

## INFLUENCE OF THE WORKING TECHNOLOGY ON Al-ALLOYS IN SEMI-SOLID STATE

### VPLIV TEHNOLOGIJE PREOBLIKOVANJA Al-ZLITIN V TESTASTEM STANJU

**Matjaž Torkar, Mirko Doberšek, Iztok Naglič**

Institute of Metals and Technology, Lepi pot 11, SI-1000 Ljubljana, Slovenia  
matjaz.torkar@imt.si

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We present two industrial technologies for working Al-alloys in the semi-solid state: thixocasting and rheocasting. The development of these processes has enabled significant progress and improved market competitiveness for the aluminium-casting industry. During both processes the share and the form of the globular solid phase are very important and they influence the flow of material in the tool. The comparison of thixocasting, rheocasting and the conventional casting process characteristics must be considered during the choice of one of these technologies. The performed investigations of rheocast components of A357 alloy revealed the important reasons for failures were the non-optimised parameters of the semi-solid working technology, the rapid opening of the tools and the non-optimised shape of the tool cavities.

Key words: thixocasting, rheocasting, semi-solid state, microstructure, Al-alloys

Predstavljeni sta dve vrsti tehnologije ulivanja oz. preoblikovanja v testastem stanju, thixocasting in rheocasting. Razvoj teh dveh postopkov je povzročil preobrat pri postopkih ulivanja aluminija in omogočil boljšo konkurenčnost na trgu. Ključnega pomena sta delež trdne faze in oblika te faze, ki vplivata na tok materiala v orodju. Primerjava thixocastinga, rheocastinga in konvencionalnih postopkov pri preoblikovanju Al-zlitine pokaže njihove značilnosti, ki jih je treba upoštevati pri izbiri za uvedbo ene od teh tehnologij. Opravljene raziskave rheocast-komponent iz A357-zlitine so pokazale, da so med glavnimi vzroki za ugotovljene napake pri preoblikovanju Al-zlitine premalo optimirani parametri tehnologije preoblikovanja v testastem stanju, tudi prehitro odpiranje orodja in neprilagojena oblika orodij.

Ključne besede: thixocasting, rheocasting, testasto stanje, mikrostruktura, Al-zlitine

## 1 INTRODUCTION

Several methods for casting Al-alloys were developed in the past, for example, gravitational casting, low-pressure die casting, high-pressure die casting and squeeze casting in porous preforms. All these methods have some advantages and some disadvantages that influence their application. The automotive industry demands better parts with lower weight (which means thinner walls) and lower price. To improve competitiveness in the market, new and improved processes are being developed.

Basic and applied research work in the past also enabled the development of new technologies for working Al-alloys in the semi-solid state. The basis of these technologies was Fleming's<sup>1</sup> discovery that a material with a globulitic microstructure in a two-phase region (L+ $\alpha$ ) behaves in a thixotropic way. In the conventional casting process the local supercooling is responsible for the evolution of a dendritic microstructure and for the evolution of a globular microstructure a lower supercooling of the melt is favourable. This can be achieved either with forced convection of the melt during the solidification or with slow cooling. Lower cooling rates support the spherical growth of the solid phase. A more detailed background to these processes is described in <sup>1-6</sup>. Semi-solid metal processing offers

several advantages over conventional technologies such as casting, forging and powder metallurgy. Semi-solid metal processing enables the manufacturing of components with complex shapes, with thin walls, with good mechanical properties and with a high dimensional tolerance and accuracy.

The thixocasting process uses stirring of the melt during the solidification of a continuous cast bar to obtain the globulitic microstructure. These bars are then cut to the required pieces and reheated to the hot-working temperature. During the rheocasting process the globular primary  $\alpha_{Al}$  phase is obtained by rapid cooling, followed by controlled cooling to the temperature range of the hot working. With the conventional casting process, the development of the microstructure depends on the cooling rate.

The comparison of the rheocasting, thixocasting and conventional casting processes is schematically presented in **Figure 1**. From this figure it is evident that during rheocasting the material is obtained with a controlled cooling of the melt, while thixocasting needs stirring of the melt during solidification and additional heating for the hot working. The analyses of both processes on real components were carried out<sup>5</sup> and a comparison of the production parameters is presented in **Table 1**. The production parameters in Table 1 allow us to compare both casting processes on the basis of data

**Table 1:** Comparison of production parameters for thixo and rheo 8V bracket <sup>5</sup>

**Tabela 1:** Primerjava parametrov izdelave nosilca 8V-motorja po thixo- in rheo- postopku <sup>5</sup>

CHARACTERISTIC	THIXOCASTING	NEW RHEOCASTING
Material	A357 alloy in billets, obtained by electromagnetic stirring during the casting (Supplier: Pechiney)	A357 alloy ingots, without any special preparation (Supplier: various)
Semi-solid slurry production	– billet sizing – induction reheating in vertical medium-frequency furnaces up to the semi-solid state	– melting in a gas furnace – metal preparation in the holding furnace – pouring into specific steel cups and cooling up to the semi-solid state
Slurry Temperature	577 °C ± 2 °C*	579 °C ± 2 °C *
Metal need	4000 g	4700 g
Metal losses	10 %	1 %
Tool	2-cavity die with 4 hydraulic cylinders	2-cavity die with 2 hydraulic cylinders
Injection	Horizontal, with the slurry laying on the shot sleeve	Vertical, with the slurry inverted in the shot sleeve
Cycle time	59 s	52 s
Scraps recycling	scraps recycled by the supplier	scraps recycled in-house
Scraps rate	3 % visual + 2 % X-Ray	1 % visual + 0.5 % X-Ray

\* temperature measured in the centre of the slug

**Table 2:** Chemical composition of A 357 alloy in mass fractions (w%)

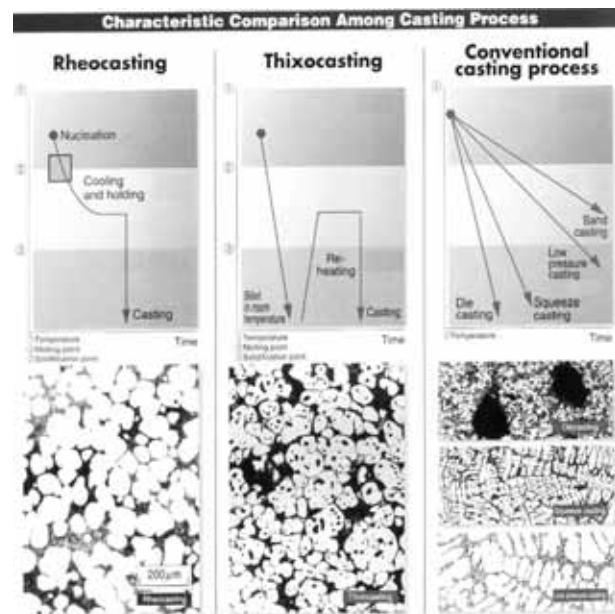
**Tabela 2:** Sestava A 357-zlitine v masnih deležih (w%)

Alloy	Cu	Mg	Si	Fe	Mn	Ti	Zn	Sr	Al
A 357	0.2	0.4 – 0.7	6.5 – 7.5	Max. 0.2	Max. 0.2	0.05 –0.2	Max. 0.2	0.03	Rest

obtained from industrial components. The comparison of the costs for the different hot-working technologies of Al-alloys is presented in **Figure 2**, where it is assumed that the cost per kg of the rheocast component is 100 %.

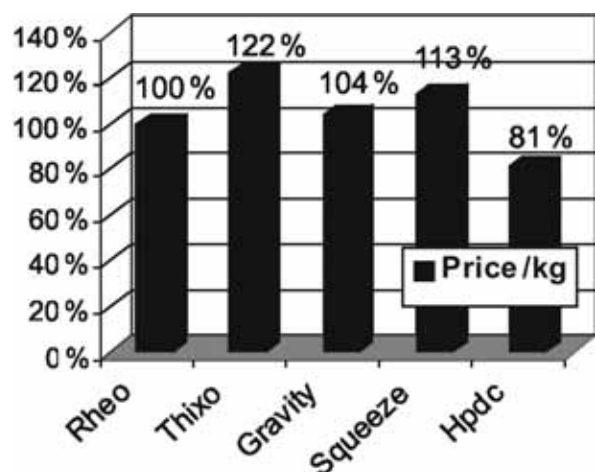
**Figure 2** shows that the price per kg of a thixocasting component, compared with rheocasting, is lower only for high-pressure die casting (HPDC), which ensures the

properties of the components of lower quality. The thixocasting is 22 % more expensive due to the more expensive technology, squeeze casting is 13 % more expensive because of the lower productivity and gravity casting is 4 % more expensive because of the cost of machining the components. From this comparison it is evident that rheocasting is a more competitive technology than thixocasting. Therefore, rheocasting is advantageous from the energy- and costs-saving points of view, when compared to thixocasting.



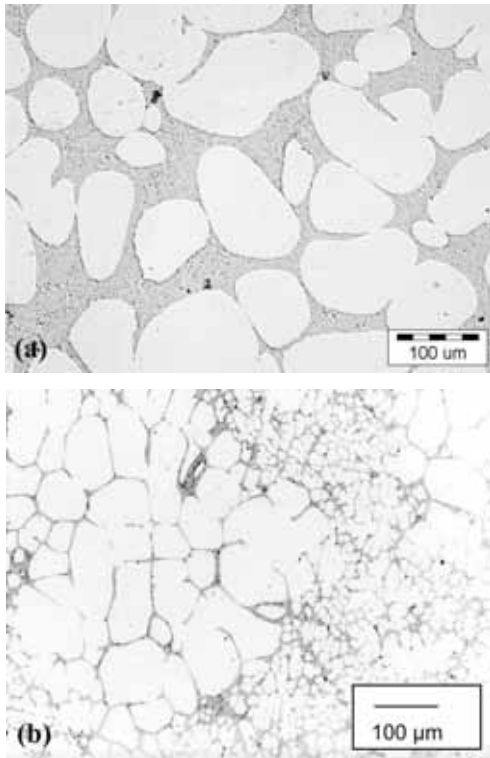
**Figure 1:** Schematic presentation of the rheocasting, thixocasting and conventional casting processes and the obtained microstructure.

**Slika 1:** Shematski prikaz rheocastinga, thixocastinga in klasičnega ulivanja ter dobljena mikrostruktura



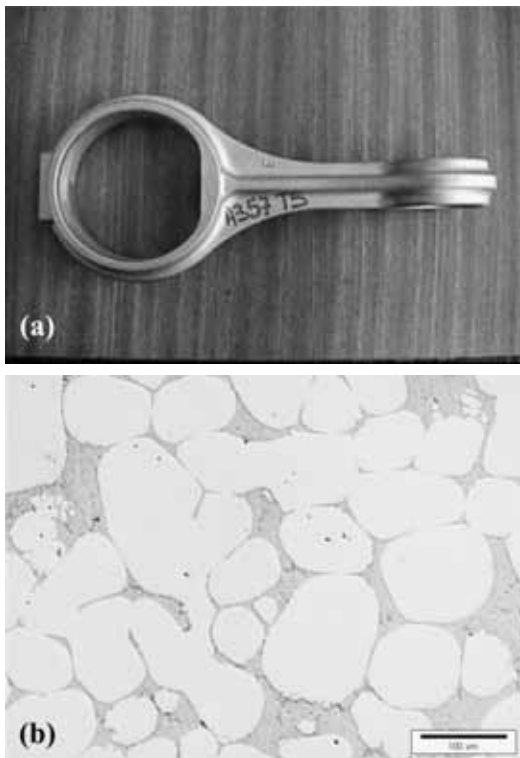
**Figure 2:** Costs comparison of technologies for Al-alloy component production. The cost per kg of the rheocast component is taken as 100% <sup>5</sup>

**Slika 2:** Primerjava stroškov tehnologij izdelave komponente iz Al-zlitine. Stroški na kilogram izdelave rheocast-komponente so prikazani kot 100 % <sup>5</sup>



**Figure 3:** Suitable (a) and less-suitable (b) slurry microstructure. Quenched in water

**Slika 3:** Primerna (a) in manj primerna (b) mikrostruktura surovca. Ohlajeno v vodi



**Figure 4:** Component (a) and microstructure (b) of the component, quenched in water

**Slika 4:** Komponenta (a) in mikrostruktura (b) komponente, ohlajene v vodi

Besides the presentations of the basic differences and characteristics of the thixocasting and rheocasting technologies, the aim of the experimental work was to evaluate and to detect typical failures in the rheocast components.

## 2 EXPERIMENTAL WORK

The rheocast components produced on an 800 t UBE rheocasting device were evaluated, and the microstructure of the slurry was investigated. Before the hot working the slurry was knife cut and quenched into water. After the manufacturing the components were quenched into water and investigated. The components were checked with an industrial x-ray device, YXLON SMART 225 kV (Andrex), for internal soundness. The surface and internal defects were also checked with metallography. The samples for metallography were cut from the components and prepared using a standard metallographic procedure. The microstructure was investigated with a light microscope (Nikon Microphot FXA) equipped with a 3CCD video camera (Hitachi HV-C20A) and software (analysis) for a quantifiable assessment of the microstructural characteristics.

## 3 RESULTS AND DISCUSSION

The slurry of A357 Al-alloy (**Table 2**) at the temperature of hot working and with an approximately 50 % content of liquid phase behaves like a butter. It can thus be cut with a knife.

The microstructure of the slurry consists of the globular  $\alpha_{Al}$  and eutectic phases (**Figure 3a**). With inadequate thermal conditions the slurry has a dendritic or mixed dendritic-globulitic microstructure (**Figure 3b**).

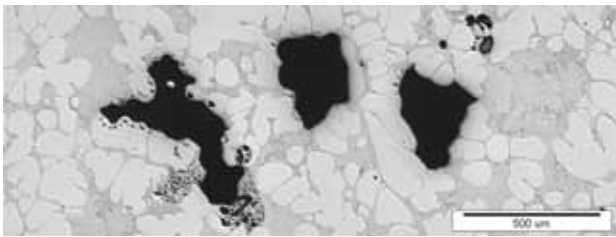
One of the investigated rheocast components is presented in **Figure 4a**, and the microstructure of the component quenched in water, in **Figure 4b**. The comparison



**Figure 5:** X-ray picture of shrinkage porosity in one of the components

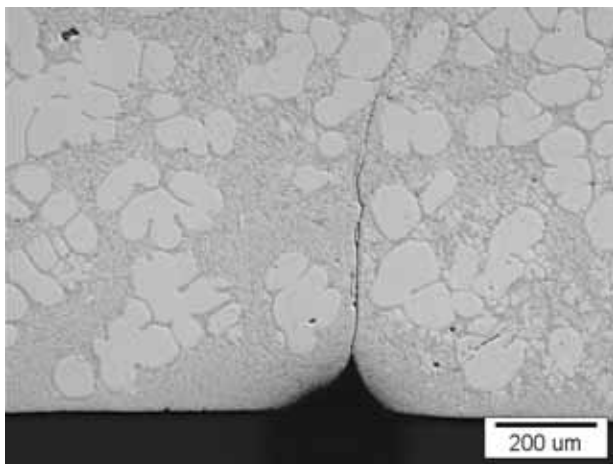
**Slika 5:** Rentgenski posnetek poroznosti v eni od komponent





**Figure 6:** Internal porosity – lack of melt, too high content of gases or to low pressure in the die

**Slika 6:** Notranja poroznost – manko taline, prevelika vsebnost plinov ali prenizka sila stiskanja orodja

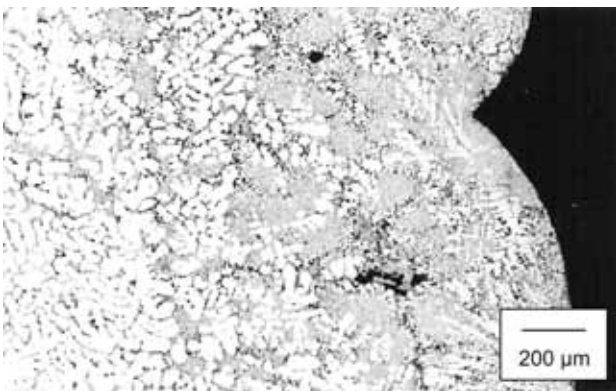


**Figure 7:** Cold joint of two melt fronts

**Slika 7:** Hladni spoj ob stiku dveh tokov taline

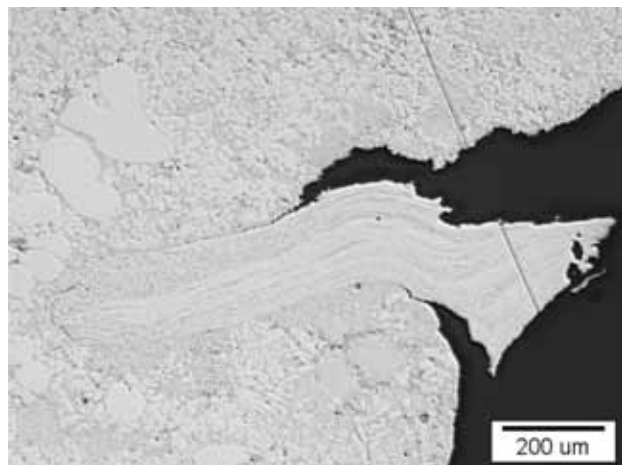
of the slurry (**Figure 3a**) and the component microstructure (**Figure 4b**) did not show any difference. As expected, in both cases the microstructure consisted of the globulitic  $\alpha_{Al}$  primary phase, surrounded by the eutectic phase.

To detect the internal defects the components were examined with x-rays. A typical x-ray picture of the shrinkage porosity in the component is presented in **Figure 5**. The metallography confirmed the presence of internal porosity (**Figure 6**). The possible causes of



**Figure 8:** Microporosity and increased share of eutectic near the surface

**Slika 8:** Mikroporoznost in povečan delež evtetika ob površini



**Figure 9:** Overflow and pull crack due to rapid opening of the die

**Slika 9:** Prelitje in razpoka zaradi prehitrega odpiranja orodja

porosity are a lack of melt, a too high content of trapped gases or a too low pressure in the die. Besides porosity in the critical regions of the component, cold joints were also observed. In these joints two fronts of the melt (**Figure 7**) in the die cavity contact with an intermediate oxide layer that greatly lower the local tensile strength of the alloy.

Metallographic examinations also revealed some other types of defects in industrially produced rheocast components. Besides microporosity, an increased share of eutectic was often observed near the surface (**Figure 8**). In some cases an overflow of the melt and pull cracks due to rapid opening of the die (**Figure 9**) were found. The increased share of eutectic near the surface is the consequence of an unequal material flow in the die cavity, where the die pressure squeezed the liquid eutectic to the surface.

## 4 CONCLUSIONS

A comparison of the thixocasting and rheocasting processes for the hot working of the Al-alloy A357 revealed, for both methods, some basic differences that should be considered during the choice of technology.

The main reasons for the failures during the hot working of the A357 Al-alloy in the semi-solid state by rheocasting were the non-optimised parameters of the semi-solid technology, the too fast opening of the tool and the non-optimised shape of the die cavity.

## Acknowledgement

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