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Microscopic Analysis of the Aluminium Castings Produced with the use of Polymer Composite Patterns

D. Czarnecka-Komorowska [a], **K. Gawdzińska** [b], **P. Popielarski** [a, *]
[a] Poznań University of Technology, Poland
[b] Maritime University of Szczecin, Poland
* Corresponding author. E-mail address: pawel.popielarski@put.poznan.pl

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Abstract

The paper presents a microscopic analysis of the surface and fracture of aluminium castings produced using the lost-wax method for patterns made of a composite material, i.e. polyethylene with the addition of bentonite. Castings are made of AlSi7 aluminium alloy (silumin) in a plaster mould. A new type of polymer waxes enriched with bentonite was used to obtain new composites, minimizing the defects caused by the casting production process. The castings were made in the centrifugal casting process. The prepared plaster moulds were removed from the furnace and poured with liquid aluminium alloy (AlSi7) at 750°C. The surface and fracture of the castings was analysed using an optical digital microscope type VHX-7000 manufactured by KEYENCE. It has been proven that the studied castings feature surface defects (raw surface defects) in the form of high roughness and the presence of bentonite inclusions classified as casting contamination. During the tests, shape defects related to mechanical damage were also detected.

Keywords: Casting, Aluminium alloys, Lost-wax method, bentonite, Digital microscope

1. Introduction

The basic element for the assessment of the quality of castings is the condition of their surface, which was specified in detail in the works by Kozakowski and Sozański [1-3] or in the standards [4-6]. Due to its complex nature, the foundry industry requires constant evaluation of product quality by means of introducing new materials and technological solutions [7-10]. It is particularly necessary in the lost-wax casting methods [11], where new materials for the production of casting patterns are still being sought [12-13]. The introduction of new modifiers/fillers for waxes [14] may streamline the casting process and improve the quality of the produced castings. The introduction of organic fillers is an important development in the process of forming foundry waxes. The additives are usually organic compounds that do not react with waxes, but form composites. The formation of composites with a matrix of polyethylene waxes is aimed at reducing and/or eliminating the occurrence of unfavourable phenomena, which undoubtedly include uncontrolled shrinkage [15-17]. Therefore, they primarily cause an improved contractility of composites with a wax matrix, which affects the quality of the raw surface of the castings.

The research carried out by the authors in [14] related to selecting innovative, desirable materials for casting patterns used in the lost-wax method shows that polyethylene-bentonite composite waxes meet these expectations. The authors of the study proved that bentonite is an effective modifier of linear shrinkage, hardness, and crystallinity. This is because the modification of polyethylene with bentonite leads to a reduction of linear shrinkage by about 90% and hardness by 30% compared to pure polyethylene wax (PE), which improves the dimensional accuracy of wax patterns and the casting process. It has also been found that the new material based on bentonite-modified polyethylene wax reduces casting shrinkage and slightly increases viscosity, which is therefore excellent for lost-wax casting. After the casting process, quality control is essential, especially when new casting methods [18-21] or new materials are introduced, such as in the case of casting patterns made of composites based on polyethylene-ceramic waxes. Destructive and non-destructive research techniques are used to analyse the surface quality of castings, internal defects, shape or continuity of the structure. In this study, it was decided to evaluate the use of digital microscopy to analyse the raw surface of the produced silumin castings using the lost-wax method for composite patterns.

2. Experimental

2.1. Materials

The PE-wax used in this paper was jewellery injection Flexible Blue wax supplied by the Freeman Manufacturing and Supply Company (Avon, Ohio, US), with a viscosity of 71 mPas, Shore D hardness of 30, ash content of 0.03% and specific gravity of 0.94. Flexible Blue Freeman flakes often used as a matrix for manufacturing patterns in the lost-wax casting method are characterized by high flexibility, long shelf life, and the ability for reproducing very sharp details. This unique mixture of wax and plastic is especially well-suited for metal moulds. The PE-wax mixture was modified with 0.4 wt.% bentonite powder (BP) content. The particle filler used with a particle size of 0.056 mm was commercially available bentonite produced by Zakłady Górniczo-Metalowe „ZĘBIEC" S.A. in Starachowice, Poland with a water content of 12%, montmorillonite content of 65%, and with a density of 0.82 g/cm^3. The bentonite powder prior to mixing with PE-wax was dried in an oven at a temperature of 100°C for 24 hours to remove water. The PE -wax with 0.4 wt.% BP content was pre-held at a temperature of 90°C for 4 hours. Next, the wax/BP blend melting was performed in a resistance furnace Nabertherm type N150 (Germany). The ingredients were blended mechanically at the temperature of 90°C for 10 min using a laboratory mixer with a rotational speed of approx. 200 rpm. In the following stage, patterns in a divisible form made of silicone rubber of the Gumosil AD type, produced by Silikony Polskie, Poland, were prepared. Patterns were injected at a temperature, of approx. 74°C, with an injection pressure of about 30 kPa using an Olimpia WW-25 wax injection moulding machine (Olimpia, Poland). The PE-wax/0.4 wt.% BP patterns were joined by melting with the main inlet into a pattern set. Figure 1 shows the wax patterns assembled on a "tree." The experimental molds were made of plaster mass Plasticast investment produced by Ransom & Randolph (USA).

Table 1.
Process parameters of polyethylene wax/bentonite composites

Parameters	Pure wax	Composite
Injection temperature, °C	73	74
Wax temperature, °C	72	75
Injection pressure, bar	0.3	0.3
Holding time, s	30	32

Fig 1. Wax system: patterns assembled on a "tree"

2.2. Preparation of the Aluminium Cast

The castings were made in the centrifugal casting process. There were ten castings in the mold. The castings has dimensions 31 mm x 20.5 mm x 1.6-2.5 mm. The moulds were made of a Plasticast investment plaster mass that keeps its dimensions during the mould annealing process. The course of the temperature program applied during the annealing of the moulds is presented in Figure 2. After the annealing process, the gypsum moulds were removed from the furnace and placed on the centrifugal casting machine. The moulds were poured with AlSi7 alloy at 750°C. When the solidification process of the castings was completed, the plaster mixture was thoroughly rinsed and the castings, after removing the gating systems, were subjected to the microscopic analysis. Detailed information related to the casting technology can be found in the authors' work [14].

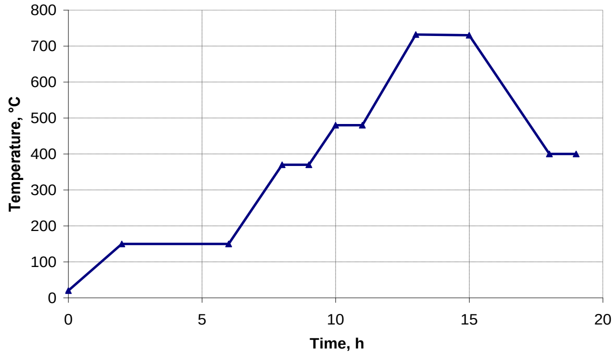

Fig 2. The heat treatment (annealing) of the plaster mould

3. Characterization Methods

3.1. Digital microscope

The surface structure of aluminium castings made by the lost-wax method was analysed using the modern digital microscope type VHX-7000 manufactured by KEYENCE. A digital microscope is an efficient tool for examining and analysing various types of objects, especially casting surfaces.

4. Results and Discussion

The analysis of images obtained with the use of the digital microscope enabled the identification of bentonite particles on the surface and fracture of the castings (Figures 3 and 4), which was characterized, according to [1,22] as a defect from the group of raw surface defects - contamination (Fig. 4). Bentonite is irregular, forming clusters of varied sizes that fill the pores in the structure of a metal casting. These are places filled completely (Fig.3b) or partially (Fig.4) with bentonite remaining from the composition based on polyethylene wax.

The cause of these impurities is the penetration into the metal filling the mold, the remnants of the composite polymer patterns material, most likely caused by the shape of the mold cavity which prevented the complete smelting of the pattern. It may also be the result of pattern burn and the penetration of bentonite from this pattern to the surface of the mould and then to casting structure or technological imperfections of the pattern performance, i.e. improper bentonite dispersion in the polyethylene matrix, favoring the formation of bentonite agglomerates.
A defect type involving roughness was also found, Figure 4. These are perceptible surface irregularities of various shapes, sizes, distributions and amounts on the surface of the casting. The surface roughness is caused by the non-smooth surface of the pattern or changes in the surface of the mould due to the temperature of the liquid metal. This disadvantage may also be the result of the formation of bentonite agglomerates in the polymer. In Figure 4b, an inaccurate representation of the pattern was observed, which was most likely a dent, hence this defect was qualified in the group of shape defects [1,22] as mechanical damage. Shape defects may in this case be caused by an excessively strong stream of liquid metal that is introduced into the mould.

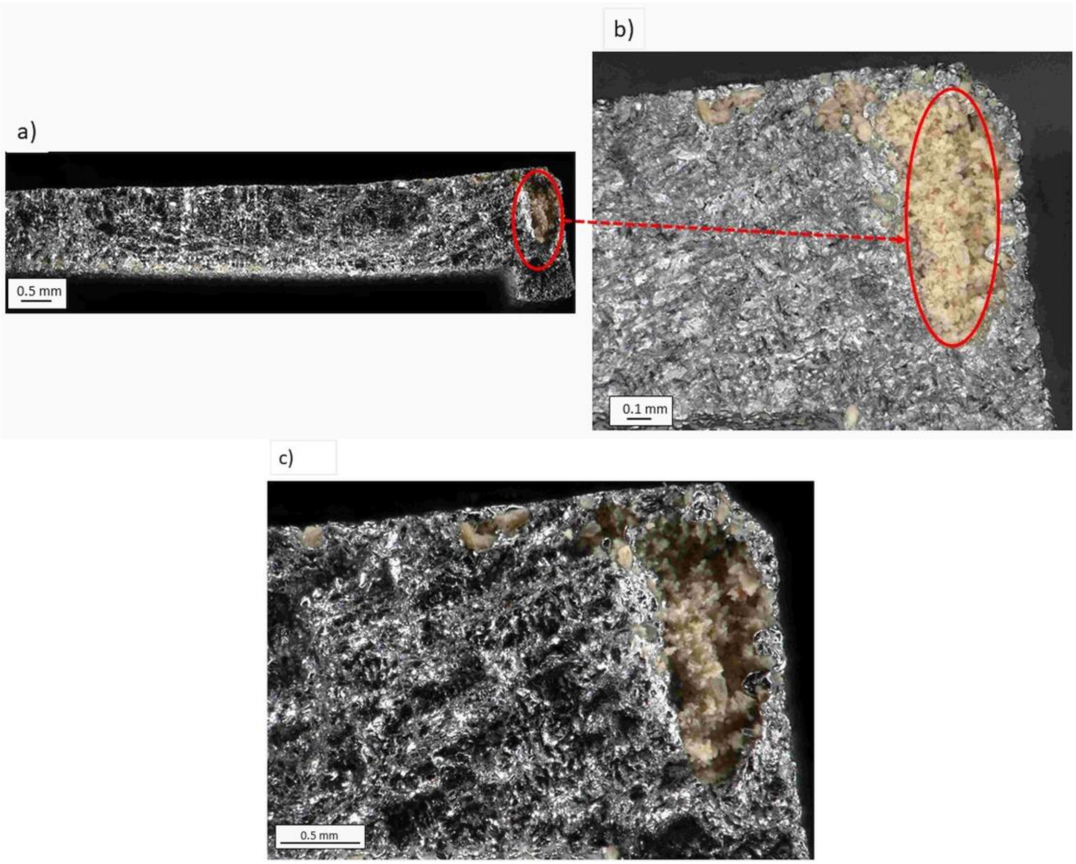

Fig. 3. Microscopic image of a fracture surface of the sample with the visible distribution of bentonite in the casting made in the lost-wax casting method: a) the entire sample, b) enlargement of the bentonite cluster, c) magnification and increased depth of field of the view b).

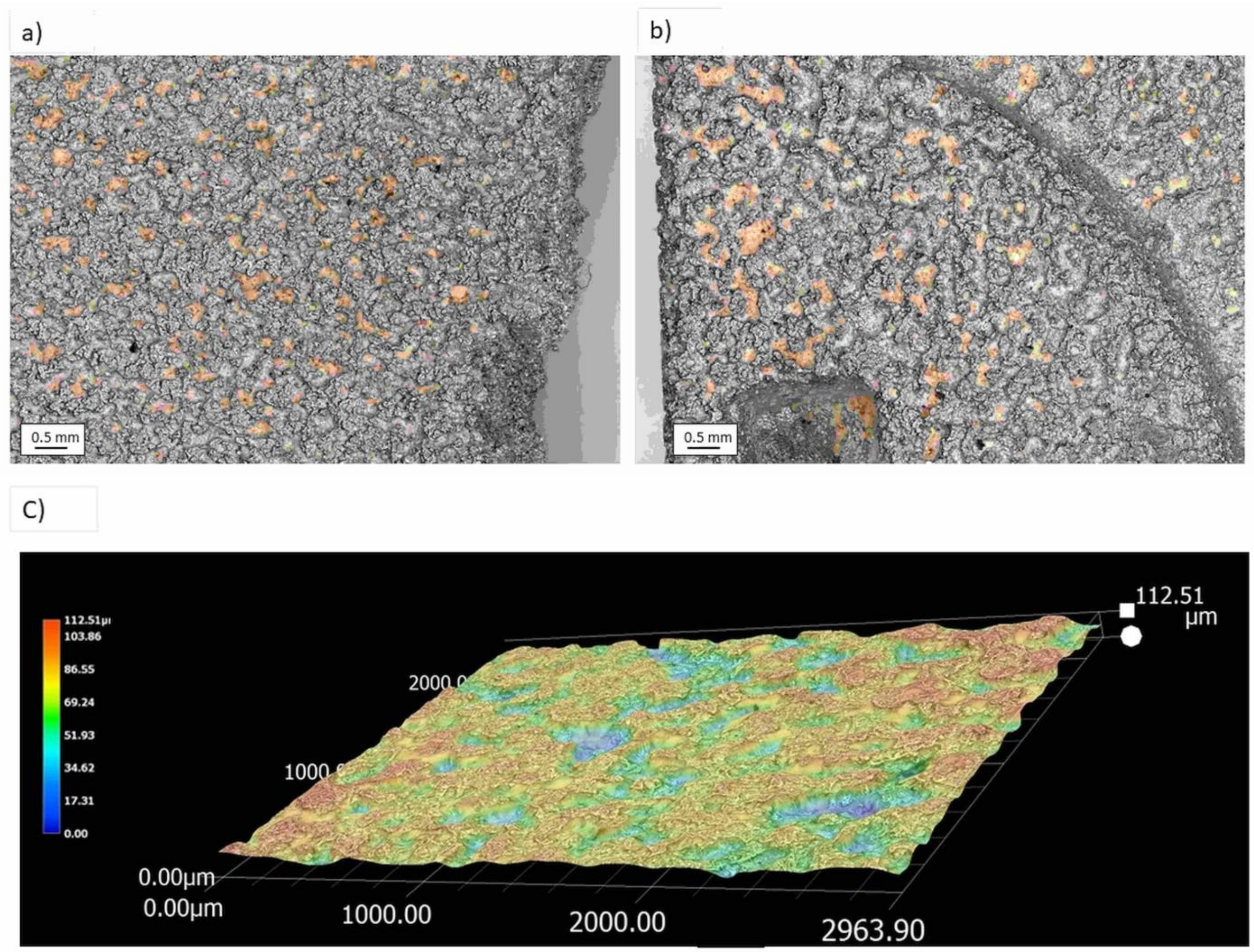

Fig. 4. Microscopic image of the types of the defects involving roughness and contamination on the casting surface: a) contamination - even distribution of bentonite (light pink colour), b) contamination (a partial distribution with visible light pink separation bentonite) and shape defects - mechanical damage, c) topography of the sample surface with visible blue separation bentonite-defects type involving roughness

5. Conclusions

The application of a digital microscope is very useful from the point of view of assessing the quality of the tested castings. It enables to realistically assess the actual surface structure of these materials.

It was also found that visible groups of bentonite particles are located in the inner layer of the casting – Figure 3. Structural changes include the actual surface of the casting and the part of the material deeper from the actual surface, which shows changed chemical and physical properties in relation to the properties of the silumin material. This defect was classified as an impurity. The surface of the casting was characterized by considerable roughness, as shown in Figure 4c.

During the tests, shape defects related to mechanical damage were also detected - Figure 4b. The colour changes observed in Figures 3-4 indicate the separation of bentonite from the produced composite in the form of polyethylene wax with the addition of ceramics during the shaping of the casting. However, the observed phenomenon requires confirmation by other studies, e.g. chemical composition analysis, which will be presented in further works by the authors.

The microscopic analysis is the first step in assessing the quality of tested castings, which were produced by applying a new polymer-ceramic material for the patterns.

Under a certain magnification, the formation of the following defects was noticed:

- uneven distribution of bentonite particles in the polyethylene matrix of the patterns,
- formation of bentonite agglomerates in polyethylene,
- stream of metal filling the mould being too strong,
- improper metal temperature resulting in a non-smooth surface of the castings or changes to the surface of the castings.

Therefore, further work by the authors should focus on a more detailed examination and description of the process parameters (e.g. metal temperature, pouring rate) of the new material used for the patterns, in the lost-wax method. This will allow the elimination of e.g. shape defects of the produced castings. The diligence of the patterns itself is also important, as the authors should place greater emphasis on bentonite dispersion in the restoration of polyethylene, which will eliminate such disadvantages as roughness and impurities.

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