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ORIGINAL ARTICLE

A comparative study on cutting performance of rake-flank face structured cutting tool in orthogonal cutting of AISI/SAE 4140

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Abstract Surface structuring on cutting tools is a modern application of surface structuring that has shown improvements in tribological phenomena at tool-chip interface. Literature suggests that this technique has been used mainly to structure the rake face of a cutting tool. This study reports on the performance of femtosecond laser-generated structures on both rake and flank faces of the cutting tool. The premise for fabricating structures on both faces of cutting tool was to have strong impact on tool wear and cutting forces so as to reduce power demands. Fabricated structures were in a form of conventional micro-grooves. Performance of structures was assessed in the machining of AISI/SAE 4140 over a conventional range of cutting speeds for the selected workpiece material. The orthogonal cutting tests to investigate the effects of structured tool on cutting forces, friction coefficient and flank land wear rate were performed. Results show that the structured tool is effective in delivering better machining performance as compared to unstructured tool in terms of reduced friction coefficient by 14 %, cutting forces by 10 %, feed forces by 23 %, and compression ratio by 10 %. Characterisation of sticking and sliding contact was evaluated.

Keywords Cutting tool · Surface structuring · Laser machining

1 Introduction

Surface structuring can be used to alter the surface topography in order to improve tribological behaviour [1]. Research on surface structuring has shown that regularly organised structures on the surface can lead to optimum performance. This improvement is linked with effective lubrication, debris entrapment, reduced contact stresses and/or hydrodynamic lift. Recently, this methodology has been applied to cutting tools. The research available on cutting tool structuring is mainly focussed on the rake face of the cutting tool. Application of rake face structured tool has shown benefits in lowering cutting forces [2–10], cutting temperature [8, 11–13], tool wear [5, 8, 11, 14–16] and anti adhesion properties [17].

It is established that compared to unstructured cutting tools, on average a 10 to 20 % reduction in cutting forces and a 20 to 30 % reduction in feed forces can be achieved when rake face structured cutting tools are used in a conventional speed regime. Koshy and Tovey [2] tested the performance of two different rake face structured cutting tools—grooves and overlapping craters in machining of steel and aluminium. It was reported that crater-structured tools were found to be more effective in reducing forces than grooved structures. Thirteen percent reduction in cutting force and 30 % reduction in feed force was reported when steel was used as workpiece while 50 % reduction in cutting forces and 75 % in feed forces were reported when aluminium were used as a workpiece. From their research study, it can be inferred that the capability of structured tools in reducing force and associated variability can be improved by using specifically formulated lubricant for the selected workpiece material. Lie et al. [3] experimentally investigate the effect of lubrication in machining of 1045 steel. Research was carried out using rake face micro-pool lubrication, i.e. structured holes were filled with lubricant, and flood cooled non-structured tools. It was proposed that structured tool with micro-pool lubrication improves contact conditions at the chip and tool interface by lowering contact length by 30 %, cutting forces by 10–30 % and promoting easy chip curl. Jianxin et al. [4] structured three different geometry of grooves on rake face namely: elliptical grooves,

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grooves parallel to cutting edge and grooves slightly angled to cutting edge. Elliptical grooves on the rake face shows smallest cutting forces, temperature and friction coefficient. Mechanism responsible for improve machining performance were effective lubrication and reduced contact length. However, no experimental evidence was provided on contact length reduction. There were 15–25 % reduction in cutting forces, 5–10 % reduction in cutting temperature, 10 % reduction in friction coefficient, and 10 % reduction in shear angle were reported. Xing et al. [5] create rake face structures on ceramic tool and study its performance in machining of AISI 1045 steel. Similar results of reduced cutting forces by 15–20 %, temperature by 10–20 %, coefficient of friction 15–20 % and wear were observed. However, deprived surface finish was reported for structured cutting tool than non-structured tool. Enomoto et al. [9] fabricated micro-grooves array on cemented carbide tool and notice their ability to reduced cutting force, friction and increased shear angle in machining of aluminium alloy. However, associated percentage reductions were not presented. It was explained that better machining performance was a result of constant good lubrication on the rake surface of the cutting tool due to cutting fluid preservation in micro-grooves structures. Similar results were reported by Wen-long et al. [10] in dry machining of Chinese #45 steel. Formerly Jianxin et al. [18] fabricated two separate tools with a single hole on (1) rake face and (2) flank face of carbide tool and filled them with solid MoS_2. Cutting test was performed on hardened steel to test their performance. Both, tool with a hole on rake face and tool with holed flank face showed greater reduction in cutting forces than conventional tool. Whereas, maximum reduction in coefficient of friction was observed in case of holed rake face tool while tool with a hole in flank face revealed more resistance to flank wear. Formation of lubrication film between chip and tool released from the holes was recognized as a mechanism for the associated reduction.

It has been established that along with the geometry, structures should be created parallel to the cutting edge in order make a strong contribution in reducing cutting forces. Kawasegi et al. [6] investigated the effect of structure direction and reported that structures created perpendicular to the cutting edge were filled more and more work material adhered to the tool surface compared to the tool with structures created parallel to the cutting edge. It was further argued that in case of perpendicularly directed structures to the cutting edge, the chip material undergoes plastic deformation over rake face along structure direction which was also parallel to the chip flow. This case increased the adherability of the chip material that required an increased cutting force. Conclusion on reduced cutting forces by 20 % due to corresponding reduction in the friction on the rake face was reported.

On machining of titanium alloys, Ze et al. [8], Wu et al. [11] and Xie et al. [12] discussed the performance of structured cutting tools. Ze et al. [8] created elliptical grooves on the rake face and linear grooves on flank face. Cutting performance comparison was made among unstructured, rake face structured and flank face structured tool. Both Rake face structured and flank face structured tool delivered better cutting performance in term of 5–35 % reduction in cutting forces and 5–20 % reduction temperature. Tool life was also improved by 10–30 %. Similar results were reported by Wu et al. [11] in a comparison performance of three different tools; namely (1) micro-textured self lubrication tool—elliptical structures created on rake face were filled with solid MoS2; (2) pulsating heat pipe self cooling tool-—pulsating heat pipe were preset on rake face of tool and were filled with fluid and (3) pulsating heat pipe and micro-textured lubrication tool—both PHP and structures were integrated. Cutting force, temperature and friction coefficient reduction were obtained maximum in case of pulsating heat pipe and micro-textured lubrication tool and was of 10–15, 15–20 and 5–20 %, respectively. Xie et al. [12] created micro-structures on tool rake face by micro-grinding. A sharpened diamond V tip wheel was employed to fabricate structures. Cutting tests were performed to study cutting temperature and cutting force in dry turning of titanium alloy. A reduction in tool temperature of 103 °C (i.e. 20–27 %) and 35–57 % in cutting force was reported for micro-grooved tool. Further it was reported that an ability of structured tool in decreasing temperature is associated with groove depth.

Research studies on coated rake face structured tools [1, 7, 13] revealed that coated structured tools were more effective in improved machining performance. Da Silva [1] studied the abrasive wear resistance of micro-structured coated tool (TiCN-Al_2O_3-TiN) and non-structured tool. For comparison and to study wear mechanism, micro-abrasion test and turning tests were conducted. It was observed that structured tool resulted in pronounced increase of coating wear rate when put to micro-abrasion test. However, with turning test, coated structured tools provide increased in tool life. However, no percentage increase was reported. It was concluded that increase in tool life was not related to reduction in abrasion wear on flank face. Obikawa et al. [7] created four types of micro-structures (Parallel and perpendicular grooves, pits and raised dots) on rake face of cutting tool and then coated tools with nickel and TiN layer. Cutting experiments were performed on aluminium alloy using structured and non-structured tools. Results confirmed that parallel grooves and raised dot structure were more effective in reducing friction forces by 10 % and coefficient of friction 7 %. Lian et al. [13] on discussing machining performance of tungsten disulfide soft-coated structured tool reports a reduction in cutting forces and temperature of 10–20 and 5–10 % respectively, compared to the uncoated structured cutting tools.

Enomoto and Sugihara [14] and Xing et al. [5] reported in their study that rake face structuring reduced crater wear. While two studies [8, 11] reported on rake face structured tools ability to reduce flank wear when machining titanium alloy. There are few research studies that are found in literature on flank face structuring of cutting tools. Ze et al. [8] reported on performance of self-lubricated structured tools in dry cutting of Ti-6Al-4 V alloy and concluded that tool life was improved by 10 to 30 % when structuring was done on the flank face. Sugihara and Enomoto [14], in their research, structured cutting tools on the rake face and the other on the flank face. Experiments were conducted on medium carbon steel to study tool wear. It was concluded in their study that flank face structured cutting tool exhibits excellent flank wear resistance (reduction of 29 %), while rake face structured tool showed effectiveness in suppressing crater wear by 66 %. Xing et al. [15] irradiated Al_2/TiC ceramic tool with femtoseconds laser on the rake face of the tool, and its cutting performance was compared in machining of AISI 1045. It was concluded that laser pre-treated tools significantly improves wear resistance and small reduction in temperature of the rake face although no significant difference in cutting forces were observed. Recently, on benefits of flank face structuring, Fatima et al. [16] reported an increase of 18 % in tool life and 37 % reduction in tip power.

Growing need for machining miniature and complex parts has put emphasis to improve the machinability of tools such as drill bits and milling cutters. Kawasegi et al. [19] developed drills with micro- and nano-structures that has enhanced machinability of aluminium alloy in a drilling process. Structures created perpendicular and parallel to the chip flow were tested in terms of thrust force. Results confirmed that structures created perpendicularly to the direction of chip flow delivers best cutting performance in terms of reduced thrust force by 20–30 % and uniform chip thickness. Ability of structures to store lubricant and its influence on contact area was established as a reason for this reduction. Ling et al. [20] studied the effects of structuring margins of drill bits for reduced work material adhesion and enhanced tool life. Straggled rectangular small slots were fabricated covering 10 and 20 % of surface of a drill margin. It was established that structured drill bits exhibits extended tool life as they were efficient to shed adhered chip from slot to slot. However, no recognizable differences in performance were reported with respect to structure density and no evident was reported in reduction of thrust force. Chang et al. [21] in a study on tool wear in micro-milling machining reported that structures created perpendicular to the chip direction delivered best performance in deferring tool wear and prolonged tool life. There were 30–40 % reduction in cutting forces and 16–55 % reduction in surface finish were reported.

Fatima et al. [22] studied the importance of structured area overlapping the contact area. The motivation for this was to define the critical parameter location and its relation to processes mechanics. In this regard, Taguchi experimental design inspired by contact length modelling was exploit to identify design principle for location of structures and ANOVA techniques to study influential structure parameter (width, depth, pitch and distance from the cutting edge) for better machining performance. Geometric and location factors for creating structures on tool were assessed. It was reported that the distance to place structures from the cutting edge greatly influenced machining performance. It was concluded that structures should cover 45 % of the contact area and be located 0.15 mm away from the cutting edge.

Literature suggests that none of the past studies have looked into the machining performance of cutting tools when structures are created at on both rake and flank face of a cutting tool. For this research work, structured tool with both rake and flank face structuring was developed. A comparative investigation was carried out into the performance of structured tools in comparison to unstructured cutting tools, in the machining of AISI/SAE 4140. The purpose of this study was to experimentally identify whether surface structuring on both faces of the cutting tool could deliver better machining performance at different cutting speed and how it affects tool-chip contact phenomenon. Cutting forces and tool wear were important performance measure as they have a direct impact on cutting power. This research also aimed to substantiate conformable cutting parameters that exert an advantage on the use of these structured tools in terms of reducing power and energy demands by lowering forces and wear.

2 Experimental details

2.1 Laser structuring setup

Structures were created on uncoated flat cemented carbide inserts (Sandvik TCMW 16T308 5015). These inserts were selected as they allow easy fabrication of structures due to the flat face geometry and no chip breaker. Ti: sapphire femtosecond laser of a centre wavelength of 800 nm was used to create slot-shaped structures on cutting inserts. This laser system has a repetition rate of 1 kHz, pulse width of 100 fs and pulse energy of 1 mJ. The energy stability was about ±12 % of the average value. The laser spot size of 30 μm was scanned at a speed of 10 mm/s to generate micro-slots. These conclusion were optimised in an earlier study on identifying a process parameter window for structuring carbide with femtosecond laser without compromising surface and mechanical properties of carbide material [23]. Cutting inserts were mounted on computer-controlled translation stage. Table 1 presents dimension specifications of surface structures. These dimensions were established from earlier research study [22]. Structure geometry characterisation was carried out by WYKO-NT-1100 white light interferometer and a scanning electron microscope. The dimensions varied to ±5 μm on average. After creating structures on the laser machining, all cutting inserts

Table 1 Dimension specification of surface texture

Width of slots (*w*)	50 μm
Distance between slots (*p*)	100 μm
Depth of slots (*D*)	20 μm
Distance from the cutting Edge (d_e)	150 μm

were washed in ultrasonic vibration tank in deionised water for 10 min for the removal of derbies. Figure 1a–c shows the images and annotations of structures fabricated on cutting tool.

2.2 Machining setup

To evaluate cutting forces, reduction due to structuring orthogonal cutting tests were performed on AISI/SAE 4140 plain carbon steel in a shape of tube with wall thickness of 2.5 mm. Figure 2 shows the setup for machining. Cutting speeds of 100, 198 and 394 m/min were selected to test the structure's performance. These speeds were selected so as to include ranges from the insert manufacturer's specification. Sandvik STGCR 2020 k-16 tool holder was used to mount the inserts. It has the zero rake angle and 7° clearance angle. Width of cut and the feed rate was set to 2.5 mm (thickness of tube) and 0.1 mm/rev, respectively. Cutting compound, Trefolex, from Warren Bestobell was used as a lubricant and this was brush on the structured tools. It was established from the pilot study for previous research [22] that cutting compound (paste) delivered maximum reduction in forces and amount of heat generated than using oil as a lubricant. This was because, despite of continuous flow of material during cutting, cutting compound retained in structures longer than oil due to high viscosity and likely maintain a thin layer which act as a restriction to separate the work and tool interfaces. All

Fig. 2 Setup for machining

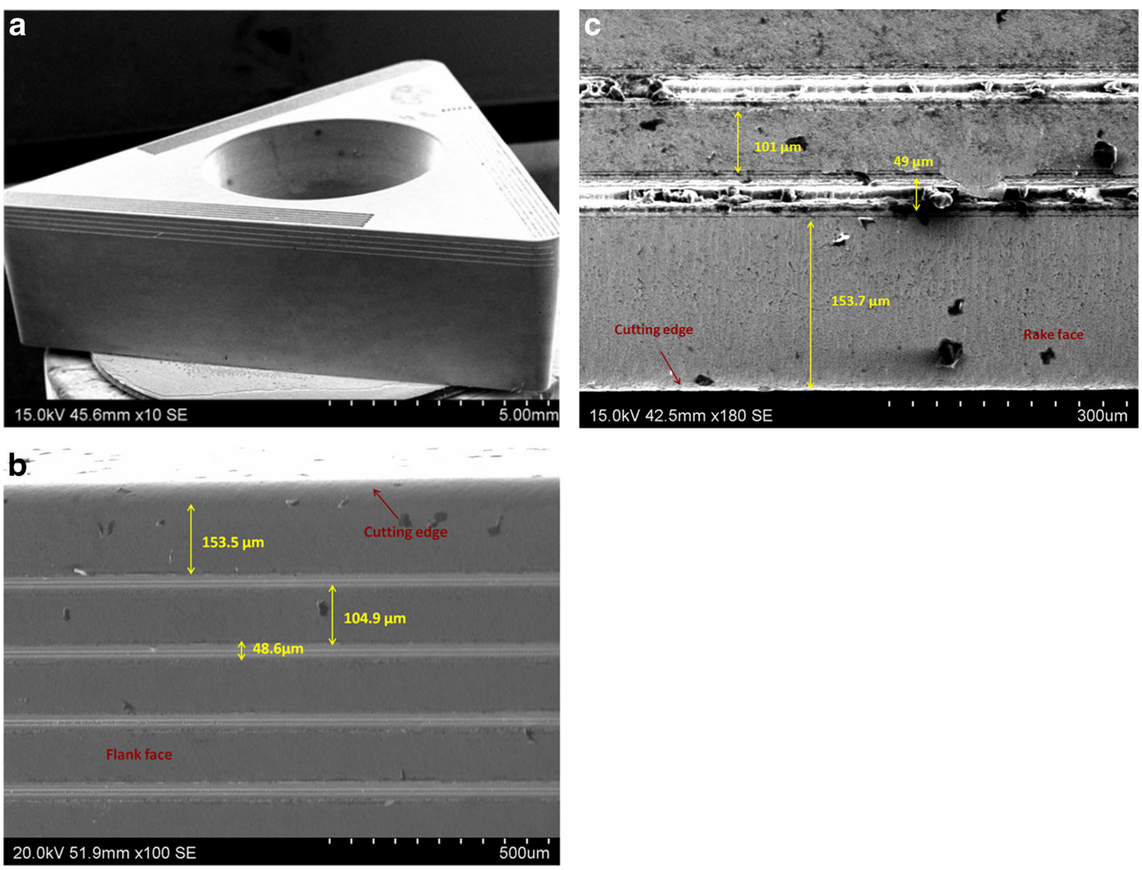

Fig. 1 **a** SEM image of structures created on cutting insert on rake and flank face. **b** Flank face SEM image. **c** Rake face SEM image after machining

the experiments were repeated twice. Length of cut for all the experiments was kept constant to 5 mm to minimise wear effects and enable structure evaluation. Fatima et al. [24] justified the limitation of 5 mm linear machining length. It was argued that since the flank wear for machining constant linear length of 5 mm lies in a very low range of values therefore, it is not expected to influence the effective rake angle and thus the wear. Another justification on stabilisation of cutting forces was made. It was explained that the phase at which tool cutting edge engaged full with the work piece is very rapid. The contact area and thus the wear happened to increase over this engagement period and then remain reasonably constant as reflected by the forces stabilisation. So the linear machining length limited to 5 mm is neither prolonged nor significant for flank wear to affect.

Cutting forces were measured using piezoelectric Kistler dynamometer type 9263. The contact length was measured on worn inserts by evaluating the contact tracks with scanning electron microscopy (SEM). Chip thickness ratio was calculated based on chip weight and geometry. In addition, temperature measurement was made using IR thermal image FLIR ThermaCAM® SC3000. The camera was positioned at a distance of 0.4 m in a way so that it can capture tool rake face thermal image profile (Fig. 2). ThermaCam Researcher software was used to analyse stored images. Thermal emissivity of cutting tool material of 0.48 at 700° C was used for temperature measurement. This range of emission was established from furnace measurement.

3 Results

Average plots for the variation of cutting force and feed force with respect to cutting velocity are shown in subpanels a and b of Fig. 3, respectively. It is observed from Fig. 3a, b that reduction in cutting force and feed force was brought by the structured cutting tool. Also, it can be observed that reduction in cutting forces is consistent over the range of cutting velocity. The total average reduction in cutting forces structured cutting tool was of 10 %. The percentage reduction of an average force corresponding to each cutting velocity for the structured tool was evaluated and from this total average, reduction associated with structured tool was established.

Figure 3b indicates trends for feed force for unstructured and structured cutting tools. Similar to cutting forces, reduction in feed forces was also brought by structured tool for a range of cutting velocities used. For selected cutting velocity range, reduction brought by structuring cutting tools on both faces was on a total average of 23 %. Moreover, it was observed that tool structuring effectiveness in decreasing feed force decreases as the speed is increased. This is in accordance with the finding of Koshy and Tovey [2].

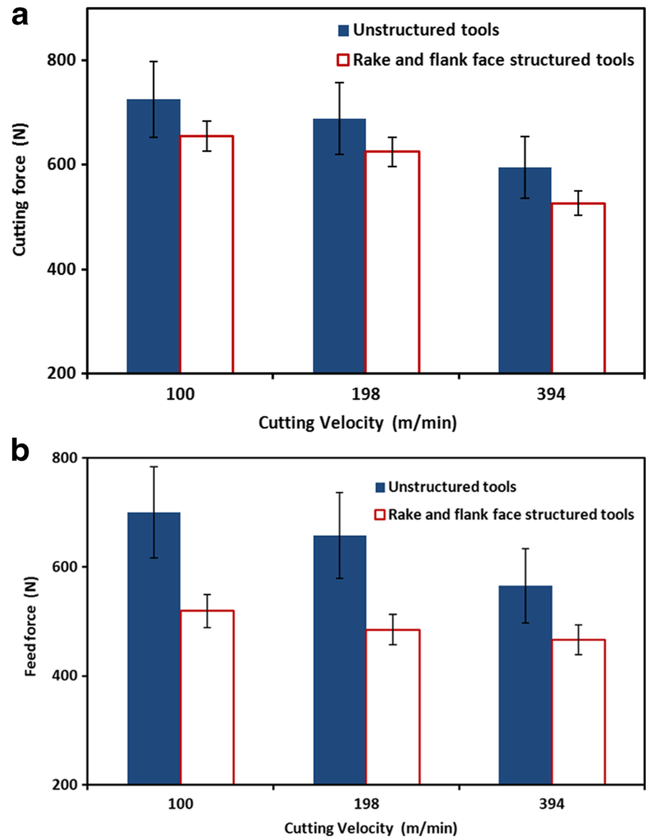

Fig. 3 (**a**) Cutting force at different cutting velocity (**b**) Feed force at different cutting velocity

The tool-chip contact area has a substantial influence on the machining process. The tribological conditions at these interfaces can be utilised in selecting process parameters for an efficient cutting process that results in the reduction of the tool wear. Coefficient of friction can be a critical parameter in determining the condition of these interfaces. Coefficient of friction is determined by using Eq. 1:

$$\mu = \frac{F_{\mathrm{v}}\sin\alpha + F_{\mathrm{f}}\cos\alpha}{F_{\mathrm{v}}\cos\alpha - F_{\mathrm{f}}\sin\alpha} \qquad (1)$$

Where μ is coefficient of friction, F_{v} is cutting and F_{f} is feed force and α is rake angle.

Figure 4 shows the variation in the coefficient of friction with respect to cutting speed. It is clear from Fig. 4 that the friction coefficient for structured cutting tool shows a decrease in value compared to unstructured tool for all selected cutting velocities. The friction coefficient for the rake and flank face structured cutting tool was reduced by 14 %. Moreover, From Fig. 4 the trend variation for coefficient of friction with respect to cutting speed for unstructured cutting tool is marginally decreasing. This is understood as the temperature rise associated with increased velocity which lowers the yield strength of chip material. This allowed the chip to flow easily over the

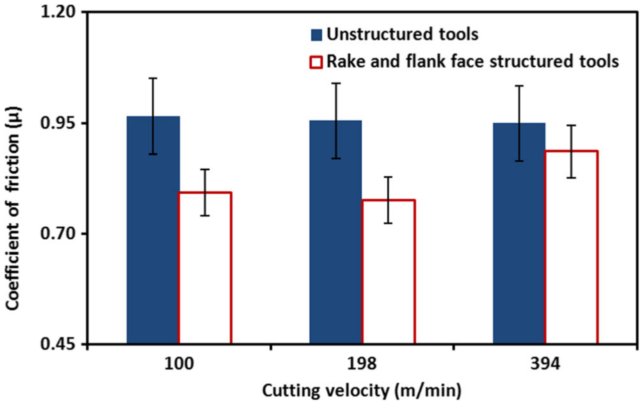

Fig. 4 Friction coefficients at different cutting velocity

tool-chip interface lowering frictional forces and thus coefficient of friction. Whereas, for the structured cutting tool, coefficient of friction increases with the cutting speed. This is possibly being the influence of lubricant applied on flank face. The behaviour of a lubricant film between the sliding surfaces is well known for centuries. It has been recognised that lubricant between sliding surfaces develops hydrodynamic pressure (lift) which is released when the lubricant exists the contact zone. Since, in machining the contact between the workpiece and the lubricant is not open at a cutting zone, therefore it is recognised that this hydrodynamic lift pushes the chip more towards the rake face interrupting the natural flow of chip. With increased cutting speed due to thermal softening of the workpiece, this condition gets more amplified and is reflected in higher values of coefficient of friction.

A chip compression ratio is a significant parameter in machining as it indicates the level of deformation work material goes through during cutting. Variation of compression ratio for the structured tools with cutting velocity is shown in Fig. 5. Structured tools enable improvement in compression ratio than an unstructured tool.

Similar to coefficient of friction, the variation trend of compression ratio is also vice versa. Due to thermal softening at higher speed, chips so produced were thinner and therefore a decreasing trend is observed in a compression ratio plot. However, for structured tool due to lubrication, chips were pushed towards rake face which might be a possibility for a slight increase in chip thickness and so as compression ratio.

Figure 6 shows contact length variation with cutting velocity. Contact length for an unstructured tool follows a traditional decreasing trend with increasing speed in conventional cutting speed regime. In the case of the structured tool, contact length was found to be higher compared to unstructured cutting tools. This could be attributed to the increased sliding region of total tool-chip contact length.

Average rake face temperature is plotted in Fig. 7 for the selected cutting velocities. It can be observed from Fig. 7 that cutting temperature increased as the cutting speed was increased. Reduction in rake face temperature was associated with structured tool. However, it is clear from Fig. 7 that a reduction in tool temperature was not evident at cutting velocity (394 m/min). This implies that the effectiveness of structured surface in the reduction of tool temperature decreased with increased cutting velocity. These results are in accordance to the finding of Ze et al. [8].

Reducing tool wear is important for process economics. In this work, the flank wear was analysed by using SEM on worn inserts (Fig. 8). Figure 9 shows flank wear for the selected cutting speed for the selected cutting tools. It is noted that flank wear for unstructured cutting tools was increased with increased cutting speed. At lower speed, flank wear was low, but at the higher range was fairly increased. Between structure and unstructured cutting tool, structured cutting tool shows lower tool wear at lower cutting velocity than unstructured tool. However, the wear was increased as the cutting speed increased to high range (394 m/min).

3.1 Contact phenomenon

The quantitative analysis of iron weight transfer was performed using scanning electron microscopy energy dispersive

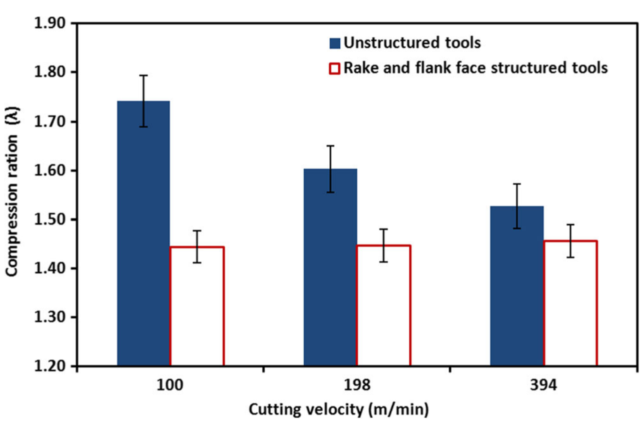

Fig. 5 Compression ratios at different cutting velocity

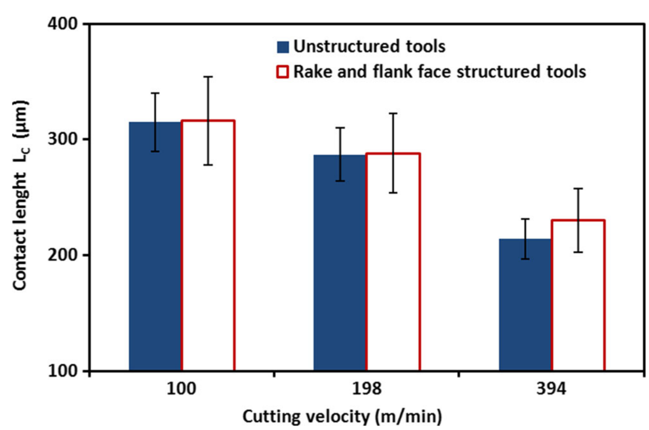

Fig. 6 Contact lengths at different cutting velocity

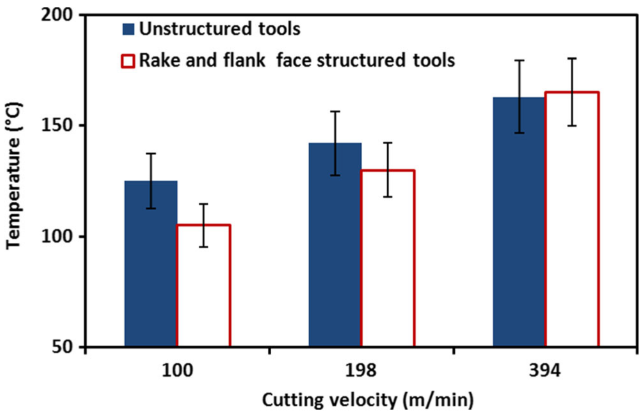

Fig. 7 Tool rake face temperature at different cutting velocity

x-ray (SEM-EDXA). The results obtained from the analysis are presented in Fig. 10. Contact length corresponding to each cutting tool is specified on each graph. At low cutting speed of 100 m/min, the average iron weight percentage was of 20 % which reduces to 14 % for structured cutting tool. For the cutting speed of 198 m/min, no evidence of the high peaks of iron was found on the rake face tool, indicating the presences of sliding region only. The average iron wt% transfer of unstructured tool was of 25 %. At the same speed of 198 m/min when structured cutting tools were used, average iron percentage weight transfer were reduced to 21 % for the cutting tool with both rake and flank face structures. For higher cutting velocity (394 m/min), high peaks of iron were identified near the cutting edge. This supports the occurrence of sticking region near the cutting edge on the tool-chip contact zone. For unstructured cutting tool, 52 % of the tool-chip contact was sticking contact which reduced to 43 % for structured cutting tool. Whereas, the average iron weight percentage transfer for the unstructured cutting tool was about 36%, which reduced to 29 % for both rake and flank face structured cutting tool.

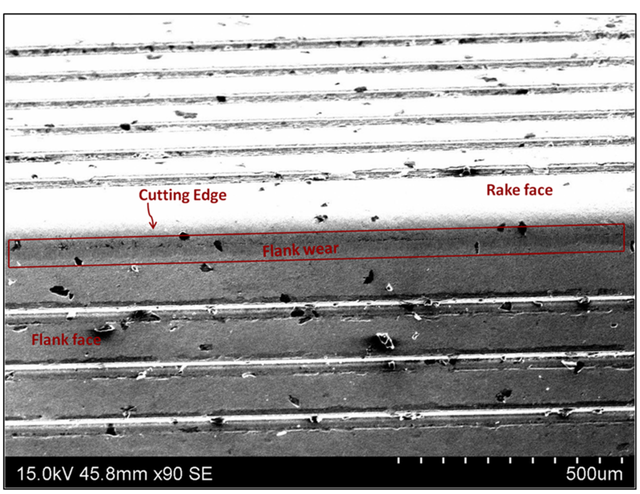

Fig. 8 SEM image of flank wear land after machining

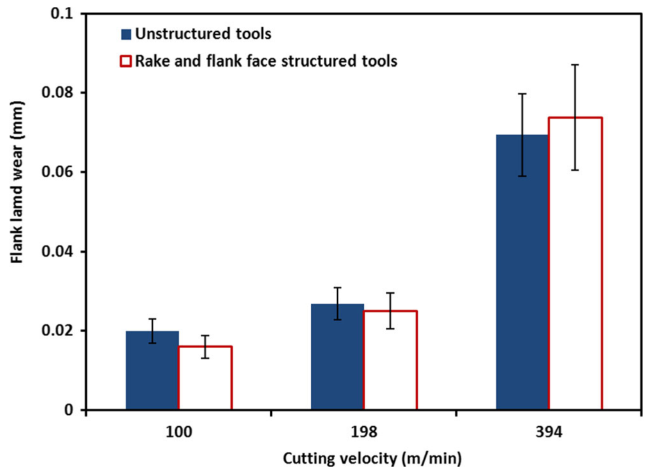

Fig. 9 Flank wear land at different cutting velocities

4 Discussion

Results presented in the previous section identified the importance of creating structures on a cutting tool to deliver optimum machining performance. Structured tool showed some evidence in reducing tool temperature and tool wear. It can be attributed as; first, for decreased real contact area at the tool-chip and tool workpiece interface. Second, the lubricant in structures may have been squeezed out and form a chemical reaction involved surface layers of metal salts (film) that readily spread over the interface further reducing the direct contact at tool-chip and tool workpiece interface. However, the effectiveness of such (chemical) film is understood to be limited by their melting point [25]. Temperatures above their melting point could cease their interpreted function. Though, the effects in reducing tool temperature and tool wear were apparent at low cutting speed than at high speed. Cutting speed of 394 mm/min is within the transition range to high speed machining for the selected workpiece material (AISI 4140). High cutting speeds are associated with high temperatures as a result of narrowing of shear plane near the cutting edge. It is observed that the ability of structures created on both rake and flank faces of the cutting tool to reduce temperature and thus wear is partially invalid due to inherited high temperature associated with high cutting speed.

The application of surface structuring on both rake and flank face of a cutting tool resulted in reduced friction coefficient at the tool-chip interface. This friction coefficient depends on the friction force and the normal force acting on the area of a chip and tool interface. Moreover, lower values of compression ratio indicate less chip load signifying less friction force that is required to shear the chip material across the interface. Since for a zero rake angle cutting tool friction forces are directly related to the feed forces, therefore a decrease in feed force is observed. Whereas, cutting forces are affected by the shearing process and the friction [2]. Reduced

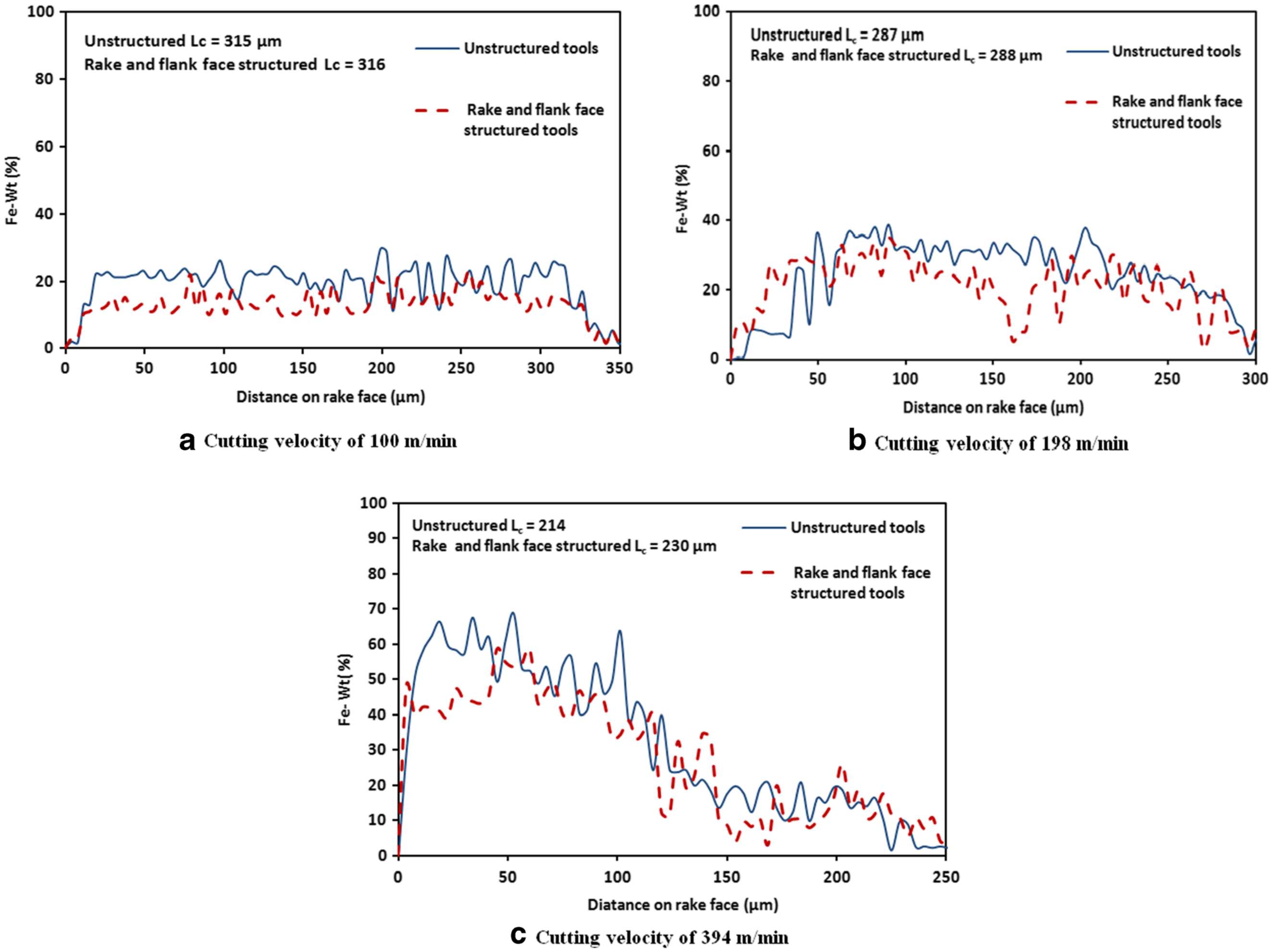

Fig. 10 SEM-EDXA results on iron weight percentage transfer on tool-chip contact zone on rake face of cutting tools

friction and low compression ratio (high shear angle) results in lower cutting forces.

The incapability of structures to reduced contact length especially at higher side of speed and thus improving machining performance at high cutting velocities can be argued in following: Friction between the chip and the rake face of a tool is highly influenced by prevailing contact conditions. Fang et al. [26] proved that the nature of chip curl and chip breaking affected tool life and cutting forces. Jawahir et al. [27] in a comprehensive study of chip formation and chip breaking for restricted tools concluded that chip-groove designs are a critical factor in obtaining effective chip breaking and hence improved the tool-chip contact and enhanced tool life. It was identified by Jawahir et al. [27] that tool face land, depth of chip groove and geometry of the back wall are the most significant chip groove parameter. From his study, it can be inferred that tool face land should blend smoothly with the groove depth which is further blended smoothly with back wall of groove. Also, the cross-sectional shape of groove should resemble spherical crater (Fig. 11). Moreover, Fatima et al. [23] in a study of femtosecond laser structuring of a carbide experienced glass shaped cross section of grooves with sharp edges due to the Gaussian distribution of laser beam. It can be attributed that structuring with femtosecond laser has resulted in grooves with a glass-shaped cross section (Fig. 11) that has preserved lubricant long and well and have affected chip curl/breaking. This might have increased the chance of chip slippage over tool rake face, maintaining

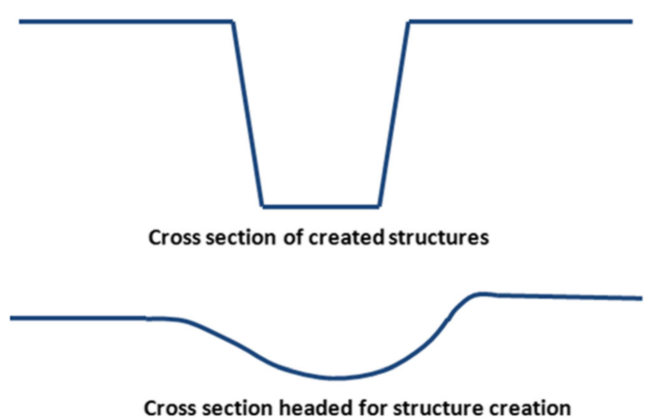

Fig 11 Comparison of created and headed for structure cross

longer contact with the cutting tool. In this observation, optimisation of structure's shape is still an area of open research for promoting reduced temperature, tool wear and cutting forces at high cutting speeds.

5 Conclusion

In this work, structures were created on rake and flank face of the cutting tool and its performance were compared in the machining of AISI/SAE 4140. Performance was assessed in terms of cutting forces, contact length, friction coefficient, tool temperature, compression ratio, tool wear and weight percentage of iron transfer. The conclusions drawn are presented as follows:

1. Structures created on both rake and flank face of a cutting tool showed better performance. The surface structuring on both faces of a cutting tool can effectively reduce compression ratio and friction coefficient up to 17 and 18 % respectively.
2. On average, reduction in cutting force and feed force of 10 and 23 %, respectively, was established when structured cutting tool was used. Reduced coefficient of friction and compression ratio was responsible for this reduction.
3. On average iron weight, percentage transfer on a tool rake face was reduced to 21 % when structured tools used, while sticking contact was reduced from 52 to 43 % for rake-flank face structured cutting tool.
4. Compared to unstructured cutting tool, structured cutting tool showed reduction in temperature and flank wear of 12 and 13 % on average relatively, when cutting velocity was no higher than 198 m/min. However, with increasing the cutting speed, effectiveness of the structured tool was ceased.
5. Contact length on rake face of the cutting tool is affected by cross-sectional shape of structures. Optimisation of structure shapes requires more research to uphold reduction in tool wear, temperature and cutting forces at high cutting speed range.

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