Study of Damage distribution over the Primary Shear Zone in the Metal Cutting using Nanoindentation

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Abstract

In our effort to develop metal cutting as a high strain rate test, we are interested in mapping the damage distribution over the primary shear zone (PSZ). The approach is to quantify the modulus degradation via nanoindentation and use this as a measure of damage. It is shown that the hardness of the material increases and the modulus degrades as it shears through the PSZ.

Introduction

There are well established methods for measurement of hardness and modulus of elasticity using nanoindentation tests [1]. It is also widely known that the modulus of elasticity is related to damage [2]. Basaran has studied damage of solder joints under fatigue loading to quantify the reduction in elastic modulus using nanoindentation tests [3]. However there are no previous studies in which nanoindentation has been used to measure damage in high strain rate tests.

We use ultra high speed photography and digital image correlation (DIC) for measuring the strain rate in the PSZ in orthogonal metal cutting which is illustrated in Figure 1. The strain rate in the PSZ is between 10^3 /s and 10^6 /s, depending on cutting conditions. By comparing FEA results for the strain rate distribution through the PSZ with the experimental values, the parameters of the constitutive model are refined.

Since the shear strain in the PSZ is of the order of 200%, damage distribution over the PSZ should be included into the constitutive models to improve its accuracy. However, the PSZ is typically only 10 to 100 μm thick, necessitating the use of nanoindentation to detect the degradation in modulus due to damage.

Approach

Specimens of the nature shown in Figure 1 were prepared using a linear slide based cutting setup (Figure 2) by stopping the machining midway through a cut. The specimen is mounted and polished for metallurgical examination and nanoindentation. On an AISI 1045 steel specimen, we performed 100 nanoindents each on the workpiece and on the chip (Figure 3). The tests were performed using our Hysitron Ubi1 nanoindenter with a Berkovich indenter at two different loads of 6 mN and 10 mN.

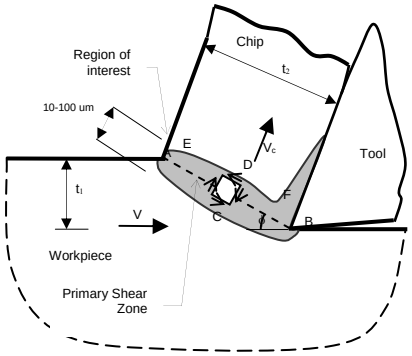

Figure 1: Schematic of orthogonal cutting showing the primary shear zone

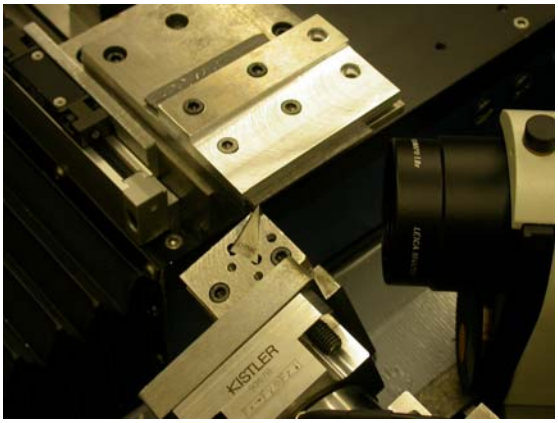

Figure 2: Close-up of the linear machining setup and the microscope which is looking at the tool while the tool is mounted on a three axes dynamometer

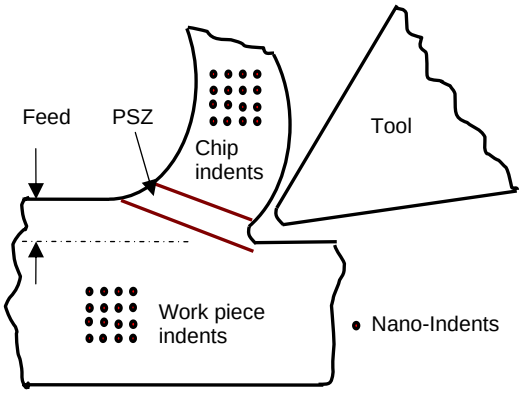

Figure 3: Schematic shows the location of indents on the chip and on the workpiece

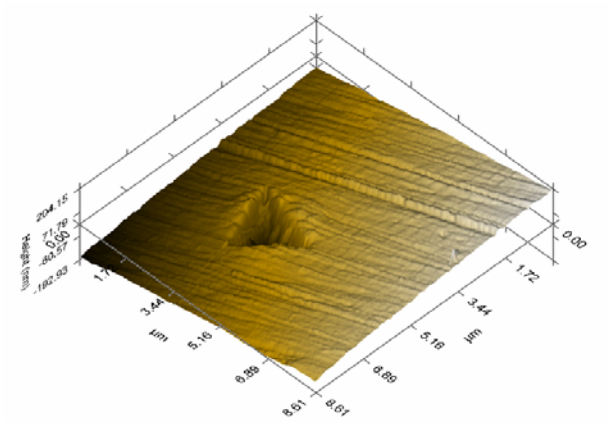

Figure 4: The SPM image of the Berkovich indent on the chip (10mN)

Results

Figure 4 shows the SPM image of a typical indent on the chip. It can be seen that there is significant amount of pile-up. The hardness and the modulus of elasticity at the location of each indent were obtained by analyzing the unloading data of the load-displacement curves based on the standard Oliver and Pharr method [1]. About 10 to 15 outliers were ignored and the remaining data was used to find the average hardness and modulus in the chip and in the workpiece that are given in Table1. Notice that there is degradation in modulus of the chip of about 10% as compared to that of the workpiece.

We tested the hypothesis that the mean value of the modulus of elasticity of the indents on the chip is smaller than the mean value of the modulus of elasticity of the indents on the workpiece. We could conclude that the modulus is degraded over the PSZ with essentially 100% confidence.

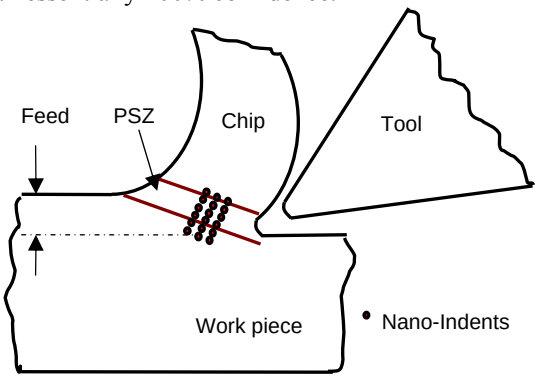

Figure 5: Performing nanoindents over the PSZ.

Conclusion and Future work

Nanoindentation testing has been successfully used to measure the change in hardness and modulus of elasticity occurs in metal cutting.

Given that there is a degradation of the modulus from the workpiece to the chip, we are gearing up to carry out experiments to relate the degradation in modulus to the strain by performing numerous indents in the region of the PSZ as shown schematically in Figure 5. We are also working on techniques to compensate for pile-up. The experimental data will be used to obtain coefficients for models of ductile damage.

References

[1] W.C. Oliver and G.M. Pharr, J. Mater. Res., Vol 7, No. 6, June 1992

[2] D. Krajcinovic and J. Lemaitre, "Continuum damage mechanics", CISM course, Springer-Verlag, 1987

[3] C. Basaran et al, 55th Electronic Components and Technology Conference, ECTC, 2005

Table: 1

The results of constant load of 6 mN indentations in the chip and the workpiece

	Contact Depth (nm)		Modulus (GPa)		Hardness (GPa)	
	Mean	Stdv	Mean	Stdv	Mean	Stdv
Workpiece	231.21	16.59	203.55	11.02	4.47	0.59
Chip	212.16	18.63	186.23	17.89	5.29	0.84