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EXPERIMENTAL INVESTIGATION OF CUTTING FORCES GENERATED DURING TURNING OF QUENCHED AND UNQUENCHED CU-AL-BE ALLOYS

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Abstract. *This work aims to study the machining cutting forces acquired during dry turning with different cutting parameters in quenched and not quenched sample. Three workpiece materials are used in this study:Cu-11.8%Al-0.60%Be, Cu-11.8%Al-0.55%Be and Cu-11.8%Al-0.55%Be-0.50%Nb-0.27%Ni. The heat treatment was carried out in orderto obtain samples with DO3 and/or martensitic structures. The cutting forces were measured with a 3-component dynamometer and it was extracted ten sequential revolutions for each tested sample. For each alloy tested, three replicates were performed with quenched workpieces and three samples without heat treatment. It was found out that the resultant forces were higher in tempered alloys due to the presence of the shape memory effect. Among these, the resulting forces were higher for samples with lower percentage of Be. However, for the additional Nb alloys were obtained the lower resultant forces.*

Keywords*: Metal Casting, Cutting Forces, Shape memory alloy, Cu-Al-Be Alloy*

1. INTRODUCTION

Shape memory alloys (SMA) exhibit a unique property that is the ability to recover, with the increasing of temperature, its original shape after being subjected to deformation, even after being under the application of high loads. To this phenomenon it is given the name of Shape Memory Effect - SME (Otsuka and Wayman, 1998; Lagoudas, 2008).Several copper-based alloys have the Shape Memory Effect. Among them can be mentioned the alloys: Cu-Al-Ni e Cu-Al-Be. Understanding the microstructural changes caused by thermal changes and/or internal stresses leads to significant industrial applications (Chentouf and Bouabdallah, 2010; Funakubo, 1987).

Considering the phase diagram of Cu-Al binary system (Figure 1), with a composition corresponding to the eutectoid point (11.8 wt% Al), there is, at a temperature above 565^{o} C, the presence of the б phase structure of CCC. Thisoccurs below the eutectoid point temperature and under conditions of thermal equilibrium in other two phases, the Ŭphase of CFCs structure, and the phase ɔ$_2$ (Cu_9Al_4) which, from the mechanical point of view is an extremely fragile Phase (Funakubo, 1987; Gonzalez, 2002).However, when the sample undergoes quenching from the б-phase region, the eutectoid state is then prevented from happening, and the б phase evolves into an ordered structure DO_3 (б$_1$ metastable phase) which is known as austenite or parent phase which may still change, due to the temperature decrease during product phase called martensitic for the case of ternary system Cu-Al-Be, 18R (Montecinos, *et al*., 2010).According to the same author and Balo*et al*. (2002), the addition of certain concentrate of beryllium in a Cu-Al system near the

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eutectoid point leads to a marked decrease of temperature for the beginning of the formation of martensite (Ms) which, according to them, something around 30 ° C for each one percentage of increase in atomic or 50° C for each 0.5% of Be in weight. The same applies to a lesser extent, by adding the mother alloy Nb-Ni (Funakubo, 1987).Currently it has become increasingly common to use shape memory alloys as raw material for the manufacture of components of different applications. In this light, the choice of manufacturing process is seen as a key item on the quality of these components. The machining is one of the most widely used manufacturing processes, and in particular, the turning operation (Chang, 1998; Tönshoff and König, 1994). The aim of this study is to compare the cutting forces generated during turning of quenched and unquenched specimens of Cu-11.8%Al-0.60%Be, Cu-11.8%Al-0.55%Be and Cu-11.8%Al-0.55%Be-0.50%Nb-0.27%Ni alloys. The cutting forces were investigated for four different cutting speed conditions.

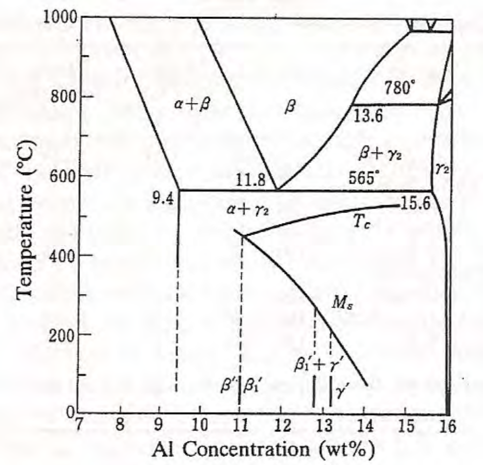

Figure 1. Phase diagram for CuAl binary system (FUNAKUBO, 1987).

2. WORKPIECE MATERIAL CASTING

The workpieces for experimental investigation were especially casted with dimensions designed to be machined by external turning in a regular lathe. A (Cu-11.8%Al-0.60%Be (wt%)), B (Cu-11.8%Al-0,55%Be (wt%)) and C (Cu-11.8%Al-0.55%Be-0.50%Nb-0.27%Ni (wt%)) alloys were melted in the permanent steel mold showed in Fig. 2a. The ingots obtained after this process are shown in Fig. 2b.

(a)

(b)

Figure 2. Workpiece Casting: (a) Permanent Mold and (b) As-cast specimens.

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The transformation temperatures were determined using a DSC (model DSC-60, SHIMADZU) on the quenched alloys in free stress state as shown in Table 1.

Table 1. Temperatures start and end to transformation martensite and austenite phases of the alloys.

Phases	Martensite		Austenite	
Alloys	M_s (°C)	M_f(°C)	A_s (°C)	A_f (°C)
A: Cu-11.8%Al-0.60%Be	-83.65	-87.92	-75.67	-57.15
B: Cu-11.8%Al-0.55%Be	-33.63	-54.56	-28.84	-6.87
C: Cu-11.8%Al-0.55%Be-0.50%Nb-0.27Ni	-52.46	-74.63	-42.91	-22.42

3. EXPERIMENTAL SETUP FOR CUTTING FORCE MEASUREMENTS

For each one of the three casted alloys, two cylindrical bars were used as samples: one of them was subjected to quenching to obtain the shape memory effect and one of them was machined as cast.Thus, six different samples were used in the experiments.Before the tests, the specimens were lightly machined in order to have a regular surface and not to induce thermal effects. Since temperature is an important variable, in order not to achieve high temperatures, the machining is done with short passes of 15 mm length. Figure 3 presents the surface as it stood before testing.

Cutting forces were taken continuously by using a piezoelectric dynamometer KISTLER model 9257 BA with amplifier 5233A and data acquisition board NI/USB 6221. Acquisition rate of 1kH_z was applied. The acquired signal was compiled in MATLAB. The components F_x and F_y can be seen in the scheme presented in Fig. 3b, F_z is oriented in cutting direction, normal to the plane shown in this Figure.

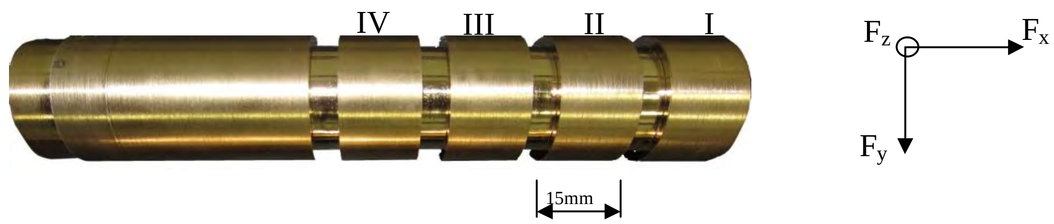


Figure 3. Experiment Set-up: Specimen used in the tests.

The fixed cutting conditions are shown in Tab. 2 where n is the speed spindle, a_p the depth of cut and f the feed per revolution. For the design of experiments it was considered three factors: one factor with two levels (with and without heat treatment), four levels of the cutting velocity (V_c)and two levels of the heat treatment (with and without quenching). The work piece diameter varies from 27-30 mm to imply different levels of the cutting velocitiesV_c (executed in the parts I, II, III and IV), as shown in Tab. 3 and Figure 3.

Table 2. Fixed Cutting Conditions

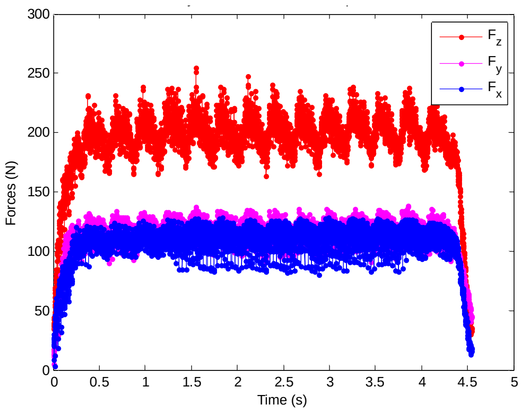
Spindle Speed (n)	1600 rpm
Depth of cut (a_p)	0.50 mm
Feed per revolution	0.091 mm/rev

Table 3. Design of Experiments

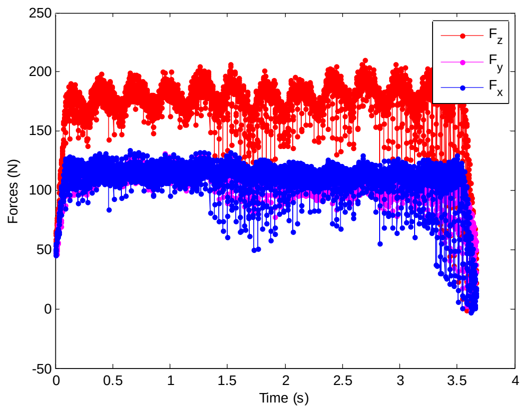
Factors	**Levels**			
Workpiece Material	Alloy A	Alloy B	Alloy C	
Workpiece diameter (Cutting Velocity)	30 mm (I) (150.79 m/min)	29 mm (II) (145.77 m/min)	28 mm (III) (140.74m/min)	27mm (IV) (135.72m/min)
Heat Treatment	Quenched		Not quenched	

4. EXPERIMENTAL RESULTS

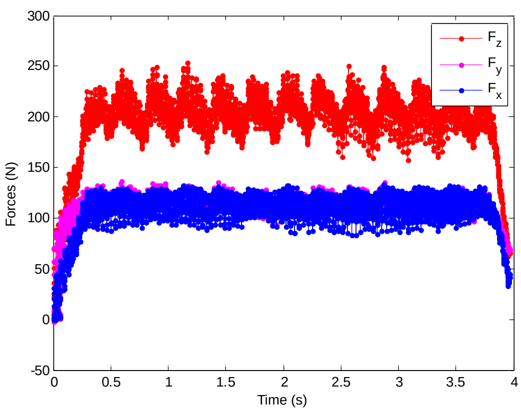
For each test, it was used a period of 10 revolutions for the analysis of the force profile. As an example, Figure 4 presents the complete cutting force experiment signals for each experiment that used V_c = 135.72 m/min.Figures 4a, 4c and 4eshows results for the quenched workpiece and Figures4b, 4d and 4f for the unquenched workpieces.



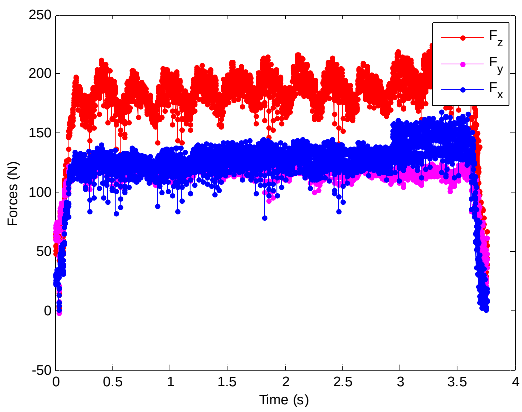
(a) Quenched Cu-11.8%Al-0.6%Be workpiece



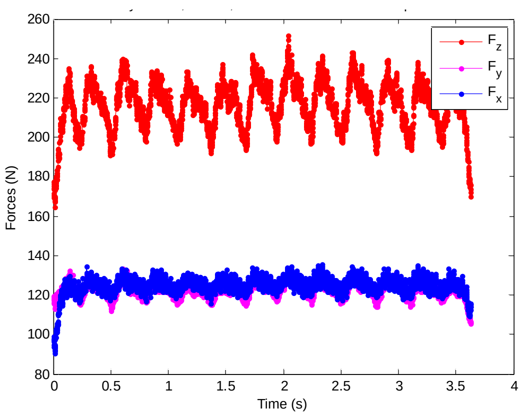
(b) Not-Quenched Cu-11.8%Al-0.6%Be workpiece



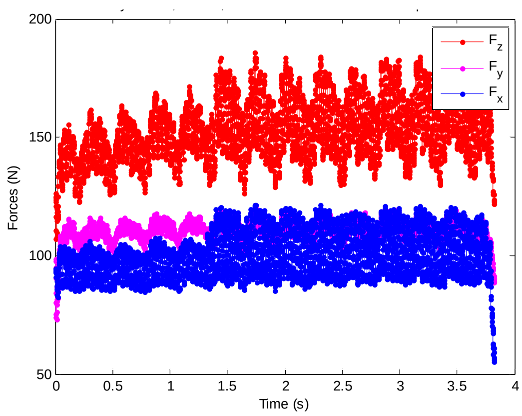
(c) Quenched Cu-11.8%Al-0.55%Be workpiece



(d) Not-Quenched Cu-11.8%Al-0.55%Be workpiece



(e) Quenched Cu-11.8%Al-0.55%Be 0.5%Nb ï 0.27%Ni workpiece



(f) Not-Quenched Cu-11.8%Al-0.55%Be 0.5%Nb ï 0.27%Ni workpiece

Figure 4. Forces Results from experiments using V_c=135.72 m/min

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Using the complete experimental results (10 revolutions of each), it was calculated the values of the maximum, mean and peak to peak resultant forces. The condensed results for the alloys: A, B and C are provided in Table 4.

Table 4. Medium resultant force in 10 rotations of piece ï quenched and no quenched.

	Maximum Resultant Force [N]					
	A		B		C	
Vc (m/min)	No-Quenched	Quenched	No-Quenched	Quenched	No-Quenched	Quenched
135.72	348.97	364.64	361.41	332.50	264.34	300.19
140.74	320.74	293.30	370.04	300.90	256.32	293.44
145.77	319.62	290.49	342.27	310.02	257.58	285.68
150.79	276.47	291.87	313.02	292.61	245.26	287.14
	Average Resultant Force [N]					
	A		B		C	
Vc (m/min)	No-Quenched	Quenched	No-Quenched	Quenched	No-Quenched	Quenched
135.72	325.86	342.44	336.32	312.65	256.91	289.98
140.74	304.98	276.63	348.29	283.91	248.72	281.92
145.77	303.15	274.25	324.03	293.19	248.89	273.71
150.79	260.25	276.93	297.59	275.94	232.67	275.13
	Peak-to-Peak Resultant Force [N]					
	A		B		C	
Vc (m/min)	No-Quenched	Quenched	No-Quenched	Quenched	No-Quenched	Quenched
135.72	43.76	34.51	52.88	35.01	15.23	19.97
140.74	27.21	36.46	49.91	35.18	13.99	21.06
145.77	32.29	37.36	38.58	30.81	16.02	22.19
150.79	25.02	34.88	27.87	30.58	22.24	22.67

Trend variations between alloys showed that the heat treatment lowered down the forces in Alloys A and B but not on Alloy C (Cu-11.8%Al-0.55%Be-0.50%Nb-0.27%Ni) as shown in Figure 5.

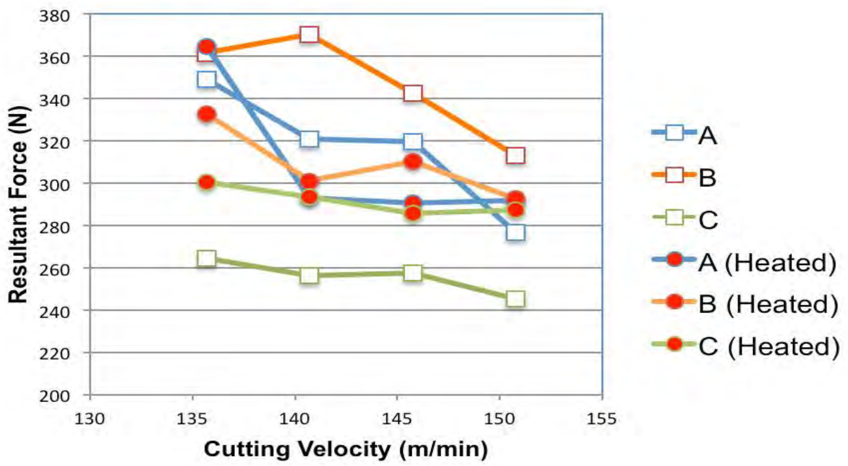

Figure 5 ï Resultant Forces with Different Cutting Velocities in All Workpieces (Heat treated and As Casted)

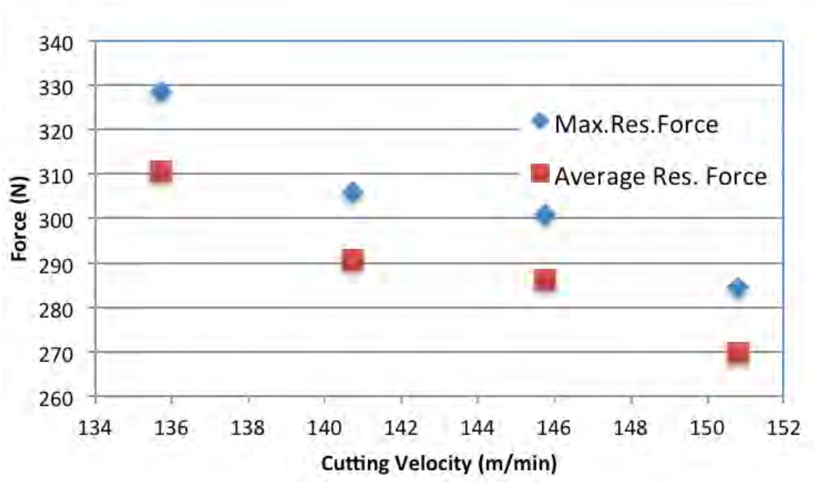

Figure 6 ï Average and Maximum Resultant Forces for Different Cutting Velocities

As shown in Table 4, Figure 5 and 6, the maximum and average forces, obtained during the machining of the samples, were increasing in intensity as the velocity decreased. Figure 6 presents the average of all the machined workpieces in different cutting velocities.

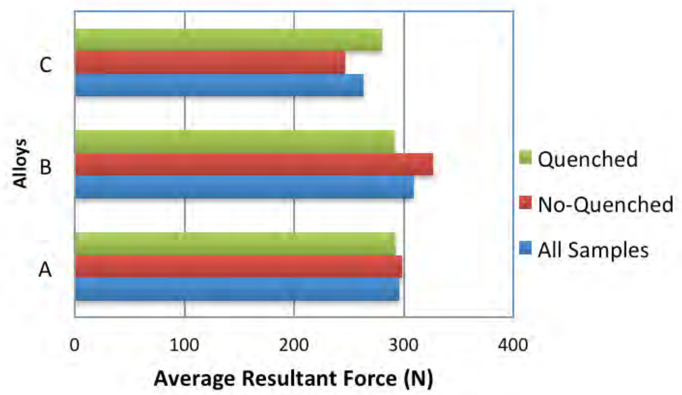

Figure 7 ï Average Resultant Forces (all cutting velocities) in the Different Alloys

The three different alloys presented different behavior. The mean results for Alloy A, disregarding the cutting velocity effect, did not show strong difference between samples. In Alloy B quenched samples had higher usinability then not treated ones while in Alloy C the heat treatment lowered its usinability.

5. CONCLUSIONS

In this work the cutting forces generated during turning of tempered and not-tempered samples of the alloys Cu-11.8%Al-0.60%Be, Cu-11.8%Al-0.55%Be and Cu-11.8%Al-0.55%Be-0.50%Nb-0.27%Ni were investigated and also four levels of cutting speed were used in the study. The following conclusions could be pointed out:

- The resultant machining forcesreduced as the increase of cutting velocities, indicating higher specific cutting forces on lower cutting velocities for all the samples.
- Comparing the three alloys, theCu-11.8%Al-0.55%Be requested higher forces for machining and the Be-Ni alloy shown higher machinability (considering cutting force as machinability factor). Although, after heat treatment this alloy required higher forces. The refinement of the grains, due to the addition of Niobium, should induce higher resistance and higher machining forces influence is presented in experimental results only in quenched niobium alloy.
- In the heat treated Cu-Al-Be alloys (without Nb and Ni) presented lower forces compared to the as casted samples. It should be verified if there is a relation between forces and the increase of the stability of the austenitic phase (DO3).Such stability was determined by this percentage amount of beryllium contained in the alloy.

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