FINAL TECHNICAL REPORT FOR AWARD DE-FG02-96ER45611

1. **PROJECT TITLE:** Design of Surface Texture For Improved Control of Friction and Formability of Aluminum Sheet Products For Automotive Applications
2. **PRINCIPAL INVESTIGATOR:** Lallit Anand
3. **REPORTING PERIOD:** Sep-15-1996 through July-14-2000
4. **ORGANIZATION:** Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139.
5. **DOE AWARD NUMBER:** DE-FG02-96ER45611
6. **SCIENTIFIC ACCOMPLISHMENTS**

(a) **Modeling of Interface Friction For Sheet Forming: Application to Al6111-T4 Aluminum Sheets Formed with D2 Steel Dies**

Successful numerical simulations of forming operations require robust and accurate tool-workpiece interface friction models. We have developed a new isotropic, isothermal, rate-dependent, interface friction model. Material parameters in the friction model are determined for lubricated interfaces between Al6111-T4 sheet and D2 tool steel. The lubricants used are MP404 and boric acid; the MP404 lubricant is currently used in industry, whereas boric acid has recently been proposed as a solid-film lubricant for forming of aluminum sheets. The interface friction model is implemented in the finite element code ABAQUS/Explicit and the finite element program is used to simulate two sheet forming operations: axisymmetric cup-drawing and square pan-drawing. The predictions from the finite element simulation are shown to be in very good agreement with experimental results.

(b) **A Novel Testing Apparatus For Tribological Studies At The Small Scale**

A novel flexure-based biaxial compression/shear apparatus has been designed and built. The apparatus is shown to provide precise, low-noise experimental data over a large range of forces and displacements of interest for studying the tribological responses of interfaces of interest in MEMS applications. Tribological tests may be performed with normal and tangential forces in the μN to N range and relative sliding displacements in the nm to mm range. Further, certain features of the frictional response (e.g. the tangential stiffness in adherence and the relative approach/separation of surfaces during sliding) that were previously difficult to measure experimentally, are now readily obtained. We note that the design of the biaxial apparatus may be scaled to allow for testing over various ranges of forces and displacements. This new experimental capability should provide the tribological data necessary to design the next generation of low friction interfaces for the optimal performance of MEMS.

DOE Patent Clearance Granted

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7. LIST OF MANUSCRIPTS

- (a) A Plasticity Model For Interface Friction: Application To Sheet Metal Forming, *International Journal of Plasticity*, 17, pp. 237-271, 2001.
- (b) A Novel Testing Apparatus For Tribological Studies At The Small Scale. *Proceedings of 2001 ASME International Mechanical Engineering Congress and Exposition*, to appear.

8. SCIENTIFIC PERSONNEL

Mr. B. Gearing and Mr. H. S. Moon