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Expanded Polystyrene (EPS) Pattern Application in Investment Casting and Chemical Removing

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Abstract

In this study, expanded polystyrene (EPS) was used as a pattern material in investment casting and removed chemically by acetone. It is shown that EPS is an alternative pattern material to the wax material which is used in the conventional investment moulding. EPS pattern usage and chemical removing change basically the investment moulding process. The ceramic shell moulds with wax and EPS patterns were produced at the same dimensions and with the same techniques. Unmodified A 413 Al-Si alloy was cast into these moulds. XRD and SEM characterizations were performed on the mould internal surfaces, and image, EDS and surface roughness analysis were carried out on the cast parts for comparison. The effects of chemical removing of patterns on the structure of mould internal surfaces were investigated.
Keywords: Investment casting, EPS, Wax

ZASTOSOWANIE MODELU Z POLISTYRENU EKSPANDOWANEGO W ODLEWANIU METODĄ TRACONEGO WOSKU I CHEMICZNYM USUWANIU

W tych badaniach ekspandowany polistyren (EPS) został wykorzystany jako materiał modelu do odlewania metodą traconego wosku i usunięty chemicznie za pomocą acetonu. Pokazuje się, że EPS jest alternatywnym materiałem w stosunku do wosku, który jest tradycyjnym materiałem formy do odlewania metodą traconego wosku. Użycie modelu z EPS i jego chemiczne usuwanie zmieniają zasadniczo proces odlewania. Wykorzystując model woskowy lub EPS wytworzono formy o czerepie ceramicznym o tych samych wymiarach i za pomocą tej samej techniki. Niemodyfikowany stop A 413 Al-Si odlewano w tych formach. Wykonano charakterystyki XRD i SEM wewnętrznych powierzchni formy; analizy obrazu, EDS i chropowatości powierzchni przeprowadzono dla porównania na odlewach. Zbadani wpływ chemicznego usuwania modeli na budowę wewnętrznych powierzchni formy.
Słowa kluczowe: odlewania metodą traconego wosku, EPS, wosk

1. Introduction

Investment (lost wax) casting is a widely used casting technique in which a pattern is usually made of wax [1]. In investment casting, a ceramic slurry is applied around a disposable pattern (wax and some kinds of plastics) and allowed to harden to form a disposable casting mould [2]. Investment casting is used in the automotive, aerospace and biomedical industries for the production of complex metal shapes. In this process, the shape to be reproduced is formed in wax and coated in a chemically bonded ceramic investment material [3]. Investment casting allows dimensionally accurate components to be produced in high or low volumes. The production of the investment casting ceramic mould is a crucial part of the whole process and can be summarized as follows. First, multi-component slurries are prepared, which normally consist of a refractory filler and a binder system. A pattern wax is dipped into the face coat slurry, sprinkled with a coarse grained refractory stucco and dried. The first or 'primary' coat applied to the wax will ultimately be in contact with the molten alloy, and its composition therefore often differs from that of secondary or 'backup' coats. The wax pattern is removed, normally by high pressure steam autoclave, leaving a hollow mould. Moulds are fired and cast with molten metal. After cooling, the ceramic is removed by mechanical or chemical methods [4]. The waxes used in investment casting are blends of waxes, polymers and resins [5]. Dimensional accuracy is essential for successful casting. The casting discrepancy (the lack of fit) has usually been viewed as some effects and one of these effects is thermal expansion of wax pattern [6]. The investment casting process involves the making of a disposable wax pattern by injecting the wax into a metal mould. After their injection, wax patterns shrink in the dies due to thermal contraction during solidification and/or crystallization phenomena and subsequent cooling at the end of the dwell time [7].

The de-waxing process is probably one of the most complex stages of the investment casting process, where matters such as steam, investment shell, wax, and different phase changes have to be taken into account in order to obtain accurate results. Moreover, the shell is a complex composite material, which does not have a well known behaviour, and the presence of steam and water has a strong influence on the shell thermal properties [5].

Expanded poly-styrene (EPS) is the most common and low cost polymer used in commercial practice [8]. The term ‘expanded polystyrene’ refers to a closed cell, lightweight, rigid plastic foam. It is usually produced by a process known as steam moulding. The expandable polystyrene beads are loaded into a pre-expander and steam is introduced to heat and soften the polymer and expand the entrapped gaseous blowing agent [9]. Expanded polystyrene (EPS) is a kind of stable foam of non-absorbent, hydrophobic, closed cell nature with low density, consisting of discrete air voids in a polymer matrix [10, 11].

In the conventional investment casting process, the pattern material wax is removed in furnaces or autoclaves while EPS pattern is removed chemically in a short time. EPS patterns can eliminate the disadvantages of wax patterns as mentioned above. In this study, EPS was used as an alternative pattern material and the effects of its chemical removing on the mould and cast parts were investigated.

2. Experimental

EPS (PETKIM, Turkey) and wax (Freeman 6549-D Filigree Pink, Jewellery Wax, United Kingdom) cube patterns were produced with the dimensions of 25 x 25 x 25 mm. Fused silica powder (mean particle size: 74 μm) and colloidal silica were used as the slurry and zircon powder (mean particle size: 74 μm), 55 AFS silica sand (240 μm), 35 AFS silica sand (390 μm) were used as the stucco. Acetone (Merck 100014) was used as a chemical removing agent. Acetone and isopropyl alcohol solution were used as cleaning agents for wax patterns. Fig. 1 shows the flow chart of the whole process.

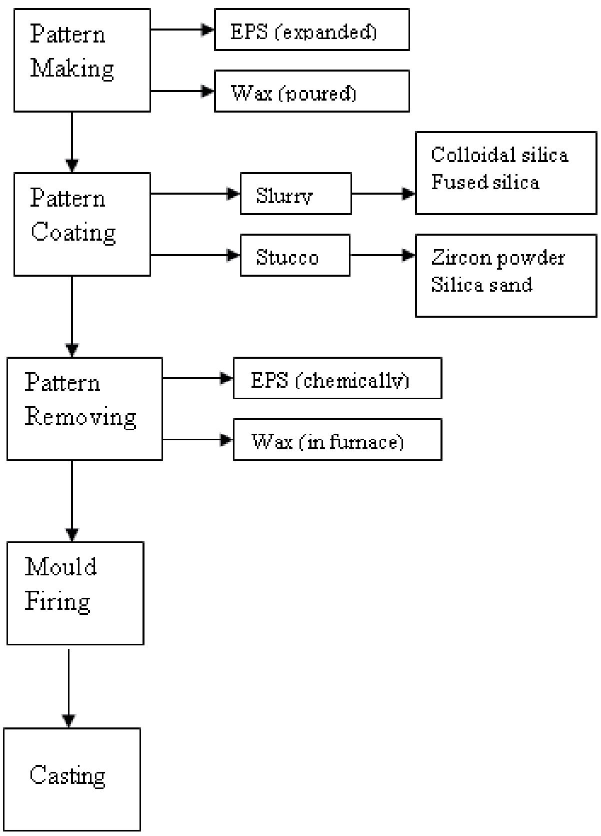


Fig. 1. Flow chart of the experimental process.

15 g wax was poured into the metal mould at 100°C. Wax patterns were immersed into the solution of 50 % acetone and 50 % isopropyl alcohol for cleaning. Expandable polystyrene beads were pre-expanded at 100°C for 50 seconds in pre-expansion machine. 1.80 g pre-expanded polystyrene was put in the metal mould and heated under 1 bar pressure for 100 seconds in the steam machine. The same moulding procedure was applied during the preparation of the moulds. 100 g fused silica as a refractory filler and 50 ml colloidal silica as a binder were stirred. The wax pattern and EPS pattern were dipped into the slurry and sprinkled with refractory stuccos and dried. The stuccos were coated twice and every coat was dried for a minimum of 2 hours. De-waxing of wax patterns was made in the furnace at 110°C for 30 minutes. For chemical removing of EPS, 3 ml acetone was dripped with a pipette over patterns and EPS patterns dissolved rapidly in 20 seconds. Some residues of EPS patterns remained and stuck inside of the moulds. These residues were removed during the firing period as wax ashes. All moulds were fired with the constant heating regime in a resistance furnace. Fig. 2. shows the graph of mould firing regime.

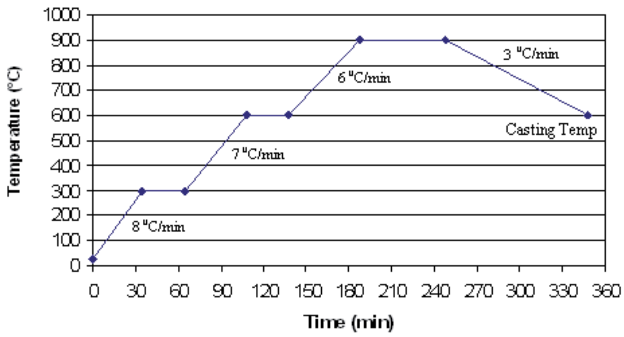


Fig. 2. Mould firing regime.

A413 Al-Si alloy (Si (11.5-13.5 wt%), Fe (0.60 wt%), Cu (0.10 wt%), Mn (0.40 wt%), Mg (0.10 wt%), Zn (0.10 wt%), Ni (0.10 wt%), Ti (0.15 wt%)) was melt at 750°C in the induction furnace in the silicon carbide crucible and cast into moulds without modification. After a short time, casting products were removed from the moulds.

The densities of patterns were measured with their weight and volume. Crystalline phases of ceramic shell moulds were identified by X-ray diffraction (XRD; Philips X Pertpro Panalytical). The microstructures of the moulds and EDS analysis of cast parts were characterized by scanning electron microscopy (SEM- JEOL JSM-5410 LV). R_a and R_z values of surface roughness of the cast parts were measured with surface tester device (Mitutoyo Surftester 211). Selected cast specimens were mechanically polished through successively finer grit of silicon carbide papers (down to grit size 1000) and diamond polishing suspension (particle size down to 1 μm). Polished specimens were etched with Keller’s reagent. Metallographic observations of cast specimens were made with Image analyser (Leica ICM 1000) The porosity, P, of cast specimens was evaluated by using density measurements in distilled water (Archimedes’ method) and calculated using the following equation:

$$P = \frac{D_t - D_a}{D_t} \cdot 100 \quad (1)$$

where D_a is the actual density of the specimen and D_t is the theoretical density of the alloy, taken as 2.66 g·cm^{-3} for A413 alloy.

3. Results and discussion

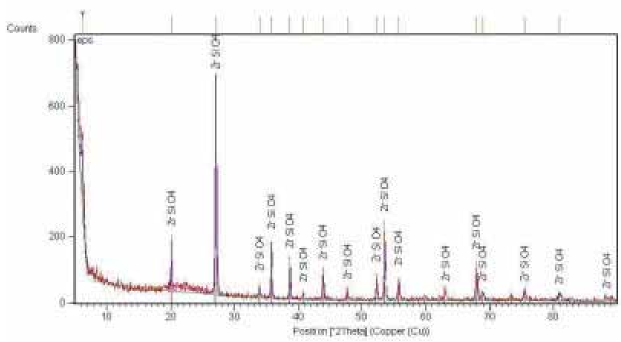
Fig. 3 shows the photo images of EPS-Wax patterns, ceramic shell moulds and cast parts. Densities of EPS and wax patterns were measured to be 0.11 g·cm^{-3} and 0.95 g·cm^{-3}, respectively. The large difference between wax and EPS densities show that the amount of EPS is smaller than the amount of wax in the pattern production at the same dimensions. Density measurements of patterns show that EPS patterns are about 8.6 times lighter than wax patterns and according to industrial prices wax patterns are much more expensive than raw EPS.

Fig. 3. EPS-Wax patterns, ceramic shell moulds and cast parts.

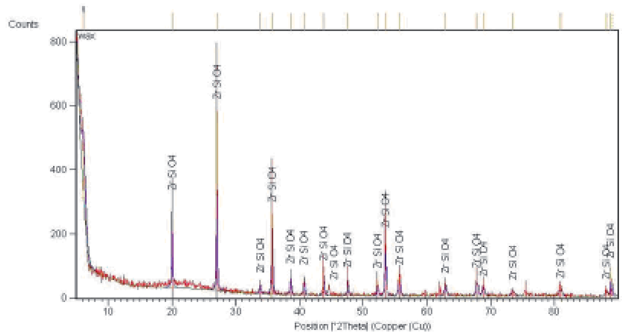
Fig. 4 shows XRD patterns of the moulds internal surfaces prepared with EPS and wax patterns. XRD patterns indicate that zircon ($ZrSiO_4$) was formed in both of the moulds internal surfaces prepared with EPS and wax patterns.

Fig. 5 shows SEM images of the interior surface of the moulds of EPS and wax patterns. $ZrSiO_4$ crystals were to be distributed within the structure in both images as shown in Fig. 5.

Appearance and size of the $ZrSiO_4$ crystals were approximately the same in both images. Chemical removing had no hazardous effect on the internal surface and did not change the structure of the moulds. Overall it is shown that heat and steam pressure are not necessary for the chemical removing of the EPS pattern. Chemical removing of EPS takes 5 seconds, while removing of wax pattern takes 30 minutes. Also chemical removing of EPS reduces gas emission during the mould firing period. Therefore we can save energy and time with using EPS pattern and the chemical removing process. De-waxing is the most important part of the ceramic shell mould making process, the most shell cracks happen on this step of the process. Many vital sensitive process



a)



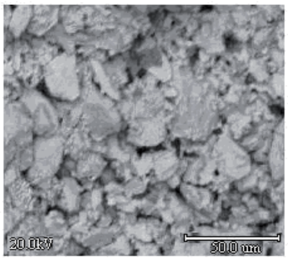
b)

Fig. 4. XRD patterns of the moulds' interior surfaces with: a) EPS and b) wax pattern.

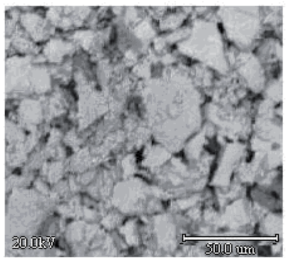
parameters, such as temperature and steam pressure, are effective in de-waxing, in the case of any improper setting moulds can be cracked easily. The chemical removing avoids this kind of mould preparation failures.

The densities of the cast specimens whose patterns were EPS and wax 2.633 g·cm^{-3} and 2.628 g·cm^{-3} and according to equation 1 porosities were calculated 2.7 % and 3.2 %, respectively. These porosity percentages are relatively high, insufficient feeding of small single part moulds without a runner and feeding system is the reason of this. On the other hand, these values must be compared to each other and they are close. Fig. 6. shows micrographs of both cast parts which are the examples of a typical hypoeutectic aluminium-silicone alloy microstructure. Unmodified flaklike silicone crystal morphology forms the dark zones of the micrographs, light zones are α-aluminium. Length of the silicone flakes and grain sizes are apparently the same in both micro structures.

Especially the edge regions of the specimens were observed with a microscope and there was not any obvious contamination noticed. Moreover, EDX analyses were carried out in the edge regions to investigate contaminants which



a)



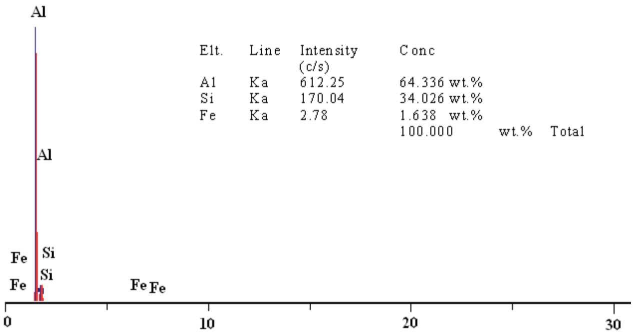
b)

Fig. 5. SEM micrographs of the interior surface of the moulds: a) with EPS and b) with wax pattern.

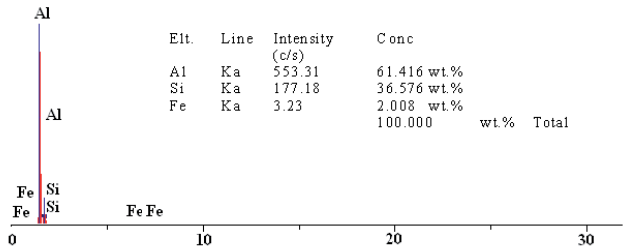
a) b)

Fig. 6. Micrographs of cast parts: a) with EPS and b) with wax pattern.

could be taken from mould materials.



a)



b)

Fig. 7. EDX analysis of cast parts: a) with EPS and b) with wax pattern.

EDX patterns are shown in Fig. 7 and according to these patterns EDX probe of the scanning electron microscope could not recognize any element that almost belongs to mould materials. This is other evidence that chemical removing of EPS does not effect the moulds and cause contamination.

Table 1. Surface roughness values of the cast parts.

Specimen/Face	R_a [µm]	R_z [µm]
EPS 1. Face	1.86	10.1
EPS 2. Face	1.31	13.5
EPS 3. Face	0.65	7.6
EPS 4. Face	1.51	8.5
WAX 1. Face	2.25	18.8
WAX 2. Face	2.00	10.4
WAX 3. Face	1.25	19.5
WAX 4. Face	1.45	12.0

Table 1 shows the surface roughness values R_a and R_z of cast parts. Roughness measurement was carried out on the four surfaces of cubic specimens.

Consequently, all analyses and observations for characterization support the view that investment moulds and cast parts which were produced with EPS and wax patterns have similar specialities. EPS pattern using and its chemical removing have large differences in the investment casting process. However, it is clear that these differences do not change physical, chemical and micro structural properties of final products.

4. Conclusions

In this work, EPS was used as a alternative pattern material for investment moulding. The ceramic investment shell moulds with wax and EPS patterns were produced in the same dimensions and with the same process steps, A 413 Al-Si alloy was cast into these mould. The basic difference between using wax and EPS patterns was the pattern removing method. Although wax patterns were removed in the furnace, EPS patterns were removed chemically by acetone in a short time. XRD and SEM analyses were performed on the moulds internal surfaces for investigating the effects of chemical removing of patterns on the structure. The comparison of XRD patterns and SEM images indicate that chemical removing did not change the structure of moulds internal surfaces. Metallographic observations and EDX analysis were carried out on the cast specimens and the results verify that applied process differences in the experimental procedure did not effect the final products. Although using EPS pattern is not a new technique for investment casting, chemical removing of EPS is a novel approach. EPS is a promising and economical pattern material and the most important benefits are low pattern material consumption, time and energy saving in the process. Beside of these advantages, developing and EPS patterns can eliminate the insufficiency of conventional wax patterns.

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