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Effect of Heat Treatment on Machining Properties of the AlSi9Cu3(Fe) Alloy

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Abstract

Automation of machining operations, being result of mass volume production of components, imposes more restrictive requirements concerning mechanical properties of starting materials, inclusive of machinability mainly. In stage of preparation of material, the machinability is influenced by such factors as chemical composition, structure, mechanical properties, plastic working and heat treatment, as well as a factors present during machining operations, as machining type, cutting parameters, material and geometry of cutting tools, stiffness of the system: workpiece – machine tool – fixture and cutting tool.

In the paper are presented investigations concerning machinability of the EN AC-AlSi9Cu3(Fe) silumin put to refining, modification and heat treatment. As the parameter to describe starting condition of the alloy was used its tensile strength R_m. Measurement of the machining properties of the investigated alloy was performed using a reboring method with measurement of cutting force, cutting torque and cutting power. It has been determined an effect of the starting condition of the alloy on its machining properties in terms of the cutting power, being indication of machinability of the investigated alloy. The best machining properties (minimal cutting power - P_c=48,3W) were obtained for the refined alloy, without heat treatment, for which the tensile strength R_m=250 MPa. The worst machinability (maximal cutting power P_c=89,0W) was obtained for the alloy after refining, solutioning at temperature 510 ^{o}C for 1,5 hour and aged for 5 hours at temperature 175 ^{o}C. A further investigations should be connected with selection of optimal parameters of solutioning and ageing treatments, and with their effect on the starting condition of the alloy in terms of improvement of both mechanical properties of the alloy and its machining properties, taking into consideration obtained surface roughness.

Keywords: Heat treatment, Machining, Machinability, Cutting power, Aluminum alloys

1. Introduction

Aluminum in connection with other elementary substances can create an alloys characteristic of high strength, low density and corrosion resistance. Such features make the aluminum as the material perfectly suited for castings of machinery components [1, 2]. Permanently growing production volumes of these components and more and more restrictive requirements connected with their mechanical and technological properties lead to research work on development of casting technology and heat treatment of ready castings [1-4]. The castings, except rolled semi-products, belong to the most often met starting materials to low volume, high volume and mass production [5].

The AlSi9Cu3(Fe) alloy is often used to production of cast machinery components, such as engine cylinder heads. This alloy stands out against other casting alloys with high hardness, strength, and relatively good castability [6].

In many cases as a criterion to acceptance of the castings is taken not only their satisfactory structure and mechanical properties, but also good surface quality after machining operations [7]. In the literature [8] the machining properties are defined as relatively easy or difficult to removal excess material in process of machining of a semi-product into ready product.

Forecasting of behavior of the material during its processing belongs to the most difficult problems in course of processing of aluminum castings [9, 10], because the machining properties are substantially different than machining properties of other casting materials.

Among alloying components the most beneficial from machinability point of view is Cu – resulting in growth of hardness of groundmass of the alloy, and the same preventing its 'blurring" during machining operation [9]. From the other hand, silicon as the main alloying component causes increase of abrasiveness of the material, reducing durability of cutting edge. Moreover, heat treatment of ready product has an effect on its machining properties [11-13].

Among methods used to determination of the machining properties it should be mentioned such methods, which are based on measurement of wear of cutting edge, cutting speed and load of cutting edge [14, 15].

Measurement of the machining properties using the reboring method with constant feedrate belongs to accelerated methods. To advantages of this method belong cutting conditions on the test bed, close to real machining conditions during machining of the material.

In this study the authors have been focused on determination of an effects of heat treatment and the tensile strength R_m of the AC-AlSi9Cu3(Fe) alloy on the machining properties, expressed as machining index of the investigated alloy [8, 14].

2. Methodology of the research

The EN AC-46000 (AlSi9Cu3(Fe)) alloy is characterized by very good founding and technological properties. This alloy is commonly used for a cast components operated under load, such as engine cylinder heads and pistons [1]. Initial state of the material depending on a method and condition of material preparation is the most influencing factor, which has an effect on the machinability of an alloy.

The first stage of the investigations comprised pouring into metal mould a standardized strength test pieces for strength tests and their heat treatment. Temperature and duration of solutioning and ageing treatments were selected on the basis of the literature [11] in order to obtain maximal tensile strength R_m. After performed heat treatment it has been determined the tensile strength R_m of the alloy. Obtained results of the investigations are presented in the Table 1.

In the next step, from grip sections of the test pieces were produced a samples with external diameter 15 mm and with length 20 mm. In each prepared sample it has been initially drilled a go-through hole with diameter 6mm. The samples were positioned in holder mounted to quartz dynamometer of the Kistler 9272 type, with signal amplification (Fig. 1).

Table 1
Parameters of the samples produced from the *EN AC-AlSi9Cu3(Fe) alloy*

Number of the sample	Constitution of the alloy	Heat treatment				Tensile strength
		Solutioning		Ageing		
		T [°C]	t [h]	T [°C]	t [h]	R_m [MPa]
1.1	raw alloy	-	-	-	-	220
1.2	refined	-	-	-	-	250
1.3	modified	-	-	-	-	260
1.4	refined+T6	510	1,5	175	5	407
1.5	modified+T6	510	1,5	175	5	406
1.6	modified+T6	545	3	320	5	130
1.7	modified+T6	545	1,5	240	8	114
1.8	modified+T6	545	3	320	2	140
1.9	modified+T6	510	1,5	175	2	395

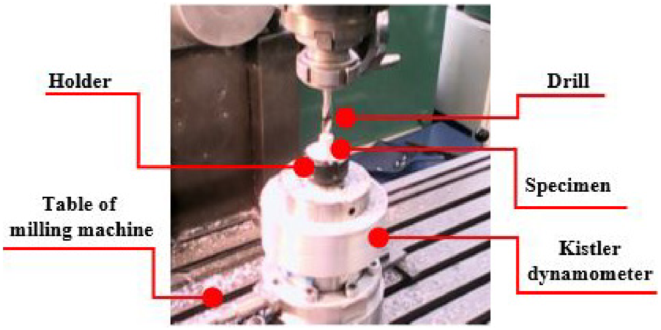

Fig. 1. Measuring module [8]

The measuring module was fixed to table of universal milling machine of the FND 32 AVIA type. To reboring of the samples it has been used a drill of the BHHG20 type having diameter 10 mm and the point angle of 140°. The machining was performed without any liquid coolant. During the reboring, however, to eliminate chips from the cutting zone it has been used blow of compressed air from the bottom. Moreover, a possible "accretion" on edges of the cutting tool was controlled after each test. Recording of the cutting forces was performed at constant parameters of the cutting:

- rotational speed of the drill – n=56 rpm,
- cutting speed - V_c=17,6m/min,
- feedrate – f=63mm/min,
- cutting depth – a=2mm,
- frequency of readouts – 5Hz,
- ambient temperature – 20°C,
- time of the drilling– t=15s.

In the Fig. 2 are presented components of the cutting force, acting on each edge of the drill during course of the investigations. Components of the force F_{p1} and F_{p2} were balanced in our case, because the cutting edges were symmetric. Resultant force from the components F_{e1} and F_{e2} generates the torque M_d, which was used in the equation (1) [14]. Sum of the components F_{f1} and F_{f2} creates the resultant force of the feed F_f.

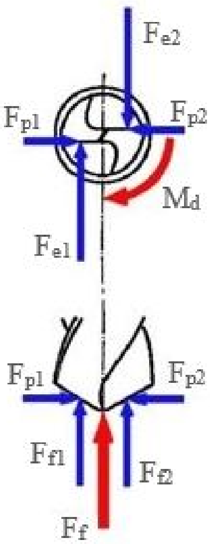

Fig. 2. Components of the cutting force during the reboring

$$M_d = \frac{(F_{e1} + F_{e2}) \cdot (D + d)}{4000} [N \cdot m] \qquad (1)$$

D – diameter of the drill [mm],
d – diameter of the initial hole [mm]

To determine machining properties of the alloy it has been used parameter of the cutting power P_c. Basing on obtained results of the measurements it has been calculated the cutting power for each from investigated specimens according to the following formula (2) [9, 14]:

$$P_c = \frac{M_d \cdot n}{9{,}554} [W] \qquad (2)$$

M_d – cutting torque [N·m],
n – rotational speed of the drill [rpm]

3. Description of obtained results

Obtained results of the investigations performed for the EN AC-AlSi9Cu3(Fe) alloy are printed in the Table 2, while in the Figs. 3-5 are presented recorded average, maximal and the amplitude values of the of the cutting torque (Fig. 3), measured resultant force of the feed force (Fig.4), and values of calculated cutting power (Fig. 5).

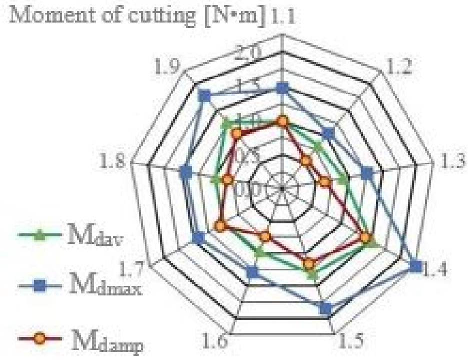

Fig. 3. Values of the cutting torque (average, maximal and amplitude)

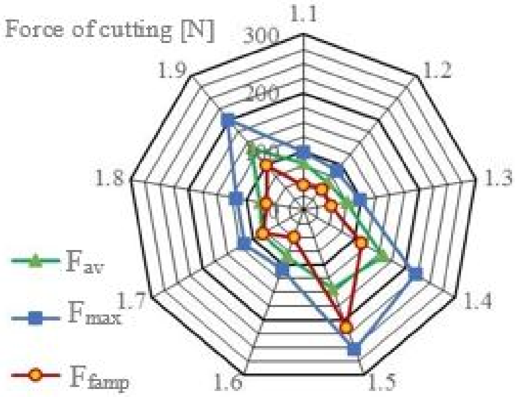

Fig. 4. Values of resultant cutting force (average, maximal and amplitude) for the AlSi9Cu3(Fe) alloy

Table 2
Results of measurements for the *EN AC-AlSi9Cu3(Fe)* alloy (marking as in the Table 1)

Number of the specimen	Results of measurements						Cutting power
	Cutting torque			Feed force			
	M_{dav} [N·m]	M_{dmax} [N·m]	Amplitude M_d [N·m]	F_{av} [N]	F_{max} [N]	Amplitude F_f [N]	P_c [W]
1.1	0,99	1,46	0,99	80,3	98,8	42,7	57,9
1.2	0,82	1,06	0,54	62,2	88,0	46,7	**48,3**
1.3	0,91	1,27	0,63	75,4	98,1	46,6	53,5
1.4	1,52	2,26	1,41	156,1	221,1	114,3	**89,0**
1.5	1,31	1,86	1,15	144	254,3	212,8	76,6
1.6	0,97	1,29	0,73	83,7	108,3	49,8	57,1
1.7	1,00	1,42	1,06	81,6	116,6	80,3	58,5
1.8	0,99	1,44	0,82	76,1	116,5	64,9	58,2
1.9	1,27	1,78	1,05	137,9	202,1	99,7	74,6

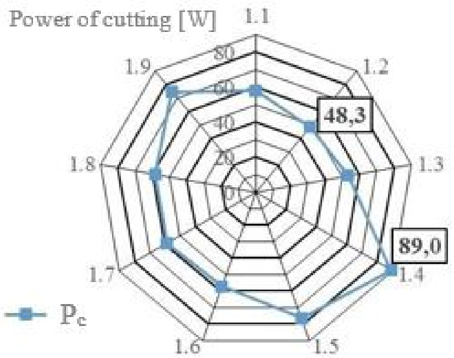

Fig. 5. Cutting power for the investigated alloy

Maximal values of the cutting torques (M_{dav}=1,52 [N·m], M_{dmax}=2,26 [N·m], of the amplitude M_d=1,41 [N·m]) and the highest value of average feed force (F_{av}=156,1 [N]) were observed for the alloy in refined state, after performed treatment of solutioning at temperature 510°C for 1,5h and after ageing at temperature 175°C for 4 hours. For the alloy after the heat treatment performed in the same conditions, it has been observed the highest value of the feed force F_{max}=254,3 [N], and its amplitude equal to F_f=212,8 [N].

On the basis of the obtained measurement results and the equations (1) and (2), it has been calculated values of the cutting power P_c. The highest value was observed for the specimen with number 1.4 (Fig. 5), corresponding to the alloy in refined state with performed heat treatment (P_c=89,0 [W]). From the other hand, the lowest value of the P_c was obtained for the specimen 1.2 (Fig. 5), i.e. without the heat treatment (P_c=48,3 [W]).

On the basis of executed investigations and data from Table 2, it can be establish, that consolidation of the structure of an alloy, by extension, its tensile strength and hardness, has a major effect on its machinability and machining properties of aluminum alloys can be modified with heat treatment.

In the Fig. 6 is presented a diagram showing dependencies between the tensile strength and calculated cutting power Pc, with marked additional line of the trend described by the second order polynomial. It can be seen, that with growth of tensile strength to values around 400 MPa comes the accrue of the power of cutting and machinability of an alloy is decreasing.

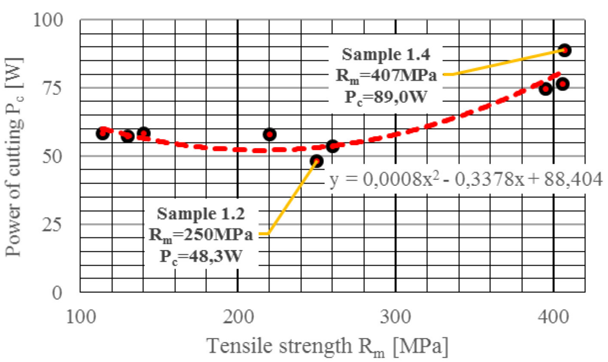

Fig. 6. Variations of the cutting power (P_c) as a function of the tensile strength (R_m)

4. Conclusions

Machinability of the AlSi9Cu3(Fe) alloy was determined on the basis of measurements of the feed force and the cutting torque, basing on assumed index of machinability, as the cutting power P_c is. The best machinability was obtained for the alloy in refined state without the heat treatment (P_c=48,3W), which the tensile strength is found to be R_m=250 MPa, whereas for the alloy characteristic of high tensile strength (R_m = 407 MPa) obtained in result of performed heat treatment, the cutting power P_c amounted to 89 W.

To perform more deep assessment of the machining properties it would be needed to perform a further investigations with consideration of another index of machinability, such as e.g. roughness of machined surface.

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