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Controlled Precipitation Gaseous Cavities in Aluminium Castings

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Abstract

At thermal junctions of aluminium alloy castings and at points where risering proves to be difficult there appear internal or external shrinkages, which are both functionally and aesthetically inadmissible. Applying the Probat Fluss Mikro 100 agent, which is based on nano-oxides of aluminium, results in the appearance of a large amount of fine microscopic pores, which compensate for the shrinking of metal. Experimental tests with gravity die casting of AlSi8Cu3 and AlSi10Mg alloys have confirmed that the effect of the agent can be of advantage in foundry practice, leading to the production of castings without local concentrations of defects and without the appearance of shrinkages and macroscopic gas pores. Also, beneficial effect on the mechanical properties of the metal has been observed.

Keywords: Aluminium alloys, Porosity, Shrinkages, Gassing in melt, Pore morphology

1. Introduction

One of the most frequent quality problems in aluminium alloy castings is the occurrence of internal cavities of the type of shrinkages, microshrinkages and cavities due to hydrogen release. In practice, microshrinkages and gas pores are collectively usually referred to as “porosity” but the causes for their appearance are different and are due to two different mechanism:

a) volume change in the course of solidification, which leads to the appearance of shrinkages and microshrinkages, and
b) the release of hydrogen bubbles due to the change in solubility during aluminium solidification, which causes gas porosity.

These cavities are responsible for leaky castings, degrade the mechanical properties and impair the look of castings.

1.1. Appearance of Shrinkage and Gas Pores

Shrinkages

In the course of solidification, the volume of aluminium alloys is reduced by ca 4-5 %. Volume shrinking results in the appearance of external or internal shrinkages. External shrinkages are in the nature of open cavities or caved-in casting surface. Internal shrinkages are formed either by larger concentrated closed cavities of by scattered microshrinkages.

External as well as concentrated internal shrinkages appear in areas of heat junctions in particular. At heat junctions that cannot be risered effectively the surface of the casting often caves in (is pulled in). External shrinkages are quite easy to see and usually not acceptable to the customer.

The appearance of internal microshrinkages is connected with the crystal morphology of the alloy and with the width of the two-phase zone. To eliminate microshrinkages is substantially more difficult than to eliminate macroshrinkages because the closed microvolumes of the melt remain without connection to liquid metal in the riser. Problematic from the user's viewpoint are in particular the scattered microshrinkages, which are usually not localized to a limited site and occur throughout a considerable volume of the casting.

Gas cavities

The formation of gas cavities is related with the release of hydrogen as a result of the change in its solubility during solidification. That is why the melt must thoroughly be degasified prior to pouring; insufficient degassing leads to the formation of gas pores during solidification.

Under current solidification rates, a part of the hydrogen remains in the solidified metal as oversaturated solid solution. The degree of oversaturation increases in particular with increased solidification rate and therefore, when casting thick-wall castings in sand moulds, the range of gas porosity is considerably larger than when casting thin-wall castings in dies. Gas bubbles have an adverse effect on the quality of machined surfaces and they also impair the gas tightness of castings.

Gas cavities are primarily formed by the nucleation mechanism on appropriate nuclei such as non-metallic inclusions, oxides, salt residues, and the like. In a properly refined alloy there are fewer crystallization nuclei for the formation of gas pores and thus the porosity of castings under identical gassing is markedly less pronounced than when casting non-refined alloys.

From the viewpoint of the effect of porosity on mechanical and technological properties, in particular gas tightness, the shape and interconnection of pores are of fundamental importance. Spherical gas pores exert a less negative effect on the mechanical properties and gas tightness of castings than ragged shrinkages. The shape is evaluated metalographically, based on the so-called "roundness" of cavities – **s**, which is defined as the ratio of the square of pore circumference to pore cross section

Internal shrinkages and microshrinkages in particular copy the structure of primary-phase dendrites; they have a high roundness index – Figure. 1. Due to their unfavourable shape, their interconnection and large extent they make the castings leaky and markedly impair the mechanical properties, elongation in particular.

Gas cavities are usually of spherical shape, the roundness index **s** of gas pores is close to the value 1. Their notch effect is not significant and their effect of mechanical properties is markedly lower than that of microshrinkages. In real conditions, porosity is usually the common result of microshrinkages and gas bubbles formation.

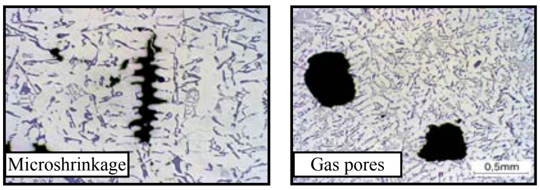


Fig. 1. Morphology of gas pores and microshrinkages

2. Controlled Release of Gas Bubbles

The release of gas bubbles partially compensates for shrinking-induced volume reduction. Castings of intensively degassed melt have therefore a larger volume of shrinkages than non-degassed alloys. This effect is often clear to note in the casting parts that are difficult to riser, for example flange-and-tube joints, and the like. External or internal shrinkages are formed at these sites or the wall caves in. The extent of shrinkages is sometimes intentionally compensated for by increased melt gassing, using gassing salts or via blowing gas with hydrogen content. These spontaneously formed pores are usually comparatively large, up to several tenths of mm, visible to the naked eye on metallographic specimens or fracture surfaces – Figure 2. Although such pores reduce the extent of shrinkages, they do not ensure gas-tight castings and, above all, they are inadmissible on machined surfaces.

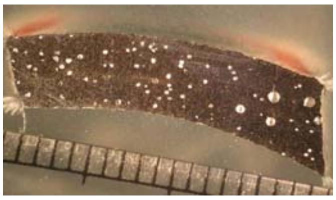


Fig. 2. Fracture through casting with gas porosity

Controlled release of gas cavities in castings is an idea that exploits the effect of shrinking being compensated for by the release of fine, mutually isolated gas pores. The aim is to obtain the release of the finest possible spherical, mutually not interconnected microbubbles, the overall volume of which compensates fully or partially for the loss of metal due to shrinking. This will reduce or even prevent the appearance of shrinkages and wall sagging while good gas tightness of castings is obtained – Figure 3.

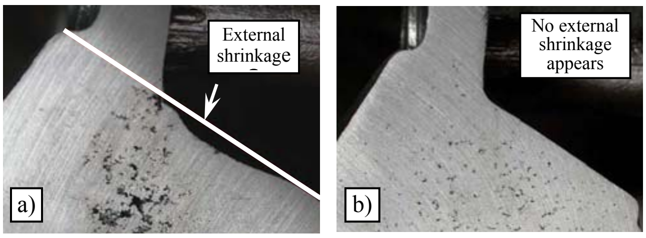


Fig. 3. a) Casting without the application of Mikro100
b) Casting with the application of Mikro100

The principle of the method of controlled formation of micropores consists in introducing into the alloy nanostructured aluminium oxides, which serve as crystallization nuclei for the formation of gas bubbles. These fine particles arise due to the liquid aluminium being sprayed into a current of air; subsequently they are formed into compact rods. This agent was developed by the Schäffer Company and is marketed under the name Probat-Fluss Mikro100 in the shape of rods – Figure 4.

Fig. 4. Rods of Mikro100 agent

It is obvious that this method is not concerned with gassing in the melt but with the creation of conditions for the release of dissolved hydrogen in the form of very fine pores. After the application of the Mikro100 agent, the method of double weighing is used to establish the increase in the Density Index. Naturally, this increase is not due to a higher hydrogen content but to its more thorough release from the metal. Therefore, prior to the application of the agent, the melt should not be degassed to a very low level of hydrogen, DI < 1, but to an optimum value of about DI = 2 – 4. The agent is applied to the bath subsequent to refining, inoculating and, possibly, modifying. The amount of the Mikro100 agent dosed ranges from 0.1 to 0.4 % of the mass of the melt. The scum formed on the surface must thoroughly be mixed into the melt until it is fully dissolved. The period of agent effectiveness is usually given as 4 – 6 hours.

3. Checking the Effect of Mikro100

The Mikro100 agent was applied and its effect checked in standard operating conditions of gravity die casting.

Test description

Melt alloys: AlSi8Cu3, AlSi10Mg

The metal was melted in an induction crucible furnace and poured into holding resistance furnaces. Refining took place prior to pouring from the melting furnace. Each series of tests started from a melt without the Mikro100 agent. Before and after the application of the Mikro100 agent, the temperature of the metal and its Density Index were measured, samples for chemical analysis and for the Tatur test as well as tensile test rods were cast, and individual test castings were successively made. Tests were carried out on castings which under usual production procedure permanently exhibited defects of the type of shrinkages. In the course of testing, the dosage of the Mikro100 preparation was successively increased from ca 0.1 % to a maximum of 0.35 %. Two melts of the AlSi8Cu3 material and one melt of the AlSi10Mg material were evaluated.

- The temperature was measured using a dipping NiCr-Ni thermocouple.
- The method of double weighing was used to evaluate the degree of gassing and establish the Density Index.
- The chemical composition was analysed on a spectrometer.
- Using the Tatur test (Fig. 5) the volume of concentrated shrinkage and the density of metal were measured.
- The die temperatures were measured with a contact thermocouple and, when possible, maintained at constant values.
- From selected sites of the castings produced, samples were obtained, and metallographic specimens were made for the evaluation of the structure and porosity.

On the Tatur test castings, the critical internal cavities were evaluated below the root of the concentrated shrinkage. It is perfectly obvious that after the application of Mikro100 the volume of internal cavities of the type of microshrinkages decreases, changing to very tiny spherical pores – Figure 5.

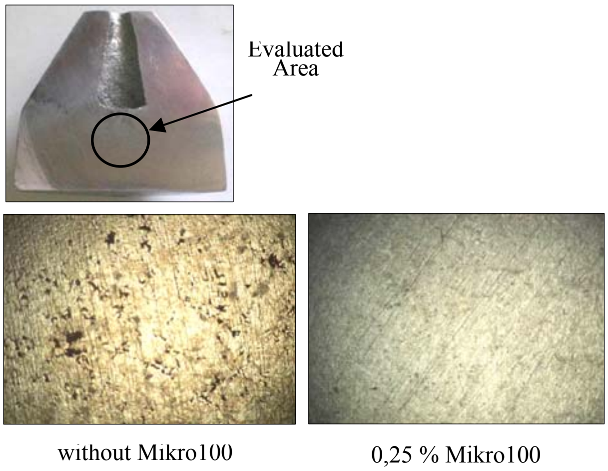


Fig. 5. Change in porosity below the shrinkage root

Figure 6 gives the pattern of DI values. It is obvious that after the application of the Mikro100 agent the DI values always increase and after 0.5 – 1.5 hr reach the maximum.

The dependence of the volume of concentrated shrinkage and of metal density (porosity volume) as obtained by the Tatur test on gassing did not yield any unambiguous results by our trials.

Tensile tests (a total of 36 test rods) revealed that after the application of the Mikro100 agent the strength (Fig. 7) and elongation usually increased. The maximum increase in strength is obtained ca 0.5 hr after the application of the agent; subsequently, the values decrease.

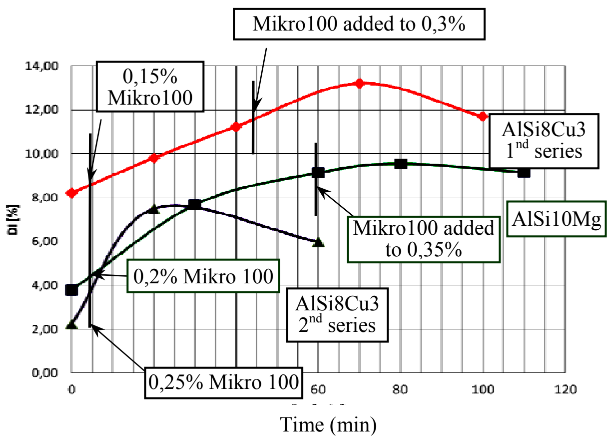


Fig. 6. The pattern of DI values in the course of testing

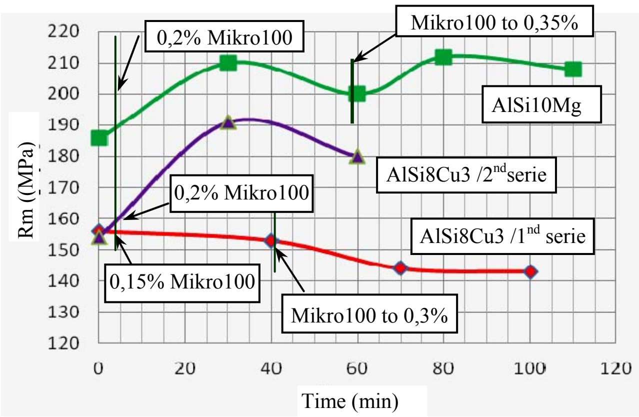
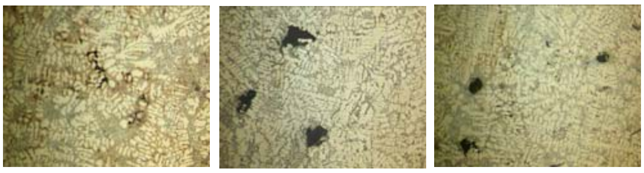


Fig. 7. Change in strength after application of Mikro100



without Mikro100 0,15 % Mikro100 0,3 % Mikro100

Fig. 8. Change in shape of pores after application of Mikro100

Figure 8 illustrates how in a castings made of the AlSi8Cu3/1st series alloy the shape of pores changed from ragged to spherical after the application of Mikro100

4. Verifying the Mikro100 agent on a problematic casting

In a separate series of tests, the effect of the Mikro100 rods on the occurrence of defects of the type of internal cavities was examined in an area of the casting shown in Figure 9.

Casting material AlSi8Cu3, chemical composition according to Table 1, pouring temperature 740 °C, gravity die temperature 300 – 340 °C (measured with a contact thermocouple).

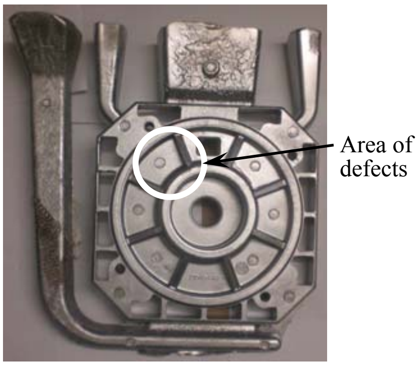


Fig. 9. Casting under examination

Table 1.
Chemical composition of the metal of the casting

Chemical composition of the EN AC-AlSi8Cu3 alloy								
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
%	8,95	0,65	2,24	0,26	0,25	0,04	0,09	0,99

The basic melt was successively poured from the holding resistance furnace under the following values of gassing:

a) the melt in the holding furnace was degassed to DI 0.75
b) adding non-degassed melt from the melting furnace increased the DI to 5.7
c) application of 0.3 % Mikro100, holding time 20 min, DI 7.6

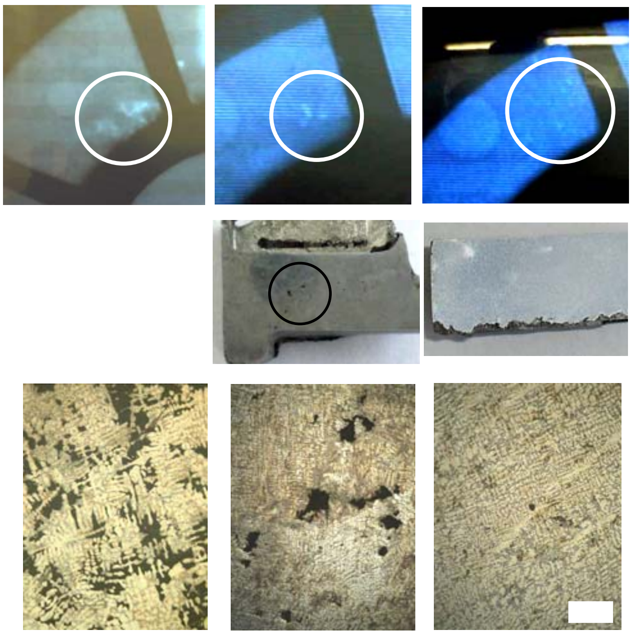
X-ray pictures in Figure 10 show evident changes in the extent and distribution of internal cavities at a critical site of the casting. When pouring a severely degassed melt – state **a),** there is a large concentrated cavity in the critical area. Increasing the gassing without resorting to Mikro100 – state **b)** resulted in reducing the area of cavities, but the defect is comparatively large. After the application of Mikro100 – state **c)** the area of concentrated cavities disappears and scattered porosity is only identified.

Apparent in sections through castings for state b) are compact cavities of the type of gas pores. After the application of Mikro100 no cavities can be seen in the section.

Metallographic pictures confirm that in state **a)** we are concerned with typical microshrinkages in a melt with liberated gas while in state **b)** the cavities are in the nature of large, comparatively compact gas pores, surely appearing under a simultaneous effect of shrinking. After the application of Mikro100, no pores appear that could be identified using optical metallography (magnification 40x). Scattered porosity established in the X-ray picture is due to the presence of a considerable portion of very tiny gas cavities – **c)**.

5. Conclusion

The tests of the Probat Fluss Mikro100 preparation carried out under operating conditions of gravity die casting AlSi8Cu3 and AlSi10Mg alloys have sown that the preparation significantly affects the morphology of internal cavities in the castings. With a high degree of degassing the alloy tends to form microshrinkages of ragged shapes, which can be expected to have a very unfavourable effect on the mechanical properties and gas tightness of castings. With a higher hydrogen content, these cavities change to a more compact type of comparatively large gas pores. The application of the Mikro100 agent results in the appearance of scattered porosity formed by very small cavities instead of large, locally concentrated pores. After the application of the agent, a larger volume of gas cavities is released overall, which shows as a higher Density Index. This change in pore morphology as established in the tests usually manifested itself in increased tensile strength and elongation.



a) DI = 0,7 b) DI = 5,2 c) DI = 7,6
– without Mikro100 +0,3% Mikro100

Fig. 10. Effect of the application of Mikro100 agent on the porosity of a selected casting

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