



ARCHIVES  
of  
FOUNDRY ENGINEERING

DOI: 10.2478/afe-2014-0011

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences



ISSN (2299-2944)

Volume 14

Issue 1/2014

45 – 48

# Investment Casting vs Replicast CS Considered in Terms of the Ceramic Mould Making and Dimensional Accuracy of Castings

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Received 28.06.2013; accepted in revised form 02.09.2013

## Abstract

The article presents an analysis of the applicability of the Replicast CS process as an alternative to the investment casting process, considered in terms of the dimensional accuracy of castings. Ceramic shell moulds were based on the Ekosil binder and a wide range of ceramic materials, such as crystalline quartz, fused silica, aluminosilicates and zirconium silicate. The linear dimensions were measured with a Zeiss UMC 550 machine that allowed reducing to minimum the measurement uncertainty.

**Keywords:** Investment casting, Lost foam patterns, Casting quality, Replicast CS

## 1. Introduction

Introducing to the foundry industry a new technology for making small-size castings, where patterns are made from foamed polystyrene, a simultaneous analysis of the casting dimensional accuracy has been made [1, 2, 3, 4, 5].

R. E. Grote [6] was studying in detail the Replicast CS process at every stage of the ceramic shell mould manufacture, paying attention to the quality of patterns produced.

The conclusions drawn from relevant publications are unambiguously favourable as regards the evaluation of the new technology, although an undeniable drawback of the process is certainly the need for making large batches of products due to the

high cost of the Replicast CS pattern tooling. All data on the dimensional accuracy are mainly concerned with the scatter of values of the casting dimensions in a single batch of products. In general it can be said that in this case the dimensional deviation

$\Delta L = L_{\max} - L_{\min}$  is described with the following equation:

$$\Delta L_{6\sigma} = \sqrt{\delta_M^2 + \sigma_F^2 + \sigma_O^2} \quad (1)$$

where:  $\delta_M$  - error of pattern making,

$\delta_F$  - error of ceramic shell mould making,

$\delta_o$  - error of casting solidification (mainly molten metal shrinkage in moulds and casting cooling). All these data refer to castings made under the conditions which are often incomparable with each other.

## 2. The dimensional accuracy of ALSi9 alloy castings evaluated for the investment process and Replicast CS

### 2.1. Types of ceramic moulds used in the study

In studies, the Ekosil binder or Ekosil alternatively with ethyl silicate (KE) were used. The liquid ceramic slurry (CMC) was a combination of the binder and a suitable ceramic flour.

The following types of ceramic moulds were made:

- Type A – CMC Ekosil alternatively with KE with the addition of SiO<sub>2</sub> flour, aluminosilicate (Molochite) as a stuccoing material – 8 coatings,
- Type D – CMC in coatings from 2 to 8 with the addition of fused silica flour, the first coating based on zirconium silicate flour, Molochite after recycling as a stuccoing material,
- Type E – CMC based on SiO<sub>2</sub> flour with the addition of Ekosil or KE (coatings 1, 3, 4, 6 and 8 based on Ekosil, coatings 2, 5, 7 with KE), SiO<sub>2</sub> as a stuccoing material,
- Type F – CMC based on Ekosil, coatings 1 and 3 KE, coatings 2 and 4 Molochite flour, Molochite as a stuccoing material. Four-coating mould made in sleeves with proper filler (coarse-grained SiO<sub>2</sub> >1mm).

### 2.2. Methodology

For the first time, in studies, a combined set of patterns (Fig. 4) was used, which comprised patterns made from foamed polystyrene (Figs. 2 and 3) and patterns made from paraffin and stearin with the addition of Montana wax in an amount of 10% (Fig. 1). To reduce the cost of studies, polystyrene patterns were cut out from a plate of proper density using a tool with a wire through which a current induced by a 4.5 V battery was flowing. This method of pattern-making was not perfectly reproducible, which naturally must have resulted in a large scatter of patterns in a batch  $\Delta M = M_{\max} - M_{\min}$ , much higher than for the melted out patterns. To evaluate the stability of the Replicast CS process and lost foam technique in terms of the dimensional accuracy of castings, the scatter of casting dimensions was evaluated as  $\Delta(M - L)_{\sigma}$  for each batch of products. Patterns were numbered to assign the casting to an appropriate pattern. To minimise uncertainty in the measurements, most measurements were taken on a coordinate ZEISS UMC55o measuring machine with HSS head and HP/UX workstation [7].

For each group of individual dimensions, mean values  $\bar{X}$  were calculated as well as the values of the six sigma deviations. After analysis, the outlier dimensions were rejected based on an average square deviation  $\sigma$ . It has been assumed later that the real

dimensions are within the interval  $L_{\min} = \bar{X} - 3\sigma$  and  $L_{\max} = \bar{X} + 3\sigma$ , where  $L_{\min}$  is the minimum dimension of casting and  $L_{\max}$  is the maximum dimension of casting. The approved dimensions were used to assess the value of (M - L).

The study was conducted on sample castings, where the sample batch size ranged from  $n = 10$  to  $n = 30$ , and where the batch size of castings made of foamed polystyrene patterns ranged from  $n = 10$  to  $n = 20$ , and the batch size of castings made of paraffin and stearin patterns ranged from 20 to 30 pieces. The ceramic moulds after the removal of patterns were fired, cooled down and preheated before pouring to 300°C. Moulds were poured with ALSi9 alloy. Castings for the analysis were shaped so as to make their solidification modulus similar to each other (Figs. 1 and 3).

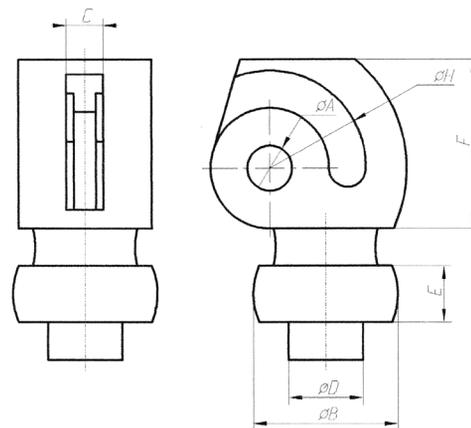


Fig. 1. Casting A, pattern material – mixture of paraffin and stearin

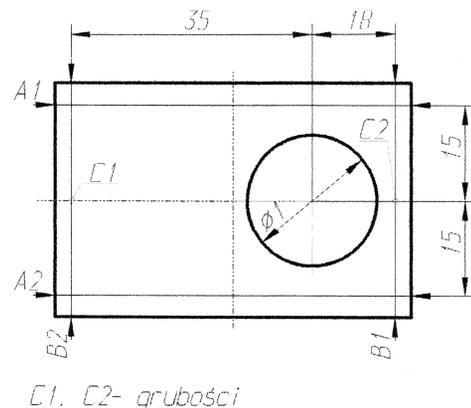


Fig. 2. Casting C, pattern material – foamed polystyrene

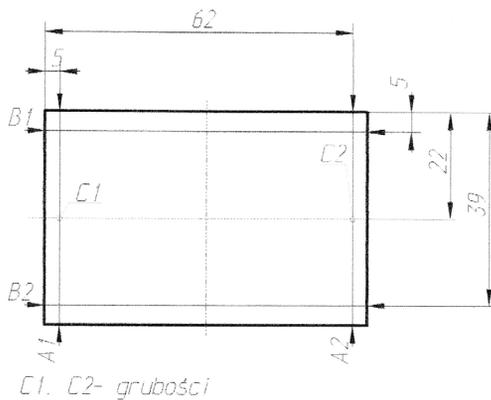


Fig. 3. Casting D, pattern material – foamed polystyrene

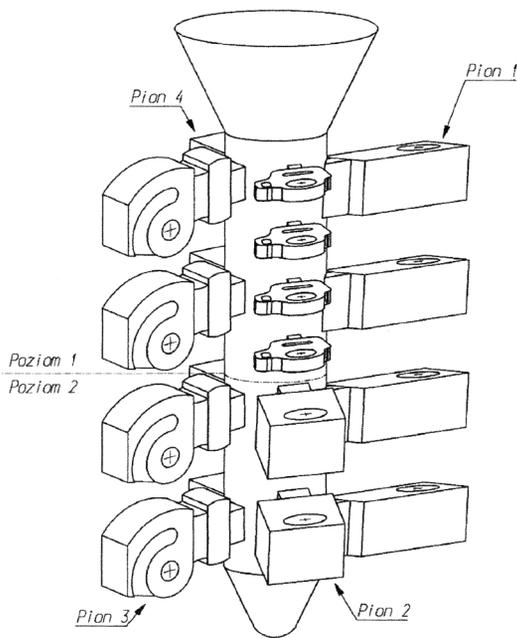


Fig. 4. Pattern cluster used in tests

### 2.3. Discussion of results

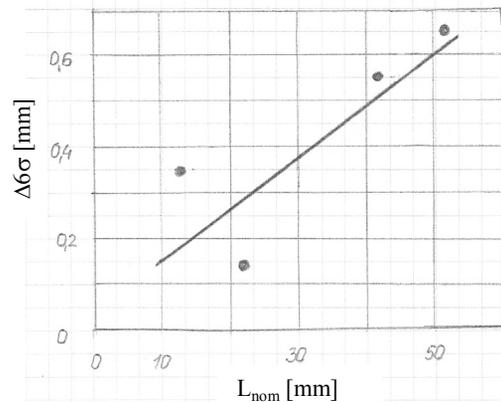
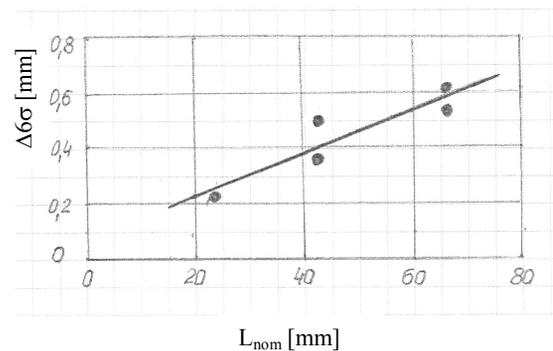
Based on the measurement results, for each type of casting (Figs. 1 to 3) and for each type of ceramic mould, the value of  $\Delta(M-L)_{6\sigma}$  was calculated, allowing for the dimensions shown in the drawings of castings.

From the regression equations, relevant slopes of the straight lines and appropriate equations for the evaluation of  $\Delta(M-L)_{6\sigma}$  were derived

- Fig. 5 -  $\Delta(M-L)_{6\sigma} = 0,011 \bar{X} + 0,049$ , where the following mean values  $\bar{X}_i$  were considered  
 $\bar{X}_1 = 43,01$ ;  $\bar{X}_2 = 51,64$ ;  $\bar{X}_3 = 12,71$ ;  $\bar{X}_4 = 16,16$ ;
- Fig. 6 -  $\Delta(M-L)_{6\sigma} = 0,0078 \bar{X} + 0,05$

$$\bar{X}_1 = 24,05; \bar{X}_2 = 43,10; \bar{X}_3 = 43,17; \bar{X}_4 = 66,31; \bar{X}_5 = 66,11;$$

- Fig. 7 -  $\Delta(M-L)_{6\sigma} = 0,02 \bar{X} - 0,372$   
 $\bar{X}_1 = 24,2$ ;  $\bar{X}_2 = 43,45$ ;  $\bar{X}_3 = 43,46$ ;  $\bar{X}_4 = 66,98$ ;  
 $\bar{X}_5 = 65,56$ ;
- Fig. 8 -  $\Delta(M-L)_{6\sigma} = 0,027 \bar{X} + 0,324$   
 $\bar{X}_1 = 23,7$ ;  $\bar{X}_2 = 43,01$ ;  $\bar{X}_3 = 43,19$ ;  $\bar{X}_4 = 66,22$ ;  
 $\bar{X}_5 = 66,26$ ;

Fig. 5. The value of deviation  $\Delta(M-L)_{6\sigma}$  in function of the dimension  $L_{nom}$ . Mould type E, casting type AFig. 6. The value of deviation  $\Delta(M-L)_{6\sigma}$  in function of the dimension  $L_{nom}$ . Mould type A, casting type C

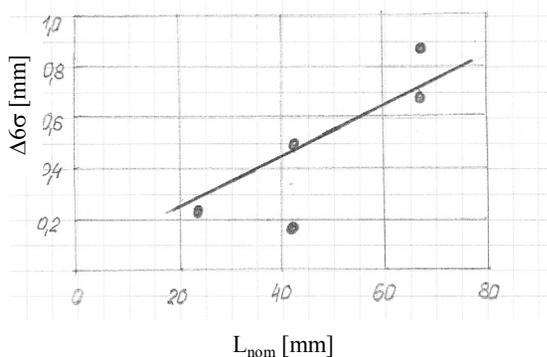


Fig. 7. The value of deviation  $\Delta(M - L)_{6\sigma}$  in function of the dimension  $L_{nom}$ . Mould type D, casting type C

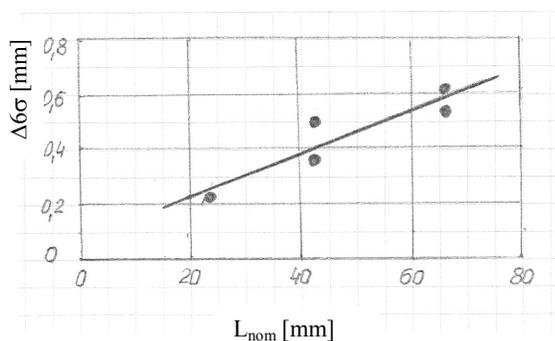


Fig. 8. The value of deviation  $\Delta(M - L)_{6\sigma}$  in function of the dimension  $L_{nom}$ . Mould type F, casting type D

Summing up the equations shown in Figures 5 to 8 for  $L_{nom} = 50$  mm, the following values were obtained:

- For casting of type A, Fig. 1, reproduced from pattern made of a paraffin, stearin and Montana wax composition (mould composed of 8 coatings based on  $\text{SiO}_2$ ) - the value obtained was  $\Delta(M - L)_{6\sigma} = 0,61$  mm
- For casting of type C (polystyrene pattern), mould composed of 8 coatings with Molochite stucco - the value obtained was  $\Delta(M - L)_{6\sigma} = 0,41$  mm
- For casting of type C (Fig. 2), mould based on recycled Molochite stucco (coatings from 2 to 8) - the value obtained was  $\Delta(M - L)_{6\sigma} = 0,54$  mm
- For casting of type D (Fig. 3), mould composed of four coatings with Molochite stucco; type F, moulding in a sleeve with  $\text{SiO}_2$  filler – the value obtained was  $\Delta(M - L)_{6\sigma} = 0,65$  mm

### 3. Summary

The application of Molochite for stucco instead of  $\text{SiO}_2$  (mould E) increased process stability, reducing the deviations  $\Delta(M - L)_{6\sigma}$  by the value of 0.06 mm to 0.13 mm for  $L_{nom} = 50$  mm. Changing the pattern type had no significant effect on the dimensional stability. On the other hand, the use of a traditional 4 coating mould, most popular in the Replicast CS process, when moulding the shell in a sleeve with  $\text{SiO}_2$  as a filler, gave the value of deviation  $M - L$  larger by 0.05 mm than for the casting of type A (mould with  $\text{SiO}_2$  as a stucco material).

In general terms it can be stated that the use of traditional investment ceramic mould in the Replicast CS process gives similar dimensional stability measured with parameter  $\Delta(M - L)_{6\sigma}$ . Moreover, the use of recycled Molochite as a stucco material introduces no major changes to the system (mould of type D) and gives the desired ecological effects [7], for example, reduces the energy consumption in production which, in turn, gives the reduced rate of  $\text{CO}_2$  emissions.

### 4. Conclusions

1. The Replicast CS process and investment casting as applied to ALSi9 alloy, using similar technology of the ceramic mould making, give similar values of dimensional accuracy expressed by the parameter  $\Delta(M - L)_{6\sigma}$ .
2. The use of recycled Molochite as a stucco material in the ceramic mould making process only minimally alters the dimensional accuracy of castings, while exerting a beneficial effect on the environment.

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