ARCHIVES
of
FOUNDRY ENGINEERING

DOI: 10.2478/v10266-012-0096-8

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

VERSITA

ISSN (2299-2944)
Volume 12
Issue 3/2012

133 – 138

Investigations of Properties of Wax Mixtures Used in the Investment Casting Technology – New Investigation Methods

J. Zych [a]*, J. Kolczyk [a], T. Snopkiewicz [a]
[a] AGH University of Science and Technology, Faculty of Foundry Engineering, Reymonta 23, 30-059 Cracow, Poland
*Corresponding author: e-mail: jzych@agh.edu.pl

Received 16.04.2012; accepted in revised form 02.07.2012

Abstract

The results of testing of the selected group of wax mixtures used in the investment casting technology, are presented in the paper. The measurements of the kinetics of the mixtures shrinkage and changes of viscous-plastic properties as a temperature function were performed. The temperature influence on bending strength of wax mixtures was determined.

Key words: Investment casting technology, Linear shrinkage, Strength, elasticity

1. Introduction

Producing ceramic moulds for investment casting by means of the investment casting method consists in cycling immersing of a wax model in a liquid moulding sand, powdering it with coarse grained ceramic materials and removing wax by melting in the autoclave and drying the obtained layers. A successive stage constitutes the annealing of the layered ceramic mould up to the moment of achieving the proper thickness and mechanical strength in the temperature range from 400-1200^{o}C.

The final stage is the process of pouring liquid metal into the finished mould and cleaning the formed casting [1-5]. There is a large variety of model sands used in industry for this technology. Substances, which are its ingredients can be divided into three main groups: waxes, fatty acids, wax substances. Waxes are esters of higher fatty acids monocarboxylic and higher monohydric alcohols of even numbers of carbon atoms from C16 to C36. Model mixtures are not homogeneous. These are mixtures of various chemical compositions but of one common feature – they consist of linearly placed particles containing from 20 to 70 CH groups. The chain of these particles can also have branches. Taking into account the origin of wax components in model mixtures, these particles contain very often ketone, oxide, alcoholic substances together with esters of higher fatty acids [6, 7].

Very important property is a mixture shrinkage, which occurs during the wax passing from a liquid state into the solid, which was indicated. among others, by Rosenthal (1979) and Okhuysen (1998) [8, 9]. The determination of the shrinkage value is very important for dimensioning and instrumentation of the model [10]. This is one of the control parameters, which decides on the shape and dimensions of wax models and decides on a suitability of the given mixture in the mould production process [6].

In this very moment none of the applied model mixtures is the universal one and therefore in each case it is selected according to the technological requirements. Masses of models are from several grams to some kilograms. Model mixtures, their features and properties are selected taking into account such technological parameters as: casting size (model), wall thickness, structure compactness, etc. For making large models the model mixtures of a low melting temperature and a small shrinkage (linear and volumetric) should be applied. This facilitates obtaining models without shrinkage type failures (shrinkage depression) and the yield of making investment patterns is at a high level. The

castability, it means the ability to filling thin-walled model parts by the model mixture is in this case not very important.

Different requirements are for mixtures used in the production of complex small models. In such cases highly fluid, which means of a low viscosity, model mixtures are used. This provides conditions for filling more complex shapes in a matrix. Since a volume of models is small, both a shrinkage and solidification time are not so important [6].

Wax mixtures at production of responsible investment castings, are in practice suitable for a single usage only. When wax is melted down from a ceramic mould it can be only used again for less important parts, e.g. for building inlet systems. It can not be reused for the preparation of model sands since there is a danger that it contains particles of strange materials or ceramic sands. This could lead to unevenness of the model surface or other surface defects and finally to rejection of products [11].

2. Assessment criteria of model moulding sands

Production of wax mixtures requires assessments of their properties since they decide on their technological suitability. Thus, the following properties should be determined:

- amount of ashes,
- specific density,
- melting temperature range,
- hardness (the most often by needle penetration),
- kinematic viscosity (dynamic),
- softening point (ring-and-ball method),
- volumetric shrinkage,
- fillers content,
- linear shrinkage,
- bending strength (bending module).

Detailed requirements concerning model sands were presented by J.I. Šklennik and V.A. Ozierow. The sand meets the basic requirements when it is characterized by the listed below properties [12].

- Sand shrinkage at solidification as well as its dilatability at heating are the smallest and stable within the given temperature range, melting temperature is in the range 60÷100˚C, while the initial softening temperature is usually lowered by 25÷35˚C and is at least by 10÷20˚C higher than the temperature in the room, in which models, model set-ups and moulds are made.
- Sand contains a minimum amount of ashes, solidification time in the matrix should be minimal, which can be achieved by applying sands of a high melting point and a narrow range of
  a solidification temperature.
- After solidification in a matrix the model sand should have hardness and strength, which prevents deformation of models in all technological operations.
- Chemical reactions of the model sand with the matrix material and binders of ceramic moulds are not allowed, the sand should not change its properties even at a few times of usage .
- Components of model sands should be rather cheap and easily available.

Model sands with thermal insulators have smaller influence on a ceramic moulds cracking. This is caused by a faster thermal energy flow through successive wax layers, a fast wax melting from the model set-up and a smaller viscosity at a melting temperature.

3. Investigations of technological properties of wax mixtures

3.1. Examinations of shrinkage kinetics – methodology of testing

A linear shrinkage of model sands is determined as the ratio of the difference between the matrix cavity and the model length to the matrix cavity size. It is expressed by the equation (1):

$$\alpha = \frac{l_o - l}{l} \cdot 100\% \tag{1}$$

where: α – linear shrinkage, %;
$l_0 - l$ – difference of dimensions of the matrix cavity and the model , mm;
l – model size obtained in the matrix, mm;
l_0 – matrix cavity size, mm.

There is not any uniform testing methodology for the current measurements of a linear shrinkage of materials and model mixtures. E.g. shaped elements of a square cross-section 10 x 10 mm and length 200 or 350 mm were used [13].

In the 80-th the method of measuring the linear shrinkage of model sands was developed in the Faculty of Foundry Engineering AGH (Fig. 1). It was based on measuring the linear shrinkage by means of the induction sensor of small displacements with the graphic recording (by the X-Y recorder) of the results. The shaped measuring sample was in a form of a roll of a diameter ø 15mm and length 85 mm. The sample together with the temperature measuring sensor was cooled with water of a controlled temperature. The results were obtained as real curves of the linear shrinkage kinetics as a function of a temperature [14].

Presently, also in the Faculty of Foundry Engineering AGH, (Laboratory of Foundry Moulds Technology), the new method of investigating the linear shrinkage of wax mixtures applied for investment patterns was developed. Due to a high accuracy of the new generation of displacement sensors and modern control-measuring equipment new possibilities, of performing precise measurements of the wax mixture shrinkage, appeared. The new experimental stand is shown in Figure 2.

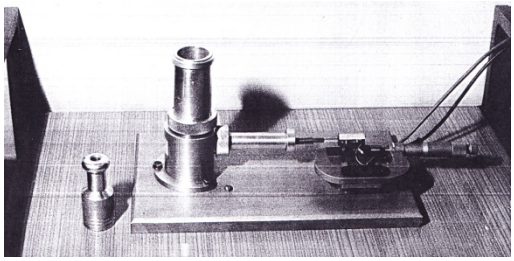

Fig. 1. View of the apparatus for testing the linear shrinkage of model sands [14]

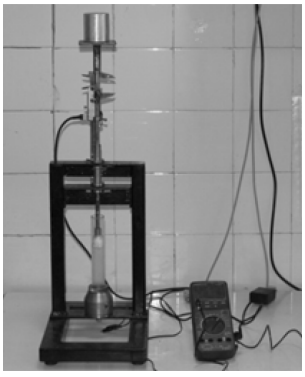

Fig.2. Experimental stand for testing the wax mixtures shrinkage

The stand consists of: 1- apparatus for measuring the linear shrinkage equipped with a probe (for wax pouring and cooling) and electronic sensor of displacement measurements, 2 – temperatures sensor, 3 – universal meter cooperating with displacement and temperature sensors, 4 - computer recording in real time the measurement results (temperature and wax shrinkage).

The measuring probe, allowing to monitor the wax shrinkage during cooling was made in two versions, shown in Figure 3a and 3b. During the measurement the probe is placed in a vertically placed stiff frame. The probe itself consists of the tube made of organic glass (plexiglass), the lower holder with a thermocouple mounted in the geometrical axis of the holder and the teflon piston closing the probe from the top. During the measurements the piston loaded with an additional weight (Fig. 2, 3) follows after the upper surface of shrinking wax. The piston displacement is controlled by means of the displacement sensor, which can be also the electronic slide caliper.

The foot with a load presses the probe piston thus pressing the model sand being inside the measuring tube. The thermocouple is also connected to control the process temperature. The digital temperature meter, in parallel with the slide caliper, gathers data and sends to the computer. When the test is finished the load is taken off and the arm with piston raised in order to remove a solidified sample from the tube. For making the next test the whole stand is prepared in the same way.

a) b)

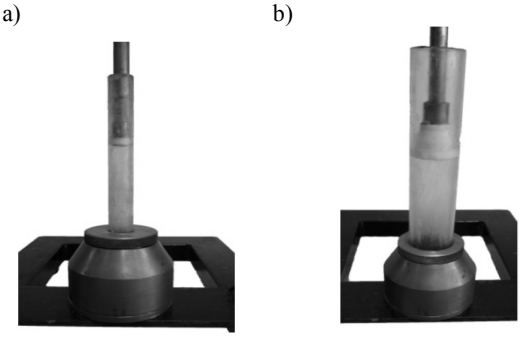

Fig. 3. Probes for investigating the kinetics of wax mixtures shrinkages: a) with smaller diameter d_1=11.5 mm; b) with larger diameter d_2=23.6 mm

3.2. Results of the kinetics of wax mixtures shrinkage

During each measurement of the shrinkage kinetics two values are recorded. They describe wax cooling and solidification process as a time function: its temperature in the sample geometrical axis and its shrinkage (going down of the upper sample surface under the teflon piston). The example of the pathway changes of the described values as a function of the sample cooling time is presented in Figure 4.

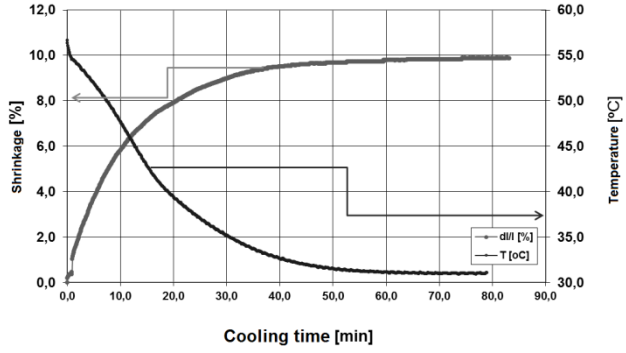

Fig. 4. Temperature changes and wax shrinkage recorded in the new experimental stand –example

The weight pressing piston causes that this piston follows the:

- movement of the upper wax surface,
- corresponding to a metal shrinkage,
- resistances to frictions on the probe side walls are overcome, shrinkages from perpendicular directions to the roll sample axis are compensated. The wax sample attains at its cross-section the size equal the inner diameter of the probe.

The effect of the performance of measurements in the whole range of wax cooling, it means from the liquid state via the liquid-solid up to the shrinkage control during cooling the solid state creates the possibility of obtaining the total shrinkage kinetics image of the given wax mixture. The recorded displacement however related to the shrinking volume in one

direction de facto is the registration of the total (three-dimensional) volumetric shrinkage of the wax mixture. Therefore the notion 'shrinkage' on the diagram axis means the volumetric shrinkage. Thus, in accordance with the rule concerning the relation between linear and volumetric shrinkage – the linear shrinkage is 3-times smaller than the one recorded at the experimental stand.

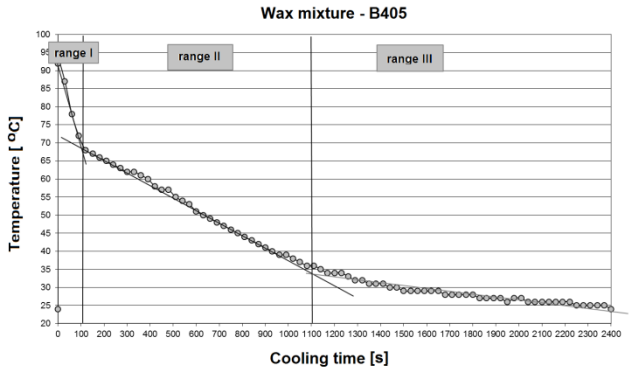

Fig. 5. Cooling process of the wax mixture B405 in the probe (d = 11.5 mm) for examinations of the shrinkage kinetics.

The pathway of temperature changes of the cooling wax mixture recorded in the probe for shrinkage investigations is presented in Figure 5. It can be noticed that in accordance with expectations it is not possible to determine the melting temperature as one value only. Whereas the total range of temperature changes, from the point of view of this changes rate, can be divided into three sub-ranges marked with vertical lines in Figure 5.

In the first sub-range the highest cooling rate is observed and this is probably the period when wax is in the liquid state in the whole volume. By comparison with metals, it can be stated that this is a period of returning overheat. In the second range, into which the solidifying wax enters without 'overcooling', and which would occur at alloys solidification, the slowing cooling rate is observed. This range, for the investigated wax, means temperatures from 67 to 35°C. Probably this is a period of rebuilding the polymer chain structure. During the third sub-range a further slowing down of the cooling rate was observed. This period comprises not only the cooling process but also the shrinkage in the solid state.

The more complex will be wax mixtures and more diversified length of polymer particles chains the longer cooling period should be expected.

Making use of the measurement data: the simultaneous recording of the wax temperature and shrinkage, it is possible to present shrinkage as a function of the wax mixture temperature. Investigations of a few industrial wax mixtures were performed and their results are shown in Figure 6. From the point of view of the volumetric shrinkage value (and after recalculation: linear) the tested mixtures can be divided into two groups: with a small shrinkage – mixtures KC4017 and A7Fr60 and with a large shrinkage – mixtures B405 and CERITA 983. There is nearly two-times difference in the shrinkage size in between these groups.

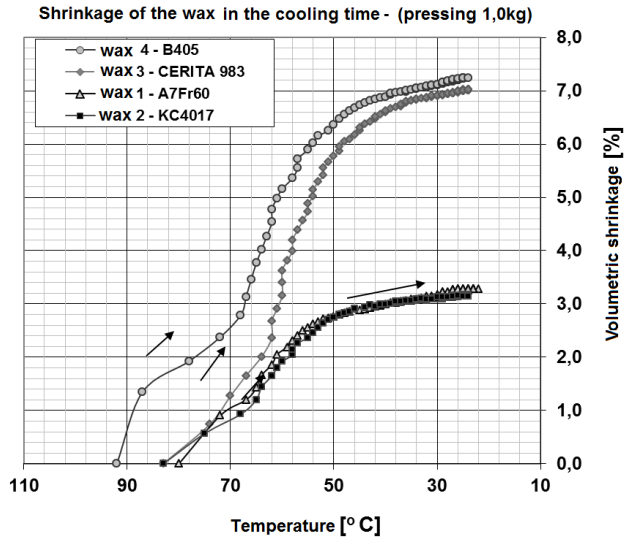

Fig. 6. Pathway of the volumetric shrinkage in the temperature range from 95 to 25°C for the selected group of wax mixtures

3.3. Temperature influence on bending strength (R_g) of wax mixtures

One of the most important technological properties of wax mixtures is their bending strength and dependence of this strength on temperature. Generally, it can be stated that practically all waxes at low temperatures (near: T = 0°C) become brittle (breakable). Also all waxes and their mixtures are becoming plastic where their temperature is slightly increased. Wax and the wax model made of it, to be technologically suitable, cannot be neither brittle nor too plastic.

In the first case the model set-ups will be subjected too easily to breaking off their parts, while in the second case the models will be deformed and making the model set ups or a deposition ceramic layers on them, can be impossible. Thus, these are reasons that the wax mixtures, before being allowed to the technological process, must have the determined strength (R_g) as a function of temperature $R_g = f(T)$.

Typical pathways of temperature influence on the strength of two, often applied, wax mixtures are shown in Figure 7. Both mixtures behave very similar, their bending strengths obtain maximum values at temperatures near 25°C. Thus, in relation to these wax mixtures, this temperature should be recognized as the technologically optimal.

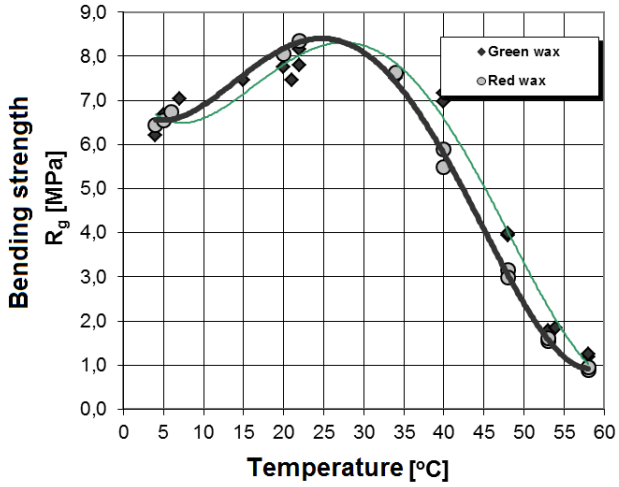

Fig. 7. Temperature influence on bending strength of the selected wax mixtures – example of a dependence: $R_g = f(T)$

4. Function of wax shrinkages (expansion) in the investment casting technology

Modern technologies of producing ceramic moulds have a tendency of applying binders with water diluents (colloidal silica). A weak side of this technology is difficulty in 'drying up' of ceramic moulds which results in a low strength in 'wet condition'. Such moulds are much easier breaking at investment casting. Therefore, specially in this technological solution an expansion of wax mixtures is important.

The test applied for estimation the tendency to breaking moulds during investment casting is shown in Figure 8. A spherical shape of the model causes that during a volume increase of heating wax the ceramic mould is subjected to uniform tensile stresses. Lines of cracks situate themselves along the weakest places of the heterogeneous, by nature, mould shell.

Not proper selection of wax mixture components causes mould cracking (Fig. 8). The sphere seen in Figure 8 was illuminated to emphasise these cracks. Cracks are caused by too high wax dilatability and insufficient mould strength (not dried up or being too thin). The defected mould is not suitable for being poured with liquid metal. The developed test is of a technological character for the comparative assessment of the cracking tendency during investment casting.

Fig. 8. Technological test of assessment of the ceramic mould cracking tendency during investment casting

5. Conclusions

On the grounds of the performed estimations of individual stages of the investment casting technology as well as applied materials, several conclusions can be drawn.

- Investment casting technology requires investigations of more properties, features and parameters than other foundry technologies.
- The developed and subjected to tests new experimental stand for investigating the shrinkage kinetics of wax mixtures allows to monitor the volume changing process (volumetric shrinkage) and dimension changes (linear shrinkage) of cooling down wax mixtures.
- Investigations of the temperature influence on bending strength at a temperature near 25°C, for the applied mixtures, indicate an occurrence of this strength maximum. Thus, at this temperature (as an ambient temperature) the main technological operations such as: preparations of models, building model set ups, ceramic moulds production, should be performed.
- The new technological test for assessing a tendency for cracking of ceramic moulds during investment casting was proposed. It could serve as a supplementing exploitation test in foundry plants.

References

[1] Zych, J. (2009). Koncepcja badań wytrzymałości powłok ceramicznych stosowanych w technologii pełnej formy i technologii wytapianych modeli. XII Międzynarodowa Konferencja Naukowo-Techniczna Odlewnictwa Metali Nieżelaznych. Nauka i technologia. Iwonicz, Polska, 117-122.

[2] Kolczyk, J. & Zych J. (2011). High temperature strength of ceramic moulds applied in the investment casting method. *Archives of Foundry Engineering.* 11(3), 121–124.

[3] Kolczyk, J. & Zych, J. (2011). Green strength of ceramic moulds applied in the investment casting metod. Materials of conference – Profuturo. Kraków, Polska, 313–318.
[4] Karwiński, A., Wieliczko, P. & Leśniewski, W. (2006). Zastosowanie środków powierzchniowo czynnych w procesach odlewania precyzyjnego. *Inżynieria Aparatura Chemiczna*. 5s, 58-60.
[5] Lechowa, L., Stachańczyk, J. & Łepniak, J. (1980). *Odlewanie precyzyjne metodą wytapianych modeli*. Instytut Odlewnictwa, Kraków.
[6] Haratym, R., Biernacki, R. & Myszka, D. (2008*). Ekologiczne wytwarzanie dokładnych odlewów w formach ceramicznych.* Warszawa: Oficjalne Wydawnictwo Politechniki Warszawskiej.
[7] Stachańczyk, J. (2008). *Własności charakteryzujące masy modelowe- proces kształtowania i jakości modeli wytapianych.* Praca Doktorska. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
[8] Sabau, A.S. (2004). Tests for determining viscoelastic properties of investment casting waxes. Investment Casting Institute , 52ND Technical Conference & Equipment Expo.
[9] Sabau, A.S. & Viswanathan, S. (2002). Prediction of wax pattern dimensions in investment casting. *Copyright American Foundry Society, Metals and Ceramics Division* 02(103), 1-14.
[10] Sabau, A.S. & Viswanathan, S. (2002). Temperature measurements in wax patterns and wax-die interfacial heat transfer coefficients in investment casting. *Copyright American Foundry Society, Metals and Ceramics Division* .
[11] Allendorf, H. (1960). *Odlewanie precyzyjne za pomocą modeli wytapianych.* Warszawa: Państwowe Wydawnictwo Techniczne.
[12] Šklennik, J.I. & Ozierow, V.A. (1971). *Lit'e po vyplavlaemym modelam. Maszinostrojenie.* Moskwa.
[13] Harabasz, M. (2011). *Badania kinetyki skurczu tworzyw stosowanych na modele w technologii wytapianych modeli*. Praca Magisterska. Akademia Górniczo- Hutnicza im. Stanisława Staszica w Krakowie, Kraków.
[14] Gadowski, B. *Badania skurczu liniowego mieszanek woskowych stosowanych na wytapiane modele.* Praca Magisterska. Akademia Górniczo- Hutnicza im. Stanisława Staszica w Krakowie, Kraków.