Proceedings of 7th CIRP International Workshop of Modeling of machining Operations.
ENSAM, Cluny, France, 3-4 May 2004

Modeling of the Contact Stress Distribution at the Tool-Chip Interface

V. P. Astakhov[1] and J. C. Outeiro[2]
[1] Astakhov Tool Service, 3319 Fulham Dr., Rochester Hills, MI 48309, USA.
[2] Graduate School of Science and Technology, Portuguese Catholic University, 3080-032 Figueira da Foz, Portugal.

Abstract

This paper deals with the modeling of the contact stress distribution at the tool-chip interface. It includes a comprehensive critical review of the various attempts which have been made to determine the stress distribution over this interface. It reveals that more than ten different types of contact stress distribution have been reported in literature. According to the latest reported results, the uniform distribution of normal and shear stresses is the case in metal cutting.

To understand the real contact stress distribution, the tool-chip interface was modeled as a contact problem of indentation of the deformable work material by a rigid punch. The analytical and FEM results are obtained, discussed and compared with those obtained experimentally. It is conclusively proven that the distribution of normal and shear stresses is not uniform. The real stress distribution is discussed on the basis of the obtained resuts.

1 INTRODUCTION

When metal is cut, the cutting force acts mainly through a small area of the rake face, which is in the contact with the chip and thus is known as the tool-chip interface. Therefore, it is of interest in cutting force determination and considerations of tool wear to determine the contact conditions at the tool-chip interface. To comprehend the contact process at the tool-chip interface, the following should be analyzed: the contact pressure (normal and shear stresses) distribution, the temperature distribution, and the parameters of relative motion.

Many studies have been aimed at obtaining a better understanding of the conditions at the tool-chip interface through studying the distribution of the normal and shear stress at this interface. A variety of experimental techniques including photoelastic tools, split-tool dynamometer, transparent tool for the direct observation of the tool-chip interface, metallurgical examination of 'quick-stop' chip-section, experimental slipline field method and others have been developed [1-9]. Figure 1 presents experimental results on the contact stress distribution obtained by different researches.

Andreev [10] using the photoelastic method, found that the whole contact length l_c is divided into two distinctive parts of approximately equal length: the plastic part which extends from the cutting edge to the middle of the contact length (or the length of the tool-chip interface) and the elastic part from the middle of contact to the point of chip separation. The results obtained indicate that the normal stress, being zero at the point of chip separation, increases exponentially towards the cutting edge (curve 1, Figure 1a). The distribution of the shear stress obtained by Andreev is shown in Figure 1b, curve 1. Kattwinkel [11] using similar experimental technique obtained similar distribution of the normal stress (curve 1, Figure 1a) but different distribution of the shear stress (curve 2, Figure 1b). Other researches using similar technique obtained the following results: Takeyama and Usui [12] obtained the normal stress as shown by curve 2 in Figure 1a and for the shear stress by curve 3 in Figure 1b; Usui and Takeyama [13] improved the accuracy of photoelastic experiments and thus concluded that the distribution of the normal stress is as shown by curve 3 in Figure 1a and that of shear stress as shown by curve 4 in Figure 1b; Chandrasekaran and Kapoor [14] found that the contact length l_c is reverse proportional to the rake angle. For positive rake angles (0, 10, and 20°) the distribution of the shear stress corresponds to that given by curve 3 in Figure 1b but when the rake angle was negative, the distribution given by curve 5 in Figure 1b was the case; Okushima et al. [15] found that the shear stress distribution is similar to that given by curve 1 in Figure 1b and the normal stress follows curve 6 in Figure 1a.

Using the split tool method, Loladze [6, 16, 17] found that the distributions of the normal and shear stresses correspond qualitatively to those found by Andreev (curve 1, Figure 1a and curve 1, Figure 1b, respectively). Using this experimental technique, other researched obtained the following results: Kato et al. [18] concluded that for work hardened and perfectly annealed aluminium, copper, and lead-tin alloy the normal stress distribution corresponds to curve 4, Figure 1a while the shear stress distribution follows curve 3, Figure 1b. For zinc, the normal and shear stresses closely (qualitatively and quantitatively) follow each other and their distribution corresponds to curve 1, Figure 1a and curve 6, Figure 1b, respectively.

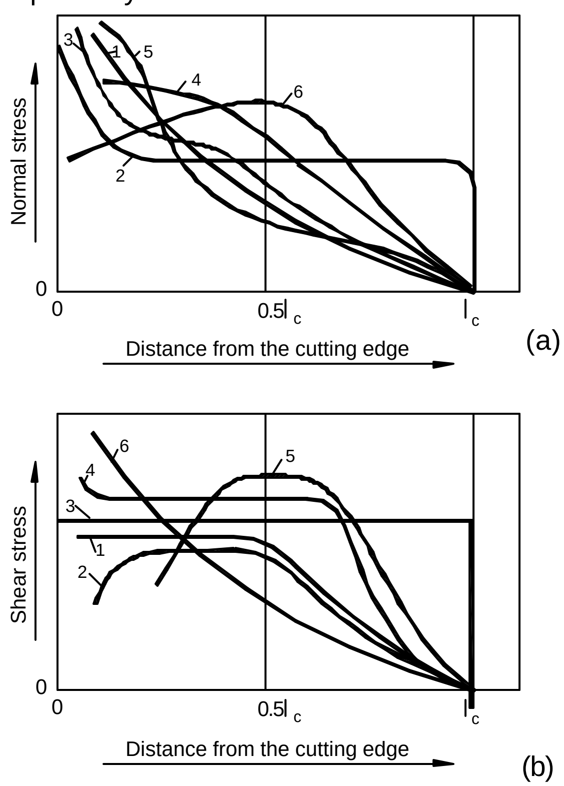

Figure 1: Stress distributions reported in literature: (a) normal stress; (b) shear stress

Using experimental slipline field method, Roth and Oxley [19] qualitatively obtained stress distributions shown in Figure 2a by curve 1 and in Figure 2b by curve 1. As seen, a stress singularity exists at the point of chip separation from the rake face that cannot be physically justified. Later on, Oxley in Chapter 7 "Predictive machining theory based on a chip formation model derived from analyses of experimental flow fields" of his book [4] concluded that "a plastic state of stress exists in the chip over the full contact length and that the deformation in the chip can be represented by a rectangular plastic zone with no sliding at the interface." (Page 100 in [4]) Further followers of this method tried to take into account the so-called ploughing force components due to the radius of the cutting edge [20]. After a number of assumptions, the distributions of the normal and shear stress were obtained to be uniform over the tool-chip contact length as shown in Figure 2ab, curves 2a and 2b, respectively. These results are in direct contradiction with those of previous experimental studies where the division of the contact length into two distinctive parts (plastic and elastic) was clearly observed. Moreover, the stresses' singularity at the point of chip separation from the rake face has never been explained.

A critical analysis of the above-mentioned and other studies related to stress distribution beyond those analyzed above (for example [2, 3, 21, 6, 22-24] shows that it is quite possible that actual stresses and stress distributions may have not yet come to light due to a significant scatter in the results obtained.

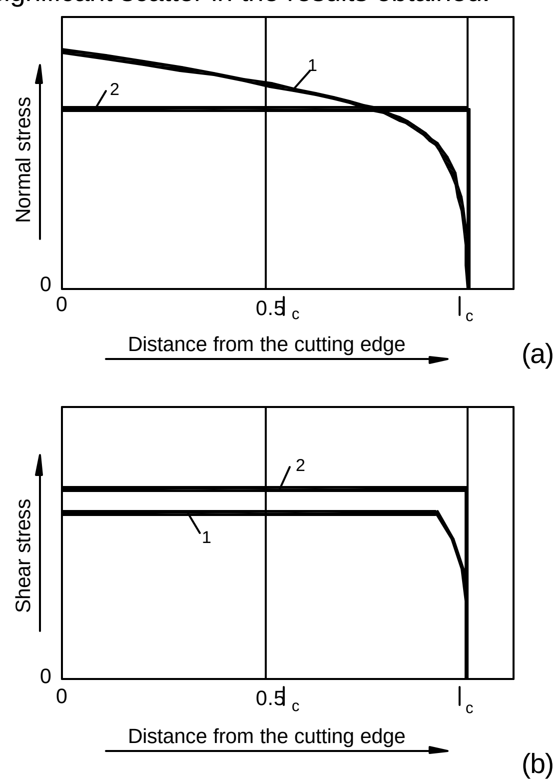

Figure 2: Qualitative representation of the normal (a) and shear (b) stress distributions at the tool-chip interface obtained by Roth and Oxley [19] for a free machining steel.