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INFLUENCE OF WAXES REMELTING USED IN INVESTMENT CASTING ON THEIR THERMAL PROPERTIES AND LINEAR SHRINKAGE

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This paper presents the results of thermal properties and linear shrinkage of jewelry waxes utilized in investment casting. Three types of jewelry waxes were cyclically processed (by heating, holding in a molten state and cooling) in the temperature range between 25 and 90 °C for about 7 hours. The samples were tested after 5th, 10th and 15th cycle. The remelting was designed to simulate the process of waxes reusability for production of patterns. Changes in thermal properties of waxes were determined using differential scanning calorimetry (DSC) and linear shrinkage values were specified. The conducted examinations allowed to establish the way of multiple utilization of waxes in producing precise models.

Key words: investment casting, thermal properties, waxes, linear shrinkage, DSC

INTRODUCTION

In the course of production, starting from processing of raw materials to obtaining finished goods, waste is generated [1].

Metallurgical industry is one of the biggest source of waste such as: slime, dust, used molding and core sand, foundry slag, rubble from the lining of furnaces and worn-out materials used for production of wax models [2-4]. Benefits resulting from waste reuse provoke foundries to analyze generated waste from the recycling point of view [1].

Recycling allows companies to use waste (recyclables) in the same or similar production process, as well as in industry for which waste becomes raw material [5]. During manufacturing precision castings using disposable models (lost-wax casting) waste, among others, is wax blends. Thermal properties and linear shrinkage determine the possibility of wax blends usage in the production of models.

Specifying the linear shrinkage values of wax blends is crucial while constructing instrumentation wherein a wax model would be produced [6, 7]. The condition for wax blends reuse to produce precise models is a stable value of linear shrinkage.

To evaluate thermal properties of waxes or their blends with plastics, differential scanning calorimetry (DSC) is used. Krupa and Luyt applied this method to determine heat enthalpy and phase transitions temperatures including melting and solidification temperatures of wax and their blends with cross-linked and uncross-linked low-density polyethylene (LLDPE) [8, 9].

The influence of multiple remelting of wax blends on thermal properties and linear shrinkage was analyzed in order to verify the possibility of their reuse in the production of precise models.

EXPERIMENTAL CONDITION

The jewelry wax blends which are presented below are used in lost-wax casting. However, their chemical compositions are unknown:

– Castaldo Red (Red wax),
– Flexible Blue Flakes (Blue wax),
– Castaldo Aqua (Aqua wax).

The remelting cycle was carried out in a resistance furnace N 150/WAX manufactured by the Nabertherm.

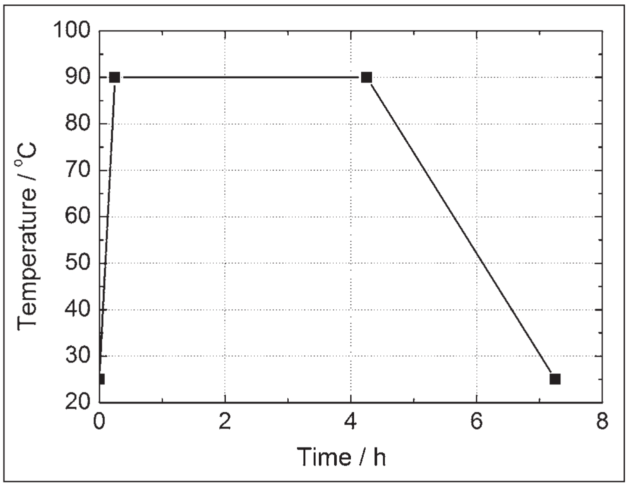

Figure 1 Course of a single cycle of wax blends melting

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The remelting temperature ranged between 25 ºC and 90 ºC while duration of a single cycle was 7,25 hours (Figure 1).

The wax blends were held at 90 ºC for 4 hours. Heating and cooling processes aimed at recreating the conditions present while forming a model (wax melting, wax retaining until matrix repletion, making a model and its cooling down to ambient temperature). In this study, 15 melting cycles of wax blends were conducted.

The samples were prepared after the 1st, 5th, 10th and 15th melting cycle from three types of wax blends in order to study the linear shrinkage. The waxes were gravitationally casted at 90 ºC into metal molds with a diameter of 100 mm and high of 22 mm. After filling the molds, each samples and molds diameter was measured. The time between filling the molds and measurements of samples diameters was about 6 hours.

The linear shrinkage (S_L) was calculated from the following formula (1):

$$S_L = \frac{D_M - D_S}{D_M} 100\% \qquad (1)$$

gdzie:

D_M – inner diameter of a mold, mm;

D_S – outer diameter of a sample, mm.

Samples for DSC measurements were collected from virgin wax blends and after the 5th, 10th and 15th melting cycle.

DSC was performed with a Netzsch DSC 204 F1 Phoenix®. The temperature scale of DSC was calibrated with indium. The instrument was computer controlled and calculations were done using Netzsch Proteus® Software. DSC analysis in accordance with ISO 11357 provides the following information for quality control of wax blends.

Samples of 5 mg were sealed in closed aluminum pans and heated from 20 to 90 ℃ at a heating rate of 20 ℃ min^{-1}, and cooled at the same rate under nitrogen atmosphere (flow rate 20 ml/min).

RESULTS AND DISCUSSION

Figure 2 presents a comparison of linear shrinkage values for wax blends after the 1st, 5th, 10th and 15th melting cycle.

A comparison of linear shrinkage values of the tested samples revealed that Aqua wax after the 15th melting showed the highest value of 3,66 %. The smallest one was noted for Red wax after the 1st melting (1,59 %). The linear shrinkage for Aqua and Blue waxes increased together with the increasing number of melting cycles. A constant increase in linear shrinkage with a rising number of melting cycles is a disadvantage due to inaccuracy in mapping of models performed in dies at ambient temperature.

The analysis revealed that the Red wax blend changed its shrinkage properties more than other blends. Although, the S_L for virgin Red wax was the smallest at the beginning, its value increased drastically by 1,21 %

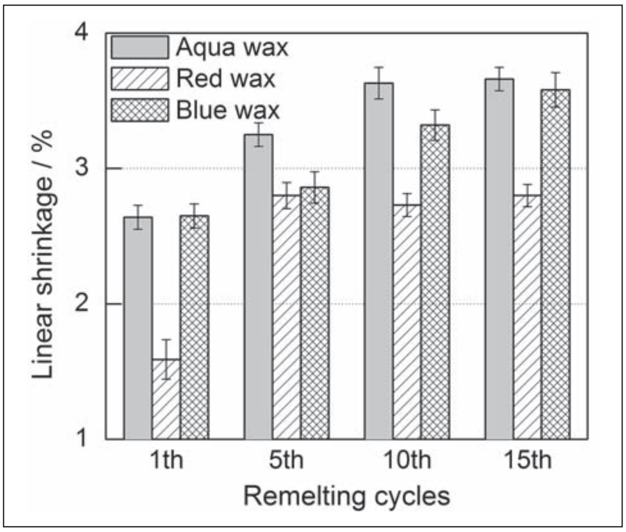

Figure 2 Linear shrinkage for wax blends after 1st, 5th, 10th and 15th melting cycle

in comparison to the 1st melting. However, its advantage was that the linear shrinkage values became constant after the 5th melting cycle.

The S_L of Aqua and Blue waxes raised, in relation to the 1st melting, with an increasing number of cycles. Stability of linear shrinkage for Aqua wax was achieved after the 10th melting cycle, while the Blue one did not achieve such stability throughout the whole range of tests (revealed a constant increase).

Table 1 summarized the DSC results obtained from exothermic curves from the second cooling.

Table 1 **Solidification temperatures obtained from DSC measurements for samples**

Remelting cycles	Aqua wax	Red wax	Blue wax
	T_s / °C	T_s / °C	T_s / °C
virgin	50,0	50,5	49,5
5 x	50,8	50,6	49,0
10 x	50,6	50,6	50,1
15 x	49,7	51,9	49,0

An influence of subsequent remelting cycles on solidification temperatures of waxes (T_s) were determined on the basis of the results summarized in Table 1. It was assumed that the highest solidification temperature (about 52 ˚C) was noted for Red wax after the 1st melting. The lowest T_s of 49 ˚C was noted for Blue wax after the 15th melting cycle. It was found that the differences in solidification temperatures between all virgin wax blends are insignificant, same as in case of the changes in melting temperatures. The increasing number of melting cycles caused a rise in waxes solidification temperatures by about 2 ˚C, only in case of Red wax. The above was as a result of a successive melting of the material which led to an introduction of impurities acting as growth centers for crystallization. In case of the remaining waxes, their solidification temperatures were similar to the ones of virgin waxes.

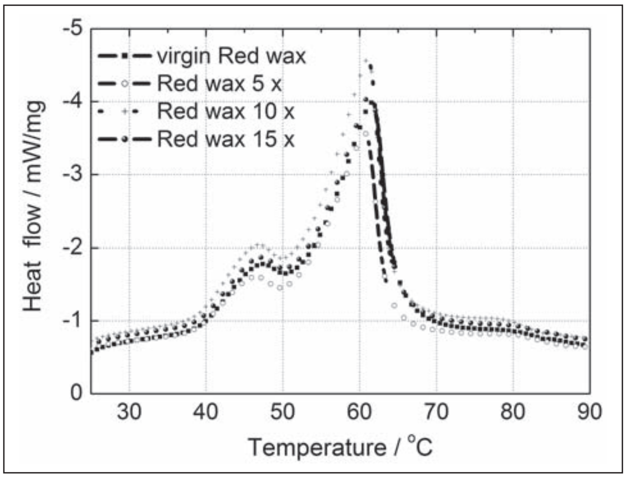

Figure 3 DSC heating curves of a virgin Red wax and after 5th, 10th and 15th cycle

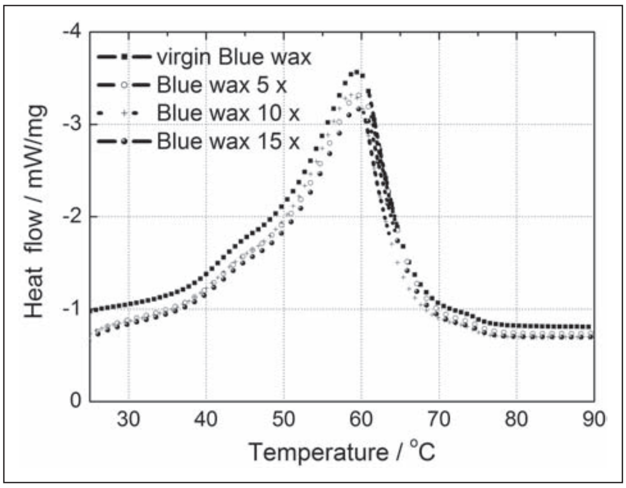

Figure 4 DSC heating curves of a virgin Blue wax and after 5th, 10th and 15th cycle

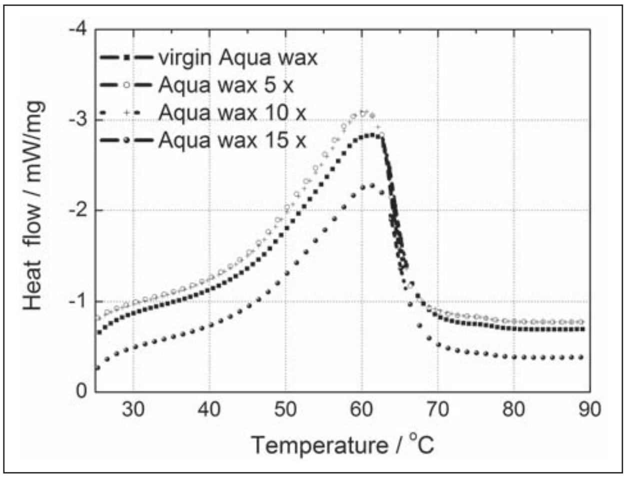

Figure 5 DSC heating curves of a virgin Aqua wax and after 5th, 10th and 15th cycle

The DSC second heating curves of virgin waxes and after processing are presented in Figures 3-5.

Value of end endothermic peaks of the curves determined the melting temperatures for each wax blend.

On the basis of the curves presented in Figures 3-5, it was assumed that the highest melting temperature (about 62 ˚C) was for the virgin Red wax blend. While, the smallest one (about 58 ˚C) of all tested samples occurred for Blue wax after the 10th melting cycle. Comparing the changes in melting temperatures for all three blends, i.e. Red, Blue and Aqua, distinct differences were noted. For Red wax, an additional melting peak at about 46 ˚C was observed and assigned to one of the blend's components.

CONCLUSIONS

The study of wax blends revealed that a process of their multiple melting, up to 15 melting cycles, significantly affected the values of the linear shrinkage. An increase in the value after the 15th melting cycle, in comparison to the 1st melting, ranged from 35 %, for the Blue wax, to 76 %, for the Red wax. The outcomes of the repeated melting of wax blends allowed to state that Red wax achieved stability in linear shrinkage value (at approximately 2,8 %) after the 5th cycle. While, the Aqua wax blend achieved stability at approximately 3,6 % after the 10th cycle. Throughout the whole research, the linear shrinkage value of the Blue wax blend did not stabilize.

On the basis of the DSC analysis, it was assumed that subsequent remelting processes (5, 10, 15 times) did not significantly affect the melting temperatures of wax blends. It indicated that the samples did not change their structures, hence the wax blends may be repeatedly used for performing cast models. However, in case of the Red wax blend, certain changes in melting kinetics were observed and will be a topic of further research.

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Note: M. Mizera is responsible for English language, Poznan, Poland