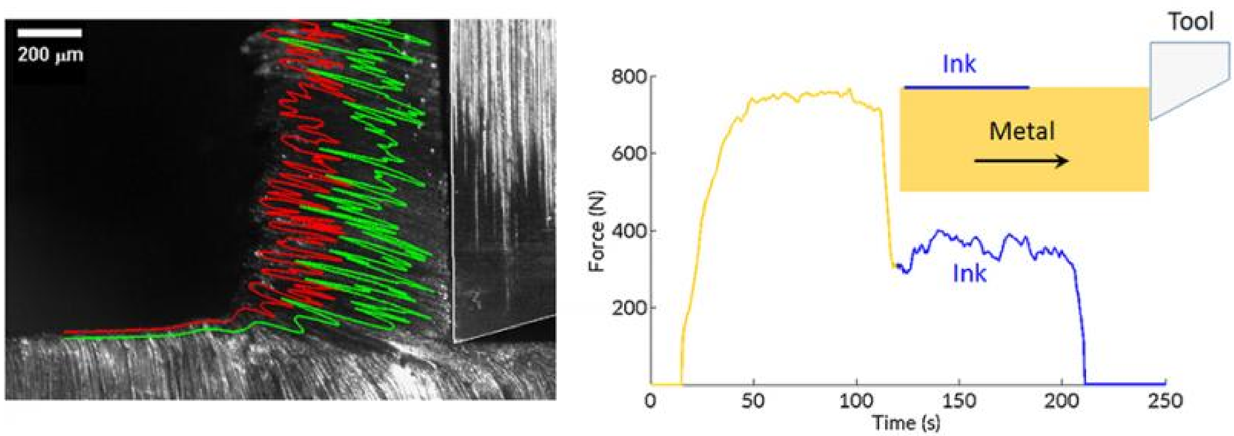
Twin discoveries, 'eerie' effect may lead to manufacturing advances

July 27 2015, by Emil Venere



This image, at left, shows a previously unknown type of metal deformation -- sinuous flow -- in which metal is deformed into folds while it is being cut. New research findings, in graph at right, reveal the cutting force can be reduced 50 percent simply by painting metal with a standard marking ink, suggesting that not only can energy consumption be reduced by 50 percent but also that machining metals can be achieved faster and more efficiently, and with improved surface quality. Credit: Purdue University/ Ho Yeung and Koushik Viswanathan

The discovery of a previously unknown type of metal deformation - sinuous flow - and a method to suppress it could lead to more efficient machining and other manufacturing advances by reducing the force and energy required to process metals.

Researchers at Purdue University discovered sinuous flow deformation and also were surprised to discover a potentially simple way to control it, said Srinivasan Chandrasekar, a professor of industrial engineering, who is working with W. Dale Compton, the Lillian M. Gilbreth Distinguished Professor Emeritus of Industrial Engineering, postdoctoral research associate Ho Yeung and graduate student Koushik Viswanathan.

The team discovered the phenomenon by using high-speed microphotography and analysis to study what happens while cutting ductile metals. They found that the metal is deformed into folds while it is being cut - contrary to long-held assumptions that metals are sheared uniformly - and also that sinuous flow can be controlled by suppressing this folding behavior.

"When the metal is sheared during a cutting process it forms these finely spaced folds, which we were able to see for the first time only because of direct observation in real time," Yeung said.

Findings showed the cutting force can be reduced 50 percent simply by painting metal with a standard marking ink. Because this painted layer was found to suppress sinuous flow, the implications are that not only can energy consumption be reduced by 50 percent but also that machining can be achieved faster and more efficiently and with improved surface quality, Chandrasekar said.

The findings are detailed in a research paper appearing this week (July 27) in *Proceedings of the National Academy of Sciences*.

"The fact that the metal can be cut easily with less pressure on the tool has significant implications," Compton said. "Machining efficiency is typically limited by force, so it is possible to machine at a much faster rate with the same power."

Applying less force also generates less heat and vibration, reducing tool wear and damage to the part being machined, which would improve the accuracy of the process while reducing cost, he said.

The discovery is intriguing to researchers because the ink was not added between the cutting tool and the metal; it was painted onto the free surface of the metal where it was not in direct contact with the tool.

"This may sound eerie, even ridiculous, to people in the field because the cutting is not happening on the painted surface, it is occurring at some depth below," Viswanathan said.

In one class of experiments, Yeung inked only half of a sample. When the cutting tool reached the inked portion, the amount of force dropped immediately by half, seemingly by magic.

He tested various coatings including the marking ink, nail polish, resins and commercial lubricants. He also tried first coating metal with a lubricant before adding the ink. Findings revealed that because the lubricant prevented the ink from sticking well to the surface, the suppression of the sinuous flow was less effective.

"It seems that the ink used commercially to mark metal is very good at suppressing the sinuous flow, probably because it is designed to stick well to metals," Chandrasekar said.

This discovery leaves open the possibility that coatings with improved adhesion might produce greater suppression of sinuous flow and further reductions in cutting force.

The observed folding in metal resembles patterns created during the flow of highly viscous fluids such as honey and liquid polymers. It also is similar to fold patterns observed in natural rock formations. The researchers borrowed methods from the geophysics community in their analysis of fold properties in metals.

Although the team made the discovery in metal-cutting experiments, Chandrasekar said understanding sinuous flow and its suppression and control could lead to new opportunities in a range of manufacturing applications that involve metal deformation such as in machining, stamping, forging and sheet-metal processes.

Another possibility is the design of new materials for energy absorption - by deliberately enhancing sinuous flow - for applications in armor, vehicles and structures.

More information: Sinuous flow in metals, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1509165112

Provided by Purdue University

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