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Optimization of Properties of Disposable Patterns in the Application for Ceramic Molds

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Abstract

Presentation of various disposable patterns variants in order to obtain accuracy in investment casting with particular focus on hard waxes. The analysis covered disposable patterns based on hard waxes, paraffin-stearic blends with addition of polyethylene wax and high density polystyrene.

Keywords: Quality of disposable patterns, Technological properties of disposable patterns

1. Introduction

In its aspect of reliability, the quality of investment casts produced during special foundry operations involving ceramic mold (e.g. in the vacuum process or the back-pressure process) often exceeds the quality of articles produced in the plastic forming process. It especially refers to investment casts produced for aviation. In this case, patterns based on hard waxes are used, as well as ceramic molds based on silica gel with addition of latexes and polymers which are supposed to replace ethyl silicate. Furthermore, ceramic molds ought to be manufactured exclusively from the highest quality ceramic materials, aluminosilicates or even fused quartz.

The quality of the casts includes, in particular, dimensional accuracy concerning the value of dimensional uncertainty $\Delta L_{6\sigma}$, resulting from distortions taking place in following phases of the technological process. Main dimensional distortions occur during the modelling phases of: 1) disposable patterns, 2) ceramic molds or 3) casts and they depend mainly on processes connected with shrinkages in castings and processes arising between ceramic mold and a cast.

The analysis of modeling of disposable patterns will be conducted here. In this phase of the process, there occur dimensional changes which constitute about 25 – 35% of the value of the $\Delta L_{6\sigma}$. Distortions of the patterns, similarly to distortions of the ceramic mold, have a major impact on the cast quality [1].

2. Methodology of testing wax pattern materials

On the basis of the conducted research, there were some measurement results chosen for the analysis and obtained during the shrinkage evaluation of the wax patterns and during the hardness measurement with penetrate testing. The shrinkage evaluation was based on the analysis of dimensional changes occurring in the process of producing step patterns (Figure 1a) and “plate” patterns of 70 x 30 mm and 7 mm thick (Figure 1b).

a)

b)

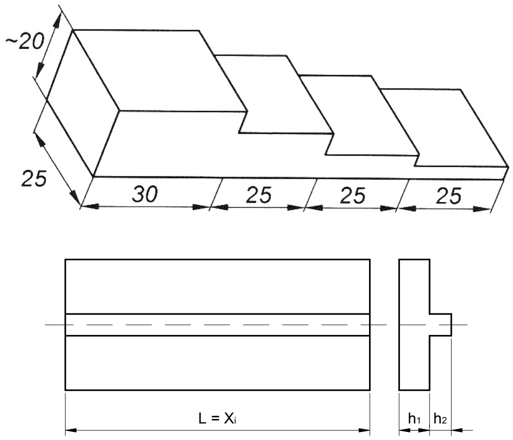

Figure 1. a) Step pattern (solidification module M_K from 0.1 to 0.5 cm), b) Pattern of a 70 x 30 mm and 7 mm thick “plate”

Moreover, there were researches covering testing the microgeometry of the patterns surface with the Mahr Zeiss profilometer (an exemplary profile of the pattern surface made of paraffin – stearic blend is presented in Figure 2).

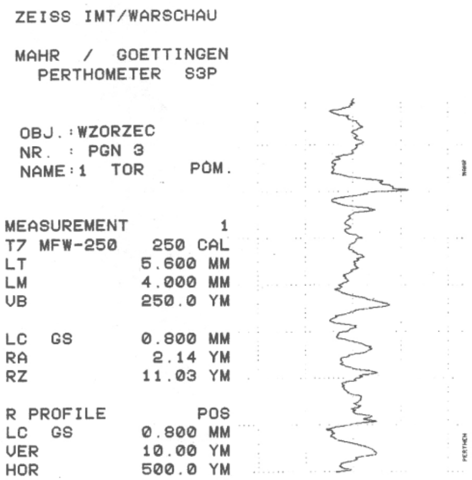

Figure 2. An exemplary profile of the pattern surface made of the PSWp blend

Simultaneously, the impact that pattern materials have on the ceramic mold surface was evaluated. Processes occurring while the first layer of a ceramic mold is forming influence the investment casts microgeometry and their cover layer. These cast parameters are crucial for the subsequent product exploitation. The properly shaped cover layer of the casts enables for a substantial prolongation of exploitation of the product. The ceramic mold surface consists of hills and cavities as it is pictured in Figure 3. Such constitution of the mold substantially influences the surface of the cast. Ceramic mold surface highly depends on the manner the pattern surface is wetted by the liquid ceramic blend. This issue was also included to the presented research.

Morphology of ceramic mold (Figure 3) indicates that it is a porous body. The cavities diameter accounts for about 0.08 to 0.1 mm with a maximum depth accounting for about 0.15 mm (evaluation uncertainty from 10 to 20 µm). This data was received due to analyzing over a dozen prophilographs of ceramic mold surfaces.

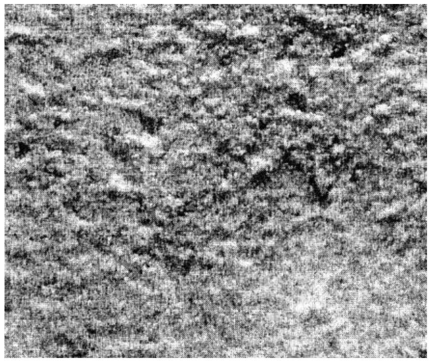

Figure 3. Morphology of ceramic mold surface made with Ekosil binder and molochite

3. Results of the research

The disposable patterns’ hardness proves their durability. The tests that were carried out (at the station presented in picture 4) used the penetration method which means penetrating the object with a special needle (the radius of the needle’s curvature is about 0.15mm) under the pressure of 100 grams.

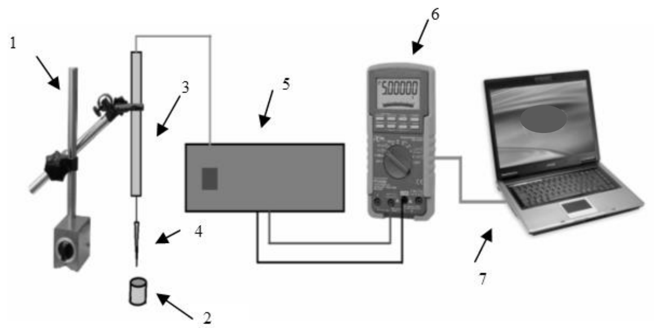

Figure 4. Computer station for hardness testing using penetration method (1 – Holed for displacement sensor; 2 – Tested sample; 3 – Displacement sensor Ptx100; 4 – Penetration needle; 5 – Transducer, Amplifier; 6 – Multimeter Sanwa PC5000; 7 – Laptop with installed PC-link plus program)

Numerous measurements were carried out for all types of samples, at the room temperature around 20 – 22 ºC. Here are some sample results of the hardness tests (the penetration unit means penetration depth of a given sample equal 0.1 mm):
1) the hard wax patterns KC 4017 – 3.1 to 3.6 penetration units,

2) the patterns made from hard wax mixture obtained after the melting of the ceramic mold in an autoclave (the recycling substance) – 5.0 to 5.8 penetration units,
3) the patterns made of paraffin wax and stearyne, with the addition of 10% polyethylene wax (PSWp) – 8.2 to 9.5 penetration units.

The micro-geometry of the patterns' surfaces, that were made of the above-mentioned substances, was based on the R_a parameter oscillating from around 1.0 to 2.5 μm (Figure 2). The results depended on a multitude of factors, the most important of which were the surface of the matrix in which the patterns were injected, the pressure of the injection itself and its temperature.

The high pressure polystyrene patterns surfaces' (the tested pattern in Figure 5) roughness averaged from 0.4 to 1.0 μm.

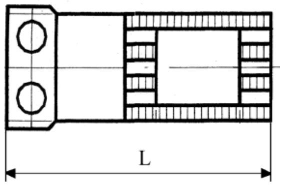

Figure 5. Polystyrene pattern

Shrinkage of the S_K mixtures, tested on the L-size step pattern (Figure 1), averaged:
a) KC 4017 mixture – S_K averaged $0{,}67^{\pm 0{,}09}$ (the plate pattern of solidification module 0.25 cm),
b) KC 4017 mixture – S_K averaged $0{,}69^{\pm 0{,}10}$% (the L-size step pattern),
c) the mixture based on the PSWp paraffin– S_K averaged $1{,}10^{\pm 0{,}14}$% (the L-size step pattern),
d) recycling mixture (WSK Rzeszów) – S_K averaged $0{,}88^{\pm 0{,}08}$% (the plate pattern of solidification module 0.25 cm),
e) high pressure polystyrene – S_K averaged $0{,}45$% measured on the L -size pattern presented in Figure 5.

3. Analysis of tests results

As one may notice, the polystyrene patterns got the best results in the tests. The quality of the patterns' surfaces and the S_K shrinkage show that this type of patterns seems the most desirable. However, this substance is only used in unusual cases:
1) if there are difficulties with the shape of the patterns, as exemplified in the Figure 5, where it is impossible to shape the wax patterns that could preserve the sharp edges,
2) if the matrix used for creating patterns is considerably more expensive than the one used for injecting the wax patterns, which requires multiple series of manufactured products,
3) it is difficult to separate the patterns from the ceramic mold as each pattern needs to be burned so that the gasification process does not damage the ceramic mold itself (no micro cracks in the ceramic mould),
4) the liquid ceramic mixture should contain the zirconium silicate powder so that more complex shapes can be manufactured (as exemplified in the Figure 5),
5) the polystyrene-based patterns are resistant to the moisture of the liquid ceramic mixtures, even with the use of special additives aimed to relieve its surface tension.

The precision in rendering complex pattern shapes in the first layer of the ceramic mold depends greatly on the surface tension of the liquid ceramic mixture. In the previous tests this quality was assessed with the use of the following two methods:
a) the du Noüy ring method, which measures the maximum force needed to lift a ring from the liquid's surface (Figure 6), however, it is understood that some liquid will always stay on the ring (Figure 6 – the shaded area)
b) the capillary rise method which uses the phenomena of the rise of liquid which wets the capillary walls (Figure 7), where the surface force, that is exerted on the capillary perimeter, is counterbalanced by the gravity force.

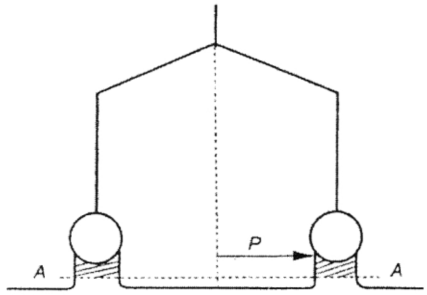

Figure 6. Du Noüya's ring metod principle

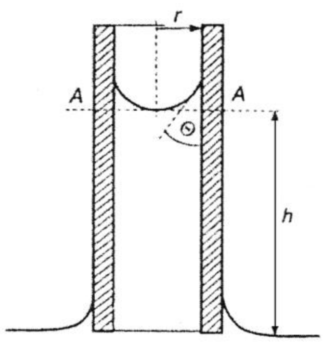

Figure 7. Rise of liquid in capillary *h*

The surface tension was measured with the du Noüya ring method by the Central Office of Measures in Warsaw. The value of surface tension of liquid ceramic mixture with a binder based on colloidal silica blended with latex and polymer (Ekosil) additives and zirconium silicate powder was estimated to be 34.2 mN/m. The rise in capillary – described as *h*, as given in Figure 7, was 1.03 mm. The value of surface tension for liquid ceramic mixture blended with molochite sand showed 32.8 mN/m, capillary h = 0.94 mm. When ceramic mixture based on SiO_2 powder was applied, the value of capillary *h* was 0.93 mm. Those ceramic mixtures, that were measured with the Ford 4 cup, exhibited ostensible kinematic viscosity worth 55 sec. Properties of the Ekosil binder are similar to those of Ludox and Remasol Ultra binders.

The uncertainty [2] of measurements of surface tension was on average 0.2 up to 0.4 mN/m.

It should be noted that liquid ceramic mixture based on ethyl silicate has a smaller capillary *h* (W_K) value, thus it fits best while wetting the surfaces of patterns.

Surfaces of polystyrene patterns got the worst results (the wetting angle was the greatest) – the evaluation based on the research led at the Faculty of Production Engineering at Warsaw University of Technology [3]).

4. Summing up test results

Evaluating pattern materials in terms of high quality obtained at investment casting [4, 5], one can admit that hard–wax based patterns satisfy casting expectations most:
1) minimize shrinkage of the wax mixture,
2) have excellent resistance properties,
3) patterns obtained from recycled hard wax have better properties than patterns made out of mixtures based on paraffin and styrene.
4) properties of hard wax patterns are much better than those of polystyrene patterns.

5. Conclusions

1) Hard waxes constitute an optimal wax mixture aimed to obtain high quality castings (the airline industry).
2) Wax mixture made out of recycled hard wax can be used to extract accurate castings for the entire engineering industry.
3) Paraffin and styrene- based pattern mixtures can be applied to extract medium accurate castings (SiO_2 based ceramic filler).

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References

[1] R. Haratym, R. Biernacki, D. Myszka, Ecological investment casting in ceramic dies, Warsaw University of Technology, Publishing House, Warsaw (2008) (in Polish).
[2] M. Szweycer, Surface phenomena in foundry process, Foundry Research Institute, Kraków (1996) (in Polish).
[3] J. Arendarski, Uncertainty of measurements, Warsaw University of Technology, Publishing House, Warsaw 2003, (in Polish).
[4] M.Horáček, Accuracy Of Investment Castings, Archives of Foundry Engineering, Year 2005, Volume 5, № 15.
[5] M. Horacek, J. Helan, Dimensional Stability of Investment Casting, Proceedings of 46th Annual Technical Meeting 1998, ICI, Orlando