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Researches on the Specific Energy and Interface Tool-Chip Temperature During Milling of Aluminum Alloys

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Abstract: *Due to the importance of aluminum alloys in a various types of industry (automotive, aerospace, naval and maritime, food etc., is important to know the phenomena that occurs in cutting processes of this alloys. One of the most important phenomena is temperature.*
For this reason, the main purpose of this paper is to study the thermal aspects in milling of three types of aluminum alloys, both by measuring, using contact method, and calculus of medium temperature at the chip-tool interface as function of the cutting parameters.
For contacts method, six thermocouples, K-type, was used. All the experiments were performed using pre-machining work-pieces, with the drilled holes, necessary for thermocouple installation.
The tools used in this study was carbide end mills and all cutting processes was performed using a conventional milling machine, with digital readout.
The results are graphically representations with discussions and conclusions about temperature and specific energy. The results show a high values, both for temperature and specific energy, for increasing of cutting speed.

Keywords: *Aluminum alloys, Milling, Specific energy, Temperature*

1 INTRODUCTION

As it known, many types of aluminum alloys are using in automotive applications, [6], [9], parts of aircraft structure, [3], [9], [11], ship buildings, [5] especially due to their high specific strength, high specific stiffness, high toughness, excellent processing, and welding performance, [11].

Because present paper is intend to study thermal phenomena that occur during milling of 5082, 6083 and 7075 aluminum alloys, is important to know that part of 5xxx, and 6xxx series are used in automotive structure, [5], [6], while 7075 in aircraft structure, [3], [11], shipbuilding applications, for 5xxx and 6xxx series, [5]
Is important to add here new development in special aluminum alloys (series 5xxx, 6xxx and 7xxx) for BIW (Body-In-White) concept, [6], with applications for structural car body.

Many parts of this aluminum alloys are obtained and used in vary fields, directly, after the primary manufacturing processes as casting, extrusion, without secondary machining processes. But to get the final shape according with the precision (surface roughness, nominal dimensions, tolerance or shape deviations) many parts are machined, using different cutting operations (turning, milling, drilling, grinding etc.).

As the milling is one of largest operation in machining of aluminum alloy, is very important to know the phenomena that occur during this process. One of this is temperature. This can affect the surface roughness, part deformation, tool wear and not only.

From this point of view, machining of aluminum alloys, was the object of many researches, under many aspects (thernal phenmomena, tool wear, surface roughness and state layer integrity etc.).

Many relevant information about the characteristics of machinability of aluminum alloys, under aspects of forces and stress, power and temperature generated, surface integrity, but also cutting tools and their wear, cutting fluids, and aspects regarding the chips control during maching of aluminum alloys, are presented in [9].

2. TEMPERATURE AT THE INTERFACE CHIP-TOOL

As it is known the cutting heat in orthogonal cutting process is generated due to the elasto-plastic deformation in the primary deformation zone (shear plane) and due to plastic deformation in secondary zone (friction between chip and rake face of the tool). The cutting heat is distributed on the chip, Q_c, workpiece, Q_w, tool, Q_t and environment, Q_{env}, so the equation of the thermal balance can be written as:

$$Q = Q_c + Q_w + Q_t + Q_{env} \qquad (1)$$

Mainly, the heat is generated due to the work consumed to the plastic deformation in the shear plane, and as a consequence, the greates value of the temperature will be in this area, fig. 1.

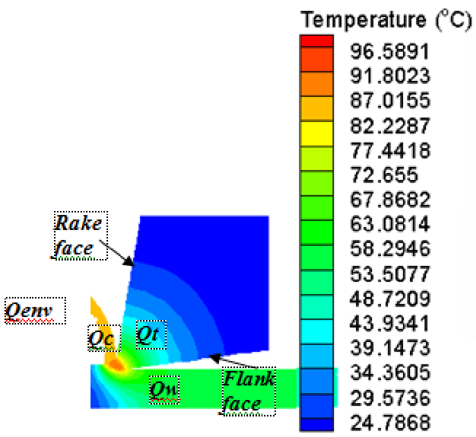

Fig. 1. Field temperature in the cutting area, simulated for milling of 5083aluminum alloy

Based of this considerations is important to appreciate the temperature in the cutting area and, in present paper, the medium temperature at interface chip tool determinated. So, in order to predict the mean value of the cutting temperature at the tool-chip interface, the next equation can be used [1], [4]:

$$\Delta T = \frac{0.4 \cdot U}{\rho \cdot C}\left(\frac{v \cdot a}{K}\right)^{0.333} \qquad (2)$$

where: ΔT mean temperature value at the tool-chip interface; U, specific energy of the operation; v, cutting speed; a, chip thickness; ρ, density of the considered material; c, specific heat of the workpiece material; K, thermal diffusivity of the workpiece material.

Thermal diffusivity,K, (heat conducted/heat stored), can be calculated with well-known relation:

$$K = \frac{\lambda}{\rho \cdot c} \qquad (3)$$

where λ is thermal conductivity of the material.

Specific energy values for machining of aluminum alloys depend of the cutting conditions and can be 0.8 J/mm^3 [4] or (0.25…0.34) J/mm^3[2].

For this reason, in the present paper, our intention is to calculate the value of the specific energy in milling process of the three types of aluminum aloys.

As result of milling process simulation, it was possible to obtain the feed and radial component of cutting forces, fig. 2 and fig. 3, the value of the specific energy can be calculated with the next equation, [8]:

$$U = \frac{v}{V_{rem}} \int_0^{t_c} \sqrt{F_a^2 + F_p^2}\, dt \qquad (4)$$

where:v is cutting speed; V_{rem}, is the chips volume removed; t_c, milling process time; F_a and F_p represent the feed and radial forces (active and passive on the fig. 2 and fig. 3).

Using the graphical representations of these two components and the values of cutting speed used in experiments and milling time, it was possible to calculate the values of specific energy.

3.MATERIALS AND EXPERIMENTAL CONDITIONS

The experiments was performed using a conventional milling machine with a digital readout, and, as tool a cemented carbides end mill, with ϕ10 mm diameter and four flutes, fig. 4, [12].

All the determinations was done on three types of aluminum alloys, EN AW-5083, EN AW-6082 and EN AW-7075 with phisical properties presented in Table 1 and mecanical properties in Table 2.

In order to measure the temperature during milling process an experimental instalation, presented in fig. 5, and consist in six thermocouples adequated placed inside of the workpiece, and a infrared thermometer, [13], in a such way to make posible the measuring of the temperature with and without contact.

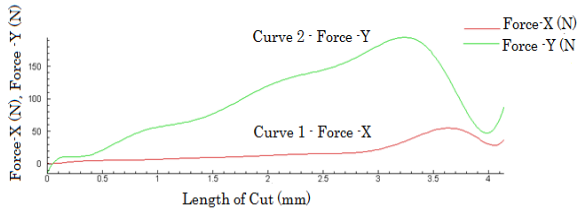

Fig. 2. Feed and radial components of the cutting forces as result of simulation process for 5083aluminum alloy, for v = 21.865 m/min

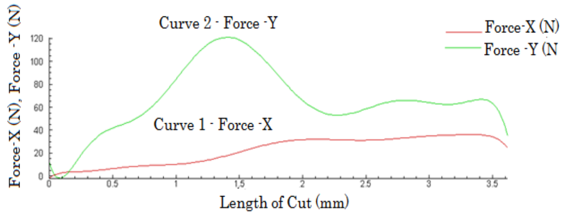

Fig. 3. Feed and radial components of the cutting forces as rezult of simulation process for 5083aluminum alloy, for v = 32.986 m/min

Fig. 4 End mill with ϕ10 mm diameter and four flutes

Table 1. Phisical properties for aluminum alloys

Material	Thermal conductivity, λ, w/m·K	Specific heat, c, J/Kg·C	Density ρ Kg/m^3
EN AW-5083	110-130	900	2660
EN AW-6082	150-190	896	2700
EN AW-7075	130-160	862	2800

Table 2. Mechanical properties of aluminum alloys

Material	Rp0,2, [MPa]	Rm,[MPa]	A5, [%]
EN AW-5083	115	270	15
EN AW-6082	297	320	8
EN AW-7075	532	594	10

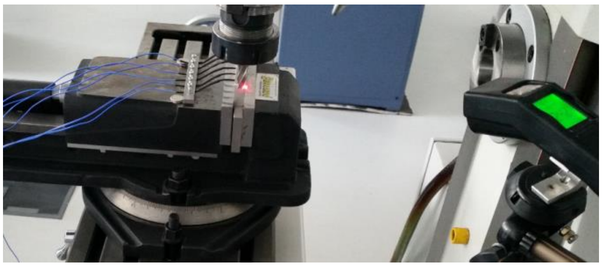

Fig. 5. Experimental instalation

The experiments was conducted using three different cutting speed 21.865 m/min, 32.986 m/min and 65.973 m/min, calculated for 720 rpm, 875 rpm and

1750 rpm, and ϕ10 mm end mill diamerer, with the next observation: in relation (5) the unit of cutting speed must be in m/sec, meaning 0.364 m/sec, 0.548 m/sec and 1.0995 m/sec.

4.RESULTS

Using the graphical representations for the two components and the values of cutting speed used in experiments and milling time it was possible to calculate the values of specific energy, and in fig. 6, graphical representation is presented.

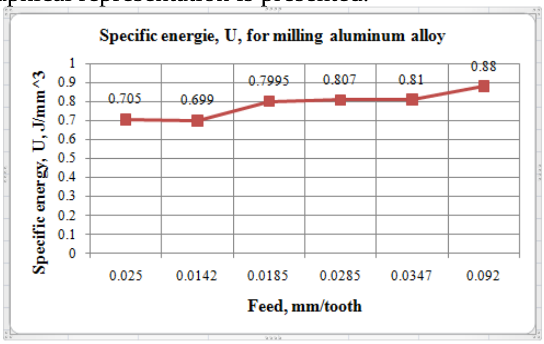

Fig. 6. Values of specific energy for milling of aluminum alloy

As it can be seen from the fig. 6, the medium value of the specific energy is U = 0.783 J/mm^3 very close value as it is indicate in [4], U = 0.8 J/mm^3, so, in order, to calculate the mediu temperature at chip-tool interface, for all aluminum alloys, will be considered this value.

In equation (2) are used the value of physical properties as it is presented in Table 1, and for chip thickness before the cut, are used the values of feed/tooth because the chip thickness, for χ_r=90^0, is:

$$a = f_d \cdot \sin \chi_r = f_d \tag{6}$$

Based on this considerations, graphical representations of medium temperature are presented in fig. 7 to fig. 9, 6082, 5083 and 7075, at different cutting speeds and chip thickness before the cut. In fig. 10 to fig. 12 the variation of medium temperature at chip-tool interface for the three types of aluminum alloys at 21.865 m/min, 32.986 m/min and 65.973m/min, cutting speed.

5.CONCLUSIONS

The main purpose of this paper is to appreciate, as results of the experiments the value of specific energy and medium temperature at interface chip tool in milling process of three types aluminum alloys

First, the specific energy of the milling process was calculated based on the values of cutting speed, volume of chips removed and two components of cutting forces active and passive components) as it is result from milling simulation .

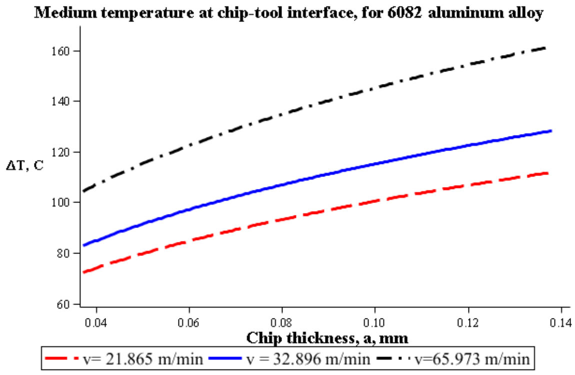

Fig.7. Variation of medium temperature at chip-tool interface for 6082 aluminum alloy

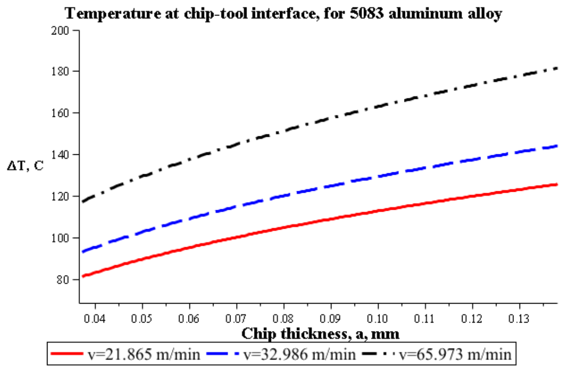

Fig. 8. Variation of medium temperature at chip-tool interface for 5083 aluminum alloy

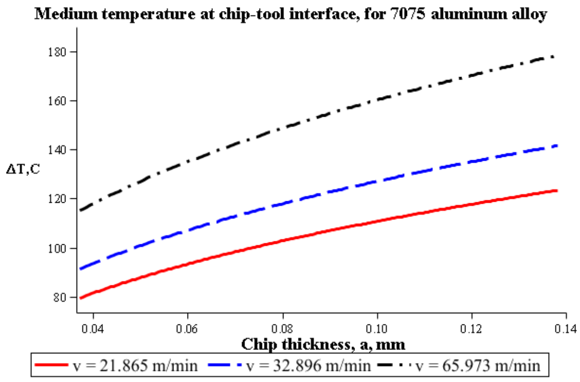

Fig. 9. Variation of medium temperature at chip-tool interface for 7075aluminum alloy

The results indicate a medium value of 0.783 J/mm^3, and the main purpose was to compare this value with other from literature. One of the authors indicate a narrow range of this value 0,232 J/mm^3 (0.463- 0,695 J/mm^3), respectivelly, but for other the value is 0.702 J/mm^{3}or 0.827 J/mm^3.

So, the value obtained in our paper is very close to the value of 0.8 J/mm^3, and in order to calculate the medium temperature at interface chip-tool, this value was used.

Value of medium temperature at interface chip-tool was calculated as function of specific energy of the milling process, cutting speed, chip thickness before the cut and physical properties of the three types aluminum.

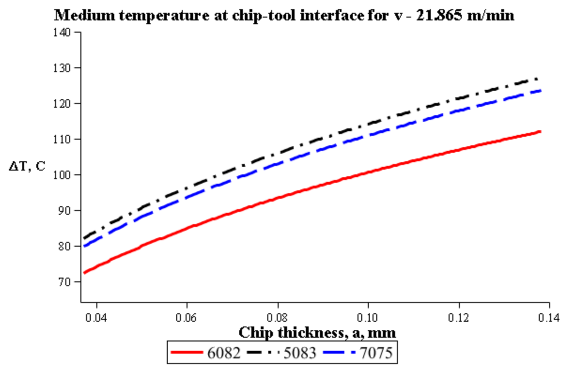

Fig. 10. Variation of medium temperature at chip-tool interface for v= 21.865 m/min

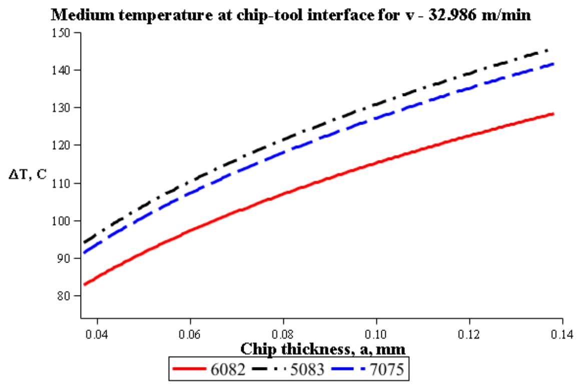

Fig. 11. Variation of medium temperature at chip-tool interface for v= 32.986 m/min

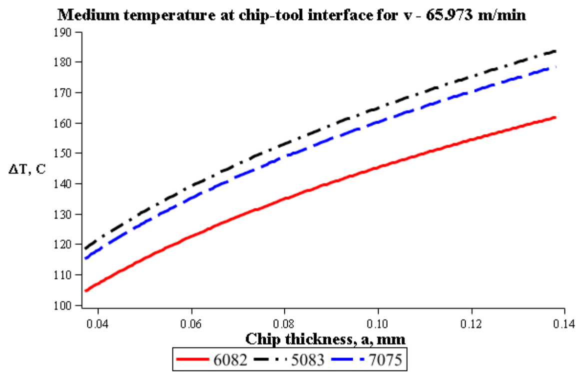

Fig. 12. Variation of medium temperature at chip-tool interface for v= 69.973 m/min

This value was found to be greater for cutting speed value of 65.973 m/min for all types of aluminum alloys studied (6082, 5083 and 7075), and for all cutting speed considered, the greater value was found for 5083 aluminum alloy.

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