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EFFECT OF CUTTING PARAMETERS AND MACHINING ENVIRONMENTS ON THE CHIPS CHARACTERISTICS AND SURFACE QUALITY OF COMMERCIAL HIGH-CONDUCTIVE MATERIALS

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Abstract: The present paper is on the physical and mechanical characterization of machined chips of commercially available highly conductive materials, namely aluminium and copper under different machining environments. More specifically, geometry and hardness of chips as well as the chips removal effect on the machined surfaces are investigated in a quantitative fashion as a function of machining fluid and cutting parameter. The machining is carried out using a horizontal shaper machine with a V-shaped HSS tool under three different machining fluids, where the feed rate is kept constant, while the cutting speed and depth of cut are varied. Results show that chips attain the lower hardness in dry machining conditions than those of under kerosene and soluble oil as a phenomenon alike to hot rolling. Discontinuous chips are formed at low depth of cut for *Al* and higher depth of cut for *Cu* in dry condition. Cutting fluid offer improved surface quality through less friction and built up edge formation. *Cu* generates more heat than *Al* since copper is harder than aluminum and cutting speed is more effective than depth of cut.

Keywords: chips geometry, chips hardness, surface quality, machining fluids, conductive metals

1. INTRODUCTION

Copper and aluminium are widely used in power transmission and generation system for their high electric conductivity. They have also variety of use in different fields of daily life [1, 2]. Therefore machining is very important for their diversity of use. High-quality machinability of materials means low power required to cut rapidly with a good surface finish and low wear of cutting tool. Machinability of the materials depends on many different variables for the duration of machining. These are cutting tool and work material, cutting speed, feed, depth of cut as well as cutting fluid [3].

Nearly all of the cases, best surface finish are found at lower depth of cut and higher cutting speed. Feed rate is the most influential parameter on surface roughness of different materials. This is due to the presence of built-up-edge at the lower cutting speeds. Inhomogeneous distribution of chip thickness at the lower cutting speeds results in variation of cutting forces which is another reason for poor surface finish [4]. Increase in depth of cut enhances vibration which causes irregular cut and defiles the surface [5]. Cutting temperature increases when cutting feed and axial depth of cut increases. Cutting speed is another imperative powerful cutting parameter on the cutting temperature [6]. Surface hardness of the materials is controlled by some key parameters like the chip thickness compression ratio, rake angle, and uncut chip thickness during machining [7, 8].

For enhancement the better macinability cutting fluid is used which act as a coolant and lubricant throughout machining [9]. There is variety of cutting fluids such as oils, oil-water emulsions, pastes and air or other gases. Cutting fluids mainly attacks in shear region, contact region of tool and work piece, contact region in tool and chips where the temperature generates and reduces [10]. Water based cutting fluid has higher cooling capacity than that of oil based cutting fluid [11]. Lubrication effect of cutting fluid forms boundary layer film on the machined surface which reduce friction, tool work-piece temperature and hinders built up edge formation [12, 13]. Machining parameter also has an important role to produce the different types of chips. At lower depth of cut continuous chips is formed while discontinuous chips are found at higher depth of cut and higher cutting speed. With the increase of depth of cut and cutting speed machined chips also loses the hardness value [14]. Comprehensive classifications of chips form based on their sizes and shapes those are generally produced in metal machining operations. This classification system has shown eight descriptive shape groups, with each of these groups being subdivided into further subgroups defining the size (long, short) and the physical conditions (snarled, connected, loose). Moreover, it also includes a third-digit numerical code for certain chip shapes, to characterize the direction of chip flow and the chip-breaking mode [15].

The main focus of this research is studying the effect of cutting environment on chips properties of aluminium and copper as the chips play the important role on machinability. In addition, this research aims at comparing different properties of generated chips hardness, surface roughness and tool chips interface temperature between them.

2. EXPERIMENTAL DETAILS

The present machining operation is carried out with two of the most widely used highly conductive metallic metals, namely, Aluminium and Copper samples of dimensions 150 mm×50 mm×20 mm. The chemical compositions of the commercially available *Al* and *Cu* samples are investigated by optical emission spectrometer, the corresponding result of major elements is listed in Table 1. The main electro-mechanical properties of the machining materials are also investigated and listed in Table 2. Vicker's Hardness tester is used to measure the micro-hardness of the test materials. Standard tension test samples are prepared following relevant ASTM standards from both *Al* and *Cu* to assess the difference in basic mechanical properties of the machining materials, that is, ultimate tensile strength and percentage elongation. These mechanical properties are measured in the laboratory using a universal testing machine (UTM). An electrical conductivity meter is also applied to measure the DC electrical conductivity of the materials.

A standard horizontal shaper machine with a V-shaped (55°) High Speed Steel (HSS) tool bit is used for machining. The geometrical specification of the cutting tool is given in Table 3. In an attempt to investigate the effect of depth of cut on the properties of chips and machined surfaces, four different depth of cuts are considered, which are 0.5, 1, 2, and 4 mm. The entire chips formation characteristics are investigated under three different machining fluids, which are, Kerosene and soluble oil, together with the conventional dry (air) machining. The machining fluid with soluble oil was prepared by mixing 5% soluble oil in 95% water. The corresponding nozzle diameter and the flow rate of the fluids were kept constant, which were 4 mm and 1.3 ml/sec, respectively. The machining speed and depth of cut are considered as the parameter of the experiment, while the feed rate is kept constant. Four cutting speeds, that is, 3.0, 6.3, 13.3 and 19.4 m/min are selected to cover the entire range available for the present machine. Here, Taylor Hobson surface roughness meter is used to assess the quality of machined surface in terms of roughness, where the center line average roughness method is used. For each representative value of roughness, the average of individual five measurements is considered.

The chips generated during machining are found to be very thin to measure its hardness. For this reason, attempt is made to mount the machined chips in Plaster of Paris moulds ($CaSO_4.2H_2O$) within a PVC casing, the details of which is shown Fig. 1. Then the molded samples are allowed to keep for one day for the requirement of drying and curing. Then using Vicker's hardness tester, micro-hardness of the chips is measured. The optical images of the machined chips are recorded using DSLR camera. Standard measuring scale is also used for measuring the chips length.

Tab. 1. Chemical composition of the machining materials (wt%)

Elements	Aluminium	Copper
Al	98.34	0.007
Cu	0.115	99.95
Fe	0.005	0.002
Mg	0.007	0.000
Mn	0.014	0.000
Ni	0.006	0.002
Pb	0.002	0.004
Si	0.055	0.000
Ti	0.022	0.000
Zr	0.013	0.011

Tab. 2. Major electro-mechanical properties of the machining materials

Properties	Aluminium	Copper
Hardness (HV)	52	120
UTS (MPa)	115	350
Elongation (%)	15.0	12.0
Electrical conductivity (S/m)	3.49×10^7	5.84×10^7

Tab. 3. Tool geometry and machining parameter/condition

V-shaped (55°)	High Speed Steel (HSS)
Back rake angle (degree)	5
Clearance angle (degree)	8
Notch radius (mm)	0.8
Feed rate (mm/stroke)	0.254
Depth of cut (mm)	0.5, 1.0, 2.0, 4.0
Cutting speed (m/min)	3.0, 6.3, 13.3, 19.4
Machining Fluids	Dry (air), Kerosene, Soluble Oil (5%)

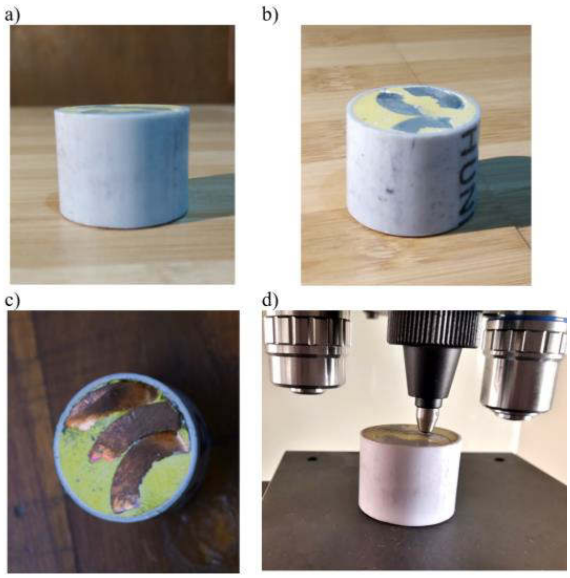

Fig. 1. Experimental details of chips hardness measurement: a) PVC casing for Plaster of Paris mould, (b) Al chips mounted in Plaster of Paris, (c) Cu chips mounted in Plaster of Paris, d) Chips under hardness tester

3. RESULTS AND DISCUSSION

3.1. Chips Hardness

First, attempt is made to measure the hardness of the machined chips following the conventional method of measurement in a Vicker's hardness tester. In this context, the effect of mounting the chips in Plaster of Paris on the measured hardness is investigated. As shown in Table 4, a decrease in hardness is observed for both the cases of *Al* and *Cu*, which is approximately 9%. Fig. 2 describes the variation of corrected measured hardness of Al and Cu chips as a function of cutting speed for three different machining environments. The hardness at zero cutting speed refers the case of base metals. As an overall observation, the hardness of the chips is higher than those of base metals. An initial increase and then slight decrease in hardness is observed for both the cases of kerosene and soluble-oil machining with the increase of cutting speed from zero, which is, however, found to be in contrast with convectional dry machining. In case of dry machining, initial decrease and then increase in hardness is observed for both the conductors with the increase in cutting speed, thereby leaving the chips state nearly unchanged from those of base materials, especially at higher cutting speeds. This phenomenon may be attributed to the fact that, at very high cutting speed, thermal softening occurs, which eventually tends to soften the chips. It is earlier reported that chips micro hardness increases up to certain level followed the more or less constant values which is similar to this study [16].

Tab. 4. Hardness correction for Aluminum and Copper chips mounted in Plaster of Paris

Hardness	Aluminium	Copper
Base metal Hardness (without mounting) (HV)	54	140
Base metal Hardness(with mounting) (HV)	49	127
Hardness reduction (%)	9.3	9.1

In dry machining, chips hardness is found to be comparatively less than those under kerosene and soluble oil conditions. In fact, in dry condition, a phenomenon very similar to that of hot rolling occurs, this eventually causes the hardness to increase to some extent. However, under kerosene and soluble oil conditions, cold rolling effect is encountered, in which the generated heat is removed quickly by the cutting fluids and thus the chips assume higher hardness. The effect of this cold rolling is found to be most prominent on *Cu* chips under soluble-oil machining, whereas the same is found to be most dominant on *Al* chips under kerosene oil machining. As a result, highest increase in hardness for *Cu* chips is found with soluble oil and that for *Al* chips is under kerosene-oil machining.

In other words, the results reveal that soluble oil can absorb heat more quickly than kerosene. Moreover, the rate of increase of hardness for *Cu* chips is found to be always higher than those of *Al*, which is because of thermal conductivity of *Cu*, which can give up heat more quickly than *Al*.

3.2. Physical Appearance of Chips

From Fig. 3, Fig. 4, Fig.5 and Fig.6 various kinds of chips are seen. They can be mainly categorized in continuous and discontinuous chips. Discontinuous chips are more desirable because continuous chips adhere with tool and reduce tool life [17]. In some case it may cause serious accident. Continuous chips are found most of ductile materials like copper. Discontinuous chips are found in brittle materials. From this study it is mostly found for aluminium as relatively low in ductile nature than copper under generated temperature. Discontinuous chips are also found when more cutting fluids are used. In kerosene and soluble oil conditions more discontinuous chips are found rather than dry condition.

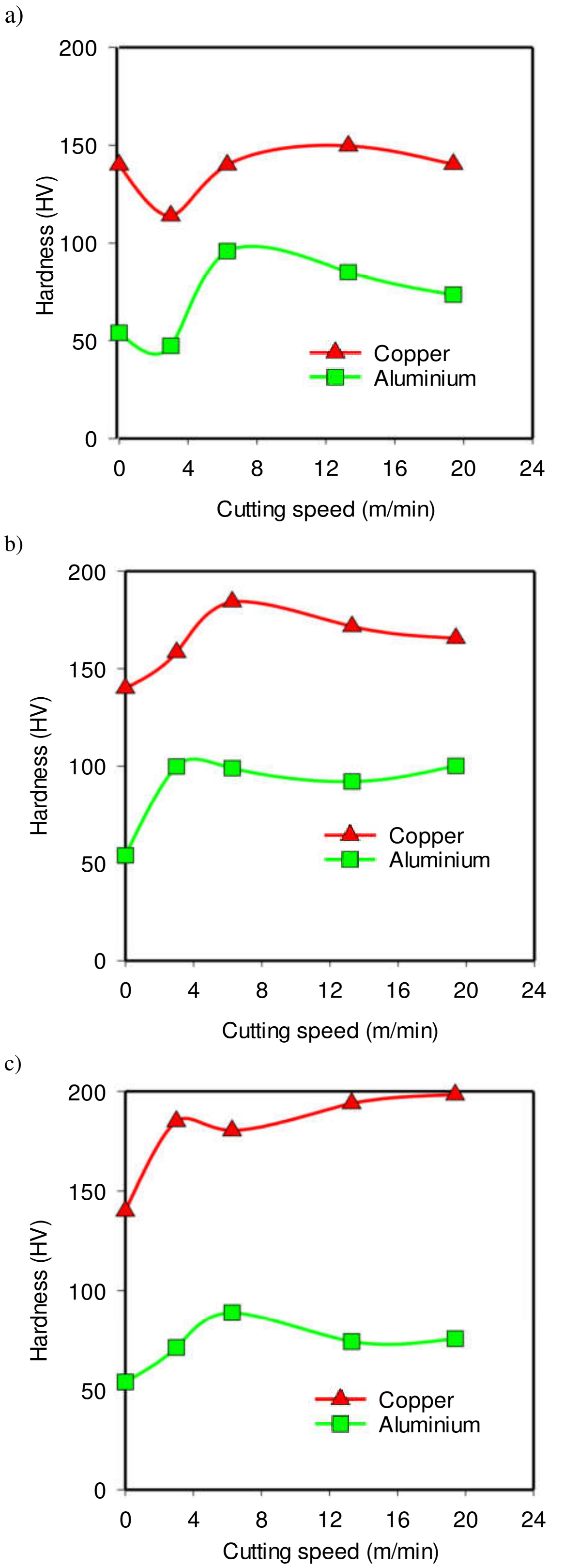

Fig. 2. Measured Hardness of machined chips under (a) dry, (b) kerosene, (c) soluble-oil conditions at 4 mm depth of cut

Because enough heat is generated in dry condition which breaks continuity of chips. In dry condition chips show much coilness because high temperature generation. At lower cutting speed and higher depth of cut discontinues chips are found and higher cutting speed and lower depth of cut continuous chips are found.

From Fig. 6 aluminium chips in at 4 mm depth of cut and 19.4 m/min under dry condition shows some difference. A very long continuous chip is seen here. This chip is generated here because at this cutting combination huge amount of heat is generated which soften the machined surface and produce this long chip. Change in colour of Copper chips is seen in dry condition. For produced heat reddish brown copper chips turned into burnt reddish brown colour at higher depth of cut and cutting speed [18].

From the experiment a chips map is created to easily identify the types of chips formation under different depth of cut and cutting speed. In Fig. 7 map is shown. Washer types helical chips and tangled chips are continuous chips. Spiral chips, short comma chips, short tubular chips are continuous chips. The red line is indicating the separation line between continuous and discontinuous chips. Above this red line continuous chips are found and below red line discontinuous chips are found. For aluminium continuous chips are generated at higher depth of cut under dry condition. In kerosene and soluble oil, discontinuous chips are found throughout the whole range of the study. For copper, discontinuous chips are generated at higher depth of cut. During machining discontinuous chips are always expected because continuous chips sometimes adhere with tool, may cause sudden machine stop. Serious injury can be occurred for the operator. This chips map will give a clear idea at which depth of cut and cutting speed continuous chips will produce and operator can avoid those depths of cut and cutting speed for safe operation which will ensure safety for the operator and machine**.**

Fig. 3. Optical images of the machined chips generated under various machining conditions: (a) 3.0 m/min speed, 0.5 mm depth of cut

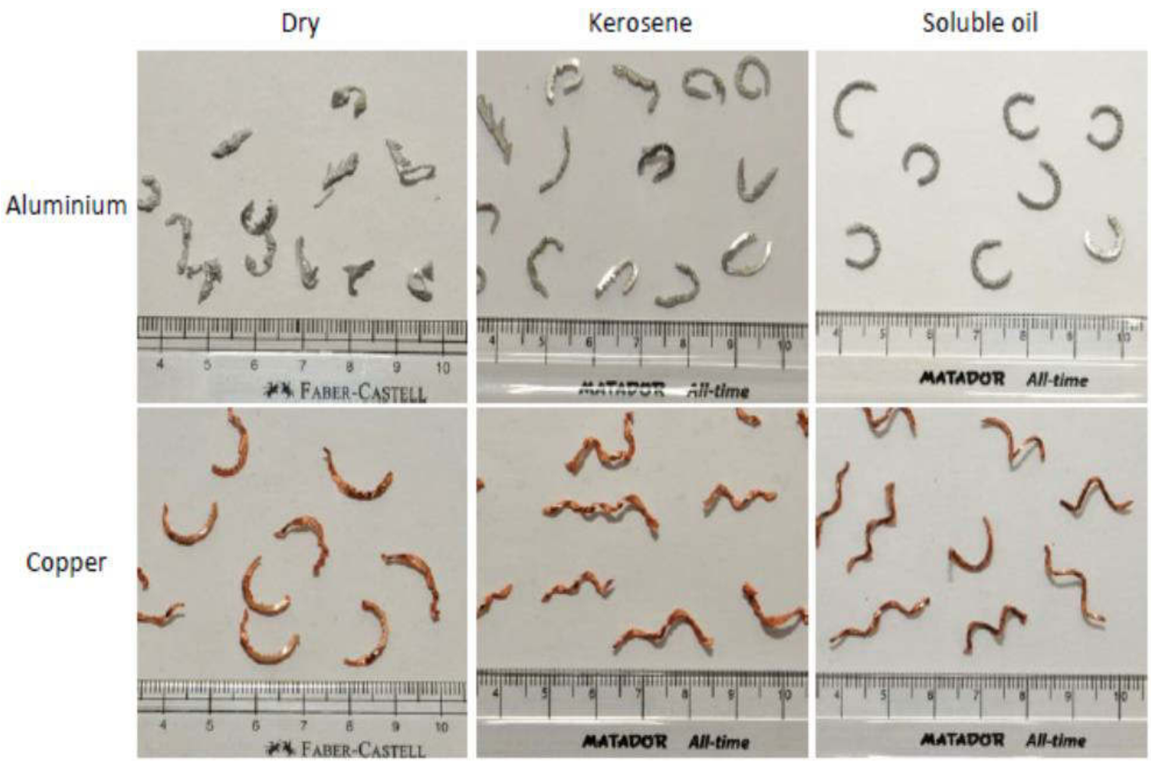

Fig. 4. Optical images of the machined chips generated under various machining conditions: 19.4 m/min speed, 0.5 mm depth of cut

Fig. 5. Optical images of the machined chips generated under various machining conditions: 3 m/min speed, 4 mm depth of cut

Fig. 6. Optical images of the machined chips generated under various machining conditions: 19.4 m/min speed, 4 mm depth of cut

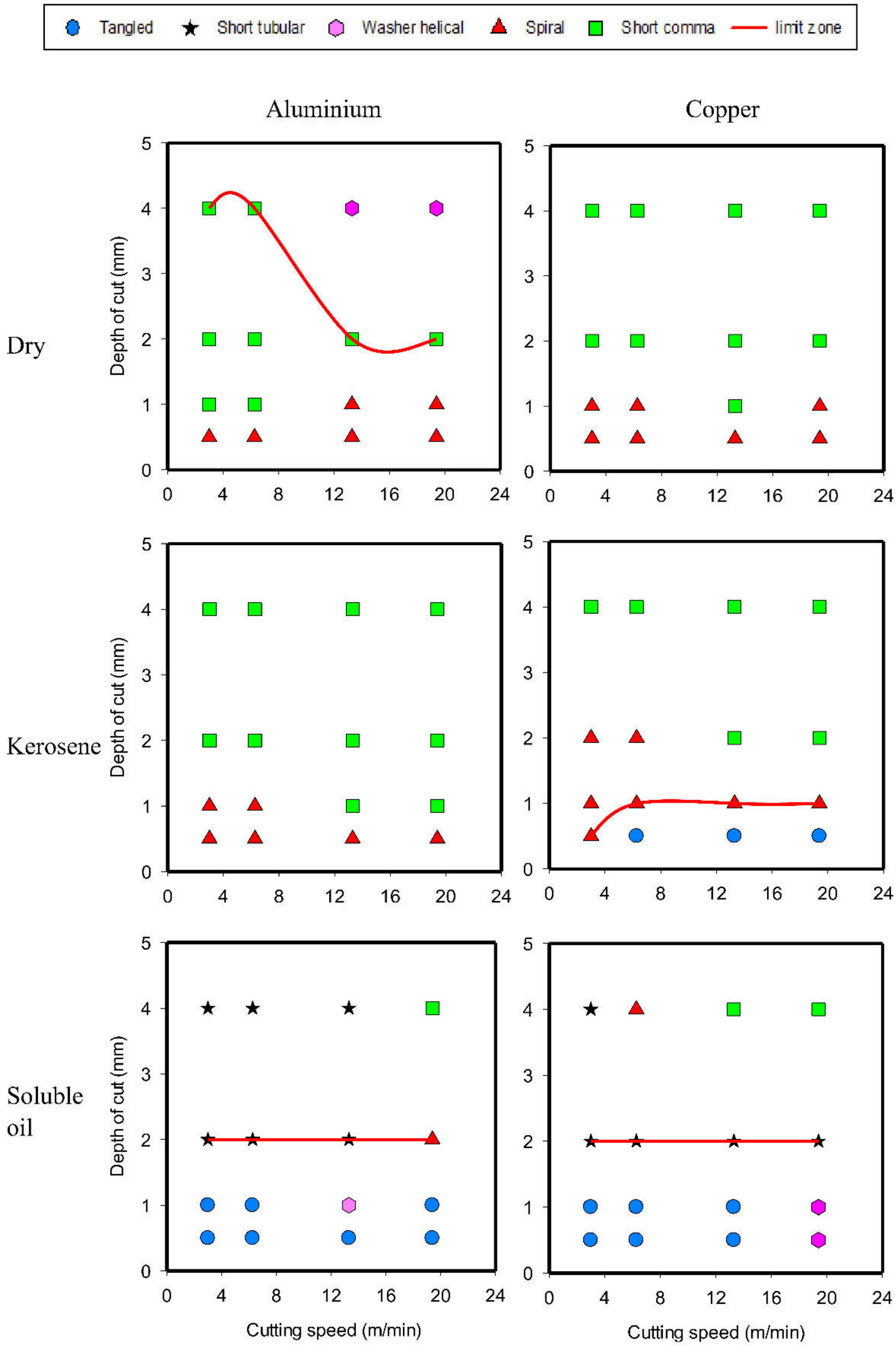

Fig. 7. General mapping of machined chips generated from the conducting materials under different machining environment/condition

3.3. Roughness of Chips Generating Surfaces

The following curves have been plotted in Fig. 8 to show the change in surface roughness as the cutting speed is varied for 1 mm depth of cut under different machining environments. It is seen from the graph that the roughness increases with cutting speed under dry environment (Fig. 8a). This scenario is absent when those are machined under both the kerosene and soluble oil environments (Fig. 8b and c. Excessive heat can damage the machined surface. In dry machining much heat generates which defiles the surface condition. In metal cutting process deformation occurs mainly in- shear region, contact region of tool and work piece where temperature is generated [10, 11]. Cutting fluid attacks these regions and reduces temperature. Lubrication property of cutting fluid is physio-chemical property which is related to boundary layer formation in the machined surface. This reduces the effect of friction, decrease tool work-piece interface temperature. It also prohibits built up edge formation and improves surface quality [19]. In this experiment oil based cutting fluid kerosene and water based cutting fluid soluble oil were used. Oil based cutting fluid always cannot meet up the specification of cooling. It is clear from the graph that these two metals show better surface finish in soluble oil condition rather than kerosene and dry condition. Soluble oil takes away heat easily. Because it is water based cutting fluid, which decrease the temperature of tool and work piece [20]. Hardness of copper is higher than aluminum as a result more cutting force is required for copper machining, more friction occurs which defiles machines surface.

3.4. Chips-Tool Interface Temperature

The variations of average temperature at the chips-tool interface with different feed and dept of cut under machining of commercially pure aluminium and copper have been shown in Fig. 9. From the figures it is seen that temperature increases with the increasing of cutting speed as well as depth of cut for experimental metals. But the influence of cutting speed is more prominent for both the samples. There is a proportional relationship between cutting speed and tool chips interface temperature. Temperature rises in the cutting zone due to plastic deformation in primary shear zone, friction in the cutting face and friction between chips and tool on the flank. During metal cutting large amount of heat is removed from the work piece by chips. As cutting speed goes higher, more heat is removed but increase the tool chips interface temperature. With the increase in depth of cut, volume affected by shear force increases for both the materials and for the same affected volume, copper shows higher temperature rise. At 4 mm depth of cut temperature rise is highest.

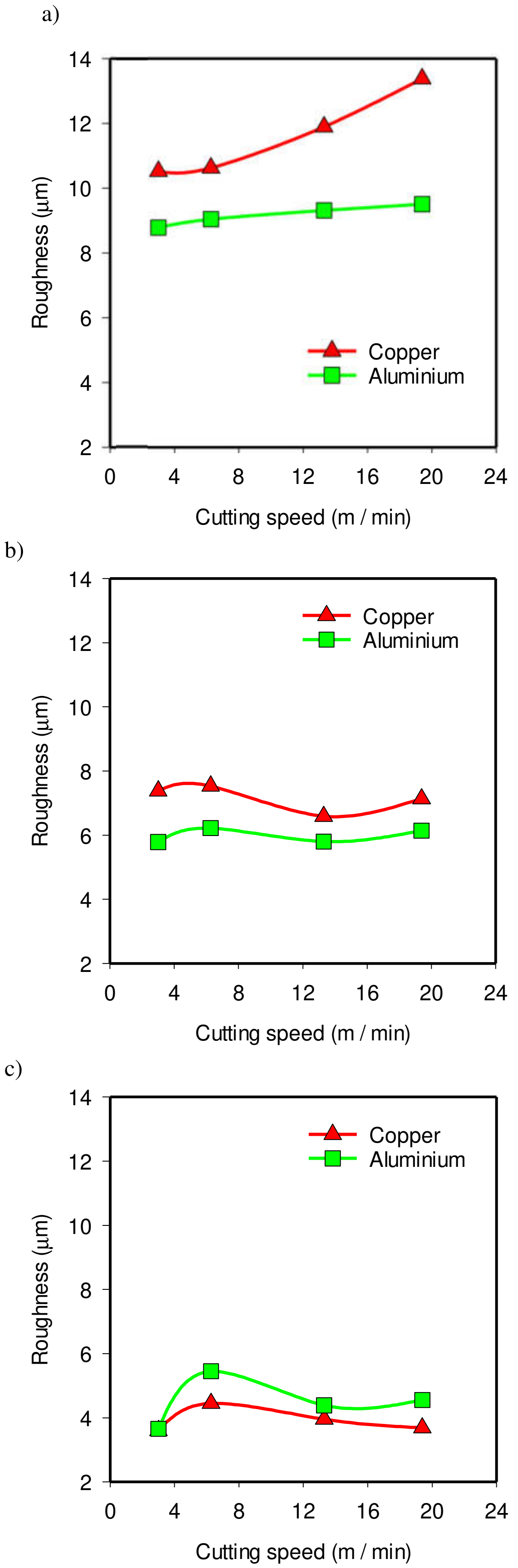

Fig. 8. Roughness of machined surfaces under different machining fluids and 1 mm depth of cut: (a) dry (b) kerosene and (c) soluble oil

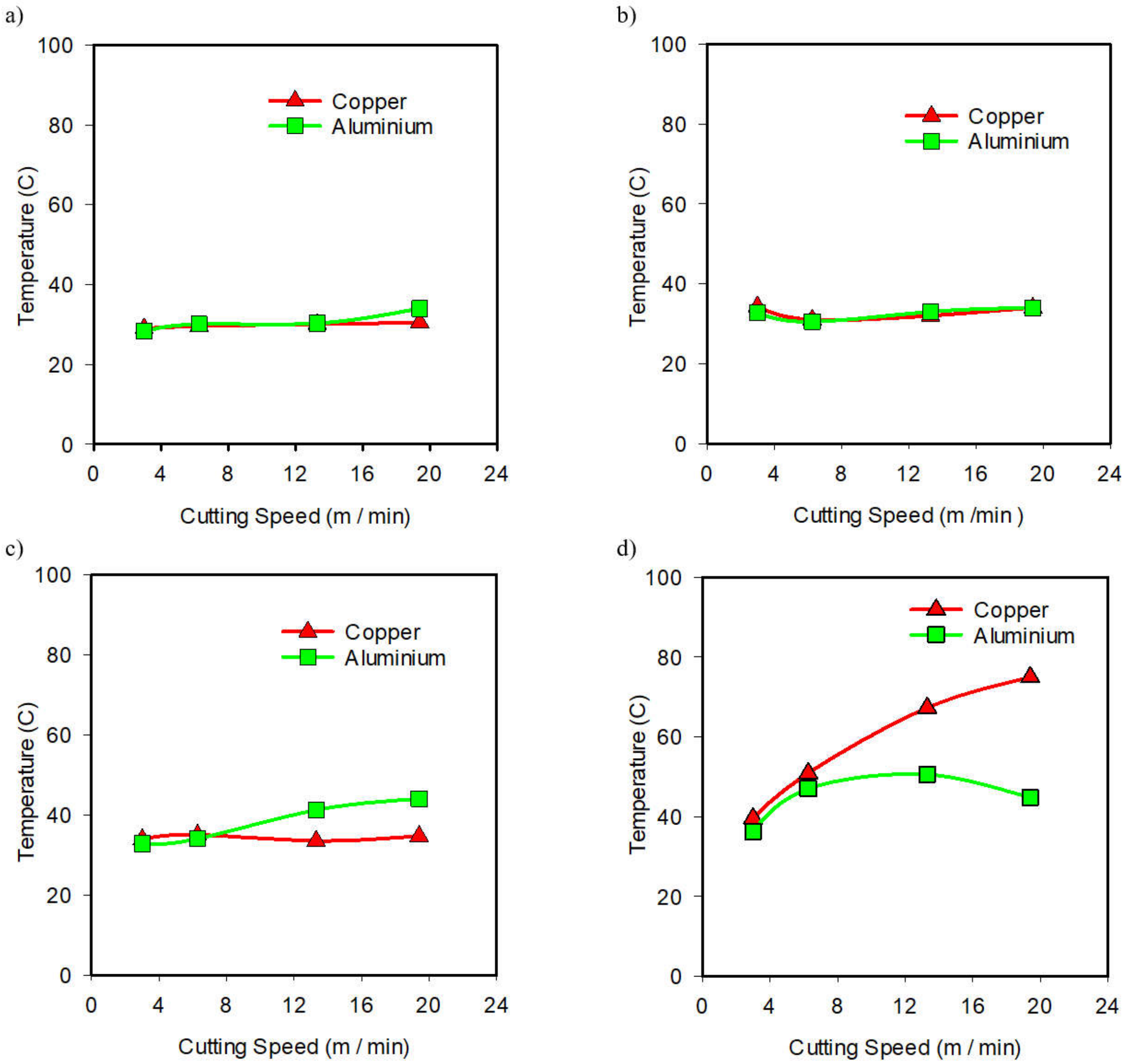

Fig. 9. Average temperature at the chips-tool interface under dry machining at depth of cuts: a) 0.5 mm, (b) 1 mm, (c) 2 mm, (d) 4 mm

Temperature rise in copper is more significant than aluminium because copper has high hardness value than aluminum, which creates more resistance during metal cutting as a result temperature increases. Further, among the two metals, copper has higher thermal conductivity as well as higher coefficient of friction, which direct to higher heat creation at the tool-specimen interface [6, 21].

4. CONCLUSIONS

Based on above discussions following observations can be drawn.

Copper chips show higher hardness than aluminium chips and both the chips hardness decrease with higher cutting speed mainly due to higher heat generation.

Chips hardness under dry machining condition is found not as much that of kerosene and soluble oil condition. To get discontinuous chips, the depth of cut for *Al* should be low in dry condition and for *Cu* it should be high.

Surface roughness increases with depth of cut and has inversely proportional relationship to cutting speed. Cutting fluid provides better finished surface by reduces friction, heat and built up edge formation.

Temperature rise in *Cu* is more significant as it is harder than *Al* and the responsibility of cutting speed is more efficient than depth of cut.

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