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Granulation of Cu-Al-Fe-Ni Bronze

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Abstract

With the increase in wall thickness of the casting of iron-nickel-aluminium-bronze, by the reduction of the cooling rate the size of κ_{II} phase precipitates increases. This process, in the case of complex aluminium bronzes with additions of Cr, Mo and W is increased. Crystallization of big κ_{II} phase, during slow cooling of the casting, reduces the concentration of additives introduced to the bronze matrix and hardness. Undertaken research to develop technology of thick-walled products (g> 6 mm) of complex aluminium bronzes. Particular attention was paid to the metallurgy of granules. As a result, a large cooling speed of the alloy, and also high-speed solidification casting a light weight of the granules allows: to avoid micro-and macrosegregation, decreasing the particle size, increase the dispersion of phases in multiphase alloys. Depending on the size granules as possible is to provide finished products with a wall thickness greater than 6 mm by infiltration of liquid alloy of granules (composites). Preliminary studies was conducted using drip method granulate of CuAl10Fe5Ni5 bronze melted in a INDUTHERM-VC 500 D Vacuum Pressure Casting Machine. This bronze is a starting alloy for the preparation of the complex aluminium bronzes with additions of Cr, Mo, W and C or Si. Optimizations of granulation process was carried out. As the process control parameters taken a casting temperature t (°C) and the path h (mm) of free-fall of the metal droplets in the surrounding atmosphere before it is intensively cooled in a container of water. The granulate was subjected to a sieve analysis. For the objective function was assume maximize of the product of Um*n, the percentage weight "Um" and the quantity of granules 'n' in the mesh fraction. The maximum value of the ratio obtained for mesh fraction a sieve with a mesh aperture of 6.3 mm. In the intensively cooled granule of bronze was identified microstructure composed of phases: β and fine bainite (α+β'+β'_1) and a small quantity of small precipitates κ_{II} phase. Get high microhardness bronze at the level of 323±27,9 $HV_{0,1}$.

Keywords: Innovative foundry technologies and materials, Complex aluminium bronze, Granulation, Sieve analysis, Microstructure, Microhardness

1. Introduction

Aluminum-iron-nickel bronze with additions of Cr, Mo, W and C or Si, are characterized by high mechanical properties and high resistance to wear [1,2]. They are designed to cast working on abrasive wear and adhesive. Castings with a wall thickness of about 6 mm have the highest mechanical properties and low wear. The increase in wall thickness reduces the cooling rate cast and promotes the growth of large precipitates κ-type phases in the microstructure of bronze, rich in introduced alloy additions. Crystallization of thick κ phase during slow cooling of cast reduces the concentration of introduced additives in the matrix and at the same time reducing the hardness of bronze. Therefore, studies was undertaken to develop technology capable of obtaining products of complex aluminum bronzes with additions of Cr, Mo, W and C or Si with a wall thickness greater than 6 mm characterized by high mechanical properties and high resistance to wear. Particular attention was paid to the metallurgy of granules [3,4]. As a result, a large cooling speed of the alloy, and also high-speed solidification casting a light weight of the granules allows: to avoid micro-and macrosegregation, decreasing the particle size, increase the dispersion of phases in multiphase alloys [3-5]. Depending on the size granules as possible is to provide finished

products with a wall thickness greater than 6 mm by infiltration of liquid alloy of granules (composites) or sintering (powder metallurgy).
Presented in this article refer to the preliminary results of the optimization process for obtaining granulated drip method CuAl10Fe5Ni5 bronze on INDUTHERM-VC 500 D Vacuum Pressure Casting Machine, evaluation of microstructure of bronze and microhardness of the resulting granules.

2. Work methodology

Experimental station shown in Figure 1. CuAl10Fe5Ni5 bronze was melted in INDUTHERM-VC 500 D Vacuum Pressure Casting Machine (Fig. 1, item a). The batch was melted in a metal stopper graphite crucible, in a temperature range above 500°C in an atmosphere of Ar. Table 1 shows the chemical composition of the researched bronze.

Table 1.
Chemical composition of the researched bronze

Chemical composition, %					
Al	Fe	Ni	Mn	Si	Cu
10.38	4.54	4.58	0.3	0.02	rest

The granules was obtained by drip method. Metal poured from the bottom of the crucible by hole having a diameter of 3 mm to a container (Fig. 1, item b) with water having a temperature of 19°C.

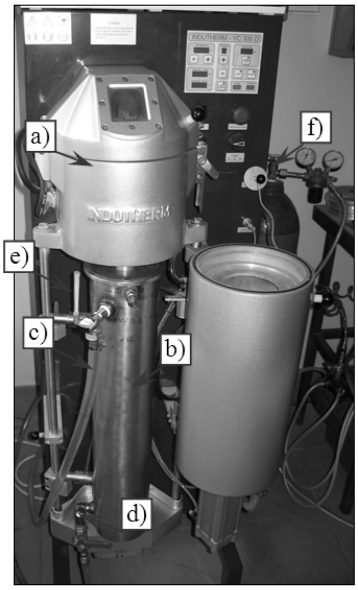


Fig. 1. Experimental station:
a) INDUTHERM-VC 500 D Vacuum Pressure Casting Machine, b) container with water, c) water supply, d) drainage of water, e) water gauge, f) cylinder of argon

Model of experiment is shown in Figure 2. For the variables in the process (INPUT x) adopted the casting temperature t in °C, and the distance h in mm, between the bottom of the crucible,
and the surface of the water in the container (space freefall of metal in ambient air). For constant (CONSTANTS c) adopted in the process: the chemical composition of the test bronze, metal charge mass (450 g), the flow of argon, the flow of water in the container. Failure to meet the constant parameters of the methodology, first of all values in the group CONSTANTS c, generates an instance during the experiment unmeasured disturbances (DISTURBANCE z). For the objective function was assume maximize of the product of Um * n, the weight fraction of the mesh fraction 'Um' and the quantity of granules 'n' in the mesh fraction.

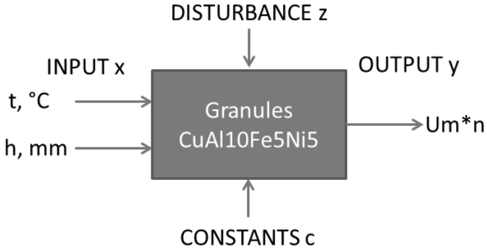


Fig. 2. Model of experiment

The study used a two-level experiment planning method. Plan of the experiment is shown in Table 2.

Table 2.
Plan of the experiment

Factor x_S (S={1,2})	x_1=t, °C	x_2=h, mm
Central point $Ec(t_0,h_0)$	1200	96
Step trial Δx_S	20	20
Upper level $x_S+\Delta x_S$	1220	116
Lower level $x_S-\Delta x_S$	1180	76
Number of experiment, n $E_n(t,h)$		
1	1180	76
2	1220	76
3	1180	116
4	1220	116

Sieve analysis of the obtained granulate was performed on a set of sieves (11 units) with an typical openings in accordance with [6] with a nominal diameter in mm, respectively: **11.2**; *10.0*; *9.0*; **8.0**; **7.1**; *6.3*; **5.6**; *4.5*; *3.55*; **2.8**; **2.0** and a pan for the granules characterized by a size <2 mm. The diameter of the mesh selected from a number of basic R 20/3 (dimensions listed in bold) supplemented with dimensions of a series of complementary R 20 (dimensions listed in italics). The minimum quantity of sieves defined by the formula (1) [7]:

$$k=1+10\cdot\log(N)/3 \quad (1)$$

where: N sample size.
For most numerous sample (Ec) of N = 926 data after substituting in equation (1) and rounded to the nearest whole number obtained k = 11. In order to visualize the different phases in the microstructure specimens was etching by Mi15Cu reagent. The microstructure of the tested specimens of bronze was observed on Nikon Eclipse MA200 optical microscope.

At the microhardness tester HV-1000B was performed measurement of microhardness $HV_{0.1}$.

3. Description of achieved results of researches

Figure 3 shows a representative to the method of granulation granules of CuAl10Fe5Ni5 bronze cast on INDUTHERM-VC 500 D Vacuum Pressure Casting Machine according to the plan of the experiment E_3(1180.116).

Fig. 3. Granules of CuAl10Fe5Ni5 bronze cast on INDUTHERM-VC 500 D Vacuum Pressure Casting Machine according to the plan of the experiment E_3(1180.116)

The shape of the granules obtained during granulation drip method shown in Figure 4.

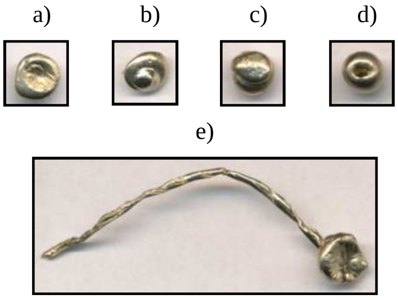


Fig. 4. Shape of the granules CuAl10Fe5Ni5 bronze:
a) concave disk, b) convex disk, c) full sphere,
d) sphere empty, e) cap with "a tail"

Regardless the granule size, the shape of granules like concave disks (a) was predominant, then the convex disks (b). Relatively few spherical granules obtained, both whole (c) and empty (d). Characteristic of the granules of casted from high temperature (1220°C) except presence the shape of granules of a–d (Fig. 4), granules in the shape of caps with "a tail" (e). The percentage weight "Um" and the value of the objective function "Um*n" shown in Tables 3–4 and in Figures 5–6.

Table 3.
Percentage weight Um, %

Sieve size, mm	Percentage weight Um, %				
	E_1	E_2	E_c	E_3	E_4
<2	0.02	0.02	0.01	0.02	0.16
2	0.07	0.16	0.35	0.27	0.24
2.8	0.10	2.76	2.95	1.33	1.28
3.55	0.76	7.99	11.67	9.91	5.52
4.5	4.63	21.38	20.94	13.08	7.61
5.6	26.92	22.63	23.27	25.00	18.44
6.3	39.13	12.99	29.97	37.55	28.18
7.1	15.18	10.02	10.57	10.33	19.24
8	4.38	8.96	0.26	2.01	12.61
9	5.20	11.97	0.00	0.50	6.70
10	1.90	0.00	0.00	0.00	0.00
11.2	1.71	1.13	0.00	0.00	0.00

Table 4.
Objective function value Um*n

Sieve size, mm	Objective function Um*n				
	E_1	E_2	E_c	E_3	E_4
<2	0.12	0.06	0.01	0.11	10.70
2	0.34	1.14	7.06	2.40	3.78
2.8	0.31	160.22	233.43	37.12	32.11
3.55	6.05	830.56	2414.84	881.70	215.47
4.5	129.66	2095.27	4984.58	1150.75	334.89
5.6	3796.18	3371.73	4049.51	3850.34	1623.10
6.3	6573.51	831.11	4765.16	**6871.63**	2676.90
7.1	835.01	300.49	496.72	372.04	1058.31
8	52.54	206.10	0.26	14.09	403.53
9	67.59	287.31	0.00	1.01	100.56
10	7.58	0.00	0.00	0.00	0.00
11.2	5.13	1.13	0.00	0.00	0.00

The presented data show that the for assumed parameters set (t, h) in the experiment (Table 2) yielded a relatively nonhomogeneous granules. The maximum weight fraction of mesh fraction was varied in the field 22,63–39,13% (Table 3, Figure 5). The maximum value of the objective function "Um*n"= 6871.63 reached for experiment E_3(1180,116) (Table 4, Figure 6) and mesh fraction on sieve with openings of 6.3 mm.
Fractions main of mesh fractions for the individual experiments (Table 2) presented in Figure 7.
The smallest granules obtained for the parameters set in the experiment E_2.

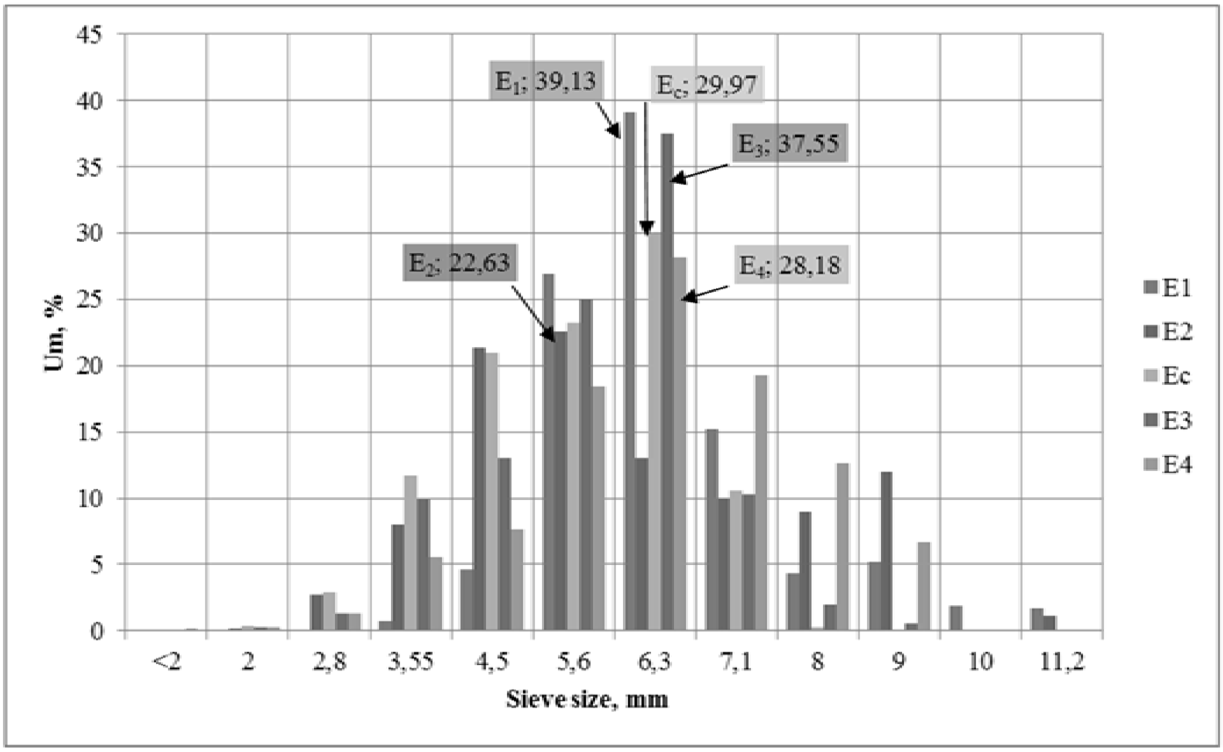


Fig. 5. Percentage weight Um, %

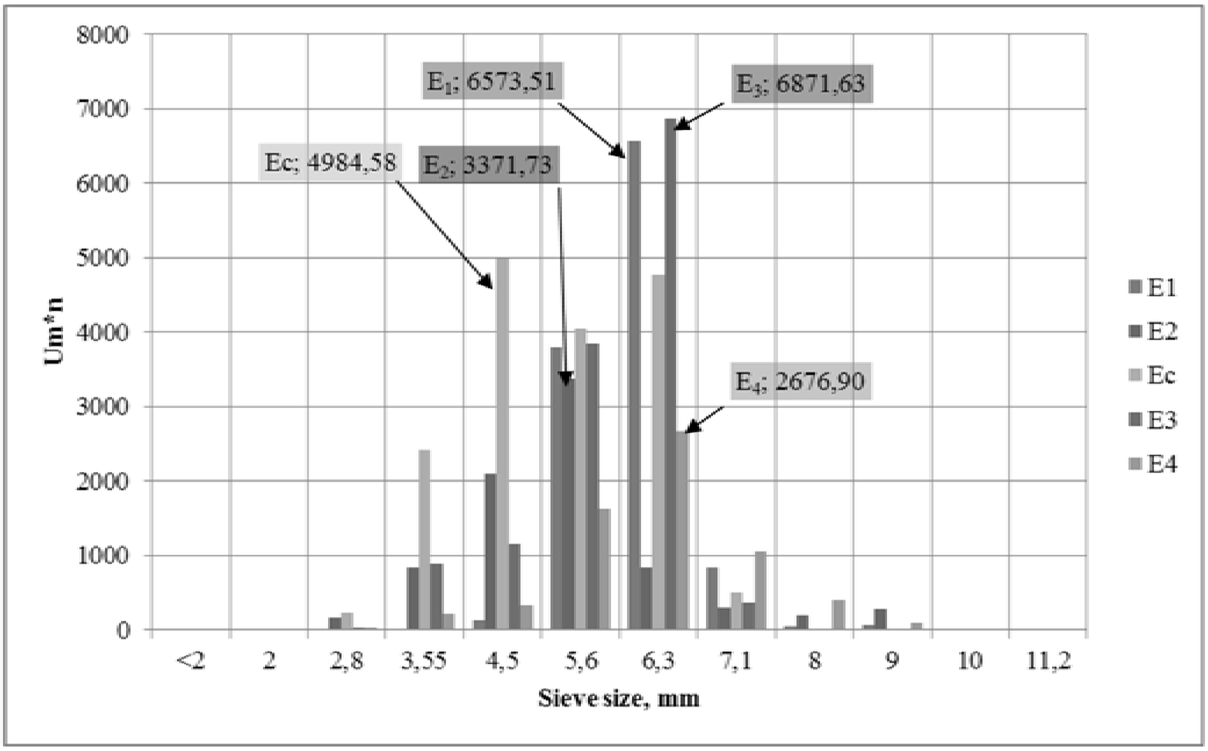


Fig. 6. Objective function value Um*n

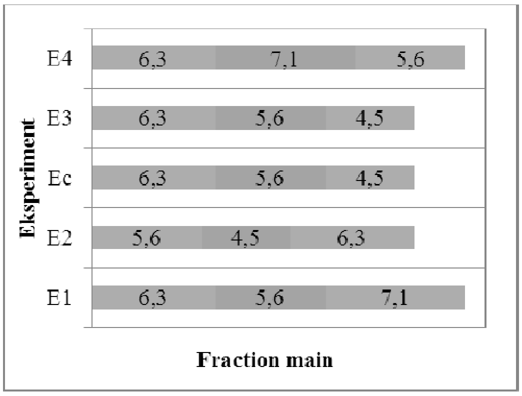


Fig. 7. Fractions main of granules of CuAl10Fe5Ni5 bronze

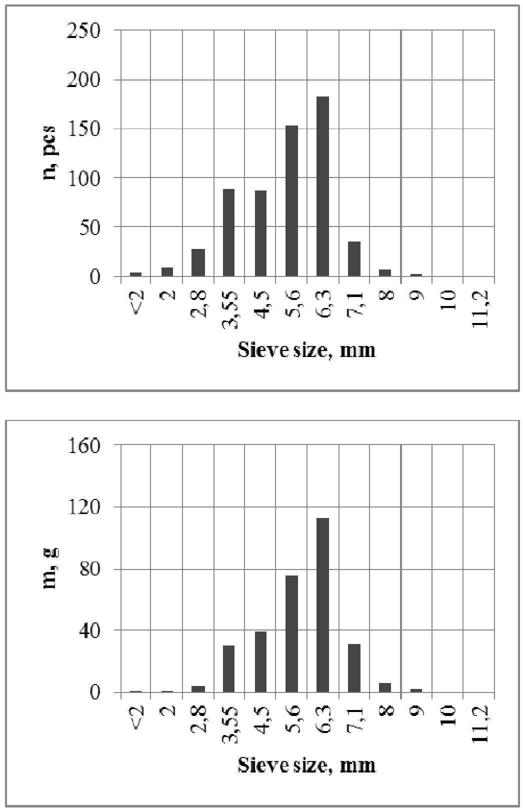
The granulate was yielded for setting parameters in the experiment E_c and E_3 have the same main fractions, and the thickest granules was yielded in the E_4 experiment.
For granules obtained in the E_3 experiment was shown in Table 5 values of: n, m, Um and Ums. In the Figures 8-9 are shown: the number of granules in each mesh fractions (n, Figure 8a), granules weight on sieve (m, Figure 8b) and theoretical granule diameter D50=5.61 mm (Fig. 9). D50 it is the average diameter of the granule read on a graph drawn abscissa at the intersection of the sums curve with the horizontal line corresponding to 50% of the mesh fraction.

Table 5.
Values of: n – number of granules, m – granules weight on sieve, Um – percentage weight, Ums - cumulative percent retained; E_3(1180,116)

Sieve size, mm	Number of granules n, pcs	Granules weight on sieve m, g	Percentage weight, Um, %	Cumulative percent retained, Ums, %
<2	5	0.064	0.02	0.02
2	9	0.799	0.27	0.29
2.8	28	3.974	1.33	1.61
3.55	89	29.697	9.91	11.52
4.5	88	39.200	13.08	24.60
5.6	154	74.949	25.00	49.60
6.3	183	112.563	37.55	87.15
7.1	36	30.979	10.33	97.48
8	7	6.034	2.01	99.50
9	2	1.509	0.50	100.00
10	0	0.000	0.00	0.00
11.2	0	0.000	0.00	0.00

The resultant as a result of high velocity of solidification bronze representative microstructure of the granules is shown in Figure 10 (a,b). The microstructure of bronze is composed mainly of β phase grains with a characteristic dendritic structure and grain β phase transformed to bainite fine (α+β'1+β'). The microstructure of bronze was also identified small amounts of very fine precipitates κ_{II} phase. Despite the high rate of cooling in the bronze microstructure not obtained β' and β'1 martensite throughout the volume of the granules. The reason for this is probably that around the granule falling the bottom of the container with water it forms a gaseous bubble of steam. This results in a considerable reduction of heat conduction from granule to the surroundings and consequently cooling of the β phase at less rate than the critical.

a)



b)

Fig. 8. Number of granules n in mesh fraction (a) and weight m granules weight on sieve (b); E_3 (1180,116)

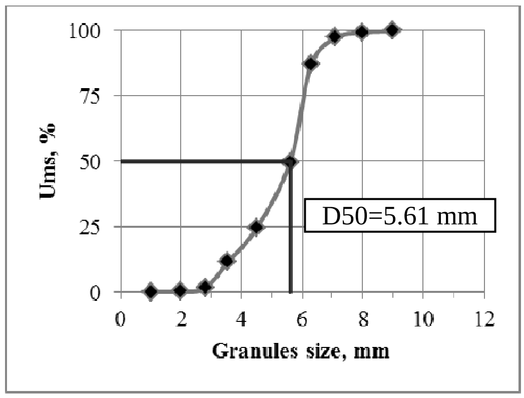
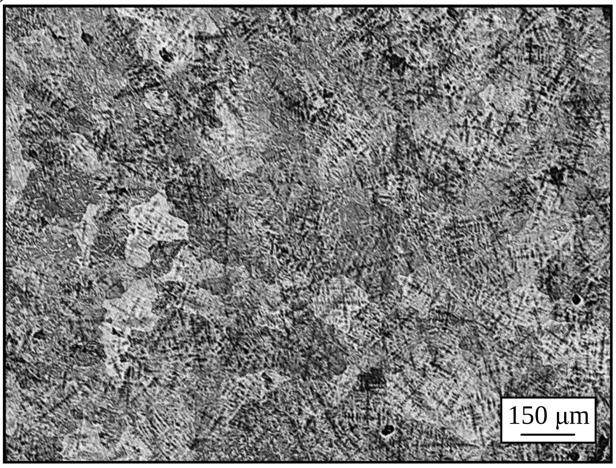


Fig. 9. Curve of cumulative percent retained "Ums" in % of mesh fraction for granulates of CuAl10Fe5Ni5 bronze; E_3(1180,116)

Thus, in the microstructure remains substantial amount of grains of dendritic β phase, supersaturated alloy additions, and the remaining β phase, supersaturated aluminium (small amount of precipitation of κ_{II} phases rich in aluminium), turned into fine bainite.

a)



b)

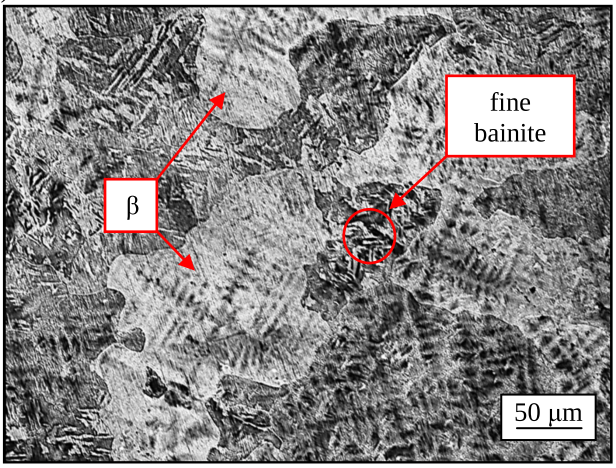


Fig. 10. Microstructure in the granule of CuAl10Fe5Ni5 bronze (a,b), E_3(1180,116)

Descriptive statistics of measurements HV0.1 microhardness of microstructure of CuAl10Fe5Ni5 bronze granules shown in Table 6.

Table 6.
Descriptive statistics of measurements of $HV_{0.1}$ microhardness

Descriptive statistics	Microhardness, $HV_{0.1}$
Measurements	335.8; 296.7; 285.2; 366.3; 321.9; 366.3; 335.8; 308.9; 302.7; 308.9
Quantity of measurements	10
Average value	322.85
Standard deviation	27.91

In Figure 11 shows a box-and-whisker plot for the measurement of microhardness $HV_{0.1}$.

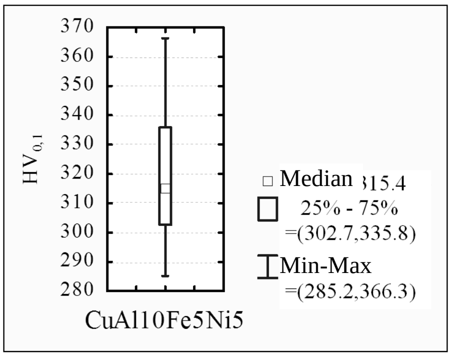


Fig. 11. Box-and-whisker plot for the measurement of microhardness $HV_{0.1}$ of microstructure of granules CuAl10Fe5Ni5 bronze

4. Conclusions

The study shows that by the use of INDUTHERM-VC 500 D Vacuum Pressure Casting Machine can be obtained of the drip method granules of CuAl10Fe5Ni5 bronze about: the main fraction 6.3/5.6/4.5; the diameter D50=5.61 mm; at the level of uniformity 37.55%, at optimal value of parameters of process like: temperature 1180°C and the height above the water level h=116 mm. The microstructure of the granules is characterized by fine grain size and high microhardness order of 323±27.9 $HV_{0.1}$.

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