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Analysis of the quality of squirrel cages rotor machined at Electroprecizia Electrical Motors

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Abstract
The paper presents methods for improving the quality of rotor squirrel cages in the casting phase at Electroprecizia Electrical Motors Săcele. For this purpose, there are analysed the results of theoretical and experimental research on the existing interdependencies between the quality of rotor squirrel cages obtained by casting and the metallurgical quality of aluminium melts, respectively the parameters of the casting process. When balancing rotor squirrel cages, the non-homogeneity of the compactness of the cast aluminium mass raises a number of technological problems. This non-homogeneity of the compactness is determined by the presence of voids (bubbles, pores) in the cast material. However, the compactness of the aluminium mass (the voids in the cast aluminium) has a decisive influence on the electrical efficiency of the electric motor due to the drastic local modification of the electrical resistivity. Based on an analysis of the results obtained, there can be concluded that the development of a new family of electric motors, of super premium energy efficiency class (IE4), also involves the analysis and detection of the causes that lead to the formation of bubbles and pores in the cast aluminium mass, on the current process flow, subsequently reducing them by improving the existing technologies or even by replacing them.

Keywords
pressure casting, aluminium, rotor squirrel cages, micro-shrinkages, quality analysis

1. Introduction

Electric motor rotors are made of aluminium using various casting methods [1-4]: static, centrifugal, under pressure, by vibration, etc., and they are successfully used in various types of industrial drives.

For the casting of rotors, in addition to ensuring that the dimensions of the parts comply with the product drawing for various standard dimensions, it is of particular importance to obtain a suitable compactness and electrical conductivity for the aluminium mass from the two end rings and from the bars within the laminations.

At Electroprecizia Electrical Motors Săcele, on the current casting process flow, Figure 1, the laminations are stiffened by introducing liquid aluminium into the mould cavity by injection using pressure casting machines with a cold, horizontal chamber, of the YIZUMI 5000 kN type [5].

The casting phase (cell) highlighted in red in Figure 1 refers only to the main melting-refining-casting operations. These include a number of secondary operations which ensure the manufacture of quality rotor squirrel cages, as follows:

- preheating of the metal charge;

- melting of the solid charge, refining of the liquid alloy;
- casting the alloy in the TSP machine room, with the help of a robot (mechanical arm);
- injecting the liquid metal into the mould (casting phase – filling the mould cavity);
- removing the cast piece from the mould;
- removing from the mandrel, removing the casting grid.

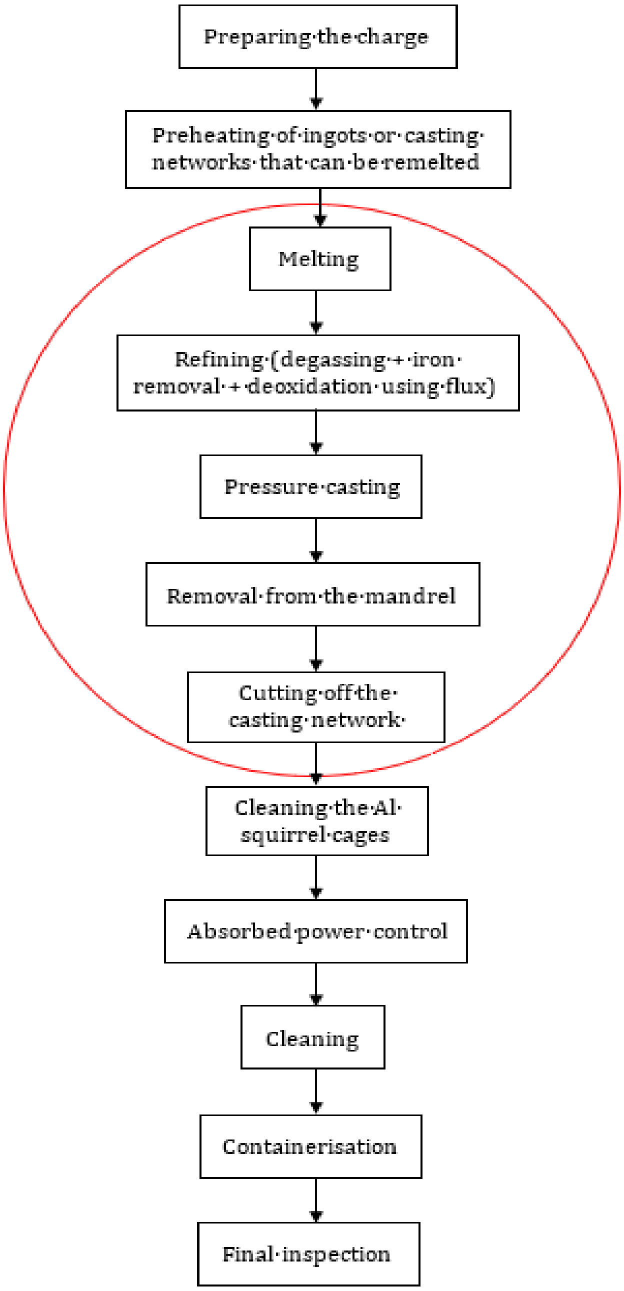


Fig. 1. The process flow for casting aluminium rotors at Electroprecizia Electrical Motors Săcele

2. Analysis of the Quality of Cast Rotors

In order to analyse the quality of the cast rotors, there must be first analysed the quality of the liquid alloy, and the degree of contamination of the melt by hydrogen and solid non-metallic inclusions is also of importance [6, 7].

The melt is contaminated by these impurities according to the reaction (1):

$$2[Al]_{(melt)} + 3\{H_2O\}_{(water\ vapours)} = (Al_2O_3)_{solid\ non\text{-}metallic\ inclusions} + 6[H]_{hydrogen\ dissolved\ in\ the\ melt} \quad (1)$$

Water vapours come from the air and from the condensation on the solid metal charge and other auxiliary materials used for elaboration and not properly dried before being inserted into the furnace.

The nomogram in Figure 2 highlights the importance of the influence of air humidity on the degree of hydrogen saturation of the melt [8, 9]. It reproduces the maximum probable hydrogen contents in the liquid alloy depending on the composition of the alloy and the elaboration conditions (air humidity and elaboration temperature).

The nomogram helps to assess that, for an aluminium melt at an air humidity of 25 g/m^3 (summer months) and a melt temperature of 730 °C, the probable hydrogen content of the melt will be of approximately 0.75 cm^3 hydrogen / 100 g aluminium. This value is much higher than (0.3-0.4) cm^3 hydrogen/ 100 g aluminium (Fig. 3), values deemed as acceptable for obtaining parts free of bubbles.

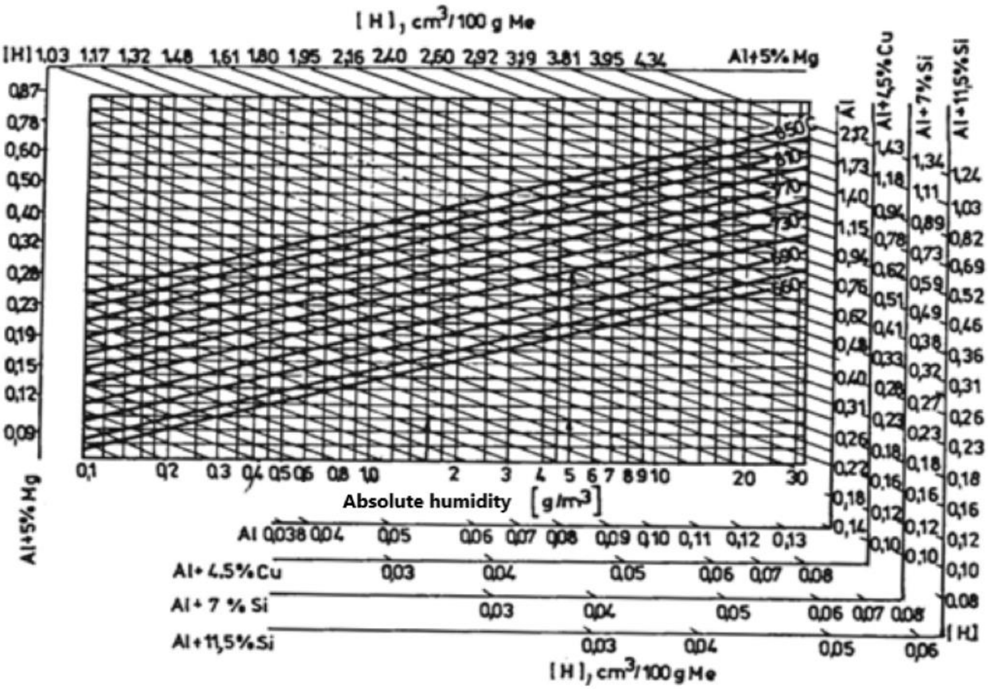


Fig. 2. Nomogram for the assessment of the maximum probable hydrogen content of liquid aluminium alloys, according to the elaboration conditions [8, 9]

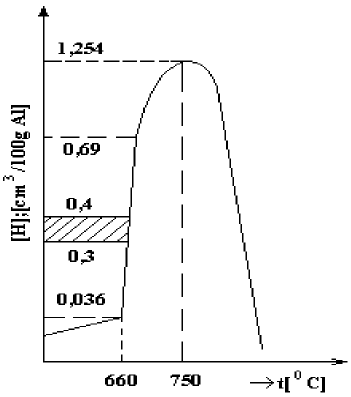


Fig. 3. Representation for assessing the tendency of bubble formation in castings according to the hydrogen content of the liquid metal [8, 9]

The diagram in Figure 3 shows the variation of hydrogen solubility in solid and liquid aluminium, respectively, with a significant jump at the melting temperature. This jump causes bubbles to form when aluminium solidifies by reducing the solubility of hydrogen by about 20 times.

Based on observations made on the current process flow, the degassed melt featured a much higher hydrogen content.

Using the simplified first bubble method for determining the hydrogen content in the melt, there was assessed that the bubbles occurred on the surface of the melt cast in a small mould (diameter 30 mm, height 50 mm) at 750 °C.

Referring to the expression describing the variation of hydrogen solubility in liquid aluminium [8, 9], the hydrogen content in liquid aluminium cast in the graphite mould is calculated as follows:

$$lg[H]Al_l = -\frac{2760}{T} + 1.356 + \frac{1}{2}lgp \quad (2)$$

$$lg[H]Al_l = -\frac{2760}{1023} + 1.356 + \frac{1}{2}lg760 \quad (3)$$

resulting in:

$$lg[H]Al_l = 0.098459582 \quad (4)$$

and

$$[H]Al_l = 1.2544 \quad [\mathrm{cm^3 \cdot H_2/100\ g\ aluminium}] \quad (5)$$

where:

T is the absolute temperature, [°K];

T = [273 + (750 °C)] °K (temperature of the melt when the first bubbles occur, 750 °C).

Therefore, both the theoretical analysis and the result of the experimental determination showed high hydrogen contents in the non-degassed (non-refined) melts, highlighting the need to perform the refining operation (degassing/deoxidation) under optimal conditions.

In order to obtain a melt of appropriate purity (without solid non-metallic inclusions and hydrogen), the consistent application of refining technologies (deoxidation, degassing) is of particular importance [4, 10].

At present, aluminium is refined in the current flow by introducing GASEX N3 degassing tablets and the COVERLUX 0234 A flux to remove solid non-metallic inclusions.

There should be noted that these tablets are introduced into the metal melt using a ladle, not a bell intended for this operation. Furthermore, there can be considered that abandoning the use of the degassing bell in favour of "self-immersing" flux tablets is not the best measure.

The degassing efficiency is highly dependent on the time in which these tablets reach the base of the melt column (at the bottom of the crucible) and on the circular movement of the bell at the bottom of the crucible.

There should be noted that, even if slightly volatile fluxes are used, immediately after introducing the flux at the base of the metal melt (using a bell) bubbles of inert/active gas are formed by evaporation and degassing continues similar to degassing by inert/active gas injection, and thus the parameters of both technologies are analysed according to similar criteria [8].

The rotor squirrel cage after casting with the casting grid is shown in Figure 4.

The cumulative effect of the quality of the metal melt, the mould cavity filling conditions and the strengthening of the aluminium laminations were examined by:

- highlighting casting defects according to the International Atlas of Casting Defects [11];

- determining the absorbed power;
- determining the compactness of the alloy in 2 end rings and bars by X-ray analysis.

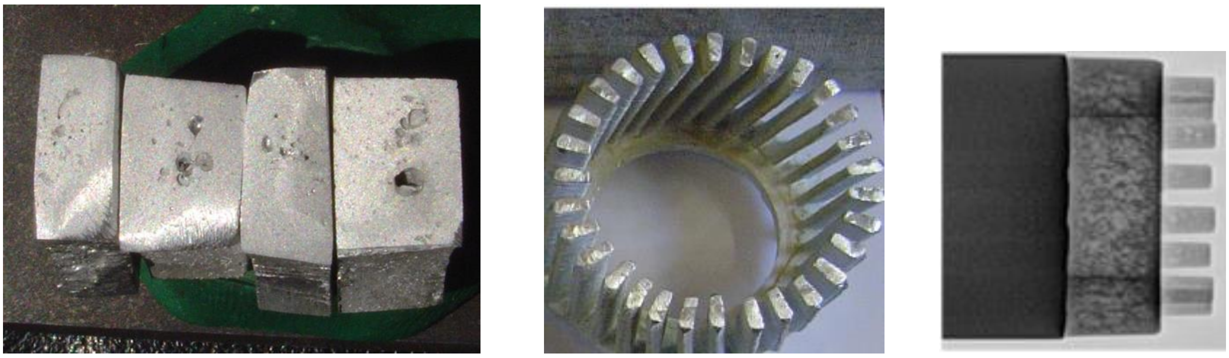
Fig. 4. Rotor squirrel cages after casting with the casting grid

The electrical and compactness X-ray measurements were carried out in the laboratories of the industrial partner, Electroprecizia Electrical Motors.

3. Results

3.1. Highlighting of casting defects

The analysis of the parts made available against the International Atlas of Casting Defects [11] revealed micro-shrinkages (B221) and bubbles and pores (B111), as shown in Figure 5.



a) b) c)

Fig. 5. Voids in the rings of the rotor squirrel cages (a, c) and in the bars inside the laminations (b)

Probable causes of shrinkages: solidification shrinkage and method of filling the cavity with liquid aluminium.

The probable cause of the occurrence of exogenous pores is the presence of air in the mould cavity, and, in this case, the turbulence should be reduced during injection, and endogenous pores likely occur due to the dissolved hydrogen present in the liquid alloy.

The waste records and statistical analysis are the methods recommended in this case to detect the causes that lead to the occurrence of defects, analysing the quality of the alloy and the parameters of the pressure casting machine.

3.2. Controlling the quality of bars in cast rotors by means of absorbed power

The installation in Figure 6 measures the power absorbed by the rotor squirrel cage while it is inserted into a stator which is supplied with a constant current during the measurement. If the power is greater than the rated (imposed) one, the part is not good.

There should be noted that the rated powers are given in tables established by the company's laboratories, which approve the part after a number of experiments.

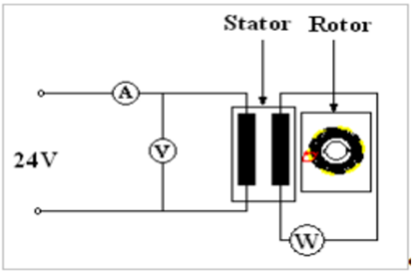


Fig. 6. Simplified diagram of the installation used to examine cast rotor squirrel cages

The absorbed power is influenced by the resistivity of the aluminium in the rotor. The electrical resistivity of aluminium is determined by:

- the hydrogen content in the liquid alloy used for casting, i.e. the bubbles which occur in the part due to hydrogen and the voids that occur in the part due to improper supply and venting of the mould cavity;
- the presence of solid non-metallic inclusions of the Al_2O_3 type, at the boundaries of the crystals;
- metallic impurities in aluminium (iron separates at the boundaries of the crystals in the form of Al_3Fe).

An ideal rotor has the same density in the entire volume occupied by aluminium and the lowest resistivity. Table 1 shows the absorbed powers recorded for the 0.55/1000 rotor.

Table 1. Measurements for rotor - 0.55/1000

Item	Current, I		Power
	[A]	[div]*	[div]*
1	1	20	5.94
2	1.1	22	7.2
3	1.2	24	8.6
4	1.3	26	10
5	1.4	28	11.6
6	1.5	30	13.4
7	1.6	32	15.1
8	1.7	34	17.2
9	1.8	36	19.2
10	1.9	38	21.5
11	2.0	40	23.8
12	2.1	42	26.2
13	2.2	44	28.7
14	2.3	46	31.4
15	2.4	48	34.2

* [div] means divisions

The wide spread of the values recorded in Table 1 shows the non-uniformity of the properties (compactness) of the parts analysed. These shortcomings can be attributed to both the alloy quality and to the pressure casting machine.

3.3. Determining the compactness of the alloy in end rings and bars by X-ray analysis

The compactness of the alloy was determined in 2 end rings and bars by X-ray analysis.

In some cases, the X-ray analysis revealed high porosities [12] determined more by the micro-shrinkages in the end rings (see Fig. 5c).

The final, non-destructive examination is carried out on a RISATTI device, as shown in Figure 7.

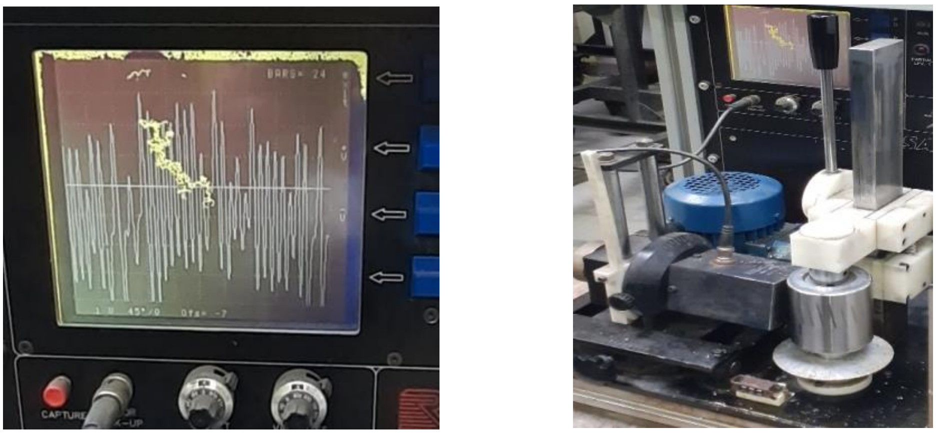


Fig. 7. The diagram recorded upon examining the integrity of the bars inside the rotor (laminations) on the RISATTI device

In Figure 7, on the recorded curve, the less pronounced peaks or their absence indicate defects (voids/pores) or even the break of the bar. All these defects result in rejecting the rotors.

According to the data collected, it is estimated that the total waste varies between 0.9-1.5 %. Any exceedance of these values indicates problems with the alloy refinement and/or the pressure casting machine adjustment. There should be noted that additional information on the quality of the metal melt can also be obtained through:

- microstructural analyses (highlighting the presence of intermetallic compounds with iron content);
- the analysis of the area of fracture on broken samples on a Charpy hammer can assess the degree of contamination with solid non-metallic inclusions.

4. Conclusions

The analysis of the experimental results shows that the properties (compactness/porosity, density, electrical resistivity, homogeneity) of the aluminium mass in the rotor are determined by:

- the quality of the liquid alloy (aluminium) used for casting, the level of the hydrogen content;
- the particularities of filling the mould cavity (casting grid-end rings-channels/bars in laminations).

The enhancement of the quality of cast rotors is greatly hampered by the difficulty of assigning the causes to casting defects, which leads to the idea of optimising the melting/refining operations and the casting phase.

The device for determining the hydrogen content, using the first bubble method, allows both the determination of the hydrogen content of non-degassed/degassed melts, as well as the evaluation of the efficiency of the degassing operation, and the melt degassing can be intensified by introducing the degassing technology with gas injection in the dynamic regime.

Acknowledgement

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