PROPERTIES OF Al ALLOY CASTINGS PRODUCED BY RHEOCASTING METHOD SEED MEASURED BY INDENTATION

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Abstract

The paper describes the metallurgical, technological and heat treatment aspects of semi-solid casting process. Rheocasting SEED method using mechanical swirling for reaching proper structure in semisolid state was applied to alloy AlSi7Mg0.3. Values of selected mechanical properties reached by different heat treatment modes are presented. Mechanical properties were measured by indentation method. For observing structure, SEM microscopy was used.

Keywords: Rheocasting, semi-solid, automatic ball indentation, Al-Si alloys, heat treatment

1. INTRODUCTION

Aluminum alloys, especially alloys containing silicon as a main alloying element, are construction material suitable for characteristic applications in automotive and other transportation industry and also other industry fields. The benefit of these alloys is good castability and other technological properties and low density, which leads to low mass of final casting parts. Especially such casting methods, as high pressure die casting (HPDC) is, can reach near-net-shape construction with proper accuracy and low surface roughness. The handicap of the casting of aluminum alloys generally, especially HPDC, is the inner as-cast structure, often containing porosity, which can lead to lower mechanical properties of final parts comparing to other construction materials. To achieve higher values of mechanical properties, it is necessary to use some of progressive methods of casting, which ensure high integrity of casting parts.

One group of these methods is the semi-solid casting. The thixotropic properties were discovered more than 30 years ago. The possible advantages of applying these properties to process material in a semi-solid state were soon recognized and two different routes were proposed: thixocasting and rheocasting. There is presently a renewed interest in the semi-solid processing associated with the rheocasting route. However, the difficulty in obtaining a high-quality semi-solid material, together with the lack of a procedure for in situ measuring the rheological properties of the semi-solid slurry, has created some hurdles for the widespread use of the semi-solid casting technologies [1].

The SEED process (Swirled Equilibrium Enthalpy Device) is one of those rheocasting processes in industrial production of semi-solid castings. The SEED process is based on achieving rapid thermal equilibrium between the metallic crucible and the bulk of metal by swirling. Morphology and size of the solid phase and the subsequent rheological properties of the semi-solid slurry are dependent upon the selected process parameters, including the pouring temperature and time of swirling in relation to the metal volume.

The special rheological properties of the semi-solid alloys are linked to a globular morphology of the solid phase, fundamental to achieving good quality final products. The key features of SEED method are quality improvements, such as production of high integrity shape complex parts with good inner quality suitable for structural applications, possibility of heat treatment of castings (blister free), parts are weldable, near-net-shape, thin and even thick wall pressure tight parts with geometrical flexibility, enhanced mechanical properties. There are also technological aspects, such as productivity improvement due to faster cycle rate, reduced total heat load on tooling, resulting in longer die life, returns can be fully recycled in the foundry. The SEED method principle is described in **Fig. 1** [2].

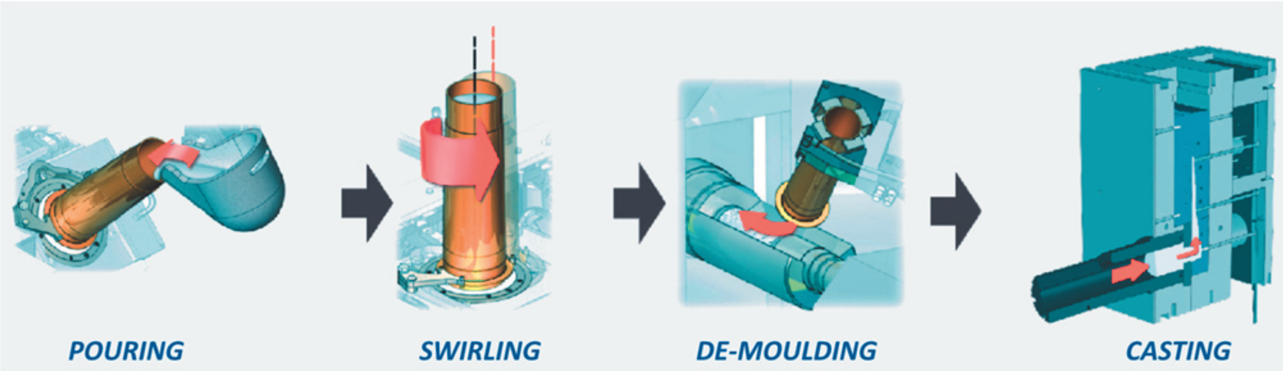


Fig. 1 SEED rheocasting method principle - phases [2]

For semi-solid methods, suitable are alloys with wide two-phase interval, both hypo- and hyper eutectic [3]. Practically, hypoeutectic alloy AlSi7Mg0.3 is one of the most applied alloys. Compare to alloys Al-Si commonly used for HPDC, this alloy has less silicon and, what is important, less iron content, which contribute to enhanced mechanical properties.

In general, it is very difficult to verify the mechanical properties of real HPDC parts because of their shape complex character, thin walls and different cooling rate in specific casting parts. The standardized tensile test specimens for castings (with circular section) are usually impossible to cut out and machine, therefore flat rectangular specimens are often used. Even though the cutting out and machining of the specimens is very expensive and achieving of sufficient statistical matching of obtained values requires relatively large number of specimens. On these grounds, indentation was applied as an investigation method for evaluation of selected mechanical properties.

The goal of this work is to examine selected mechanical properties of parts processed by rheocasting method SEED in as cast state and after heat treatment by indentation method. There is also the aim to find out, whether the theoretical values of mechanical properties of the alloy were reached. The practical goal of the work is to find out the proper temperatures and holding times of heat treatment mode T6 for specific casting of engine bracket.

2. EXPERIMENTAL

2.1. Rheocasting

In 2011 two workplaces of SEED method were installed in Kovolis Hedvikov, a.s. One of the projects cast by this method is the engine bracket casting (see **Fig. 2**). In this study, aluminum alloy EN-AC AlSi7Mg0.3 was used to produce semi-solid castings with the SEED process. Chemical composition of the alloy is in **Table 1**. SEED and HPDC process parameters are described in **Table 2**.

Table 1 Chemical composition of experimental alloy EN-AC AlSi7Mg0.3 (wt %)

Si	Fe	Cu	Mn	Mg	Zn	Ti	Others (each / total)	
6.5 - 7.5	0.15	0.03	0.10	0.30 - 0.45	0.07	0.10 - 0.18	0.03	0.10

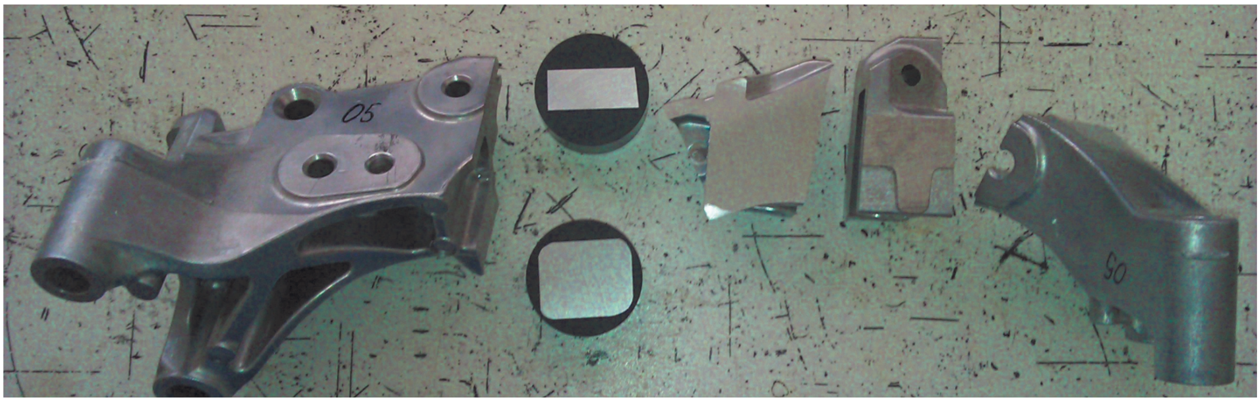


Fig. 2 Experimental casting: engine bracket; places of cutting out the samples

Table 2 SEED and HPDC process parameters used in experiment

SEED process parameters		HPDC process parameters	
Furnace metal temperature (°C)	655 (-14/+9)	Piston position (mm) / shot speed (m/s)	40 / 0.20
Ladle angle (°)	31		280 / 0.20
Crucible inside diameter (mm)	80		380 / 1.00
Crucible length (mm)	250		500 / 1.00
Target pouring temperature (°C)	638		509 / 1.00
Swirling time (s)	89	Casting pressure (MPa)	95
Swirling speed (rpm)	150	Cycle time (s)	63
Rest time (s)	7		

2.2. Heat treatment

Table 3 Variants of heat treatment modes and marking of samples

Sample marking	Solution annealing	Artificial aging
01	As cast	
11	520 °C / 6 h	180 °C / 6 h
21	520 °C / 6 h	150 °C / 6 h
31	540 °C / 2 h	180 °C / 6 h
41	540 °C / 2 h	150 °C / 6 h

Table 4 Theoretical mechanical properties of rheocast alloy AlSi7Mg0.3

AlSi7Mg0.3	As cast	T6
Tensile strength (MPa)	240	303
Yield strength (MPa)	140	228
Elongation (%)	1	12
Hardness HBW 5/250	55	90

After casting, the heat treatment T6 was applied to castings. Heat treatment T6, also called “complex heat treatment” consists of solution annealing, quenching and artificial aging. To determine the proper heat treatment mode for in question casting part engine bracket, 4 different modes of T6 heat treatment were applied, with varying temperatures and holding times at the temperature - see **Table 3**. In **Table 4** theoretical mechanical properties of alloy EN - AC AlSi7Mg0.3 are described for heat treatment T6.

2.3. Testing methods

Samples, marked as described above, were taken from different areas of the casting, both from thin and thick part (as shown in **Fig. 2**). Together it was prepared 10 samples, 5 from thin and 5 from thick wall. On each sample were made min. 3 indentation measurements, values displayed in charts in **Figs. 4, 5** are the average.

Indentation tests were carried out by a special device, which due to its design is capable of continuous recording of load and indentation depth of the used indenter. The system includes: the recording device, analog-to-date converter, PC with software, tensile-testing machine Instron 5582 as a force-producing mechanism. Maximum load indentation was 2.5 kN with the indenter diameter of 5 mm. Plane-parallel samples were used for ABI (Automatic Ball Indentation) testing.

The hardness was calculated by the formula (1):

$$HB = \frac{P}{\pi\ D\ h}, \tag{1}$$

where *HB* - Brinell hardness, *P* - load (kN), *D* - diameter of indenter (mm); *h* - indentation depth (mm) (**Fig. 3**).

For determination of the tensile strength R_m we used the dependence (2) [4]:

$$R_m = c\ HB, \tag{2}$$

where *c* - coefficient of hesitate. For present series of alloys, we used the value of the coefficient - 2.8 [5].

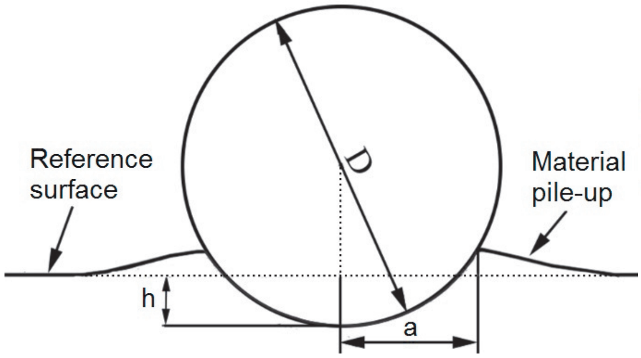
For determination of the yield strength $R_{p0.2}$ methodology proposed by the authors [4] (3) were used.

$$R_{p0.2} = c\ HM \tag{3}$$

Meyer hardness was calculated by the formula (4).

$$HM = \frac{P}{\pi\ a^2} \tag{4}$$

where *c* - coefficient of hesitate (2.8), *HM* - Meyer hardness, *a* - contact radius. Using the values of indentation depth (*h*), according to the formulas (5) and (6), strain values (ψ) and the contact radius (*a*) were determined. Value of deformation for the yield stress was 0.2 %, by analogy with tensile tests.



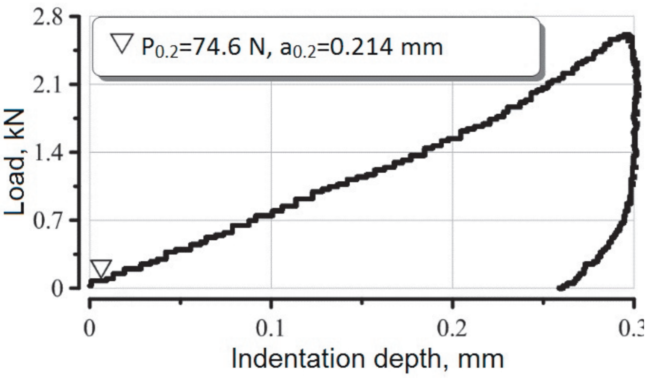


Fig. 3 Scheme for determination of contact radius (a) and indentation curve for the AlMg6Mn alloy (b)

Fig. 3b shows the resulting indentation curve for the AlMg6Mn alloy. The point with the deformation of 0.2 % is marked on the curve.

$$\Psi = \frac{h}{D} \quad (5)$$

$$a = \sqrt{D\,h - h^2} \quad (6)$$

3. RESULTS AND DISCUSSION

Measured values of mechanical properties are shown in charts in **Figs. 4** and **5**. Red columns are samples taken from the thin wall, blue from the thick. As seen, reached values of selected properties are generally low. It cannot be stated, that in general values of properties in thin wall are higher, than in thick part. Also it was not confirmed, that whether any heat treatment mode dramatically increases the values of properties in comparison to as cast state. The worst results of strength and hardness gives the sample 11, even worse than as cast sample 01, only Young modulus is lower for sample 21. Best results of all measured properties gives the sample 31, but still the values do not reach the theoretical values mentioned in **Table 4**.

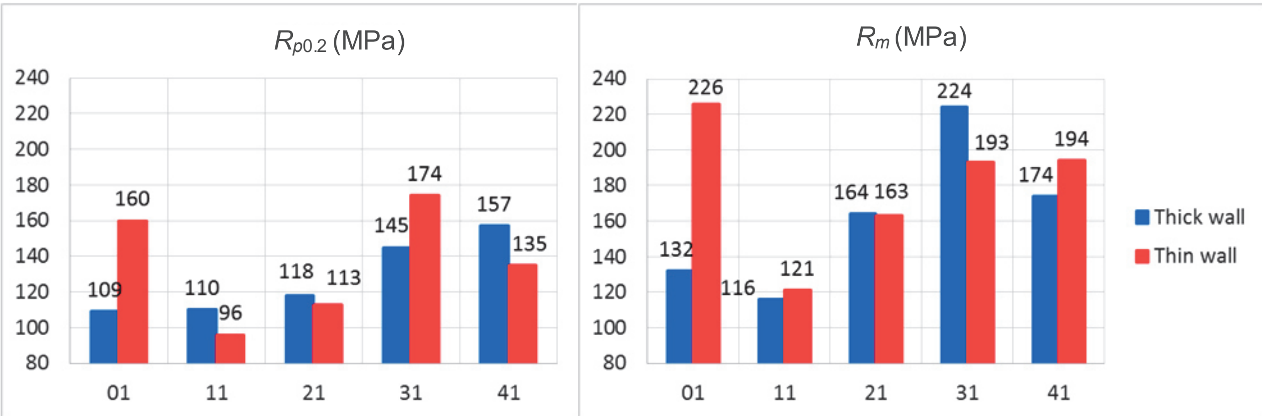


Fig. 4 Resulting values of yield strength $R_{p0.2}$ and tensile strength R_m

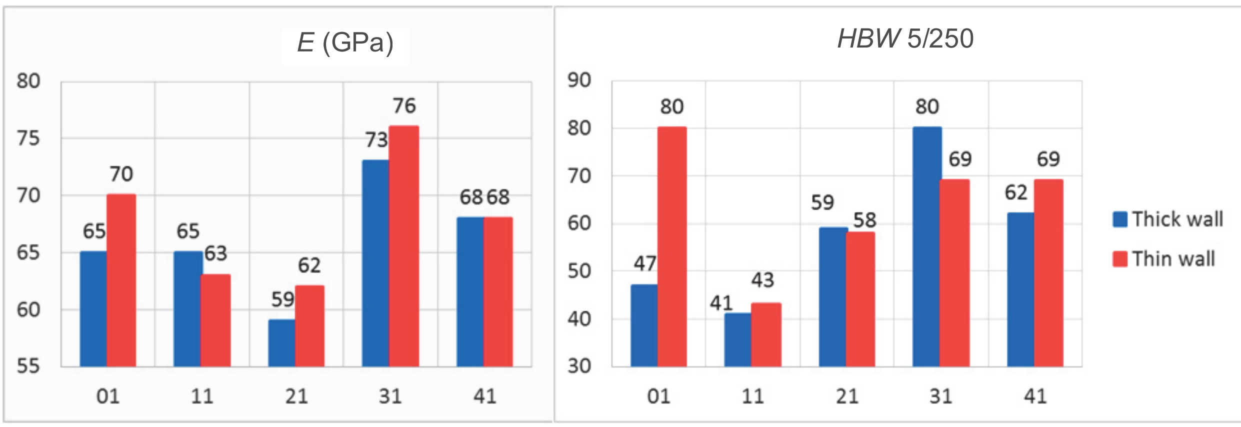


Fig. 5 Resulting values of Young modulus *E* and Brinell hardness HBW 5/250

To explain the cause of such low values of mechanical properties measured by indentation method, observation by electron microscopy was performed, especially in sample 11 (**Fig. 6**). It was found, that the structure contains unexpected porosity and intermetallic phases. It can be assumed, that such structure defects as porosity can be the reason of obtained low values of mechanical properties. To make sure, more investigations and also comparative tensile tests should be done. Some previous and further works of authors are dedicated to analysis of characteristic defects of castings processed by rheocasting method SEED.

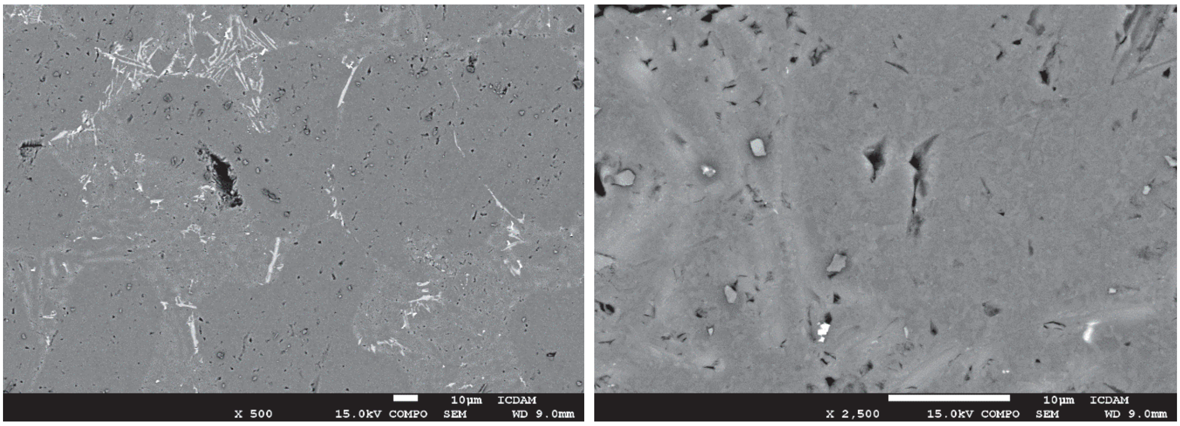


Fig. 6 Structure of sample 11 obtained by SEM

4. CONCLUSIONS

Selected mechanical properties (yield and tensile strength, Young modulus and hardness) of casting processed by rheocasting method SEED without and with different heat treatment modes were measured by indentation method. So far, by this method cannot be obtained results for elongation, which would be useful especially for specific castings such as those processed by rheocasting. This possibility is expected after further development of the device.

Values of mechanical properties of alloy AlSi7Mg0.3 cast by rheocasting SEED method measured by indentation method did not reach the theoretical values, which is also in breach with previous measuring by conventional methods. Low values of mechanical properties measured by indentation can be influenced by unexpected porosity and intermetallic phases found in structure. The cause of these defects is the subject of further works. Also will be processed more comparative tests of indentation and conventional tensile testing.

Highest values of mechanical properties were reached by heat treatment mode consisting of solution annealing 540 °C/2 h, quenching and artificial aging 180 °C/6 h.

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