FRACTURE AND CRACKS IN METAL CUTTING

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ABSTRACT

The different forms of wear that take place on a cutting tool are crater wear and chip notching on the rake face, flank wear and grooving on the clearance face. Fracture usually occurs across the chip notch. In addition to fracture, cracks can also occur. Comb and transverse cracks have been observed on the rake face of cutting tools. This has also been observed by the author on TiC coated tungsten carbide tools, tools in popular use today; cracks promote diffusion wear by the Kirkendell effect. The author has developed a crackless coated tool consisting of a TiC coating on a TiC substrate. This tool outmatches other coated carbides. These developments are also discussed in this paper.

KEYWORDS

Cracks in workpiece, metal removal by fracture, comb and transverse cracks in cutting tools, cracks in coatings on tools, crackless coatings.

INTRODUCTION

In the International Conference on Fracture, there are likely to be many participants unfamiliar with manufacturing and in particular with the theory of metal cutting. The first part of this paper therefore deals with fracture in the workpiece and draws attention to a popular misconception. There is no crack ahead of the tool during a cutting operation like when wood is split. If at all fracture occurs, it is at the end of a cut of a brittle material, or during ultra high speed machining, or in impact machining of highly brittle materials like glass.

The second part deals with fracture of the cutting tool and the cracks that appear on it. Present day concern is over the brittle failure of cutting tools rather than cracks in the workpiece.

The final part of the paper covers coated carbide tools. These tools have

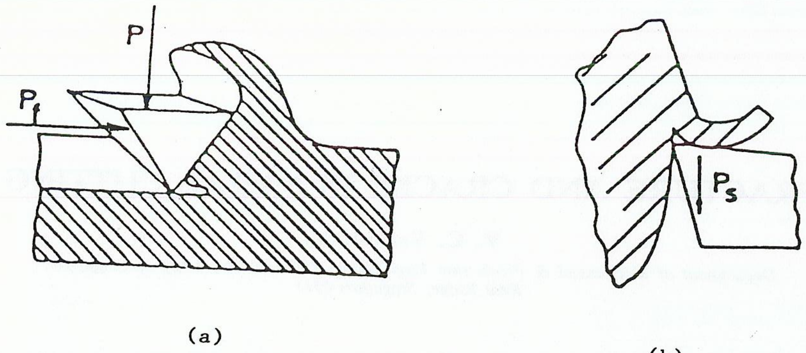


Fig. 1. Two erroneous models that appeared recently, one for (a) abrasive machining and the other for (b) turning. Both show cracks ahead of the tool.

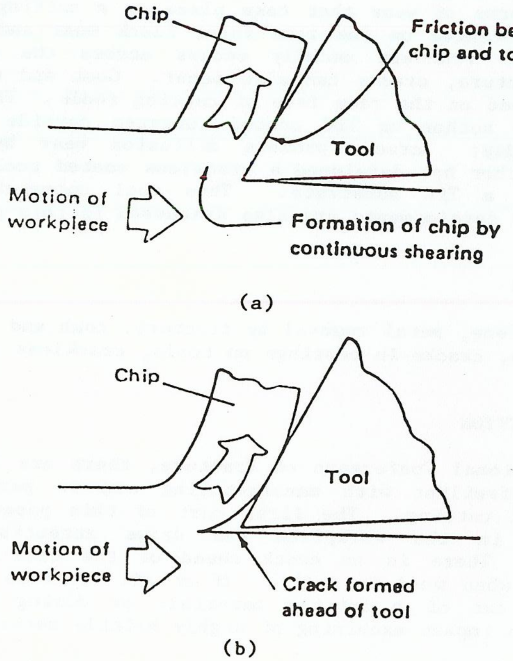


Fig. 2. (a) Present day concept of machining where the chip is the result of plastic deformation.
(b) An earlier misconception arising out of a paper by Reuleux in 1900.

been in use for a little over a decade and are rapidly gaining in popularity. A TiC coating of 5 microns is deposited over a tungsten carbide substrate and results in a 50% increase in cutting speed and a two fold increase in tool life. Its performance would be even better if no cracks appeared on the coating. The cracks are due to differences in the coefficient of thermal expansion of the TiC coating and the WC substrate. A new crackless coated tool developed by the author is highlighted.

FRACTURE IN THE WORKPIECE

It is often wrongly believed by those not familiar with the mechanics of cutting that a crack develops ahead of the cutting tool similar to that when a wedge is driven into a wooden plank. In a paper by Zum Gahr (1977) this impression seems to be conveyed. Fig. 1 shows two figures taken from his paper and which indicate this erroneous belief. Fig. 2. shows models of the cutting process (Boothroyd, 1975), one the present day and the other an earlier misconception. The latter arose from Reuleaux's work in 1900 when he suggested that a crack occured ahead of the tool and that the process could be likened to the splitting of wood. This misconceived model found popular support for many years and it should not again find a place in scientific literature. This would be a negative step. However, Zum Gahr's introduction of fracture toughness in the friction equation is a step ahead and might help identify regions where fracture or burrs might occur.

Chip root studies (Venkatesh and Chandrasekharan, 1982) clearly demonstrate that chip formation is by plastic deformation with no cracks ahead of the tool. Fig. 3. shows chip roots obtained at low speeds and at high speeds. (Venkatesh and Philip, 1972).

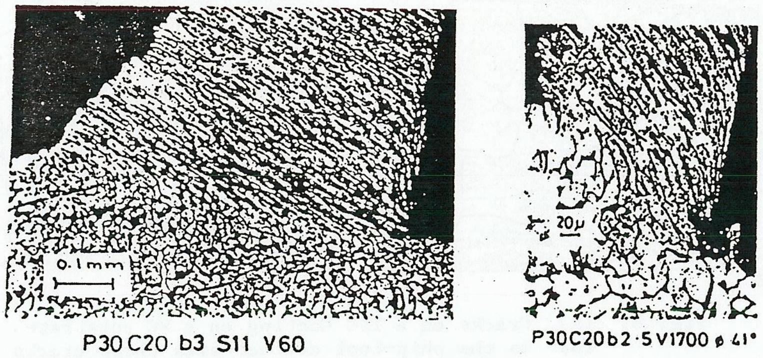
If at all a crack does develop it should be at the end of a cut as indicated by Shaw (1979) whose model is shown in Fig. 4. In Shaw's model, a crack is seen to occur in the tool and in the workpiece at the end of a cut. This is due to the sudden release of stored elastic energy in the tool. A brittle work material like cast iron might fracture at the end of a cut as would a brittle tool. On the other hand a ductile material would result in a burr the removal of which has generated so many methods and machinery in production shops and which has become an art by itself. This model, suggested by the author, is shown in Fig. 4(b).

In the ultra-high speed machining region, each material is said to have a critical speed at which instantaneous failure of the material occurs, probably by fracture. This Utopian region is shown in Fig. 5. with a transition from "the valley of the shadow of death into green pastures." (Venkatesh, 1982).

It is interesting to note that the only prevalent cutting processes that remove material by fracture are the impact machining processes - abrasive jet machining (AJM) and ultrasonic machining (USM). In both the processes, only materials having the property of impact brittleness, like glass, can be machined. (Venkatesh, 1983).

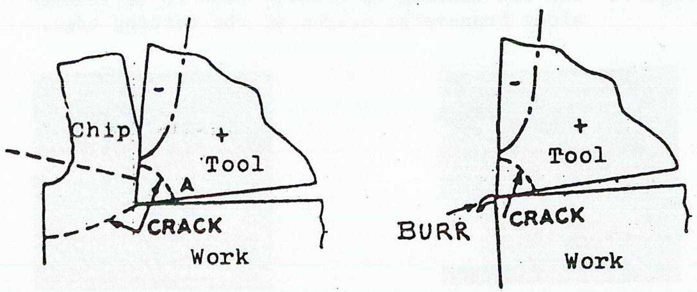
FRACTURE AND CRACKS IN CUTTING TOOLS

Fracture and edge chipping are major modes of failure of brittle cutting



(a) (b)

Fig. 3. (a) Chip root obtained at a low speed of 60 m/min. There is no crack ahead of the tool and the chip is completely deformed.
(b) Chip root obtained at a high speed of 1700 m/min. The upper part of the chip shows undeformed grain. With increasing speeds the amount of undeformed grains at the top will increase until in the ultra high speed region the entire chip will consist of it, showing that the material is removed by fracture.



(a) (b)

Fig. 4. (a) Shaw's model showing that fracture can occur in tool and in the work at the end of a cut [5].
(b) Author's model showing burr formation with a ductile work at the end of a cut.

tools that lack ductility. Such tools are sintered aluminium oxide (ceramics), titanium carbide (solid TiC), and finishing grades of tungsten carbide having a low cobalt content (ISO P.01 type). Fracture occurs easily in interrupted cutting like milling even if the tool material is not brittle.

Fig. 6 shows wear forms on the three faces of a cutting tool (Venkatesh and Sachitanandan, 1980). Fracture occurs in brittle tool materials across the chip notch (Baker, 1982). It starts with a crack and subsequently results in fracture. The fracturing of tools at the end of a cut has been discussed by Loladze (1975) and Pekelharing (1978). Two distinct types of cracks have been observed in a cutting tool during interrupted cutting:

a) cracks running perpendicular to the cutting edge - popularly known as comb cracks.

b) cracks running parallel to the cutting edge - known as transverse cracks.

Comb cracks are said to be the result of thermal effects. During the non-cutting or idling part of a cut the surface of a tool cools at a faster rate as compared to the body of the tool and on this account tensile stresses are set up in the tool, thus causing cracks. Transverse cracks are attributed to both thermal and mechanical impact causes. Pandey et al [12] have developed a safety operating chart and modes of failure during intermittent cutting. This is shown in Fig. 7.

FRACTURE AND CRACKS IN COATED CARBIDE TOOLS

Thin 5 μm coatings of TiC have been deposited by the chemical vapour deposition process on tungsten carbide substrates. The resulting tools are used at 50% higher speed giving at the same time a two fold increase in tool life. These tools are commercially produced and are available from conventional carbide manufacturers.

The author (1977) has observed comb and transverse cracks on the coating (Fig. 8). Diffusion could occur through the comb cracks by the Kirkendall effect. The transverse cracks can chip off at the edge as shown in Fig. 9. The cracks are due to substantial differences in the coefficient of thermal expansion of the TiC coating and the WC substrate. The cracks initially have a polygonal/square/rectangular pattern but in the chip tool contact region, they undergo changes due to thermal stresses, realigning themselves into comb and transverse crack patterns.

By putting a TiC coating on a TiC substrate the author (1980) was able to get a crack free coating as there are no differences in the coefficient of thermal expansion of the TiC coating and the TiC substrate. (Fig. 10).

The tool performed extremely well (Venkatesh, 1984). Titanium carbide tools are brittle tools but with addition of Mo_2C their ductility is increased. These tools do not contain the highly strategic elements W and Co and should therefore be more economical in the future, especially in uninterrupted cutting.

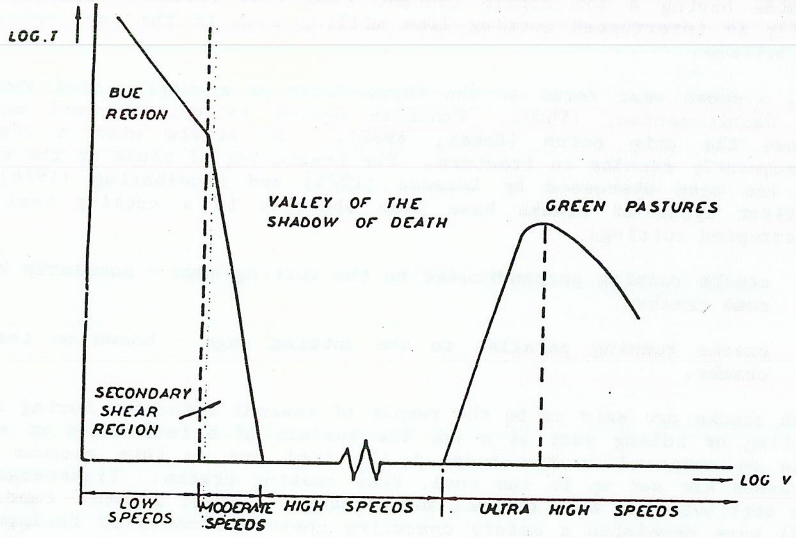
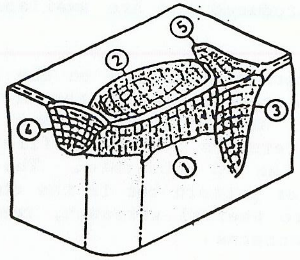


Fig. 5. "From the valley of the shadow of death into green pasture" is what ultra high speed machining promises. Speeds will be in the region of 50,000 m/min and material removal will be by fracture.



1. Flank wear
2. Crater wear
3. Outer diameter wear
4. Oxidation wear
5. Chip notch

Fig. 6. Five forms of wear on a cutting tool. Fracture occurs across the chip notch.

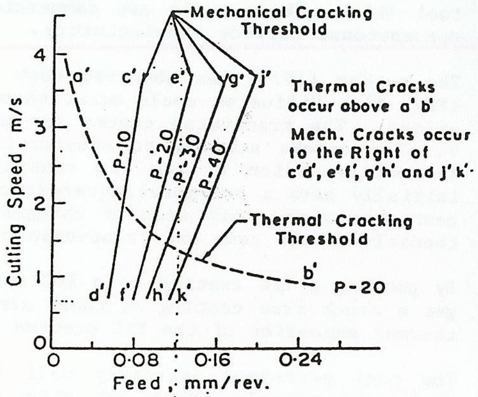


Fig. 7. Pandey's safety operating chart and modes of failure during intermittent cutting.

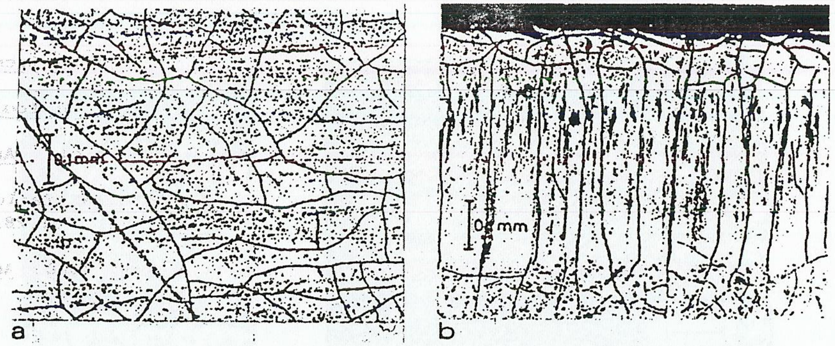


Fig. 8. (a) Cracks on a TiC Coating on a WC substrate.
(b) In the chip-tool contact area these cracks realign into comb cracks in the crater and into transverse cracks at the cutting edge. The latter cracks are easily removed during a subsequent cut.

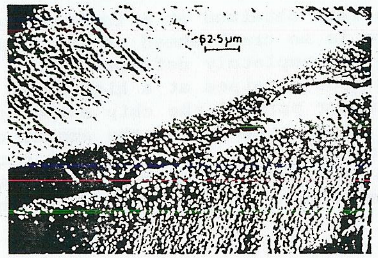
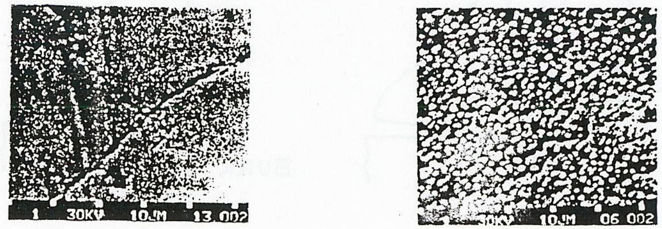


Fig. 9. The TiC coating is clearly seen to be removed along transverse cracks at the cutting edge.



(a) (b)

Fig. 10. (a) Cracks on a TiC coated WC substrate.
(b) Crack free coating of TiC on a TiC substrate. Though free of cracks, there are a large number of pores which presumably act as stress relievers. This tool is far superior to the tool shown at (a).

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