Mechanics and Design Space Exploration of Wire Sawing

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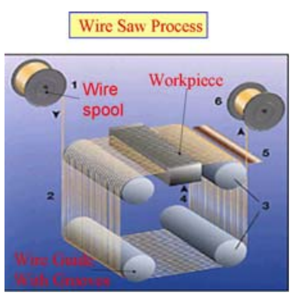
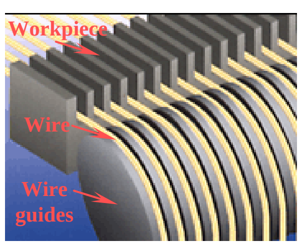
Objectives

- Understanding the salient critical features of Wire Sawing (e.g. effect of Silicon crystal anisotropy, low frequency waviness, surface pulverization, diamond pull-out & wire wear rate) by developing mechanistic and experimentally verified models.
- Utilizing the developed models to enhance the scope of design space exploration for Wire sawing.

State-of-the-Art

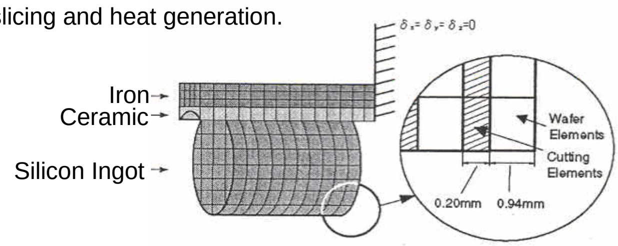
- The loose-abrasive diamond wire saw uses a long (40 – 50 km), thin (0.14 – 0.15 mm diameter), high-tensile strength steel wire wound around three or four polyethylene rollers and stored in two spools.
- The abrasive in an oil-based slurry is fed from a plate to the wire and is carried by the wire to the workpiece.
- A set of 200 to 300 Si wafers, 300 mm in diameter, can be sliced in about 8 hours (Merritt, 1999)





Approaches

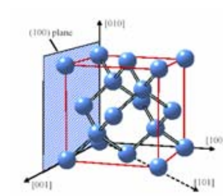
- Prediction of warping in Silicon wafer slicing using finite element method with silicon anisotropic material properties.
- Experimental investigation of silicon wafer warping during slicing and heat generation.



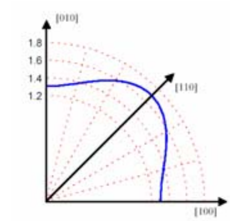
Finite Element Model with Cut Elements

Accomplishments

- Silicon crystal anisotropic property modeling and thermal and mechanical coupled problem study

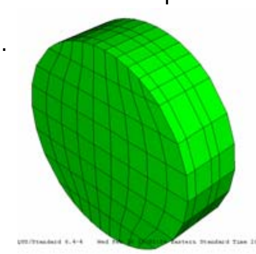


Silicon crystal structure



Silicon young's modulus in (100) plane

- Parameterized meshing of silicon wafer in Abaqus
  - 6 principal meshing variables (e. g. wafer diameter, wafer thickness, rows of one wafer in simulation, etc.)
  - Node coordinates, node index, node ordering on element and element index in Abaqus.
  - Element set and node set



An example of parameterized meshing

- Element removal in Abaqus
  - Insert new steps to remove elements with a short time duration. Function: Model change, type=element, remove
  - For data line, if element number is input, assembly sentences needs to be deleted; otherwise, element sets are required.

Future Work

- Complete wafer slicing FEA model; adding top plates onto the wafer ingot
- Quantify FEA result, especially the wafer warping

Sponsors

- National Science Foundation (NSF)

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Cost-effective Machining of Ti Alloys

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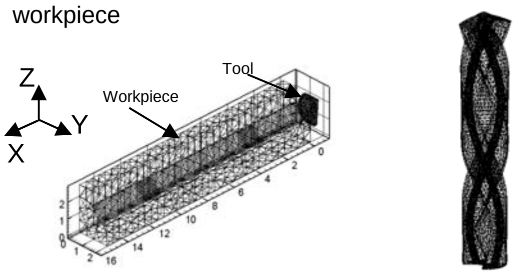
Faculty: *A.J. Shih*

Objectives

- Investigate new technologies for cost-effective, high-throughput machining of Ti alloys
- Provide accurate prediction of temperature and stress for tool selection and design
- Evaluate the influence of high-throughput machining on Ti microstructure and mechanical properties

State-of-the-Art

- High-throughput turning and drilling tests to investigate the cutting forces, tool temperature and wear mechanism, and verify the finite element modeling
- 3D finite element simulation to provide detailed results of stress, strain and temperature distributions in the tool and workpiece



Initial finite element mesh for 3D turning and drilling model (unit: mm)

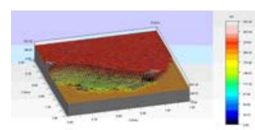
- Metallurgical analysis by scanning electron microscopy (SEM), X-Ray diffraction (XRD), electron microprobe and nano-indentation

Approaches

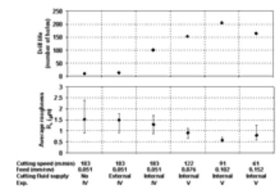
- Conducting high-throughput turning and drilling tests to investigate the tool performance using various process parameters and tool geometries
- Applying 3D finite element modeling of the turning and drilling process to gain better understanding of machining mechanism, investigate the effects of machining process parameters and tool geometries, and predict chip morphology and temperature/stress distribution in the tool and Ti workpiece
- Using the metallurgical analyses, including SEM, XRD, electron microprobe, and nanoindentation to study the Ti-6Al-4V machined surface and the chips in high-throughput drilling tests

Accomplishments

- Achieved high-throughput turning and drilling of Ti over 180 m/min cutting speed

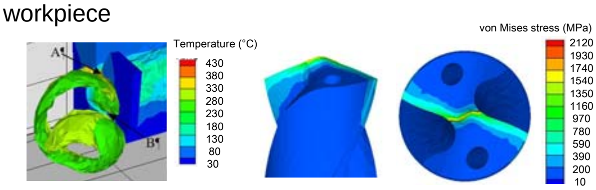


Optical scanned 3D image of the worn tool after turning grade two Ti



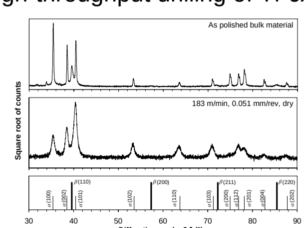
Tool life and machined surface roughness in high- throughput drilling of Ti-6Al-4V

- Provided accurate predictions of the chip formation, temperature and stress distributions of the tool and workpiece

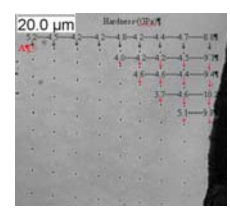


Temperature and stress distributions in finite element modeling

- Analyzed the phase transformation and hardness change as a result of high temperature and large deformation in high-throughput drilling of Ti-6Al-4V



X-ray diffraction patterns of the as-polished bulk material and hole surface after dry drilling



Nanoindentation on the cross-section of Ti-6Al-4V drilling workpiece

Future Work

- Continue high-throughput drilling with high pressure fluid supplied through the drill spindle
- Develop 3D coupled thermal-mechanical modeling of Ti drilling modeling

Sponsors

- A portion of this research is sponsored by the Heavy Vehicle Propulsion Systems Materials Program and Advanced Materials for High BMEP Engines Program, Office of Transportation Technologies, US Department of Energy.

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Milling Tool Design for High Speed Machining of Titanium Alloys

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Objectives

- Understand the milling tool's failure modes
- Develop analytical & mechanistic models to predict milling tool performance
- Optimize cutting conditions and tool geometry to yield maximum productivity at minimum tool cost

State-of-the-Art

- Current industry practice in developing new milling tools has been largely based on experience coupled with iterative machining trials to develop a tool/process combination that achieves the manufacturing requirements, hopefully at a low cost.
- Several analytical and mechanistic models mentioned in the literature show some promise in reducing the need to perform machining trials to find a tool/process that not only meets manufacturing requirements, but also meet the increasing demand for low manufacturing costs.
- These models, on the other hand, have not addressed the issue of tool design and have mainly concentrated on process parameter modification and control
- Chip evacuation and chip shape prediction also has been mostly ignored in literature. Knowledge of the chip evacuation rate and the chip shape, however, is necessary to understand the factors leading to chip clogging.

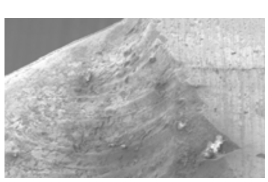
Approach

- Tool Failure Analysis
- Tool Material Analysis
- Bulk Geometry Measurement
- Edge Radius Measurement
- 5-axis Milling Force Model
- Chip Evacuation Model
- Model Optimization

Accomplishments

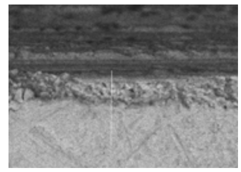
- Chipping is dominant failure mode; beachmark evidence indicates fatigue failure

Chipping Example

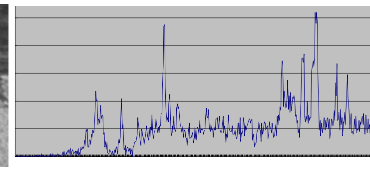


Beachmark Evidence

- Cobalt percentage difference from the edge to the center of tool has been observed in the material analysis



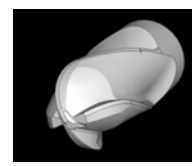
Line scan



Cobalt percentage along the line

- Bulk geometry measurement has been completed using a point laser measurement system, and will be compared with the CAD model in the near future

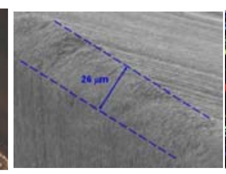
Point Cloud of Bulk Geometry



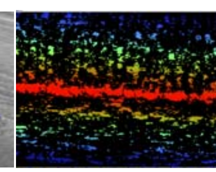
CAD model of tool

- Edge radius has been measured using 3 different methods:

PG1000



SEM



WYKO

- A mechanistic 5-axis milling force model is being constructed. More accurate uncut chip thickness and milling path approximations, Cutting coefficient calibration and calculation is in progress.
- Chip Evacuation modeling requires input from the cutting force model. Validation chip evaluation tests are currently underway and will be used for comparison in the future.

Future Work

- Complete 5-axis milling force model, validate forces
- Perform a fatigue analysis using the predicted forces and tool material property knowledge gain
- Develop code to generate chip shape using forces predicted; simulate chip evacuation, validate chip evacuation rate
- Optimize cutting conditions and tool geometry using the chip evacuation model and the milling force model developed

Sponsor

- This research is sponsored by GE Aviation

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Abrasive Jet Machining for Edge Radius Generation

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Faculty:
A. Shih

Objectives

- Present research related to Abrasive Jet Machining (AJM) for edge radius generation on Inconel.
- Examine the important AJM process parameters for radius generation on Inconel 718.
- Analyze the edge radiuses and surrounding collateral damage developed during the AJM process.

State-of-the-Art

- Burrs and sharp edges on turbine disks can be located in areas where conventional machining process cannot reach.
- Therefore, a method that is quick, flexible, and repeatable needs to be implemented.
- AJM is a flexible method that uses micro-particles suspended in a compressed air stream to remove material through an erosive action.

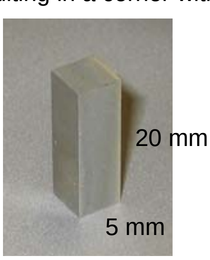
Approaches

- The blasting of the sample is accomplished by impinging particles onto a sample of Inconel 718 with a 90-degree corner.

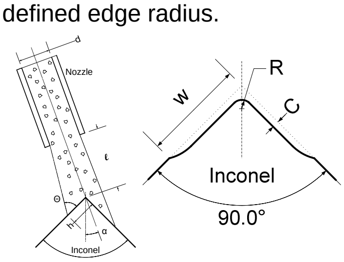
Abrasive Jet Machine

Experimental Setup

- Electrical discharge machined (EDM) square samples are cut to simulate a part edge.
- As the erosion of the edge occurs, the shape changes resulting in a corner with a defined edge radius.



EDM Sample

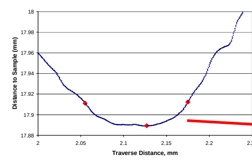


Important AJM parameters

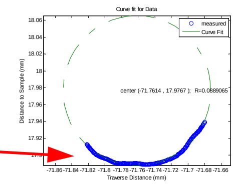
- The creation of this edge radius is dependent on the following important parameters: the time of blasting and the stand-off distance (*l*).
- The amount of collateral damage around the created edge radius is examined.

Accomplishments

- Erosion definition and measurement of the edge radius is accomplished through the use of a 25 μm Optimet laser sensor.

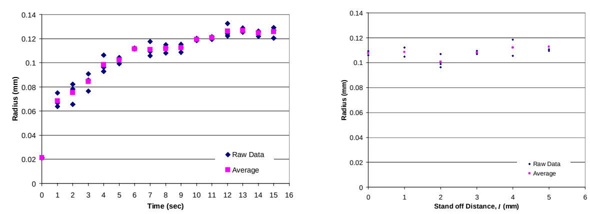


Generated edge radius



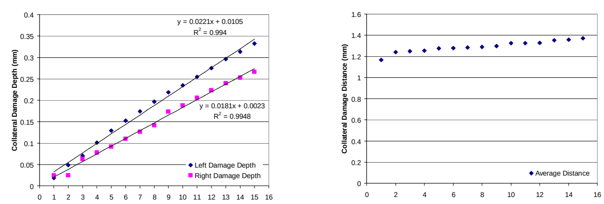
Curve fit

- A curve is fitted to the created edge to determine the radius of the corner.



Effect of time and distance on the size of radius created

- As the blasting time increases, the radius size increases. There is little change in the radius size as the stand-off distance (*l*) is varied.



Collateral damage depth and distance as blasting time is varied

- The collateral damage depth (C) and distance (w) increases as the time and the stand-off distance (*l*) increase.

Future Work

- Examine the effects of changing the blasting angle (α) on the radius size and shape.
- Introduce other types of media and different sizes of particles to see what affect they have on collateral damage and radius size.

Sponsors

- This research is sponsored by General Electric as part of the GE USA program.

For more information, contact Prof. J. Ni; Phone: 734-936-2918; Email: junni@umich.edu