, will be fully used throughout the proposed investigation in generating control trajectories of drawbead action, analyzing sheet formability, and die and drawbead design.

Prediction of Forming Limits Based on Hill's 1993 Yield Criterion and the M-K Approach

K.J. Weinmann and S.G. Xu
ALCOA

Forming limits are the most important information required for the control of sheet metal formability in press operations. Much work by previous researchers has been focused on forming limit analysis using various homogeneous yield criteria since the yield function has a significant influence on the prediction of forming limit strains. However, the results are not satisfactory due to the fact that yield functions are mostly applicable to a certain type of material. In 1993, Hill proposed a user-friendly and non-homogeneous yield function for planar anisotropic sheets. This yield criterion is expected to be able to cover the plastic deformation characteristics for a wide spectrum of materials ranging from steel to aluminum and brass. The application of this yield criterion in the forming limit prediction is investigated. The analysis which is based on the M-K approach, shows that the forming limit prediction agrees well with experimental data for both steel and aluminum due to the flexibility of the yield criterion.

Predicting Forming Limits Based on Bifurcation Analysis and Hill's 1993 Yield Criterion

K.J. Weinmann, A. Chandra, and S.G. Xu
U.S. Department of Energy/ALCOA

To further investigate the applicability of this yield criterion, the bifurcation analysis is pursued based on the deformation theory of plasticity. A general form for the instantaneous moduli of the rate form of the constitutive equation is derived and strain rate sensitivity is introduced in the analysis. It is found that the bifurcation analysis predicts forming limits lower than those of the M-K analysis, which makes the bifurcation analysis basically applicable for aluminum.

Finite Element Analysis of the Effect of Drawbeads on the Formability of Sheet Metal

K.J. Weinmann, A. Chandra and S.G. Xu
U.S. Department of Energy/ALCOA

Real time control of the drawbead restraining force by active drawbeads can compensate the external disturbances to the forming process and enhance the formability of panels. However, industrial application of the active drawbead requires a thorough understanding of the effect of drawbeads on deformation characteristics of sheet metals. To investigate the effect of different drawbead penetration trajectories on sheet formability, a finite element model of full panel forming is created. The simulation based on the LS-Dyna3d finite element package illustrates that a trajectory with early penetration and early retraction of drawbeads increases sheet formability. This observation by FEA is verified by tests conducted by drawing full panels with an experimental die. Comparison of predicted with experimental data shows that predicted strains in the part are lower than measured strains in the critical zone which is prone to necking, since the use of one-shell elements in the sheet thickness direction cannot simulate localized necking.

Formability Studies of Non-symmetric Aluminum Panel Drawing Using Active Drawbeads

K.J. Weinmann, A. Chandra, and R. Li
U.S. Department of Energy/ALCOA

Previous work on symmetric part forming conducted at MTU has indicated that active drawbeads are advantageous to improving the formability of material in sheet metal forming. In this work, the research is extended to non-symmetric panel forming. The experimental panel was designed to simulate an automotive front fender. An experimental investigation and finite element analysis were both carried out to study the effect of active drawbeads on the formability of AL 6111-T4 in forming such a non-symmetric panel. The results are compared to flat binder tool forming and fixed drawbead forming. It was proven that active drawbeads result in improved draw depth compared to the other two nodes of drawing. The finite element analysis supports the experiments.

Finishing Processes

Mechanics of Material Removal in Ceramic Grinding

A. Chandra, G. Subhash, and Y. Huang
National Science Foundation

Grinding is essentially a dynamic material removal process with strain rates of the order of 103-105/s. However, the existing models do not fully capture these inherent rate effects. Hence, a mechaNational Institute of Standards & Technologyic study depicting these dynamic and high strain rate characteristics of ceramic grinding is the focus of this project. This involves well coordinated experimental and modeling efforts to identify the material removal mechanisms and their associated damage evolution modes. Insights gained from this parametric study will facilitate exploration of the 'design space' to seek novel avenues for optimizing the effectiveness and efficiency of ceramic grinding processes. Here, we will primarily focus on accelerating propagation of lateral cracks (and hence material removal rate), while suppressing radial and median cracks (thus reducing residual damage in the finished product). Influence of various process (e.g., machining speed, feed, grit size and density, force/grit) and material parameters (e.g., grain size) on nucleation and propagation of these crack systems will be investigated in detail.

Modeling the Self-Dressing of Resin Bound Grinding Wheels

T.S. Kakumanu and M.H. Miller

Society of Manufacturing Engineers

For grinding brittle materials resin binders tend to perform better than metal binders. Their greater compliance puts more grits in contact with the workpiece and their lower hardness causes faster wear and more self-dressability. Both effects occur simultaneously, and it is unclear which effect is more important in terms of ductile grinding performance or if both contribute equally. In this project we focus on the wheel wear and self-dressing of resin bound wheels. There are two dominant wear mechanisms for resin bound wheels: grit pullout for blocky diamonds and grit fracture for friable diamonds. Focusing on grit pullout as the primary mechanism, we are developing a model to describe the self-dressing process and to predict the growth and stabilization of the cutting force. We are also conducting grinding experiments with different wheel binder grades to test the model.

The Effect of Workpiece Modulation on the Grinding of Brittle Materials

W. Qu, M.H. Miller, and A. Chandra

National Science Foundation, State of Michigan Research Excellence Fund

Ductile regime grinding is an enabling technology in the manufacture of ceramic components because it produces accurate shapes determiNational Institute of Standards & Technologyically and without fracture. However, the process requires very small chip thicknesses which limit material removal rates (MRR) and consequently economic viability. To increase MRR without increasing fracture, we are investigating ultrasonically-assisted machining. In the past year we have investigated crack shielding as a potential effect of modulation. We conducted single grit scratch tests on glass workpieces that were modulated at frequencies of 1 to 4 kHz. The results indicate that modulation can reduce the radial subsurface damage produced during scratching. Modulation rapidly loads and unloads the cutting grit. The unloading cycle initiates lateral cracks that seem to shield propagation of the more detrimental radial cracks.

Manufacturing Systems

Chatter Onset and Tool Wear Detection in Machine Tools

W. J. Braun, J. F. Schultze and M. H. Miller

State of Michigan Research Excellence Fund

In this project we are developing the analytical and experimental tools for predicting chatter onset and tool wear in machining. These tools include the evaluation of spatial filtering and spectral-signal analysis. We are developing an experimental model of a machine tool and analytical models of chatter and tool wear. The long term goal is to integrate chatter and tool wear identification into machine tool controllers to increase process throughput, maintain surface quality, adjust feedrate, and aid in preventative maintenance programs.

White Light Interferometric Microscopy for 3-D Micro-Measurement

K. Moon and C.R. Friedrich

State of Michigan Research Excellence Fund

The proposed project aims to provide 3-D coordinate measurement environment for very small and ultra precision manufactured products. The system will consist of three main modules. They are computer-aided microscope module, geometric modeling module, and application module. The computer-aid microscope module will provide a non-contact and 3-D shape measurement capability with the range from a few micrometer scales to over several millimeters. The shape data of a product will then be fed into the geometric modeling module. In the geometric modeling module, the 3-D shape data will be recreated as an object image in a geometric modeling environment. With the assistance of geometric modeling platforms, the module will provide a conventional CMM like environment. Finally, the application module will utilize the geometric modeling results for 3-D metrology, reverse engineering, and quality control purposes.

Data-dependent System Profilometry of Two-dimensional Surfaces

S.M. Pandit and D.P. Chan

Michigan Technological University

The data-dependent systems profilometry, DDSP, is able to separate the surface from noisy measurements in a single interferogram so it is ideal for measurements under industrial environment. It is also a non-contact and non-destructive technique that has immense potential for on-line surface characterization for smooth surfaces commonly seen in computer and telecommunication industries. Most analyses on the DDSP are one-dimensional. The objective of this research is to develop a DDSP procedure for two-dimensional fringe pattern analysis. The concept of using a common order is introduced to reduce the amount of computations and the errors caused by the heterodyned phase removal procedure. A comparison of the DDSP and Fourier-traNational Science Foundationorm profilometry, FTP, shows the advantage of using the DDSP in recovering very detailed surface profiles.

Monitoring Tool Wear and Predicting End-Mill Failure Using Acceleration Signals

S. M. Pandit and J.T. Roth

U.S. Department of Education

The goal of this research is to develop an on-line algorithm that is capable of using acceleration signals to monitor the wear of an end mill and warn when tool failure is impending. By adapting a Data Dependent Systems algorithm that was previously developed by the investigators to detect bearing wear, a method was developed to monitor an end mill using force signals. This method is now being applied to acceleration data that was collected from an end mill life test. The spectral content of the acceleration signals is established using autoregressive models. The condition of the tool is monitored by comparing changes in the models over time. Two indices that are sensitive to tool wear have been identified from the initial data. Future research includes running additional end-mill life tests and optimizing the monitoring technique so that it can be used on-line.

On-Line Machine Tool Monitoring via Fiber Optic Sensing

A. Chandra, J.W. Sutherland and G. Shen

National Science Foundation Engr. Res. Ctr. for Reconfigurable Machining Systems

A fiber optic sensor system for on-line monitoring of machining processes is being developed. The thrust areas of the project are: investigating the properties of the sensor as well as calibrating the sensor, installing the sensor in the machine tool system for optimum response under various machining conditions, and development of the sensor system, collection and analysis of the sensor signal. This will require the parallel development of an inverse dynamics algorithm to provide an avenue for real time identification of the state of the machining process. The sensing system would be integrated with this algorithm

Environmentally Conscious Manufacturing: Graduate Assistance in Areas of National Need (GAANN)

S. M. Pandit, J. W. Sutherland, S. Behm, K. Gunter, S. Mattson, D. Soine, N. King

U.S. Dept. of Education

The primary objective of this project is to produce a generation of engineers capable of designing manufacturing processes and systems that prevent pollution and advanced treatment systems that destroy, recover, or immobilize pollutants. The GAANN support provides for Ph.D. fellowships for five domestic students.

Development of a Database of Cutting Fluid Properties and Establishment of a Classification System for Cutting Fluids

J. A. King (Chem.E), D. J. Michalek, J.W. Sutherland, K. Zuidema, and J. Eppert

Machine Tool Agile Manf. Res. Inst.; National Science Foundation

Thermo-physical properties of metal working fluids are being measured to create a database of values that will be used with other research projects. This information is vital to understanding how properties of the fluids such as viscosity, specific heat, surface tension, and slope of shear rate vs. shear stress relate to the performance characteristics of the fluids. A selection and classification system that takes basic properties of metal working fluids into account is proposed as a way to enable industry/consumers to make more informed decisions that are independent of the manufacturer.

The Effect of Cutting Fluid Application Variables on Convective Heat Transfer Coefficients

D. J. Michalek, J.W. Sutherland, and B. Mathews

A. W. Chesterton

Machining experiments will be performed to gather information on the cutting fluids while in use. The data obtained from these experiments will be used to assess the heat transfer capabilities of the cutting fluids, validate the fluid property model, and quantify tool wear. An assessment of the heat transfer capabilities of the cutting fluids will be obtained by performing side-by-side comparison with dry machining processes. Two machining processes will be tested; boring and turning.

Reducing the Hazardous Airborne Emissions of Manufacturing Processes

J.W. Sutherland, Y. Yue, D. Xu, V. Kulur, and K. Gunter

National Science Foundation

Cutting fluid mist is becoming an increasing concern for manufacturers as additional information is obtained on the health risks that it poses. An effective strategy is to modify the machining process itself to minimize the amount of cutting fluid mist formed. Such a strategy requires a fundamental understanding of the underlying process conditions affecting mist formation. Experimental designs conducted on a turning process have examined the role of several process-related variables on mass concentration of particulate matter having diameters less than 10, 2.5, and 1.0 micrometer respectively. Experiments were also performed to collect information on submicron particle sizes, particles of greatest interest from a health standpoint. An analytical characterization of the mist formation problem has also been undertaken, considering both vaporization/condensation and atomization mechanisms.

Environmentally Conscious Design and Manufacturing with Input/Output Analysis and Markovian Decision Making

J.W. Sutherland, S.M. Pandit, H. Xue, and A. Filipovic

National Science Foundation/Environmental Protection Agency

The goal of this research is to combine principles of Life Cycle Analysis and Markov Decision Processes to achieve environmentally Conscious Decision Making. Markov Decision Process (MDP), an application of Markov chains theory, will be used as a decision making tool. In order to make an appropriate input to the Markov Decision Process, the steady state model of the system should be generated by applying the Input-Output theory. Historical data need the DDS approach to define the steady state. We plan to apply the decision making tool to a cutting fluid system as an example. Cutting Fluids are very hard to maintain and dispose off. Such degradation of the cutting fluid system will be modeled as discrete states and the economic as well as the environmental costs of different decisions and policies adopted during the coolant life cycle, will be determined. From these costs, the most optimal maintenance policy will be determined. This policy will not only be the most economical but simultaneously provide us with the least environmentally harmful policy.

Environmentally Conscious Manufacturing: Reduction of Process Waste Streams

J.W. Sutherland, N. Soni, L. Yan, A. Bhargava, and W-K Chan

Center for Clean Industrial and Treatment Technologies

The long-term costs associated with manufacturing processes needs to account for environmental and health factors. This economic aspect provides the motivation for developing tools and enhancing knowledge related to reducing machining wastes. The aim of the project it to develop “Process Evaluation and Selection Tools” to characterize the waste streams generated during manufacturing. Multi objective decision making is providing a means to maintain product quality while reducing machining waste streams and health hazards due to cutting fluid mist.

The Effect of Form and Assembly Inaccuracies on Machine Tool Errors

J.W. Sutherland, C. Daniel and R. Kuchibhotla

Machine Tool Agile Manf. Res. Inst.

Errors in a machine tool system often define the accuracy that is achievable on machined components. It has been estimated that 75 percent of machine tool errors originate from its manufacture and assembly. This research seeks to model these fundamental errors and map them into tracking errors of the machine tool through analytical and experimental efforts. Form, orientation, and dimensional variations are being analyzed for their effect on tracking errors using rigid body assumptions and coordinate traNational Science Foundationormations. Additionally, asperity level deformations at the sliding joints are being incorporated into the model. Once developed, the model may be used in error budgeting and tolerancing of machine tool components.

Origin of Machine Tool Damping in Fixed and Sliding Joints

J.W. Sutherland and C. Hung
Michigan Technological University

The dynamic performance of machine tool systems is highly dependent on the ability of the system to dissipate energy. Much of this energy is dissipated in the joints of the machine tool structure. This project is investigating the origin and mechanisms associated with these dissipation/damping mechanisms. Specifically, the interaction of asperities on mating surfaces is being examined as the chief source of damping. It is envisioned that this work may provide information on such design decisions as clearance and required surface texture.

Advanced Methods for Closed-Loop Control of Restraining Force via Drawbeads

K.J. Weinmann and S.U. Jurthe
Johnson Controls, Inc.

A classical (PID, Proportional Integral Derivative) as well as an advanced controller (LQG, Linear Quadratic Gaussian) is to be developed to control restraining force in the process of deep drawing. Special emphasis is given to the fact that the performance and disturbance rejection are limited due to delay and saturation in the control loop. An estimator (Kalman Filter and Smith Predictor) eliminates part of the delay in the control loop and on the other hand, a Fuzzy Logic Controller corrects the PID or LQG generated control signal to an appropriated value to minimize saturation related performance drawbacks, if needed. The analysis of the controller robustness is shown analytically utilizing the gain and phase margins of the controller. Finally, a user-friendly application for Windows95 is programmed for the entire data acquisition of deep draw experiments and the real time control of the restraining force as well as drawbead position and blankholder force.

The Effect of Blankholder Force on the Die Shoulder Transducer Output in Strip Drawing with Adjustable Drawbead

K.J. Weinmann and R. Baumann
U.S. Department of Energy/ALCOA

In order to expand the use of a die shoulder sensor for sheet metal drawing operations, a calibration method for dynamic tests has to be established. The output of the die shoulder sensor in a deep drawing tool is primarily influenced by two forces. One is the tangential force in the sheet metal. The other is the force applied to the part by the upper blankholder. In this project, these influences are examined using the strip test machine. To simulate the upper blankholder force on the die shoulder sensor, the installation of an additional hydraulic cylinder in the strip drawing machine for direct application of the blankholder force to the sensor become necessary. The influence of the upper blankholder on the sensor was then examined. Using these results, a new calibration method for the die shoulder sensor is established and proven in closed-loop tests.

Material Removal Processes

An Analytical Model to Predict Cutting Forces in Microdrilling

C. Friedrich and A. Zhu
National Science Foundation

Micromechanical machining processes such as microdrilling and micromilling present a very different machining environment from conventional metal cutting. In micromechanical machining the depth of cut of the tool into the material is often much less than the cutting edge radius (sharpness) of the tool. This results in large negative rake angles at the cutting edge and also results in considerable ploughing of the work material. As a result, the thrust force component of the total cutting force is very high. This work takes into consideration the large negative rake angle and associated ploughing. The predicted thrust force in microdrilling at a diameter of 125 micrometers is compared with experimental data for 6061-T6 aluminum. There is good agreement among the data and the model will be extended to **p**redict the stresses in micromilling tools smaller than 20 micrometers is diameter.

Experimental Identification of Conditions for Reduced Cutting Fluid Flow Rates / Dry Machining and Assessment of Dry vs. Wet Machining Economics

J.W. Sutherland, N. King, A. Bergstrom and S. Basu
Ford Motor Company, Caterpillar

Due to the rising costs associated with coolant use, dry machining and processes that use reduced quantities of coolant are becoming more favorable in many applications. This research is in an effort to determine when a reduction or elimination of cutting fluid is feasible, by considering product quality and environmental issues, as well as addressing economic concerns. A spreadsheet has been prepared in which all costs associated with both wet and dry turning are itemized and compared in detail. Experiments, with the goal of obtaining an insight into the relationships between coolant use and tool life, product quality, heat removal, and worker health are currently in progress.

Machinability Comparison of Virgin and Recycled Magnesium

M. H. Miller and A. B. Canestrelli
Dow Chemical

The purpose of the project was to assess the machinability of virgin and recycled magnesium. Dow provided die cast plates. During facing cuts on a lathe, we measured machining forces in three orthogonal directions with a strain gage dynamometer. Over multiple tests on the same work material we monitored tool flank wear and changes in machining forces. Comparisons between the two compositions were then made.

Development of a Micromechanical Fabrication Laboratory

C.R. Friedrich
State of Michigan Research Excellence Fund

An ultra-precision CNC micromilling machine will be acquired to perform micromechanical machining including micromilling, microdrilling, and diamond micromachining. The machine will be used to push these processes beyond the current levels of miniaturization which is 20 micrometer-diameter tooling for milling. The machine utilizes air bearing sliders and closed-loop servo technology throughout. The commanded work piece resolution is 1.25 nanometers and the accuracy and repeatability are 0.1 micrometers per 2 millimeters or travel. The machine will be used for a variety of education and research including direct machining of x-ray masks and molds, microfluidic structures, tooling development, coordinate measuring metrology, and manufacturing.

Impact of Material Microstructure on Machinability of Cast Aluminum Alloys

J. W. Sutherland and M. Mikula

Ford Motor Company

Material microstructure can play a significant role in the performance of machining processes. Casting problems can result in microstructures that negatively affect tool life and surface finish. This effort is focused on characterizing this behavior with the goal of describing what amount of microstructural variation can be tolerated in production.

Development of a Model for the Dynamic Behavior of a Peripheral Milling Process

J.W. Sutherland and S. Ranganath

Machine Tool Agile Manf. Res. Inst.

End milling is a widely used material removal process especially in the automotive and aerospace industry. Force and surface texture prediction models have thus become key areas for research. Most of the dynamic force models include the effects of structural damping in the prediction of forces. However, process damping, which plays a vital role in stabilizing the cutting process, is not well characterized. Process damping is attributed to the flank face interference mechanism in which the clearance face of the cutting tool `rubs' or interferes with the wavy machined workpiece surface. This damping is also responsible for the increased cutting process stability in the low to medium surface speed machining range. The goal of the research is to model this mechanism by the sliding indenter theory of contact mechanics and use this to compute the ploughing forces. These forces can be used along with the tool indentation speeds to compute the instantaneous viscous damping coefficients. Key issues like the process stability, comparison of the damping in up and down milling will observed during actual cutting tests will then be addressed through these relations and the simulation results.

Predicting the Performance of a Tapping Operation

J.W. Sutherland, T. Cao, and S.A. Batzer

Machine Tool Agile Manf. Res. Inst.; Michigan Technological University

A mechanist model of the thread tapping operation is being developed. The model inputs include the tap geometry, workpiece material, cutting conditions, cutting fluid type, and cutting fluid application conditions. The model will incorporate both tap geometry inaccuracies as well as chip evacuation effects. The model incorporates both the cutting force system effects and tap/work interference effects. The model outputs include torque, axial force, form error, and surface texture.

Vibration Abatement in a Turning Process via Active Manipulation of a Magnetostrictively Actuated Tool Holder

J.W. Sutherland and D. Liu

Machine Tool Agile Manf. Res. Inst.

The ability to position a cutting tool with respect to a workpiece is often desired to rectify positional inaccuracies/disturbances during a machining process. In a turning process, fast and precise repositioning of a cutting tool may permit the manufacture of unconventional workpiece shapes (i.e., non-circular cross-section) on a conventional lathe. Repositioning of the cutting tool may also be used to reduce vibration levels and improve the surface finish generated by the process. In this project, magnetostrictive and piezo-based actuation systems are being investigated for potential use in machining applications, e.g., turning, milling, and grinding processes. The goal of the project is to develop actuation schemes and control strategies for real-time active control of machining processes.

Characterization of Chip Size and Shape to Promote Dry Machining in Drilling

J.W. Sutherland, S. Batzer and J. Huang

Michigan Technological University

This effort seeks to create predictive chip morphology models facilitating chip control and evacuation in metal removal processes. To that end, research is ongoing in the following areas: Development of governing equations and mechanisms of chip morphology; Study of experimentally created orthogonal chips; Development of computer models of orthogonal chips; Study of chips developed by drilling processes under production conditions; Study of chip evacuation to include vacuum extraction.

Characterizing the Role of Cutting Fluids in Machining Processes

J.W. Sutherland, A. Gandhi, Y. Zheng, and H. Li

Machine Tool Agile Manf. Res. Inst.; National Science Foundation

Although much research has been done on cutting fluid action, much still remains undone. To date, no adequate model of mean heat generation/ heat transfer in orthogonal machining exists. The non-coulombic friction mechanism on the chip/tool interface must be better explained. Much work on chip fluid carryoff and mist formation remains completely unexplored. Previously, an empirical approach has been adopted, merely stating what is occurring, and neglecting the why of the occurrence. No modeling of the process beyond simple empirical relationships can be performed until each mechanism of the machining process is better explained. Hereafter are the identified research issues we are working on: data, Environmental metrics & LCA, modeling, process performance issues, cutting fluid system characterization, and mist formation mechanics.

Cutting Fluid Mist Formation in Machining Processes

J.W. Sutherland, Y. Yue, Y. Siow, and K. Gunter

National Science Foundation

Cutting fluid mist represents a significant environmental safety and health hazard. The primary objective of this research is to develop a better understanding of the fundamental mechanisms of cutting fluid mist formation (evaporation, atomization, splashing and dragout processes). The mechanism of mist formation via atomization has been described. A hardware testbed has recently been established to validate the atomization model associated with a rotating workpiece. Attention is also being focused on mist formation via an evaporation/condensation mechanism. Analytical computations have been made to predict the evaporation rate of the cutting fluid under ambient conditions for typical cutting fluid systems. A boiling-evaporation model is also being developed and validated to predict the vapor generation rate.

A Continuum Mechanics Model for Heat Generation in Machining

J.W. Sutherland and Y. Zheng

Machine Tool Agile Manf. Res. Inst.

A continuum mechanics model for heat generation in orthogonal cutting has been developed. Along a family of assumed streamlines, the velocity, Eulerian strain, Eulerian strain rate, and deformation rate distributions, based on the finite deformation theory of continuum mechanics, are analytically obtained and consistent with some results from the shear plane theory of orthogonal cutting in certain limit states. A simple iterative incremental method is able to predict the temperature on the shear plane as well as the average chip temperature when the behavior of cut material is dependent upon strain, strain rate, and temperature. After two constraints are imposed on both the streamline and contact length geometries, the shear angle may be predicted by using the principle of minimum work. For a wide range of cutting conditions predicted cutting pressures and shear angle match experimental results from the literature.

Abrasive Water Jet Machining of Brittle Materials

M. H. Miller and K. Y. Tiew

State of Michigan Research Excellence Fund

Abrasive water jet machining is a useful technology for making two dimensional cuts and slices. In this project we investigate its applicability to the cutting of brittle materials. We are trying to understand the trade-off between material removal rate and finished surface quality. We began this investigation by looking at the impact of a single particle on glass. We performed single particle impact experiments and finite element simulations. The results provide guidelines for choosing particle size, incident angle, and particle velocity that minimize fracture damage while maximizing material removal rate.

Materials Processing

Interfacial Issues in Multi-Chip Module Conductive Adhesive Interconnects

A. Chandra and Y. Huang

National Science Foundation; National Institute of Standards & Technology; Motorola

Recently, US material manufacturers have developed polymer matrix composites, consisting of an organic resin matrix permeated with conductive (silver, nickel, metal plated glass or metal plated polymers) particles or flakes. These Conductive Adhesives (CA) are typically available as pastes or films, and provide a new avenue for achieving very fine pitch in Multi-Chip-Modules (MCMs). With its high thermal and electric conductivity, the CA interconnect can be highly suitable for many higher end applications of high density MCMs, chips-on-glass technology, and crystal oscillators. In view of the commercial potential for CA interconnects and the current state of the art in predicting life and reliability of CA interfaces, we will pursue the following technical objectives: 1) Mechanical, thermal as well as electrical properties of CA interfaces will be characterized experimentally and modeled theoretically over the full temperature range of applications. 2) Due to thermal mismatch between the chip and the substrate under thermal cycling, CA interconnects will experience severe fatigue and creep loading. Characteristics of CA interconnects in such situations will be investigated in detail. 3) Based on the analyses and experimental observations, a life prediction model will be developed for CA interconnects. 4) Design recommendations in terms of material properties of CA and processing parameters will be made to improve reliability of CA interconnects in MCMs.

Discontinuous Chip Formation and the Role of Shear Bands in Machining Processes

E. C. Aifantis, J. W. Sutherland, J. Huang, and W.W. Olson

Michigan Technological University

A theory of thermo-viscoplastic instability in simple shear is applied to analyze the formation of serrated chips in orthogonal machining. Parameters for estimating shear band width and spacing are derived based on the theory in terms of associated cutting conditions and properties of the work material. A criterion for forming serrated chips is established in terms of cutting conditions and work material properties. It is found that the predicted shear band spacing increases with the increase of feed rate and the decrease of cutting speed. The results agree well with the experimental observations found in the literature.

Flow Simulation and Mold Design for Plastic Encapsulation of Microchips

M. Gupta and D. L. Crouthamel (Lucent Technologies)

National Science Foundation, Lucent Technologies

To provide mechanical strength to a microchip and to protect it from the nearby environment, a plastic encapsulation is used. A proper encapsulation is essential for high-assembly yields and a long-term reliability of the chip. However, if the mold-geometry, encapsulating material and the processing conditions are not selected properly, the flow during the transfer molding of plastic may produce a gapwise movement of the microchip/leadframe assembly (paddle shift) as well as deform the connecting wires (wire sweep). Presently, repeated molding tests are carried out to improve the mold design, the encapsulating material and the process condition during the molding. This trial-and-error approach consumes a significant amount of time and money, but rarely provides the optimal design. In this research a software for computer simulation of the flow during the encapsulation process is being developed. By using this

Establishment of a Cleanroom Infrastructure for Microfabrication

A. Kulkarni (EE) and C. Friedrich

Michigan Technological University Research Excellence Fund

To provide the basic microfabrication processes whereby microelectromechanical systems and miniaturization technologies are developed, a 400 square-foot Class 10,000 cleanroom is being installed. The facility can easily expand to 1,200 square-feet as the research and education programs develop. The facility will have the equipment required for silicon lithography and etching, microstructure evaluation, and system packaging.

Other

Vehicle Dynamics Evaluation Via Human Factor Engineering Approach

K. Moon and M. Osborne (KRC)

GM

The project investigates the relationship between various drive systems of vehicle and the resulting vehicle performance under winter driving condition. It develops the required information and measurement metrics to evaluate vehicle performance effectively. It also investigates a correlation between the subjective data collected from general public and the objective data obtained using the metrics.

Precision Micromanufacturing Processes Applied to Miniaturization Technologies

C. Friedrich and H. Zhang
National Science Foundation

Micromechanical machining is being applied to a variety of microscale applications. To support and train students in this and other closely allied microprocesses, curriculum development was undertaken resulting in the development of six new senior / introductory graduate courses in microscale processing, applications, and evaluation. The course development was accompanied by the development of extensive tutorials available on the world-wide-web at www.me.mtu.edu/~microweb. A CD-ROM was also developed which contains processing videos in addition to the graphic-based tutorials available on the web.

Development of Internet-based Manufacturing Education Materials

J.W. Sutherland and M. Greca
National Science Foundation

The goal of this National Science Foundation-funded undergraduate research project is to develop a comprehensive set of manufacturing-related education materials and to make these available via the internet. Materials being compiled include tutorials on manufacturing processes, graphs/figures to illustrate equipment, and movies/animations.

Journal Papers and Books

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A. Chandra

K.-P. Wang (Ph.D), “Mechanics of Defect Evolution During Machining of Brittle Materials”.

M. Miller

Thrinath S. Kakumann (MSME), September 1998, “Model for Self-Dressing of Resin Bound Grinding Wheels”.

Kee Yoon Tiew (MSME), August 1998, “Fracture Elimination and Minimization in Abrasive Water Jet (AWJ) Machining of Brittle Materials”.

S. M. Pandit

Atul Godbole, (MSME), Winter 1997, "Development and Testing a Fourier Analyzer Microcomputer Interface for Data Dependent Systems Modeling".

John Roth (Ph.D.), Spring 1998, "Monitoring End-mill Wear and Predicting Tool Failure Using Accelerometers".

J. W. Sutherland

Hong Li (MSME), May 1997, "Prediction of Cylinder Boring Surface Errors With and Without Cutting Fluids" (with W. W. Olson).

Vivek Saxena (MSME), May 1997, "A Study of Structural Characteristics of a Stewart Platform Based Machine Tool."

Hrishikesh Gowaikar (MSME), July 1997, "Characterization of the Dynamic Behavior of a Cutting Fluid System," (with W. W. Olson).

Praveen D. Rao (MSME), August 1997, "Prediction of Chip Morphology in Orthogonal Machining Processes," (with W. W. Olson).

Amy Wheaton Bergstrom (MSME), November 1997, "Reducing the Environmental Impact of the Drilling Process" (with W. W. Olson).

Nilesh Soni (MSME), December 1997, "Application of Goal Programming to Reduce the Envionmental Impact of Machining Processes" (with W. W. Olson).

Dongming Liu (Ph.D.), February 1998, " Vibration Abatement in a Turning Process Via Application of an Activity Controlled Tool Holder."

Cecil Daniel (Ph.D.), April 1998, "Analysis and Modeling of Angular Errors in Precision Sliding Motion with Application to Machine Tools."

Yuliu Zheng (Ph.D.), April 1998, "A Continuum Mechanics Model for Orthogonal Cutting."

Steve Batzer (Ph.D.), April 1998, "An Analytical and Experimental Investigation into Chip Morphology in Orthogonal Machining."

Ching Hung (MSME), June 1998, "Experimental Investigation of Vibration and Damping of Machine Tool Slideways."

Aleksandar Filopovic (MSME), August 1998, "Cutting Fluid System Dynamics: Modeling and Control."

Tengyun Cao (Ph.D.), August 1998, "Modeling of the Thread Tapping Process: Chip Formation and Cutting Fluid Lubrication.".

K. Weinmann

Brian Boudreau (Ph.D.), Spring 1997, "Near-Field Thermal Imaging of Surfaces Below the Diffractions Limit" .

Stefan W. Jurthe (MSME), Fall 1997, "Design, Analysis and Implementation of Advanced Classical and Advanced Methods for Restraining Force Control Via Drawbeads," .

Siguang Xu (Ph.D.), Spring 1998, "On the Formability of Sheet Metals--PartA: Prediction of Forming Limits Based on Hill's 1993 Yield Criterion; Part B: Effect of Drawbeads on Sheet Formability".

Honors & Awards

Abhijit Chandra

National Science Foundation, Presidential Young Investigator Award, 1987

J. F. Lincoln Arc Welding Foundation Award of Achievement 1989

Alexander von Humboldt-Stiftung, Germany, Humboldt Research Fellowship, 1991

Fellow, American Society of Mechanical Engineers, 1996

Yonggang Y. Huang

U.S. National Science Foundation Junior Investigator Fellowship, 1995

ALCOA Foundation Fellow, 1995

Wakonse Fellow, 1993, awarded by the University of Arizona for commitment to excellence in teaching.

Kee S. Moon

Listed in Who's Who Among Asian Americans

Sudhakar M. Pandit

Michigan Technological University Faculty Research Award, 1994

Michigan Association of Governing Boards of State Universities Recognition, 1995.

John W. Sutherland

Presidential Early Career Award for Scientists and Engineers, 1996.

National Science Foundation Career Development Award, 1995.

Society of Manufacturing Engineers Outstanding Young Manufacturing Engineer Award, 1992

Michigan Technological University Distinguished Teaching Award, 1992.