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EVALUATION OF MACHINABILITY OF AlCu11 CAST ALLOY AT CONVENTIONAL CUTTING SPEEDS

BY

CRISTIAN CROITORU[1*], ANA-MARIA BOCĂNEŢ[1], ROMEU CHELARIU[2] and **DANIELA CHICET[2]**

“Gheorghe Asachi” Technical University of Iaşi, România,
[1]Faculty of Machines Manufacturing and Industrial Management
[2]Faculty of Materials Science and Engineering

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Abstract. The emergence of a new metallic material must be accompanied by specifications regarding its cutting machinability. Assessment of machinability aims, on the one hand framing the respective material in a particular category and, on the other hand, seeks on performance in that category. In addition, determining the machinability of a material is useful if the actual working conditions are outside the range recommended by the specific literature.

An effective way of assessing the machinability is evaluating the power consumption by cutting through specific cutting force or specific cutting energy.

This paper presents an expedient methodology for assessing the machinability of an aluminum alloy through a parameter frequently used in current industrial practice, specific cutting force.

Key words: cutting force’s components; specific cutting force; machinability; dry machining.

[*]Corresponding author; *e-mail*: ccroitoru2003@yahoo.com

1. Introduction

Al-Cu alloys have received an important interest due to their wide range of applications in leading industries such as aerospace and automotive.

Most times, processing these materials is performed with high rates of cutting speed, usual for ferrous alloys based on aluminum (Sornakumar & Senthil Kumar, 2008; Sandvik Coromant, 2010; Toenshoff & Denkena, 2013).

Current practice proves that in case of small dimensions of the tools or workpieces machining runs with averages values of cutting speed, due to the limitations imposed by the characteristics of the machine tool (Sekulic *et al*., 2010; Gonzalo *et al*., 2010).

In these cases, there are difficulties in estimating of forces and cutting power due to lack of information concerning the various coefficients to be used in their calculation.

The purpose of this study was to investigate the machinability of cast AlCu11 alloy for possible application and to compare the results with those encountered in literature.

2. Materials and Methods

2.1. Presentation of AlCu11 Alloy

The alloy is symbolized AlCu11 and it is a hipoeutectoid alloy (Fig. 1), whose structure in the diagram Cu-Al balance system consists of solid solution αAl and eutectic (E).

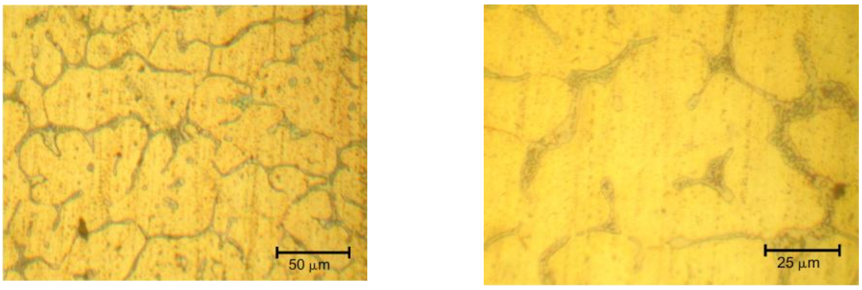


Fig. 1 − Microstructure of alloy AlCu11 (optical microscopy).

The alloy composition, given by the producer, is presented in Table 1 in mass percent.

Table 1
Chemical Composition of AlCu11 Alloy in Mass Percents

Al	Cu	Fe	Si	Zn	Ni	Mn	Sn	Pb
88.60	11.00	0.20	0.10	0.04	0.03	0.01	0.01	0.01

The alloy has been elaborated in a furnace flame and molded into bars shape having a diameter of 50 mm using a continuous casting process.

Metallographic samples were obtained by a classic procedure, consisting of grinding and mechanical polishing using metallographic sandpaper and suspension of alumina followed by chemical attack with NaOH solution and analyzed in terms of microstructural and chemical composition by scanning electron microscope VEGA TESCAN.

Microstructural analysis emphasizes dendrites of solid solution αAl having a quasi- round form and uniform sizes (Fig. 2).

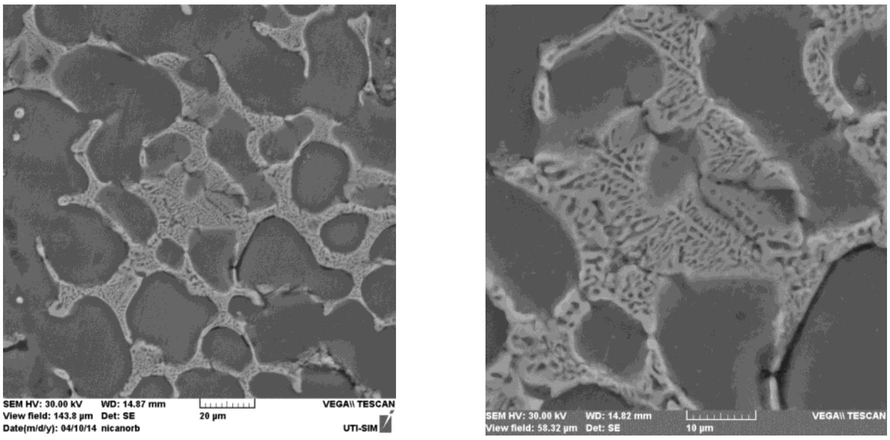
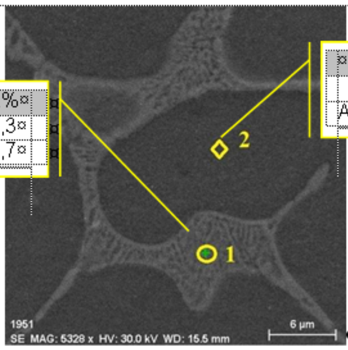


Fig. 2 – The electron microscopy of CuAl11 alloy.

The eutectic is placed in the space between dendrites, forming in his turn a mechanical mixture of αAl solid solution and an intermetallic compound $CuAl_2$.

The above observations are referred by elemental chemical analysis performed by EDS (energy-dispersive and ray spectroscopy) method using analysis module mounted on electron microscopy.

	wt.%	at.%
Copper	40,3	22,3
Aluminium	59,7	77,7



	wt.%	at.%
Copper	5,0	2,2
Aluminium	95,5	97,8

Fig. 3 − The elemental chemical analysis in two points.

The result of chemical analysis items is presented in Fig. 3: in point 1 of the network of eutectic is characterized by a higher percentage of copper, which confirms the existence of mechanical mixture αAl-$CuAl_2$, and in point 2, the element copper is present in an amount close in solid state solubility limit of copper in aluminum.

2.2. Specific Cutting Force

Considering the cutting tool and the workpiece oriented in the reference system of the machine tool it follows that the cutting force F acting on the cutting tool can be decomposed as shown in Fig. 4, wherein:

- F_c (F_z) is the cutting force or the main component of the resultant force F;
- F_a (F_x) is the feed force of the resultant force F;
- F_p (F_y) is the passive force of the resultant force F.

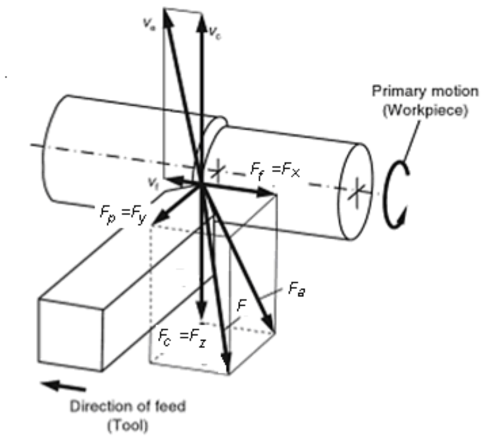


Fig. 4 – Decomposing of resultant force F (Klocke, 2011).

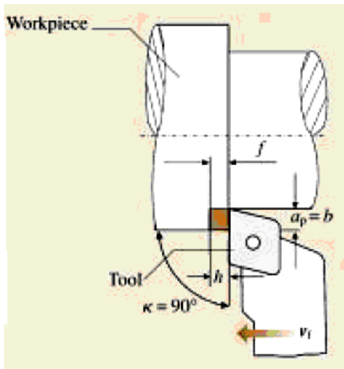


Fig. 5 – Cut and chip variables.

According to the hypothesis supported by Kienzle (Klocke, 2011; Toenshoff & Denkena, 2013), each of these components depends on the area of the theoretical chip which in the case of the main component (cutting force) F_c takes the form given by eq. (1):

$$F_c = k_c \cdot A = k_c \cdot h \cdot b \tag{1}$$

where: k_c is the specific cutting force; b − the theoretical chip width (Fig. 5); h − the theoretical chip thickness; a_p − the depth of cut; f − the feed.

The specific cutting force k_c is also described in terms of an exponential curve in line with eq. (2)

$$k_c = \frac{F_c}{A} = \frac{b \cdot k_{c1.1} \cdot h^{1-m_c}}{b \cdot h} = k_{c1.1} \cdot h^{-m_c} \tag{2}$$

where: $k_{c1.1}$ is the unit specific cutting force (*i.e*. $k_{c1.1}$ is k_c at h=b=1) and m_c − the exponent of the specific cutting force (Pérez *et al*., 2007).

Considering eqs. (1) and (2), the following form of the Kienzle equation for main cutting force can be deduced:

$$F_c = k_{c1.1} \cdot b \cdot h^{1-m_c} \tag{3}$$

The two constants $k_{c1.1}$ and 1-m_c are listed for various ferrous materials (Toenshoff & Denkena, 2013, Sandvik Coromant, 2010). It should be emphasized that Toenshoff (2013) do not recommend a direct comparison of the $k_{c1.1}$ values of different materials to indicate machinability as the exponent m_c may vary significantly.

2.3. Graphic-Analytical Method for Determining the Specific Cutting Force

In order to determine values $k_{c1.1}$ and m_c the linear equation corresponding to relation 3 was considered:

$$\lg \frac{F_c}{b} = \lg k_{c1.1} + (1 - m_c) \cdot \lg h, \tag{4}$$

whose graphical representation is shown in Fig. 6.

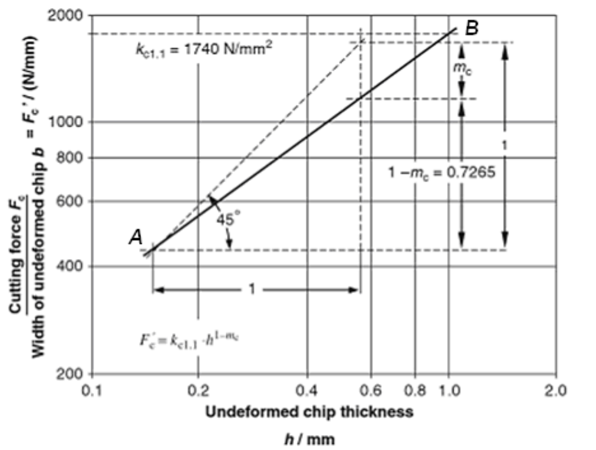


Fig. 6 – Graphical determination of characteristic values $k_{c1.1}$ and m_c (Klocke, 2011).

If in the plot presented in Fig. 6 we consider that the AB line represents the interpolation line obtained for different experimental values for coordinates F_c/b and h, from the same figure may be determined $k_{c1.1}$ values and $(1-m_c)$, with which one may calculate k_c and m_c.

Specific cutting force values k_c are obtained by replacing constants $k_{c1.1}$ and m_c in eq. (2) corresponding to different points of the experimental plan.

These values were used in the final assessment of machinability of the material studied in this paper.

3. Results

In order to evaluate the machinability of AlCu11 alloy was chosen the direct observation of the chips and the value of specific cutting force of which determination methodology was described above.

3.1. Machining Conditions

Experiments were carried out on a conventional lathe SNA 560x1500.

The diameter of the alloy bars used was 50 mm. To eliminate the material heterogenities produced in the continuous cast specimen, material thickness varying from 0.5 to 1 mm was machined off the external diameter.

Machining tests were conducted by using un uncoated carbide P20 turning tool insert having the following features (Figs. 7 and 8).

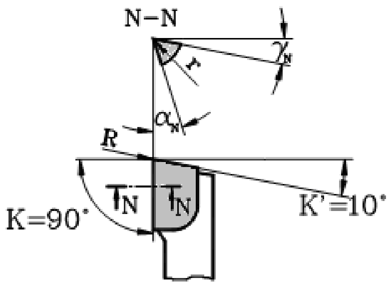


Fig. 7 − Geometric features of the utilized cutting tool.

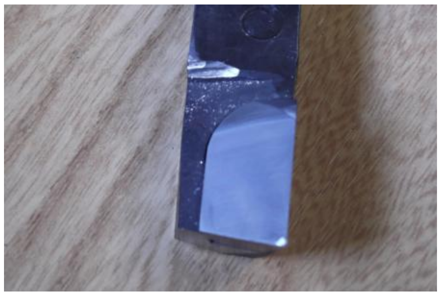


Fig. 8 − Cutting tool.

- major cutting angle K= 90°;
- minor cutting angle K'= 10°;
- nose radius R < 0.05 mm;
- inclination angle λ = 0°;
- clearance angle α_N = 10°;
- cutting edge roundness r < 0.02 mm;
- rake angle γ_N = 0°, 10° and 20°.

To avoid the influence of free formation o the chips the flat form face of the tool was adopted.

Machining experiments were conducted in dry conditions, with following cutting parameters:

- cutting speed V_c = 89...95 m/min;
- feed rate f = 0.1; 0.14; 0.18 and 0.22 mm/rev.

3.2. Observation of Chips

Direct observation of the formation of chips led to the following conclusions:

− Flat shape of the tool rake face made the chips to be formed following a process of free flow (Stahl & de Vos, 2014);

− Detached chips fall within the category of long-chipping, non-uniform fragmented;

Fig. 9 – Formation of built-up edge.

− During the experiments frequently it was observed the phenomenon formation of built up edge (BUE – Fig. 9);

− This built-up edge functioned as a chipbreaker, which made the chips to take shape “ear” with non-dimensional size (Shaw, 1997).

3.3. Determining the Specific Cutting Force

A piezoelectric dynamometer Kistler 9272 was used to measure the component force during the experiments (Fig. 10).

For each experiment, we recorded the evolution of components F_z (F_c), F_x (F_f) and F_y (F_p) of the resultant cutting force and were calculated their average values (Fig. 11).

It specifies that the feed F_x (F_a) and passive F_y (F_f) components is not the subject of the present study.

Fig. 10 – Measuring the resultant force and its components.

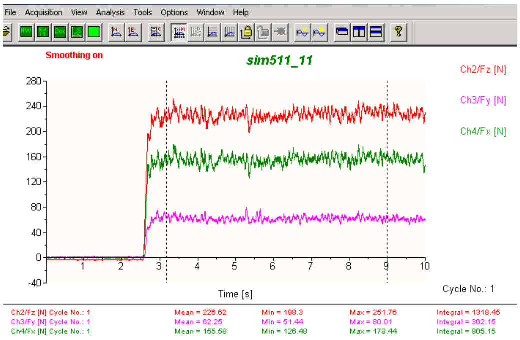


Fig. 11 – Registration of the resulting cutting force components.

Were performed three sets of experiments in random order, considering three values of rake angle and 4 values of the feed, according to data presented in Table 2.

Table 2

Measured Average Values of Components of the Resultant Force

No. test	f [mm/rot]	Cutting conditions	F_z (F_c) med. value [N]
1.	0.10	γ = +10°; K = 90°; V_c = 95 [m/min]; a_p = 1 [mm];	110.53
2.	0.14		133.31
3.	0.18		163.29
4.	0.22		189.36
5.	0.10	γ = 0°; K = 90°; V_c = 89 [m/min]; a_p=1 [mm];	149.4
6.	0.14		192.33
7.	0.18		226.73
8.	0.22		258.28
9.	0.10	γ = +20°; K = 90°; V_c = 89 [m/min]; a_p = 1 [mm];	95.72
10.	0.14		123.57
11.	0.18		149.96
12.	0.22		173.65

We studied the evolution of the main component F_z (F_c) for different values of rake angle γ by using the data from Table 2 and we obtain the chart shown in Fig. 12.

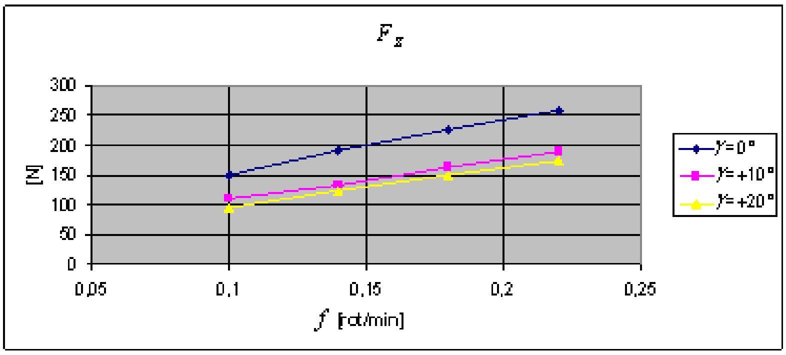


Fig. 12 – Evolution of cutting force F_c depending on rake angle values for different feed rates.

Examination of the progress of the main component F_c from Fig. 12 reveals the anticipated as normal, of it diminishing with increasing the value of clearance angle γ.

To evaluate the machinability of AlCu11 alloy was considered only the set of values corresponding to the value of 0° to rake angle (reference value in literature) and proceed as follows.

Table 3

$\lg\frac{F_c}{b}$ *and* $\lg h, b = 1mm$

h	0.10	0.14	0.18	0.22
lgF	−1	−0.8538	−0.74472	−0.6575
$\frac{F_c}{b}$	149.4	192.33	226.73	258.28
$\lg\frac{F_c}{b}$	2.17319	2.2833	2.35545	2.41162

After applying the logarithm function of values shown in Table 2 were obtained data from Table 3, with which to draw diagram of Fig. 13, representing the interpolation line that particularizes the relationship (4) as (5)

$$\lg\frac{F_c}{1} = 2.87236 + 0.695403 \cdot \lg h\,, \tag{4}$$

From this relationship were deducted values of the two constants $k_{c1.1}$ and m_c:

- $k_{c1.1}$ = 745.349 N/mm^2;

• m_c = 0.304.

By using the relationship 3 were obtained specific cutting force values presented in Table 4:

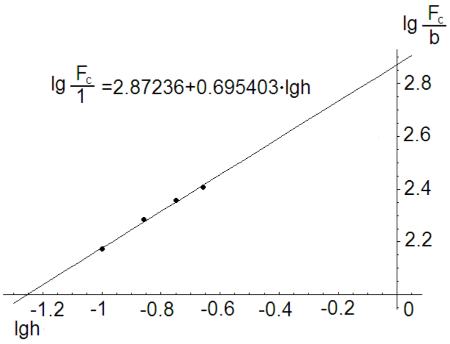


Fig. 13 – Plot of experimental data in $\lg \frac{F_c}{1}$ and lg*h* coordinates.

Table 4

f [mm/rot]	k_c [N/mm^2]	k_c approx. value [N/mm^2]
0.10	1500.92	1501
0.14	1354.99	1355
0.18	1255.32	1255
0.22	1181.03	1181

4. Discussions

Comparing the specific cutting force values from Table 4 with the values encountered in literature for different values of the advance *f* (Klocke, 2011; Catalog SECO 2008; Nagi Elmagrabi *et al*., 2008; Balkrishna *et al*., 2011) leads to the following observations:

The shape of chips obtained after a free flow process is specific to a material having ductile qualities;

The calculated values that are specific to the class of aluminum alloys having superior mechanical qualities;

The calculated values for specific cutting force k_c are relatively high for the class of aluminum alloys;

It can be concluded that the machinability of the studied material falls into the upper class of aluminum alloys.

5. Conclusions

The machinability of a cast aluminium alloy was evaluated based on the observation of the metal chips and the value of the specific cutting force calculated by means of a specific methodology.

The study proved that the analyzed material has a superior machinability corresponding to aluminum alloys having high mechanical qualities.

The study methodology adopted proved viable, resulting in a useful tool by which it can be estimated the cutting machinability of a certain material that allows direct comparison of a parameter (specific cutting force k_c) met in modern technical literature.

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EVALUAREA PRELUCRABILITĂŢII ALIAJULUI AlCu11 LA VITEZE CONVENŢIONALE DE AŞCHIERE

(Rezumat)

Elaborarea unui nou material metalic trebuie însoţită şi de precizări privind prelucrabilitatea acestuia, în vederea stabilirii clasei de prelucrabilitate căreia îi aparţine şi, eventual, în vederea comparării caracteristicilor acestuia cu alte altor materiale.

Din cele trei categorii de criterii consacrate pentru stabilirea prelucrabilităţii (durabilitatea sculei aşchietoare, calitatea suprafeţei prelucrate şi puterea necesară desfăşurării unui proces de aşchiere), lucrarea de faţă abordează criteriul puterii de aşchiere, propunând o metodologie pentru determinarea unui factor necesar calculării acesteia, respectiv forţa specifică de aşchiere. Odată stabilit acest parametru se creează şi posibilitatea alegerii operative a unui regim de lucru adecvat, literatura tehnică actuală oferind o mulţime de posibiltăţi în acest sens.

Determinările experimentale au fost realizate în laboratoarele facultăţilor de Construcţii de Maşini şi Management Industrial şi de Ştiinţa şi Ingineria Materialelor, utilizând echipamente aflate în prezent în dotarea acestora.