The Machinability Of Copper-Nickel Alloys

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Abstract

In this study evaluated the machinability of Cu-Ni, cutting forces, tool wear, chip morphology, and surface roughness. Several factors that affect machinability are work-piece related (mechanical properties, microstructure), tool related (strength, geometry), and machine related (accuracy, force requirements). Forces generated when machining Cu-Ni alloy have been large due to a relatively large contact length along the tool rake face, and reduce frictional forces between the chip and the cutting tools. The depth of cut notching was observed as the wear pattern and both abrasion and adhesion as the wear mechanism for the WC tool.

Chips generated using the WC tool showed heat induced burrs occurring regularly along the chip for Cu-Ni alloy, These burrs increased tool wear and deteriorated workpiece surface finish.

Microstructure of the Cu-Ni alloy using scanning optical microscopy give poor results due to sample preparation. Although it can be seen some grain growth has occurred for machined samples.

الخلاصة

تم في هذه الدراسة حساب قوى القطع ، البلى Wear وشكل النحاتة Chip Morphology الناتجة عند تشغيل سبيكة النحاس – نيكل (Cu-Ni) وكذلك خشونة السطح Surface Roughness. هنالك عدة عوامل تؤثر على تشغيل سبيكة النحاس – نيكل وعلى المعادن وسبائكها بصورة عامة مثل القوة اللازمة للتشغيل وضبط الأبعاد للعينة. إن القوة المتولدة أثناء تشغيل سبيكة Cu-Ni تؤدي إلى مساحة تماس عالية على طول وجه العدة وانخفاض قوى الاحتكاك بين النحاتة وعدة القطع Tool Wear. إن حزوز عمق القطع واضحة كنموذج للبلى والحك والالتصاق Wear and Abrasion وتعتبر كميكانيكية لبلى عدة القطع. عند استعمال عدة القطع الكاربيدية WC فأن الحرارة المتولدة تكون منتظمة على طول النحاتة لسبيكة Cu-Ni وهذا بدوره بسبب زيادة بلى العدة وإعطاء سطح ذو إنهاء رديء. البنية المجهرية كانت غير الجيدة بسبب صعوبة التحضير لسبائك Cu-Ni ، مع ذلك أتضح أن هنالك نمو في حجم الحبيبات بعد تشغيل العينة وخاصةً عند الحافة.

1. Background

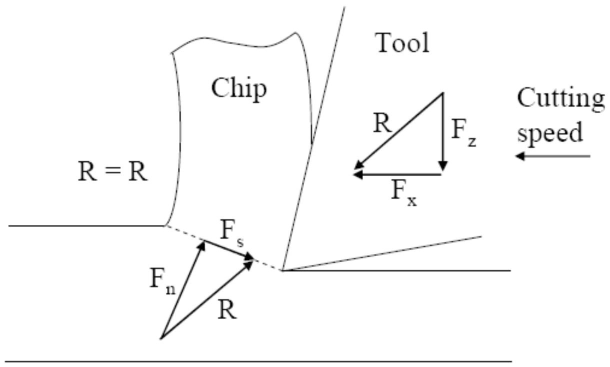
Machining is a material removal process in which a workpiece material is mounted into a mill or lathe while a cutting tool, made of a harder material than the workpiece, is used to cut the part’s shape.

There are two main in this research, one which is focused on obtaining information on how to carry out machining, while the other is concerned with what happens at the cutting edge during cutting and why this occurs.

Several factors that affect machinability are work-piece related (mechanical properties, microstructure), tool related (strength, geometry), and machine related (accuracy, force requirements)(Lllia, E.,2003).

In order to evaluate the machinability of materials, cutting forces, tool wear, chip morphology, and surface roughness are typically considered. It should be noted that these factors are not independent of one another and may cause changes in others. In addition, some of these affects of machinability may be deemed more important than others depending on the application.

Cutting Forces Collecting cutting force data is done for numerous reasons. Knowledge of these forces is required in selecting a machining center and workpiece holding fixtures that is rigid enough, while the workpiece itself must be able to withstand the cutting forces generated to prevent distortion(Kalpakjian, S. 2003). In a turning application, typically three cutting forces are measured: the tangential cutting force (F_x), the radial thrust force (F_z), and the axial feed force (F_y). These forces are depicted below in Figure (1).

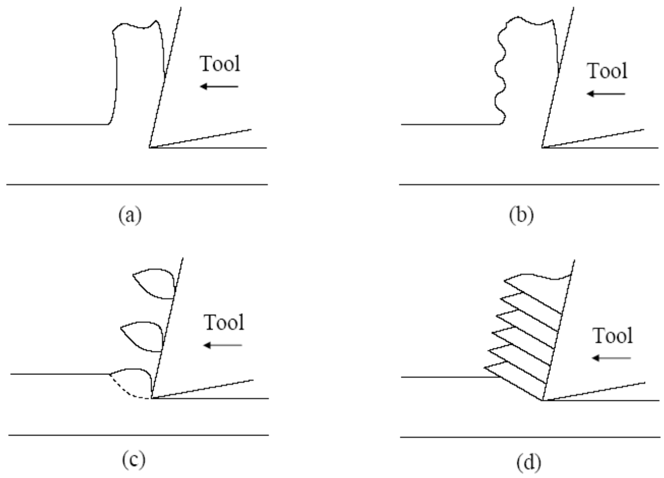


Figure(1): Diagram of cutting force for orthogonal cutting (Komanduri, 1993)

Tool wear, is of interest in machining because of its detrimental affects on part production and part quality. Cutting speed has been found to have the greatest influence on tool wear (Kalpakjian, S. 2003), yet this wear is a function of tool material, tool geometry, and the physical, mechanical, an chemical properties of the workpiece(Huang, 2002).

Chip morphology is an important consideration in measuring machinability because of its influence on workpiece surface integrity and tool wear(Kalpakjian, S. 2003). Chips are typically studied for their overall shape and cross-sectional geometry using high powered microscopy. Examining how chips evolve throughout the cutting process and during different cutting conditions may give insight into manufacturing productivity where tool wear and workpiece dimensional accuracy are closely monitored.

Chips produced from machining most metals and alloys can be classified into four distinct geometrical categories: flow chips, wavy chips, segmented chips, and discontinuous chips. Examples of these types of chips can be seen below in Figure (2). (Shaw, 1993).



Figure(2): Diagram of chip categories: (a) flow or continuous chip, (b) wavy chip, (c) discontinuous chip, and (d) segmented chip(Shaw,1993).

Flow type chips arise in machining of ductile materials and can be classified by their uniform cross-section. Wavy chips occur when the shear angle oscillates widely causing fluctuations in cutting forces and chip thickness (Shaw, 1993). Discontinuous chip formations are common in many brittle materials machined at low cutting speeds (Tonshoff, 2000) and are classified by their nearly identical discontinuous broken segments. Segmented chips show areas of intense shear strain in cyclic form causing sharp segments to be distributed along the free side of the chip. These chips typically arise when machining hardened steel and other difficult to cut alloys such as titanium (Hua,.2004,), nickel, and 60/40 Brass(Shaw, 1993).

1.1 Introduction

Copper-Nickel alloys were developed for service in severe marine environments. The copper-Nickel alloys are ductile and suitable for the manufacture of plate, sheet and tube that combines the resistance to befouling of copper with a corrosion resistance in fast-flowing seawater that is significantly better. Additives to improve machinability would have a disastrous effect on properties such as weldability and are therefore very uncommon. With experience, copper-nickel alloys can be machined with greater ease than alternative materials such as stainless steels. With an exception to a small number of advanced engineering components, most engineering metals are composed of atom clusters arranged in groups of periodic fashion called crystals or grains, hence the name polycrystalline materials. Grains of the same lattice structure but in different orientations are separated by planer defects in the lattice structure called grain boundaries. Copper exhibits some very unique properties such as extremely high conductivity and ductility. Copper is second only to silver in its ability to conduct electricity making it an obvious inexpensive choice for the manufacturing of electrical wires and computer chips. For more structure demanding parts, the addition of alloying materials such as zinc, tin, lead, and aluminum (producing brass and bronze) will significantly increase copper’s strength. This increase in strength however is typically countered by a decrease in electrical conductivity. Even though copper has been manufactured for centuries, it is still considered to by difficult to machine due to its high ductility(Kuyucak, 1996). This property can cause copper chips to adhere to cutting tools, thus disrupting the tool-chip interface and causing poor surface finish. One specific application in which this material is used is in the machining of copper optical mirrors and molds for injection molding of fine lenses used in lasers(Zhong, 2003).

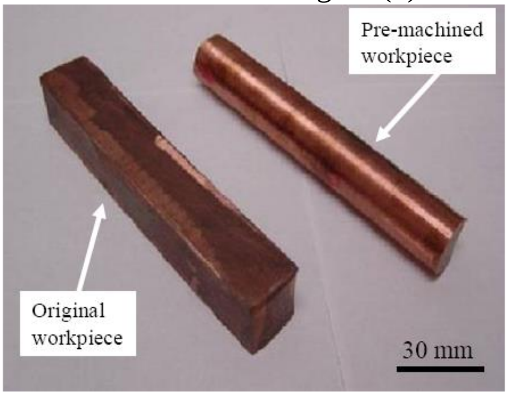
2. Experimental Work

Tungsten carbide tools were chosen for this study, Carbide tools are economically more feasible (approximately 8$ per tool) in machining regular copper-nickel that chemical composition is:

Elem.	Al	Mn	Pb	Zn	Ni	Cu
W%	0.5	0.2	0.7	0.6	6	Rem.

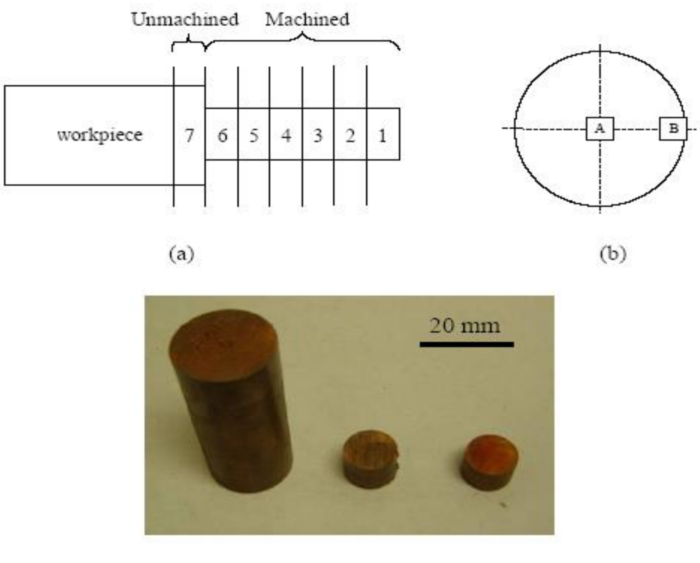
Wear patterns that developed on the rake face and flank areas of the cutting tools were studied using an optical microscopy and the non-contact surface profilometer.

Chip morphology was measured and quantified throughout the cutting of materials using optical microscopy. Chip cross-sectional dimensions along with their overall shape were examined and compared for different cutting times, cutting conditions, and tool materials. The samples , which were received in square shapes. were first turned down to round shapes to fit into the collect as well as avoid interrupting cutting in turning a squared workpiece. The square bars that were 25.4 mm x 25.4 were machined down to 23.6 mm bars as shown in Figure (4).



Figure(4):Preparation of copper-Nickel bars for.

The process to prepare the round workpieces for further machinability research was done with a low feed rate and small depth of cut. They were also flooded with coolant to minimize any heat effect to the workpiece, which may cause microstructural changes. The length of the bars (152 mm) was not affected by this pre-machining process. To determine the cutting conditions used for cutting both Cu-Ni alloy bars, numerous cutting speeds, depths of cuts, and feeds were tested on the ECAP bars to find the best workpiece surface finish by minimizing any smearing effect. The following cutting conditions were selected based on the best achievable surface quality using the tungsten carbide tool: cutting speed of 1 m/s, feed rate 0.15 mm/rev, and depth of cut 0.05 mm. Such a small depth of cut was chosen because it allowed maximum number of passes on each bar while still conserving material removed. One hundred passes were first cut on the free end of the Cu-Ni alloys bars with a length of 38.1 mm (sections 1-3 of Figure 5 (a)), then another set of 100passes of the same cutting conditions was then performed on the next 38.1 mm of the bars (sections 4-6 in Figure 5 (a)). Forces were acquired, chips were collected, and flank wear measurements were taken regularly on each of the Cu-Ni samples.



Figure(5): Experimental preparation (a) sample preparation, (b) a representative cross section, and (c) actual sample.

Machining tests were stopped after completion of the 200 passes described as above. Tool wear geometry and workpiece surface roughness were observed more thoroughly using the profilometer.

3. Results and Discussed

3.1 Cutting forces

Cutting forces generated during machining are generally functions of not only the tool material and geometry, but also of the workpiece physical properties. Figure (6) shows a summary of three dimensional forces (tangential cutting force Fx, radial thrust force Fy, and axial feed force Fz) as a function of machining time in turning.

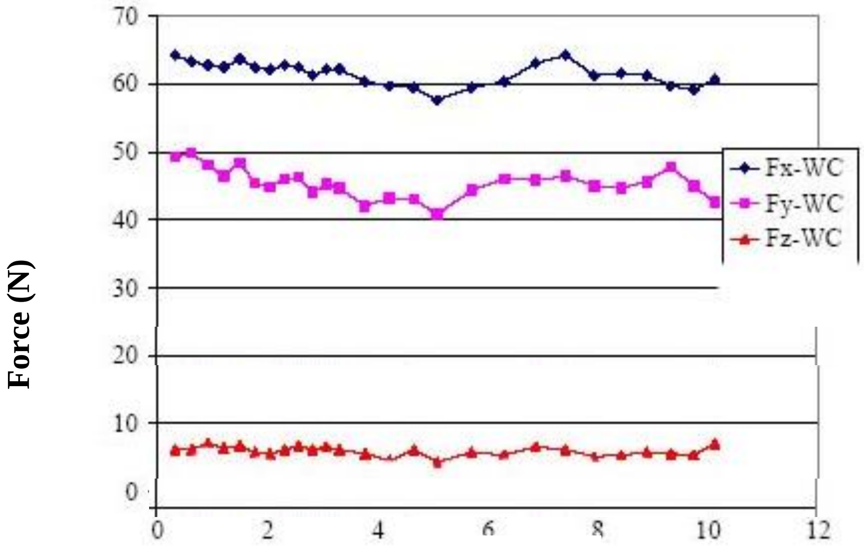


Figure (6) Forces during machining at V = 1 m/s, doc = 0.05 mm, f = 0.15 mm/rev for Cu-Ni alloys using WC tools.

Typically, forces generated when machining Cu-Ni alloy have been large due to a relatively large contact length along the tool rake face(Lee, Y.,2002). From Figure (6) Because the axial feed forces (Fz) were so small under the specified cutting configuration, the tool-chip interface friction coefficient is calculated using the following Equation by approximating the turning as an orthogonal process(Kalpakjian, S.,2003).

$$\mu = \frac{F_t + F_c \tan \alpha}{F_c - F_t \tan \alpha}$$

The computed friction coefficient value of the WC tools in cutting the workpieces is:

Cutting Force (F_c) (N)	Thrust Force (F_t) (N)	α	μ
65	45	5^0	0.83

Tangential cutting forces were around 15% and 25% lower in cutting the Cu-Ni alloy, It has been shown that cold-worked materials reduce frictional forces between the chip and the cutting tools.

3.2 Tool Wear

Depth of cut notching (DOC) or grooving was observed as the main wear pattern in cutting the Cu-Ni alloy using the WC tool (Figure 7)

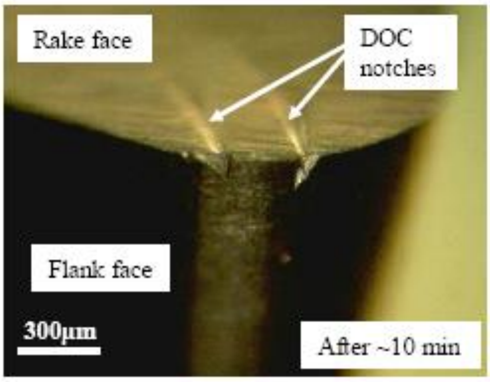


Figure 7 - Wear patterns in machining Cu-Ni alloys.

Figure(8) shows the flank wear progression in turning the Cu-Ni alloy bar with the carbide tools.

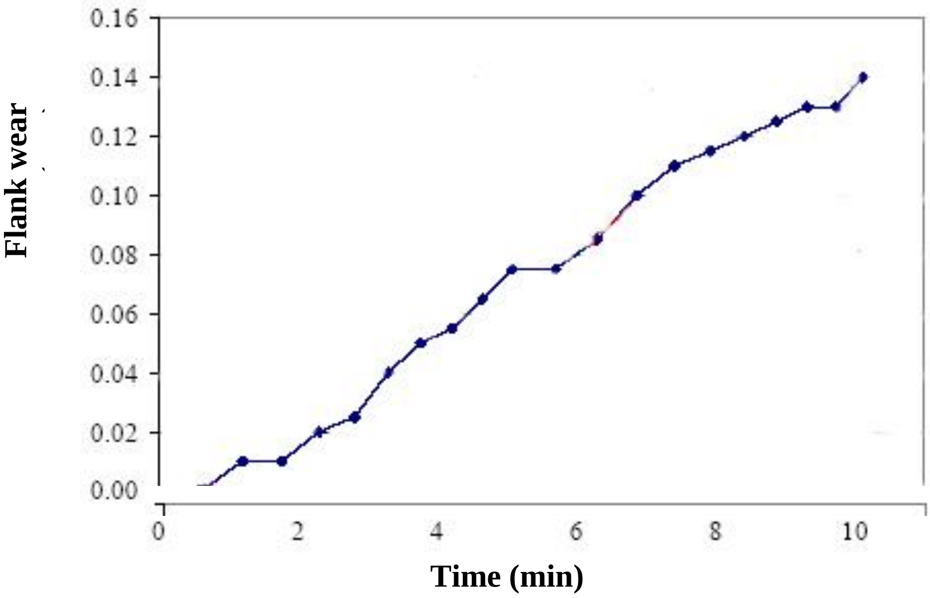


Figure 8 - Flank wear progression in machining Cu-Ni with WC tools.

Depth of cutting notching, as seen from machining with the tungsten carbide tools, is attributed to excessive heat generation at the tool chip interface. This wear pattern, caused mostly by abrasion, is common when cutting high temperature copper alloys. This Depth of cutting notching wear pattern of the carbide tool is attributed to the much lower thermal conductivity (100 W/mK), which causes the heat generated difficult to dissipate, thus raising its temperature. Most of the energy produced from friction and plastic deformation is transformed into heat in machining, and approximately 80% of this heat is dissipated into the chip while the other 20% is conducted into the cutting tool (Davis, J. R.,1995). Since the heat transfer rate from the chip is greatest on the edges than in the center, more thermal energy moves to the tool surface from the edges of the chips. These hot chips produced by the carbide tool due to the low thermal conductivity abrasively rub over the tool rake and flank faces. This eventually causes Depth of cutting notching caused by abrasion at a width equal to that of the chip. While machining the Cu-Ni alloy using the WC tool, Cu-Ni alloy particles were found in the form of residue along the tool rake and flank faces (Morehead, 2005). This leads to the conclusion that adhesion was a wear mechanism in machining the Cu-Ni alloy using the WC tool. Adhesion is caused by the fracture of hot welded asperity junctions between the alloy chip and the tool tip as summarized by Huang, (2002), thus leaving bits of Cu-Ni alloy welded to the surface of the cutting tip. The wear mechanism of adhesion rarely occurs independently from other mechanisms since often the material transferred from the adhered asperities by the movement of the chip causes abrasion on the cutting tool, which produced the depth of notches in this study. So, both abrasion and adhesion are concluded as the two main wear mechanisms in cutting the Cu-Ni alloy using the tungsten carbide tool.

Given that no Cu-Ni alloy trace was found on the tool rake face, it is concluded that diffusion is not a wear mechanism in cutting the Cu-Ni alloys using the WC tool. Chips with burrs were found in machining of Cu-Ni alloys bars using the WC tool. This phenomenon is attributed to an excess of heat at the tool chip interface in machining. The thermal energy generated and retained in the metal causes the chips to cluster and melt , at the primary and secondary shear zones. Once the clusters become large and unsteady, they break off and the majority of their content is carried away by the chip. This occurrence is somewhat similar to built up-edge (BUE), except the burr is deposited on the free side of the chip as opposed to the tool side. Some portions of the burr may get forced between the tool and the workpiece causing a chip to adhere to the machined workpiece, thus reducing surface quality and tool life. Because of the burr’s highly strained and much harder microstructure (up to twice as high as that of the workpiece (Kim, 1999)), the burr embedded chip may also help in propagating the groove formations on the tool faces of the carbide tool. The close up image of the burr, shown in Figure (9).

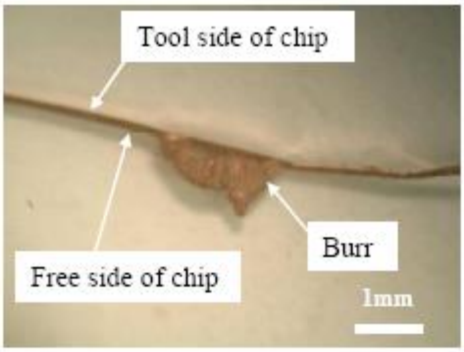


Figure 9 - Micrographs of Cu-Ni chips produced in machining with WC tool.

3.3 Sur

The average surface roughness value, Ra, was acquired using the profilometer. Since the average surface roughness may vary up to 50% along the cutting area (Zhong, 2003), 5 random locations were chosen for surface roughness testing and then averaged. As mentioned before, the profilometer allows images to be taken of the surface and Figure (10) illustrates the Surface information of Cu-Ni alloy at the end of machining using the WC tool.

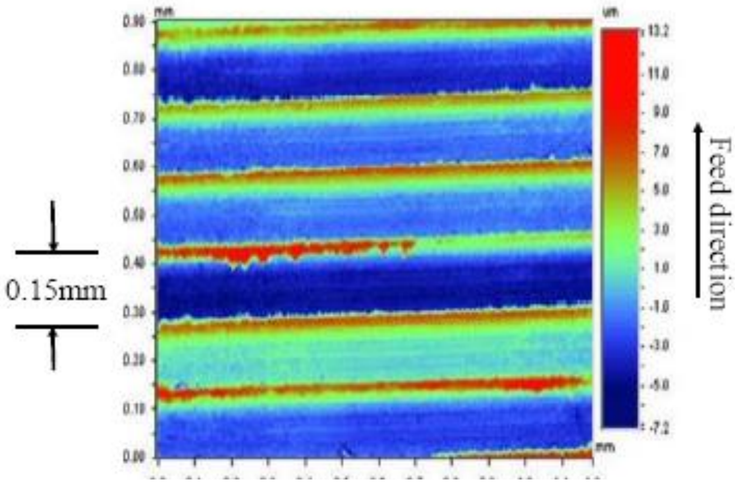


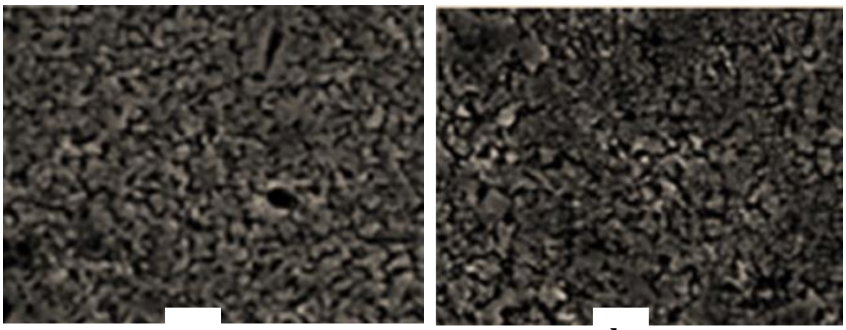
Figure 10 - Surface information of Cu-Ni alloys machined with WC

As shown, the machining marks from two workpieces show the same spacing as the feed rate (0.15 mm/rev). A summary of surface roughness values obtained after machining is 2.97 μm. The resulting surface finish is normally mediocre or poor compared to other pure metals. Even after finishing passes, the Cu-Ni workpiece surface roughness may still be relatively large.

The Cu-Ni alloy bar gave superior surface finishes when turned with tool. This observation agrees with the conclusion that cold working of metals improves the surface integrity and finish after machining . Zhang et al., 1994 also found surface finish to improve when machining Cu-Ni alloy that had been cold worked.

3.4 Optical Microscopy(OM) Results

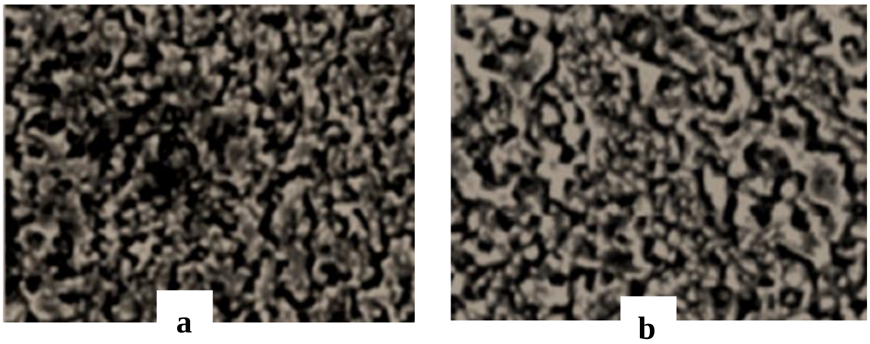
Samples were etched of 15 seconds with the Nital solution of 5g iron nitrate, 25ml hydrochloric acid, and 70ml water. This is a commonly used chemical etchant used for viewing grain boundaries in Cu alloys. An OM image of the unmachined Cu-Ni alloy sample can be seen below in Figure(11).



a **b**

Figure 11- OM images of the unmachined Cu-Ni alloy bar obtained at the (a) center and (b) on the outer radius using WC tool.

As seen in the images showing the structure of the center and outer radius of the sample before machining (Figure (12) (a) and (b)), the machined samples' microstructure looks almost porous. Etching ultrafine grain materials processed from SPD is typically very difficult since, with high internal energy, their grain boundaries and highly dislocated areas within the grains are easily attacked by an etchant. And for this reason, transmission electron microscopy is typically the preferred method for viewing their internal structure.



a b

Figure 12 - OM images of the machined Cu-Ni alloy bar obtained at the (a) center and (b) on the outer radius using WC tool with V= 1 m/s, doc = 0.05 mm, f = 0.15 mm/rev

Comparing Figure (11) with Figure (12) it can be speculated that some grain growth has occurred during the machining process. It can also be seen that this growth may have been more predominant on the outer radius of the sample which is closer to the cutting tool. This speculation however is only enforced by four images and may no attest for a true average grain size throughout the sample.

4. Conclusion

1- forces generated when machining Cu-Ni alloy have been large due to a relatively large contact length along the tool rake face.
2- It has been shown that cold-worked materials reduce frictional forces between the chip and the cutting tools.
3- In machining the Cu-Ni alloy, depth of cut notching was observed as the wear pattern and both abrasion and adhesion as the wear mechanism for the WC tool.
4- Chips generated using the WC tool showed heat induced burrs occurring regularly along the chip for Cu-Ni alloy, These burrs increased tool wear and deteriorated workpiece surface finish.
5- Quantifying the microstructure of the Cu-Ni alloy using scanning optical microscopy proved to be difficult due to over etching of the samples, also was shown to give poor results due to sample preparation.

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