CONCERNING THE RESULTS OF NON-DESTRUCTIVE TESTING OF SOME ALUMINIUM ALLOYS

Maria BROJBOIU, Marin POPA

University of Craiova, Electrical Engineering Faculty, mail: mbrojboiu@elth.ucv.ro
S.C. Electroputere Holding

***Abstract* - The article presents the results of a non-destructive testing of three samples of Aluminium alloys. The analysis of the results points out the chemical, metallographic composition and the mechanical and electrical features. It comes out, by using different methods of non-destructive testing and tests (penetrating liquids, ultrasounds and X-radiation), the influence of the moulding technology and of the tests position in relation with the material supply, the influence over the material features and parameters.**

Keywords: *moulding methods, non-destructive testing, micro-structural analysis.*

I. INTRODUCTION

Moulded Aluminium alloys like ATSi10, ATSi10Cu3 and ATCu4MgTi are frequently used in making massive tools of contact and electric power paths with complicated and non-standard geometrical configuration, from the construction of the electrical equipments (medium and high voltage circuit breakers). The main characteristics required to these tools having the role of power path or electrical contact are the ones tied to the value of electrical resistance, which should provide the framing of the power path temperature between the imposed limits of functioning: in conditions of duration and short-circuit [1]. At the same time, restrictions are being made concerning the insurance of the mechanical resistance, which the assembled tools on equipments of switching need, such as the medium and high power oil circuit breaker, which have to resist to the dynamic shock in the moment of switching off the electrical spring. Years of experience demonstrated that these characteristics, belonging to the tools obtained through the technology of moulding, are depending on the composition of the moulding charge and on the moulding method. Thus, it becomes necessary to analyse the moulding charges for the different technologies and positions of the moulding shape compared to the material supply. The methods of non-destructive testing put in evidence the faults of the deep or surface moulding. Non-destructive methods with penetrating liquids, ultrasounds and X-radiation are being recommended [2]. The moulding technology used is the one which is specific to the specialized compartments of S.C. Electroputere Holding Craiova. Three different types of methods have been used: moulding in iron mould, moulding in sands and moulding in easily volatile models. There were elaborated charges from three types of alloys ATSi10, ARSi10Cu3 and ATCu4MgTi. The moulding tests were obtained through the simultaneous moulding in three positions: horizontal PO, vertical PV and in a 45 degrees inclination P45. The test that had been moulded in a raw shape were submitted to: a) the analysis from the aspectual (visual) point of view, b) the analysis of the chemical composition, c) the mechanical tests: the Brinnell hardness; the dragging test (the breaking resistance, lengthening and the flowing limit); the test of compression (the resistance, the technical limit, the shortcut and the swelling), d) electrical features: resistivity and volume conductivity.

2. METHODS, TESTS, RESULTS

2.1. The micro-structural analysis.

It was realised using a metallographic microscope of Epiquant type and the micrographs using an automatic equipment of photography of DFAM-2 type. The structure was put in evidence using a stroke of 2 % HF watery solution. The micro-structural analysis was made on cylindrical tests, which had been obtained by processing through splinting the moulding tests. The metallographic tests were put together with the resin. The metallographic analysis which was made in the magnifying orders of x125, respectively x500 times shows that the crystallization is dendritic fine in all tests, the degree of fineness is different according to the test position (PO, PV, P45), the wall thickness, the solidification speed and so on. It was obvious in all tests the inter-dendritical distribution of the AlSi eutectic and of the Fe, Cu, and Mg compounds. The Fe presence as an accompanying element determines the appearance of the compounds of Al5Fe type and/or Al8Fe2Si type which crystallize in a shape of skeleton-like crystals. In table 1it is synthetically presented the chemical analysis of the tests from the mentioned moulding alloys in easily volatile models.

2.2. Mechanical tests.

The mechanical tests were made on some test tubes that were taken from the moulding alloys, after the thermal treatment of hardening. The measurement of Brinell hardness was made in standardized conditions [3] (ball with 2,5 mm in diameter, power of 625 N and a 60 s duration). Within the dragging test it was verified in standardized conditions [4] the breaking resistance, the shortcut/swelling and the technical limit of test tubes with a round section, obtained through the mechanical processing of moulding alloys [5].

Produced code	Alloy type	U.M	Al	Si	Mg	Cu	Ti	Mn
A	ATSi10Mg	%	base	9,65	0,31	0,015	0,04	0,25
B	ATSi10Mg	%	base	9,85	0,29	0,019	0,04	0,27
C	ATSi10Mg	%	base	9,90	0,35	0,013	0,05	0,29
I	ATSi10Cu3Mg	%	base	10,2	1m40	3,2	0,07	0,37
II	ATSi10Cu3Mg	%	base	10,4	1,37	3,5	0,06	0,40
III	ATSi10Cu3Mg	%	base	10,0	1,35	3,4	0,05	0,35
1	ATCu4MgTi	%	base	0,12	0,28	4,7	0,21	<0,02
2	ATCu4MgTi	%	base	0,11	0,27	4,6	0,27	<0,02
3	ATCu4MgTi	%	base	0,12	0,29	4,45	0,18	<0,02
Produced code	Alloy type	U.M	Fe	Zn	Ni	Pb	Sn	
A	ATSi10Mg	%	0,08	0,05	<0,02	<0,02	<0,02	
B	ATSi10Mg	%	0,09	0,06	<0,02	<0,02	<0,02	
C	ATSi10Mg	%	0,09	0,05	<0,02	<0,02	<0,02	
I	ATSi10Cu3Mg	%	0,12	0,14	0,03	<0,02	<0,02	
II	ATSi10Cu3Mg	%	0,13	0,15	0,04	<0,02	<0,02	
III	ATSi10Cu3Mg	%	0,14	0,16	0,03	<0,02	<0,02	
1	ATCu4MgTi	%	0,07	0,07	<0,02	<0,02	<0,02	
2	ATCu4MgTi	%	0,08	0,06	<0,02	<0,02	<0,02	
3	ATCu4MgTi	%	0,08	0,06	<0,02	<0,02	<0,02	

Table 1. The chemical composition of moulded alloys in easily volatile models.

2.3. The check-up of the electrical parameters.

The electrical volumetric conductivity was measured in IACS %, on samples prepared for the compression test, using the Magna Flux method by palpating the samples with a FM Conductivity Meter Apparatus. The electrical resistivity was calculated using the following relation: $\rho = 172{,}41 / \%IACS \ [\mu\Omega cm]$.

Table 2 presents the features of the tests samples moulded in easily volatile models, putting in evidence the influence of the polystyrene quality and of the test positions compared to the moulding network. The analysis of the experimentation leads to the conclusion that the test positions influence the features so the bigger the distance is the finer the structure is. After analysing the external aspect and in break and also after the metallographic analysis it can be said as a conclusion that: the test sample having a vertical positioning shows a finer granulation than the horizontal ones, the test sample positioned at 45 degrees having an medium granulation. Also all test samples have a porosity which is distributed non-uniformly both in the section and in the test length. The test sample porosity diminishes with the material density of the model. The highest porosity is shown by the test samples moulded in polystyrene models with a high density of 42 kg/m^3. The conductivity of moulded tools increases with the increasing of the material density of the model , as it is shown in figure 1.

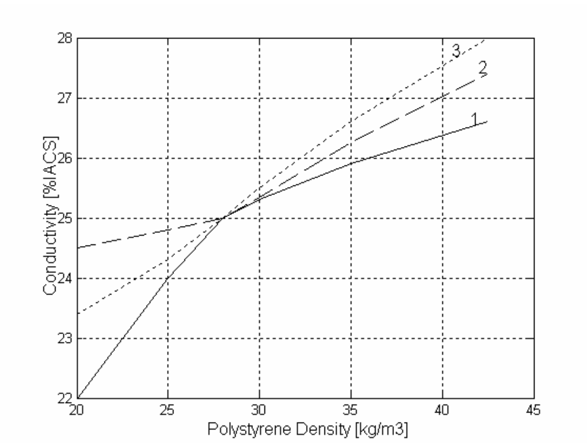

Figure 1. The conductivity variation depending on the polystyrene density: 1 – P45, 2- PV, 3- PO

When the polystyrene having the 28Kg/m^3 density is used, all test samples have the same 25% IACS conductivity. In figure 2 is shown that the hardness of the moulded samples diminishes with the increasing of the polystyrene density used as a model.

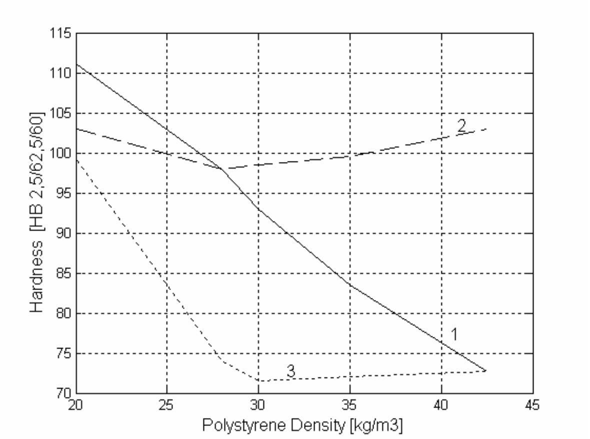

Fig. 2. Variation of medium hardness depending on the polystyrene density: 1 – P45, 2- PV, 3- PO

The highest values of hardness were obtained for the test samples that had been put in an horizontal line PO, while for the test samples that had been put in a vertical line PV, the lowest values were obtained. The smallest difference between the density values was obtained for the moulding test samples of polystyrene models with a 28 kg/m^3 density, beyond this value the difference between the values are substantial. Consequently the physico-mechanical and structural features of the samples are influenced by the test position in relation to the direction and distance from the supply network and the polystyrene density. In order to obtain samples with the best characteristics it has to be taken into account the position of the model from the moulding shape in relation to the supply network. For the alloys of Aluminium moulded in easily volatile models the best density for polystyrene is of 28 kg/m^3.

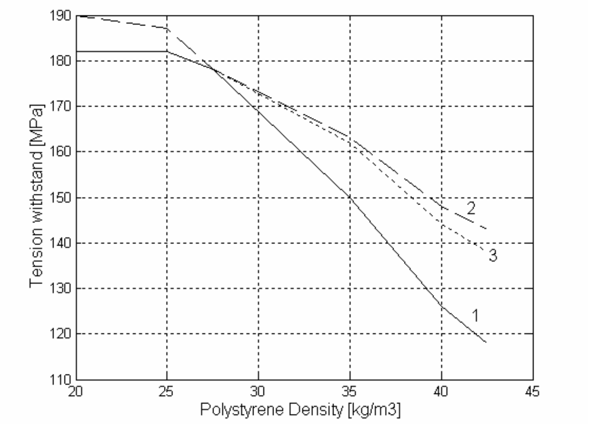

Fig. 3. The tension withstand variation at dragging depending on the polystyrene density: 1 – P45, 2- PV, 3- PO

2.4. The non-destructive testing using penetrating liquids.

For the non-destructive testing there had been moulded test samples from Aluminium, having 210x110x24mm in size, using special designed moulding models. The surface of the test samples was examined using penetrating liquids having the contrast colour according to technological norms [6]. The visual observation of the surfaces and the evaluation of the information given by the penetrating liquid were carefully done during the testing. The real dimensions of the discontinuities or their type are difficult to evaluate, if the penetrating liquid has too much spread in the fluent. The first interpretation of the results examined with the penetrating liquids was made in 5...7 minutes after the eluent drying on the surface, while the final interpretation was made after 30 minutes. The results of the testing with penetrating liquids, presented in table 2, show that the minimum porosity is presented by the moulded samples in static moulding models. The test samples, moulded in sands, shown a medium porosity with pores of medium and big size, sometimes with strong blisters.

2.5. The non-destructive testing using penetrating radiation.

The testing using penetrating radiation had been done according to the technological norms [7] using X radiation generators over the same test boards having the 25mm thickness, respectively 20mm thickness after the milling of all surfaces. The interpretation of the radiographies was made according to the foresights of the technological norms [8]. The results of the testing using penetrating radiation are shown in table 3. It can be seen that in the testing using penetrating radiation of the rough board without moving off the superficial strata, the most intense porosity is presented by the test moulded in easily volatile models. After the processing of the surfaces and the moving off of the 5mm of additional material, the class of quality is improving, getting to first class or second class, which means that we have to deal with superficial porosity at a depth lower than 5mm. The tests moulded in sands act in the same way, but the difference is that, after the processing through splinting, in same cases the intensity of porosity is maintained, which means that the porosity is maintained also in depths higher than 5mm. The samples moulded in iron mould present a minimum porosity.

2.6. The ultrasounds testing.

The ultrasounds testing had been done according to the technological norms [9] using ultrasonic apparatus Sonic 136 PLUS, USD 10, ULTRASONIC

2001. The adjustment and the standardization of the control equipment using ultrasounds had been done according to [10], [11], [12]. The ultrasonic translators used are with a normal incidence of longitudinal waves of mono-crystal type, respectively a double crystal of a 1MHz frequency and an inclined incidence of transversal waves of mono-crystal type having a 45 degrees penetrating angle. It is known that [2] the attenuation of the ultrasonic waves in polycrystalline materials depends on the microstructure. This phenomenon is explained by the fact that the attenuation is determined, on the one hand by the wave absorption and on the other hand by their dispersion. The research made on the tools moulded in an Al 4,5% Cu alloy shows a linear dependence between the speed of the longitudinal wave and the degree of porosity, in a sense of speed decreasing. Regarding the compression test it was verified the resistance, the specific elongation and the technical limit, witch were taken in standardized conditions on test tubes having a round section, obtained through the mechanical processing of moulded alloys. In table 4 are shown the results of the ultrasounds testing.

Alloy	Method of moulding	Test number	Result of testing
ATSi10	Sands	0	Macro-blisters, Intense porosity
	Iron mould	2	Three bigger pores, the rest is small porosity
	Easily volatile model	3	Intense porosity covering the entire surface
ATSi10Cu3	Sands	4	Intense porosity on the entire surface
	Iron mould	1	Two pores of bigger dimension, the rest is small porosity
	Easily volatile model	7	Extended porosity of small and big dimension
ATCu4MgTi	Sands	5	Three bigger pores, the rest is diffuse porosity
	Iron mould	8	Without porosity.
	Easily volatile model	9	Extended porosity of small dimension

Table 2. The results of the testing with penetrating liquids.

Allay	Method of moulding	Test number	Thickness [mm]	Result of testing
ATSi10	Sands	0	25	Blister IV class, small pores
			20	I Class pores
	Iron mould	2	25	II Class pores
			20	I Class pores
	Easily volatile model	3	25	IV Class pores
			20	II Class pores
ATSi10Cu3	Sands	4	25	IV Class pores
			20	IV Class pores
	Iron mould	1	25	I Class pores
			20	I Class pores
	Easily volatile model	7	25	IV Class pores
			20	IV Class pores
ATCu4MgTi	Sands	5	25	II Class pores
			20	II Class pores
	Iron mould	8	25	I Class pores
			20	I Class pores
	Easily volatile model	9	25	IV Class pores
			20	III Class pores

Table 3 . The results of the testing with penetrating radiation.

Alloy	Method of moulding	Test number	Density [g/cm^3].	Number of Doran echo	Attenuation [dB/mm].
ATSi10	Sands	0	2,5498	3	0,48
	Iron mould	2	2,6776	4	0,37
	Easily volatile model	3	2,5398	2	0,53
ATSi10Cu3	Sands	4	2,7330	4	0,52
	Iron mould	1	2,7700	5	0,42
	Easily volatile model	7	2,6692	4	0,56
ATCu4MgTi	Sands	5	2,7280	2	0,61
	Iron mould	8	2,7499	3	057
	Easily volatile model	9	2,5955	3	0,64

Table 4. The results of the testing with ultrasounds.

Alloy	Density Polystyrene [kg/m^3]	Test features			
		Conductivity [%IACS]	Medium hardness [HB,2,5/62,5/60]	Dragging resistance [MPa]	Compression resistance [Mpa]
ATSi10Cu3Mg/I /PO	21	24,50	102,8	191	590
ATSi10Cu3Mg/I /P45	21	22,20	111,8	183	573
ATSi10Cu3Mg/I/PV	21	23,47	97,8	184	615
ATSi10Cu3Mg/II/PO	21	25,13	95,3	178	568
ATSi10Cu3Mg/II/P45	21	24,90	96,1	194	606
ATSi10Cu3Mg/II/PV	21	25,00	74,2	179	560
ATSi10Mg/I/PO	42	25,63	78,1	162	487
ATSi10Mg/I/P45	42	25,10	98,8	144	588
ATSi10Mg/I/PV	42	26,73	81,3	163	595
ATSi10Mg/II/PO	42	26,93	69,1	139	474
ATSi10Mg/II/P45	42	26,90	65,3	142	435
ATSi10Mg/II/PV	42	26,20	68,8	135	447

Table 5. Electrical and mechanical features of moulded alloys depending on the method of moulding.

The medium values of the features (conductivity, medium hardness, dragging resistance, compression resistance) of moulded samples depending on the moulding conditions are synthetic shown in table 5. The moulded samples have been obtained using the easily volatile model made from polystyrene, having two diffrents values of the density.

3. CONCLUSIONS

The article presents the results of a non-destructive testing of three samples of Aluminium alloys (ATSi10, ATSi10Cu3 and ATCu4MgTi), used frequently in the manufacturing of conducting parts of medium and high voltage circuit breakers. The results analysis points out the impact of the moulding technology (sand, iron mould and easily volatile model- polystyrene) on the chemical, metallographic composition, the mechanical and electrical features. In the same time, the influence of the moulding position (horizontal, vertical and 45^o inclination) on the moulded samples' features has also been noticed. The measurements and the analyzing of the chemical, metallographic composition and the mechanical and electrical features have been made using different methods of non-destructive testing and tests (penetrating liquids, ultrasounds and X-radiation). The following procedures have been performed: a) the analysis from visual point of view, b) the analysis of the chemical composition, c) the mechanical tests: the Brinnell hardness; the dragging test (the breaking resistance, lengthening and the flowing limit); the test of compression (the resistance, the technical limit, the shortcut and the swelling), d) electrical features: resistivity and volume conductivity. The next main conclusions must be drawn: after analyzing the external and in-break aspect and also after the metallographic analysis, the following conclusion can be drawn: the test having a vertical positioning shows a finer granulation than the horizontal ones, the test positioned at 45 degrees having an immediate granulation. Furthermore, all test samples have a porosity which is distributed non-uniformly both in the section and in the test length. The test porosity diminishes with the material density of the moulding model. The highest porosity is found in the tests moulded in polystyrene models with a high density of 42 kg/m^3. The conductivity of moulded tools increases with the increasing of the model's material density. Concerning the ultrasound testing, the next main conclusion is drawn: there is a linear dependence between the speed of the longitudinal wave and the degree of porosity, in a sense of speed decreasing, in case of the moulded Al 4,5% Cu alloy. Consequently, the importance of correctly choosing the moulding methods in order to obtain the needed level of electrical and mechanical features of the moulded components is pointed out.

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