Comb Cracking in Cemented Carbides

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ABSTRACT

Rapid developments have taken place in cutting tool materials; yet the selection of cemented carbides for intermittent cutting is an unique process. During intermittent cutting, the carbides are subjected to both mechanical and thermal stresses caused by alternate heating and cooling. This has resulted in comb crack occuring normal to the cutting edge. Comb cracks usually originate at the depth of cut line farther away from the cutting nose and occurs subsequently closer to the cutting nose. The cracking chracteristic gets saturated around specific number of cracks and time of machining. The coated carbide resists comb cracks more than conventional cemented carbides.

KEYWORDS

Intermittent cutting; Comb cracking; Work material; Hardness; Plain, Coated carbides.

INTRODUCTION

The continued research and development in cutting tool materials has resulted in the generation of newer materials for cutting applications, especially for turning. Despite these achievements in cutting tool materials, the selection of a cutting tool for intermittent cutting such as milling remains unique depending on application. This could be attributed to the availability of only limited published data on the performance of tool materials subjected to combined mechanical and thermal stress cycles. It is well known that the cutting tool is subjected to transient shocks at entry or exit due to varying chip thickness, associated with alternate heating and cooling in milling. Application of cemented carbides in such situations involving interrupted cutting has proved to be uneconomical due to premature tool failure by fracture.

The tool fracture normally occurs well before the permissible limit of wear is attained. Earlier works (Pekelharing, 1978, Keigi Okushuma et al., 1967) on the performance of cemented carbides in milling, have illustrated the occurrence of tool failure due to chipping at low cutting speed, chipping of larger sizes without a preceding crack and chipping at high cutting speeds. The tool failure at low speeds is attributed to the impact load and insufficient fracture rupture strength of the tool materials to resist it. At low speeds, the entry shocks are higher especially with face milling cutters having reduced number of teeth.The tool failures at higher cutting speeds have been attributed to chipping on the rake face and tool breakage due to thermal fatigue. Published literature on the rake face chipping (Shaw, 1979, Pekelharing, 1984, Van Luttervelt et al., 1984) have reported the occurrence of cracks running parallel to the cutting edge on the rake face and subsequent chipping. This tendency is further aggrevated due to stress reversal at the rake face. During intermittent cutting, the tool material is subjected to reversal of stress field due to rapid release of stored elastic energy at the end of cut. This stress reversal usually leads to higher tensile stresses near the cutting edge resulting in tool chipping. Fig.1 illustrates this phenomenon. Further, the alternate heating and cooling of the cutting tip results in thermal stress causing tool chipping. During cutting depending on the cutting condition, the cutting tip gets heated up to around 1000° C (Chandrasekaran 1985) expanding the surface. Due to the resistance of the relatively cooler substrate, this results in surface compressive stresses. During the idling/non-cutting period, the tip is usually cooled to around 200° C, with the surface tending to contract. This results in surface tensile stresses. This is illustrated in Fig.2. When this tensile stress exceeds the permissible limit, the material exhibits cracking. The literature on thermal cracks (Kunio Uehara 1984) reports the occurrence of cracks running perpendicular to the cutting edge (Comb-cracking) and parallel to the cutting edge. This paper presents data on comb cracking during face milling steel workpieces with plain and coated carbide tools.

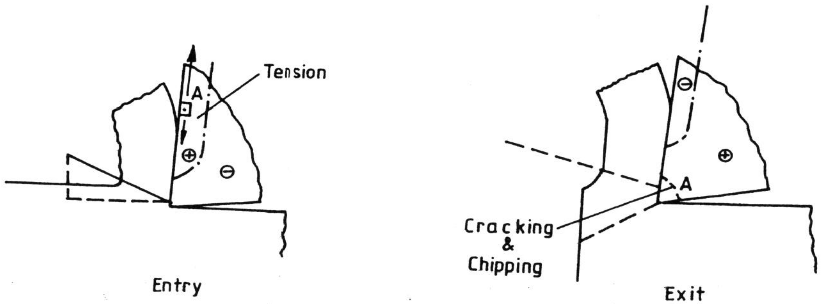


Fig. 1. Stress reversal on the rake face of milling tooth

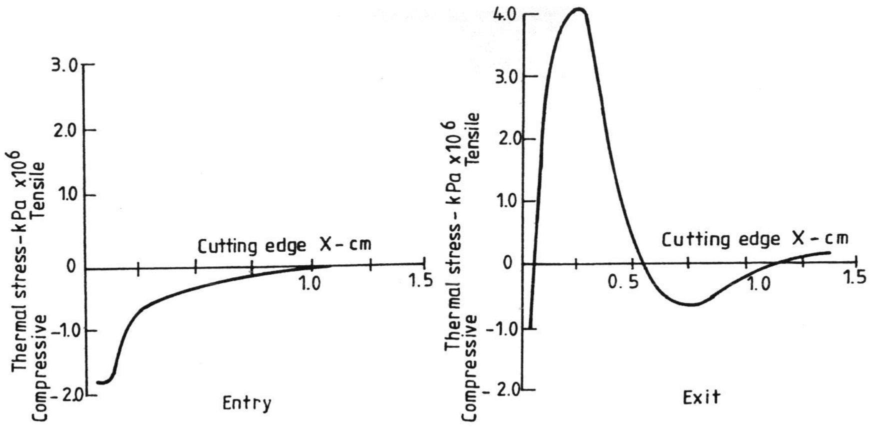


Fig. 2. Typical stress pattern on the rake face of a milling tooth

EXPERIMENTAL

Milling experiments were conducted in FRITZ WERNER milling machine using plain and coated cemented carbide tools. The experimental details are presented in Table 1. During the milling trials, the number of comb cracks occurred on successive intervals of machining time, and the pitch of the comb cracks were measured. The influence of cutting conditions, the type of tools and the workpiece on comb cracking have been assessed.

Table 1. **Studies on Comb Cracks**

Machine Details:		
Machine	:	Fritz Werner Vertical Milling Machine
Power	:	11 KW
Spindle speed	:	18 - 1800 rpm
Cutting Tools:		
Cutting holder	:	WIDAX M40 cutter
Inserts	:	P20-P30 Grade
(i) Uncoated specification	:	SPAN 1203 EDR
(ii) Coated specification	:	TN 35 M
		CVD coated - TiC, TiCN, TiN
Work Materials:		
(i) C45 Steel	:	Normalised
	:	C 0.45%; Mn 0.75%
Hardness	:	180 -190 (BHN)
(ii) En 24 Steel	:	Hardened and tempered
	:	Ni 1.3%; Cr 1.1%; Mo 0.3%; Mn 0.6%; C 0.4%
Hardness	:	38 - 40 Rc

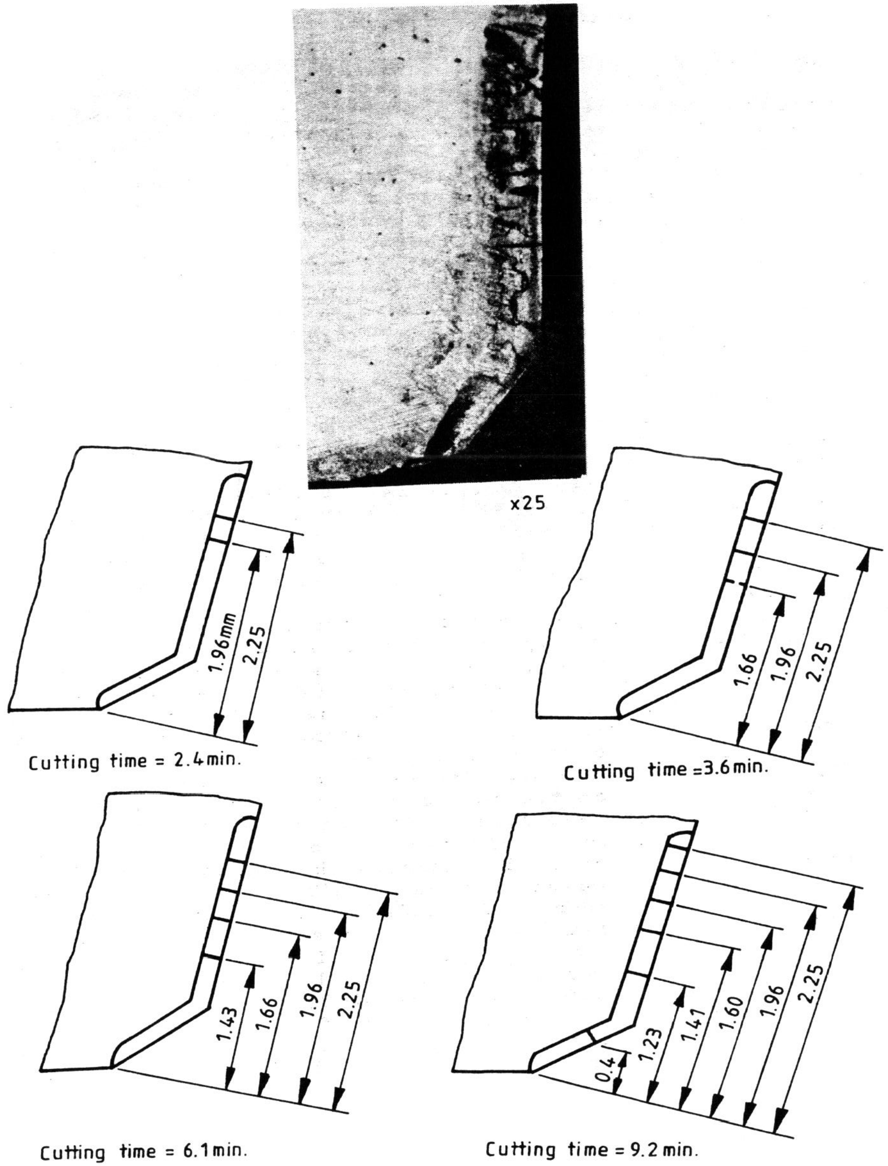
RESULTS AND DISCUSSION

Origin of Comb Crack

As reported earlier, comb cracks normally occur on the rake face perpendicular to the cutting edge. The occurrence of such cracks would reduce the inherent tool strength, resulting in tool fracture. Fig.3 is a typical illustration of the observed cracking. It is seen that the first comb crack occurs on the primary cutting edge side, (farthest away from the cutting tip zone), where the temperature is maximum. Generally during machining the cutting tool experiences maximum temperature at three distinct zones; they are the depth of cut line zone, the cutting nose zone and the secondary zone immediately behind the cutting tip. Once originated, further cracking occurs nearer to the cutting tip zone. It is known that once the crack is initiated, the tensile surface stress which caused the cracking in that zone, decreases, there by increasing the material resistance to cracking in that zone. With further cutting, the zone of maximum temperature and tensile surface stresses shifts towards the cutting tip, promoting further cracking in that zone. This is illustrated in Fig.3. Fig.4 presents typical Scanning Electron Micrograph of comb cracks. It is seen that the cracks are V shaped, with bell mouth opening at the cutting edge. Some of the cracks are discontinuous, probably due to localised resistance to crack propagation from the tool material matrix. It is reported that the alternate heating and cooling of the tool surface results in establishment of higher order tensile stress, causing cracks. During milling, the surface stress on the cutting tools before and after comb cracking (first) were measured using X-ray (Macherauch 1965). For measuring the surface stresses on the cutting tool, X-ray method ($\mathrm{Sin}^2\psi$) was adopted. The milling inserts were irradiated with Cr radiation in Philips Generator P.W. 1140. The X-ray beam was collimated and allowed to impinge on the tool surfaced (used portion). Tbe back reflected X-ray was made to fall on an X-ray film kept at a suitable distance. This reflection was obtained for different orientation of the insert with respect to the X-ray incident beam (Gonimated setting og '4'0. For the different settings, the difference in the radii of the emergent beam (on the film) was measured (Δx_{ϕ} , ψ), This was plotted against $\mathrm{Sin}^2\psi$. The slope on the plot multiplied by the stress constant of the cemented carbide would give the residual surface stress. Fig.5 shows typical $\mathrm{Sin}^2\psi$ plot. From the figure, it is seen that the slope of the $\mathrm{Sin}^2\psi$ plot is positive before comb cracks and is negative after comb cracks. This indicates the presence of surface tensile stress during comb cracking.

Influence of Cutting on Comb Cracks

During milling of steel workpieces, the cutting conditions such as cutting speed (V), depth of cut (a) and feed rate (S) were varied to assess the influence of milling conditions on comb



Speed = 223 m/min. Feed = 0.141 mm/rev. Depth of cut = 2.5 mm

Fig. 3. Typical comb crack propagation observed during intermittent machining

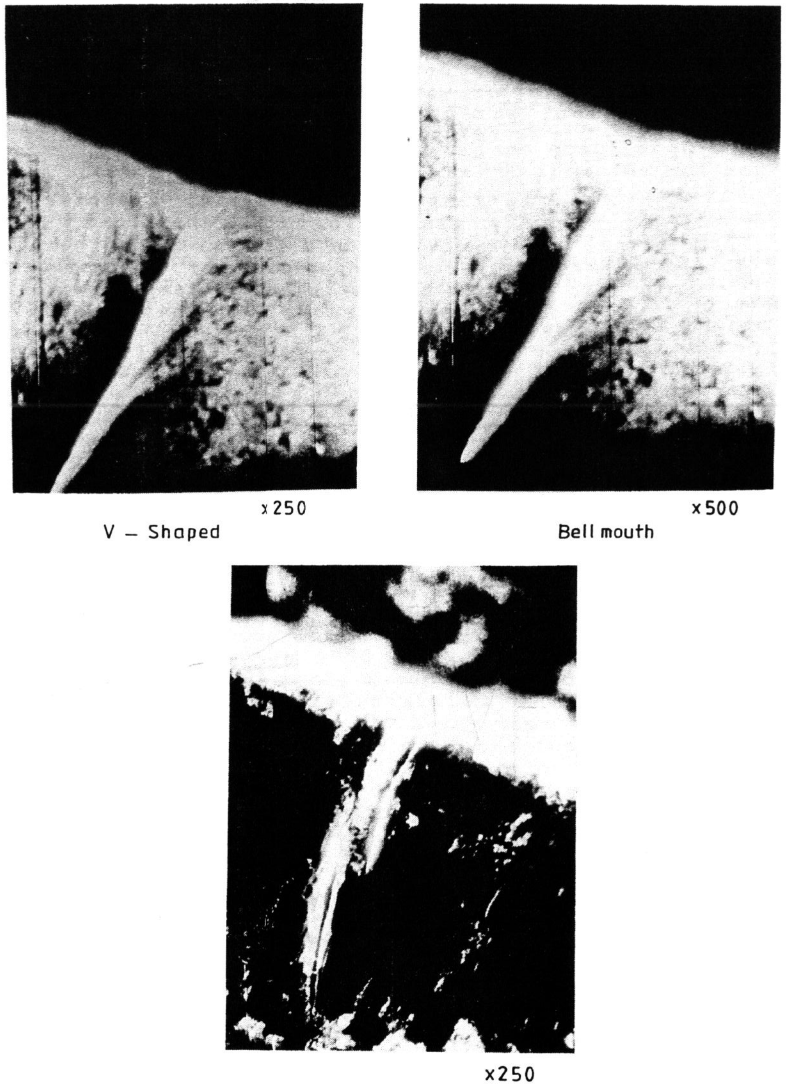


Fig. 4. Typical V shaped comb cracks with bell mouth opening - illustrating the fatigue process during cracking

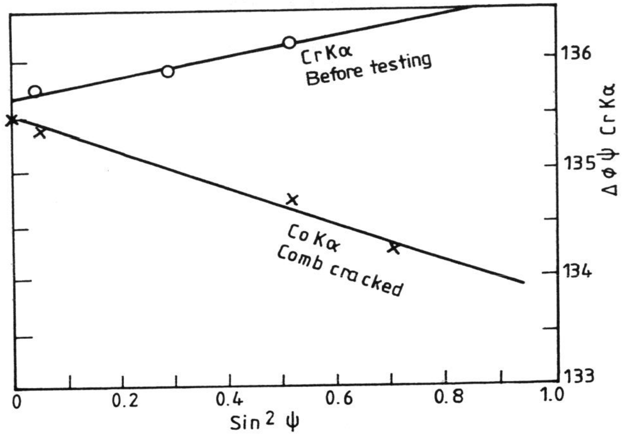


Fig. 5. $\mathrm{Sin}^2\psi$plot showing occurrence of tensile stress over the rake face during comb cracking

cracking. Fig.6 shows the influence of cutting conditions on number of cracks. From the figure, it is seen that practically there is no cracking at all upto around 8 min of milling, when milling with cutting speed of 180 m/min. After 8 min. of machining, number of cracks suddenly occurred. However, with higher milling speeds, more number of cracks occurred and the occurrence of cracking was rather steady from the beginning of milling. The sudden occurrence of cracking after a lapse of 8 min. of milling under low milling speeds could be explained as follows. Under low speeds of milling, the cutting tool tip may either chip off due to shock load or be subjected to cumulative stress which when exceedss a threshold limit, causes sudden comb cracking. When operated with higher milling speed, large number of comb cracks occured. It is well known that temperature of machining Θ is correlated with cutting speed V as

$$\theta = K_1.(V)^b$$

where K_1 - constant

b - material dependent exponent

The higher cutting temperature associated with higher milling speeds enhances the magnitude of thermal stresses on the tool surfaces, resulting in comb cracking. It is also seen in the figure, that the comb crack characteristics get saturated around 6-10 min. of machining depending upon the cutting speed; further, the tool exhibits a saturation level of 3-4 cracks, for a given depth of cut, feed rate and tool-work interface. Milling beyond this saturated level, resulted in the occurrence of cross cracking (parallel to cutting edge) and subsequent chipping of the tool tip.

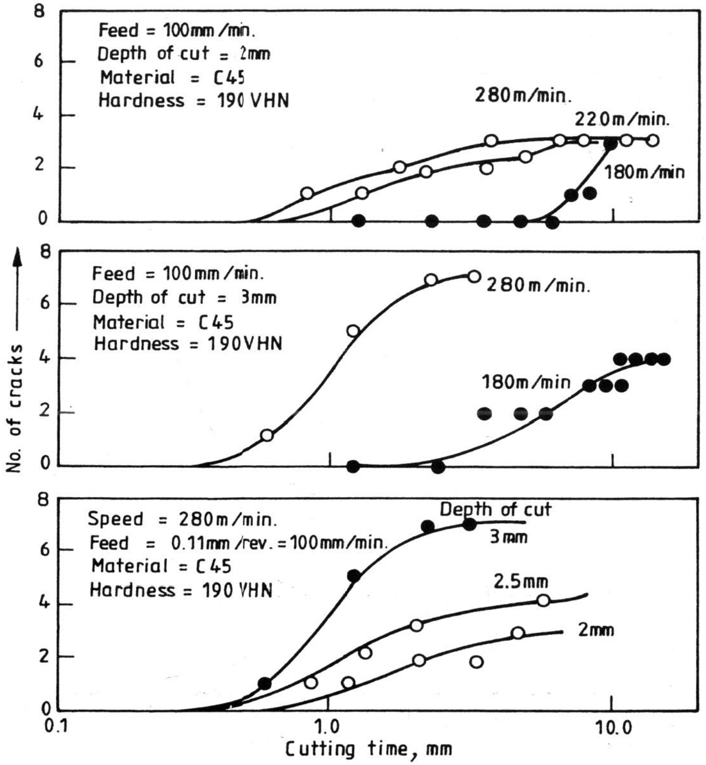


Fig. 6. Influence of cutting conditions on number of cracks

Fig.6 also shows the influence of depth of cut on comb cracking. The cracking characteristics also exhibited a saturation trend. Fig.7 shows typical comb cracking characteristics of milling inserts, when machining En24 steel. It is seen that compared to C45 steel milling, more cracks occurred when En24 steel was machined. Further, coated inserts performed better than un-coated, plain cemented carbide inserts as shown in Fig.8. The coated inserts used were of the TiN coated tools. The inserts coated using Chemical Vapour Deposition proces A multi-layer coating consisting of TiC, TiCN and TiN was present on the tool, with TiN layer forming the outer most surface.

Machining of softer materials, usually results in the tendency of the chip to adhere to the cutting tool rake face; this adhering chip protect the cutting tip by reducing the quenching effects during the non-cutting period. This would delay the occurrence of cracking and also the number of cracks would be reduced. It is well known that the coated tools perform better in turning. The performance of such tools in intermittent cutting is rather mixed in nature. In the present trials, the coated tool performed better. With coated tools, higher milling speed is realizable and the number of comb cracks is also smaller.

Coating on cutting tools generally improve the machining performance by minimising the adhesion at the tool-chip interface. This would reduce the frictional heating. However, due to reduced thermal conductivity of the coated material, one could also expects higher interface temperature. The observed reduction in number of cracks with coated carbides, could be explained as follows:

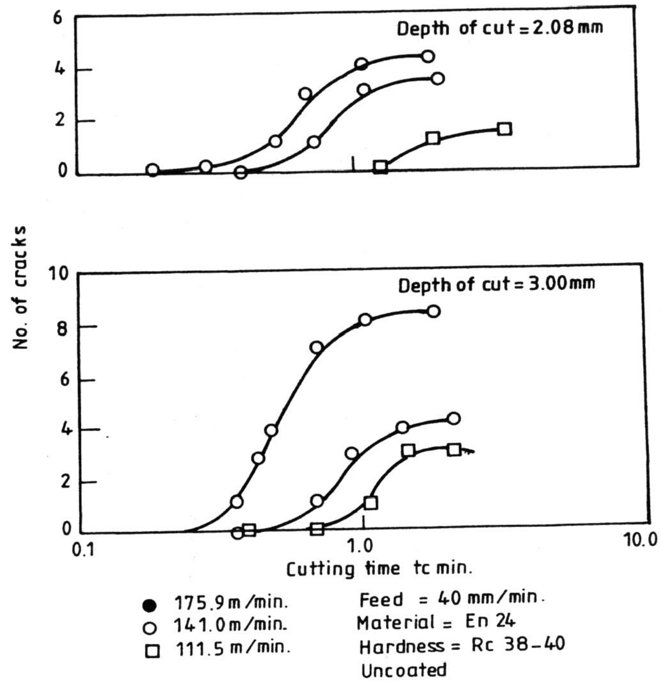


Fig. 7. Comb cracking of uncoated carbides in machining EN24 steel