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Experimental Investigation of Chip Micro-Hardness under Minimum Quantity Lubrication

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Abstract: This study presents an experimental investigation of chip micro-hardness under Minimum Quantity Lubrication (MQL) conditions using castor oil. The experiments were conducted by varying cutting speed (100–170 m/min) and feed rate (0.16–0.24 mm/rev), while keeping the depth of cut constant. Micro-hardness measurements were obtained using a Shimadzu micro-hardness tester at different regions of the saw-tooth chip, namely the tooth, middle, and bottom. The results show that chip micro-hardness values ranged between 47.2 and 49.4 HRC. It was observed that micro-hardness increases with increasing feed rate, while cutting speed showed a comparatively smaller effect. The highest hardness value was obtained at low cutting speed and high feed rate. This behavior is attributed to increased plastic deformation, higher cutting temperatures, and strain hardening at elevated feed rates. The findings indicate that cutting parameters significantly influence chip micro-hardness, which in turn affects machining performance and surface integrity.

Keywords:, Micro-hardness, Chip micro-hardness, Minimum Quantity Lubrication (MQL)

1. INTRODUCTION

The micro-hardness of the chip has an effect of changing the properties of machined part, tool life and surface roughness which has an influence on the mechanical properties such as wear resistance and fatigu [1, 2]. Minimum Quantity Lubrication (MQL) is a technique which sprays small amount of lubricant to the cutting zone area with the aid of compressed air. MQL has become an attractive option to dry and flood cutting in terms of being able to increase tool life and reduce the cost of the product. It is also known to be environmental friendly and brings about economic benefits. MQL technique consumes oil in the range of approximately 10–100 ml/h [3]. In turning, it was used with carbide tools in machining various workpiece materials, including steels, aluminum alloys, and inconel [3-6]. Positive results have been reported on the use of MQL compared to conventional flood cooling technique or to dry machining (no cutting fluid used) on steel workpieces, especially in terms of tool life, cutting forces, and surface finish [5, 7].

Micro-hardness of machining chips is an important indicator of material behavior during cutting processes. It plays a significant role in determining the properties of the machined surface, tool life, and surface roughness, which ultimately influence mechanical characteristics such as wear resistance and fatigue strength. Understanding chip micro-hardness is therefore essential for improving machining performance and product quality [8, 9].

During metal cutting, severe plastic deformation and high temperatures occur in the shear zone, leading to micro structural changes and strain hardening of the material. These changes are strongly affected by cutting parameters such as cutting speed and feed rate. In particular, feed rate influences the amount of material removed and the level of deformation, while cutting speed affects the thermal conditions at the tool–chip interface [10].

2. EXPERIMENTALWORK

Micro-hardness of chip was measured using the Shimadzu micro-hardness tester. The measurements were taken at different area (at the tooth, middle and the bottom of chip). All measurements were in range of 47.2- 49.4 HRC.

Shimadzu micro-hardness tester (Figure 1)

- Max force: 19.61 N
- Resolution: 0.01 µm
- Weight: 42 kg

Figure 1. Shimadzu micro-hardness tester

Table1. Process parameters

Input Variables	Selected Values		
Coded no	-1	0	1
Cutting speed (m/min)	100	135	170
Feed rate (mm/rev)	0.16	0.2	0.24
Depth of cut (mm)	0.2		

Table 2. Micro-hardness results under MQL

Std	Cutting speed (m/min)	Feedrate (mm/rev)	(micro-hardness)
1	100	0.16	48
2	135	0.2	48.3
3	135	0.2	48
4	135	0.2	48.4
5	135	0.24	49.2
6	100	0.2	48.6
7	170	0.2	48.8
8	100	0.24	49.4
9	170	0.24	49.1
10	170	0.16	48.3
11	135	0.16	47.2

3. RESULTS AND DISCUSSIONS

The highest value of hardness was obtained at low speed and high feed. As can been seen in Table 2, micro-hardness value increased as feed rate increased. As feed rate increase resulted in large amount of metal removed which is subjected to higher temperature and also plastic deformation because of the increase in cutting forces which result in higher cutting temperature of the chip [11]. Also, an increase in feed rate results in an increase in shear strain rate thus strain hardening resulted an increase in micro-hardness of chip. Same results were reported by Senussi (2007) when turning stainless steel at speed up to 200 m/min and feed of up to 0.20 mm/rev. The micro hardness at the bottom of the chip which is the area of contact with the rake face of the cutting tool was in the same range of 47.2- 49.4 HRC. The hardness of the workpiece was also tested after the experiments were conducted and was still in the same range of 47-48 HRC .

4. CONCLUSIONS

An experimental investigation of chip micro-hardness under MQL conditions was successfully conducted by varying cutting speed and feed rate. Based on the obtained results, the following conclusions can be drawn:

- The micro-hardness of the chip ranged between 47.2 and 49.4 HRC under all tested conditions. Feed rate was found to have a significant effect on micro-hardness, with higher feed rates leading to increased hardness values. This is attributed to higher plastic deformation, increased cutting forces, and elevated temperatures, which promote strain hardening.
- Cutting speed showed a comparatively smaller influence on micro-hardness, although lower speeds combined with higher feed rates resulted in the highest hardness values. The distribution of micro-hardness across the chip (tooth, middle, and bottom) remained within a similar range, indicating uniform strain hardening throughout the chip.
- Additionally, the hardness of the workpiece remained nearly unchanged after machining, suggesting that the cutting conditions primarily
- affected the chip rather than altering the bulk material properties.

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