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INDIRECT RAPID TOOLING USING CERAMIC MOULDING AND INVESTMENT CASTING PROCESSES

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Abstract

A fast answer to the present market requirements is one of the main actual conditions of industrial competitiveness. One of the sectors in which this demand is relevant is the moulds industry for plastics, where the fastness on making tools for functional prototypes, small series or pre series is very important to achieve the success on launching new products.

On indirect rapid tooling processes, a model is quickly converted in the final tool by conversion technologies, which are less expensive and more versatile than the direct processes. The model is obtained by rapid prototyping or other rapid fabrication processes. With fine ceramics it becomes possible to produce tools by foundry technologies, with high accuracy in the reproduction of textures and details, without machining.

In this work the authors present the results of a dimensional control performed to accurately determine the solid-state contractions of an indirect rapid tooling process. The process starts with a LOM (Laminated Object Manufacturing) or a HSM (High Speed Machining) model, which are then converted in a ZAMAK (Zn-Al alloy) tool using ceramic moulding or investment casting processes.

A comparative study of costs, using ceramic moulding and investment casting conversion processes, is also presented.

Introduction

Presently, the conversion of models, obtained through rapid prototyping techniques, into metallic moulds or tools using ceramic moulding or investment casting processes, plays an important role in many different industries. This is essentially due to the need to obtain working parts or prototypes as quickly as possible without having to resort to making moulds through conventional machining processes which are slow, expensive and wasteful in the use of raw materials [1].

Ceramic moulding

Ceramic moulding allows parts or tools production by foundry, with fine details and very smooth surfaces, good dimensional precision and a good metallurgic integrity in several metallic materials. Ceramics have refractory properties, which allow metal pouring at high temperatures, with an excellent thermal stability [1].

This unique foundry fabrication process fulfils the gap between investment casting, limited to a rather small parts, and the sand casting, which produces parts rather rugous and without fine details. Dimensional tolerances are very close to the investment casting, and the cost can be very close to the sand casting, depending however on the ceramic materials used [2].

Investment casting

This process converts a non-metallic model into a metal one. The model can be obtained by rapid prototyping or other fabrication processes.

Basically, to make this conversion, there are two different processes that may be used: the direct and the indirect one (figure 1) [3].

On the direct process, the conversion is likewise the investment casting. A wax, a plastic or paper model (obtained by rapid prototyping processes) should be used. This model will be burned until the full transformation into CO_2, or other combustion gases.

On the indirect process, the model (obtained by rapid prototyping processes) is not lost, being more tolerant to processing mistakes. However, has the disadvantage of being slower. This was the adopted process in this experimental work.

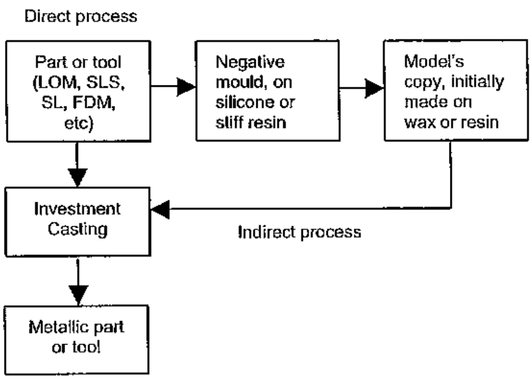


Fig. 1. Conversion technologies: direct and indirect processes.

Experimental work

This work was divided in two phases. In the 1st phase a pattern part was defined. The respective core and cavity were produced using ceramic moulding process, in order to adjust this process. The gained experience with this phase, allowed the selection of an industrial part (2nd phase), and production of the respective core and cavity using ceramic moulding process. In the 2nd phase, the metallic tools were also performed by investment casting process.

1st Phase – Pattern part

- Pattern part definition (figure 2), and respective core and cavity (figure 3);
- Ceramic moulding of the core and cavity;
- Dimensional control.

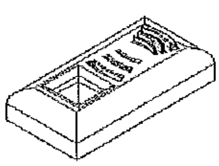


Fig. 2. Pattern part in CAD.

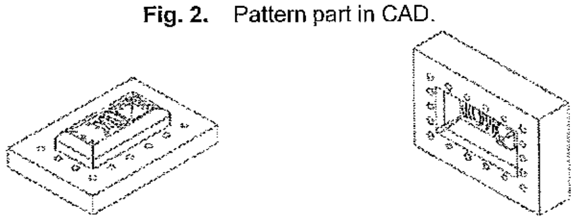


Fig. 3. Core and cavity in CAD of the pattern part.

The main steps for ceramic moulding to obtain the cavity and core in zamak of the pattern part, were [2]:

- Cavity production in LOM (figure 4);
- Manufacturing the cavity in silicone (figure 5);

Fig. 4. Cavity in LOM.

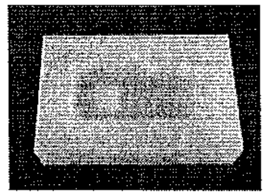


Fig. 5. Cavity in Silicone.

- Placing the silicone model in a moulding box;
- Weighing the refractory powders, containing a high proportion of fine particles to guarantee a good details reproduction and a low surface roughness, and thick particles to give resistance to the ceramic moulding;
- Mixing of the ceramic powders, together with a hydrolysed ethyl silicate binder;
- Catalyst addition when the mixture is homogeneous, to trigger the hardening;
- Pouring the ceramic slurry (ceramic powders + binder + catalyst) into the moulding box, containing the model to be reproduced;
- Manual ceramic demoulding (figure 6);

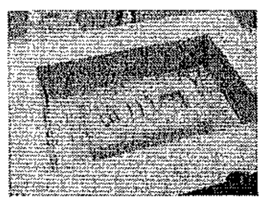


Fig. 6. Ceramic moulding.

- Ethylic alcohol addition to stabilize the ceramic moulding, and stop the hardening reaction;
- Ceramic moulding burning – This stage produces a three dimensional crack network that not affects the final mould quality, because there is no metal penetration, and allows air extraction from the cavity;
- Sintering of the ceramic moulding to increase the resistance and inertness;
- Gluing the two half ceramic mouldings;

- Pre-heating the ceramic moulding (figure 7) to avoid the thermal shock and guarantee an easier metal filling;

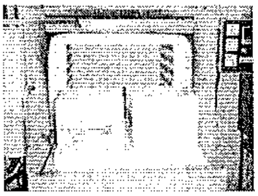


Fig. 7. Ceramic moulding pre-heating.

- Liquid metal (zamak) pouring into the ceramic moulding cavity;
- Shake out to remove the metallic tool, and cleaning with a high pressure water pistol;
- Cut of the risers and the feeding system, and minor surface finishing operations.

The final aspect of the metallic tools is shown on figure 8. More details about all these steps of the ceramic moulding process can be find on the references [1, 4, 5].

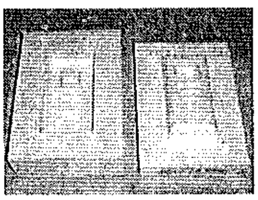


Fig. 8. Metallic tools in zamak.

Results

The table below presents the practical shrinkage (average values of three cores and three cavities obtained by this process).

	Core		Cavity	
Lenght	x1	y1	x2	y2
Nominal Lenght	71mm	146mm	75mm	150mm
LOM - ZAMAK shrinkage	1,6% (1,2mm)	1,4% (2,0mm)	1,5% (1,1mm)	1,1% (1,7mm)

Core

Cavity

- Medium contraction = 1,4%;
- Results dispersion.

In the attempt to diminish the results dispersion, a 2nd phase of the experimental work was performed, where a mechanical demoulding system was used to guarantee perpendicularity between the separation plan and the demoulding direction. In this phase two different ceramic conversion processes (ceramic moulding and investment casting) were also tested.

2nd Phase – Industrial part

- Industrial part selection (figure 9), and respective core and cavity (figure 10);
- Ceramic moulding and investment casting of the core and cavity;
- Dimensional control;
- Comparative costs of both processes.

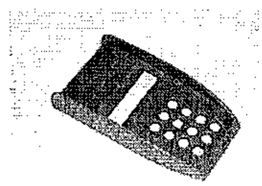


Fig. 9. Industrial part.

Fig. 10. Core and cavity in CAD of the industrial part.

Ceramic moulding

The main steps for ceramic moulding to obtain the cavity and core in zamak of the industrial part, were the same as the ones used for the pattern part, however with the following differences:

- Start with a HSM model of the industrial part (figure 11);
- Mechanical demoulding (figure 12), as suggested after the 1st phase of the experimental work.

The final aspect of metallic tools is shown on figure 13.

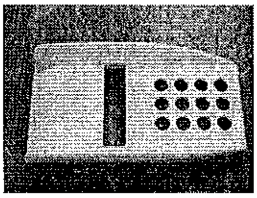


Fig. 11. HSM model of the industrial part.

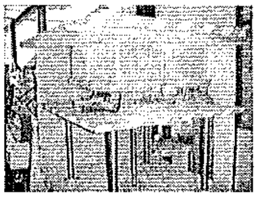


Fig. 12. Mechanical demoulding.

Fig. 13. Metallic tools in zamak.

Investment casting

To reduce the weight and the costs of the zamak tools, and simultaneously the wax models and the assembling weight, both core and cavity's back surface were ribbed.

The main steps for the investment casting of the cavity and core in zamak of the industrial part, were:

- Negative moulds production in resin, using silicone moulds;
- Box manufacturing to inject wax (figure 14), in order to obtain a wax cavity model (figure 15);

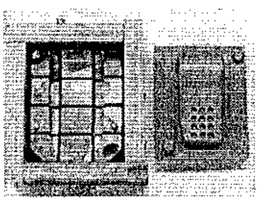


Fig. 14. Wax injecting box.

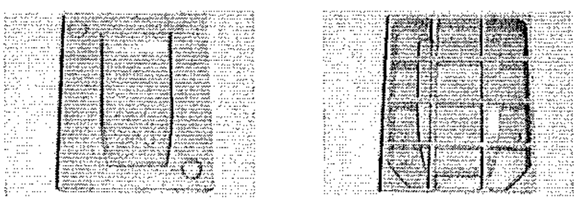


Fig. 15. Wax cavity (front and back).

- Glue all the wax parts, cleaning and degreasing (figure 16);
- Ceramic shell production with 11 layers (figure 17);
- Sintering the ceramic shell, and pre-heating;

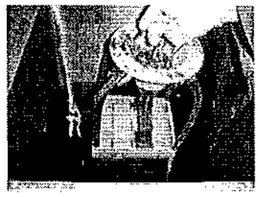


Fig. 16. Degreasing the wax assembling.

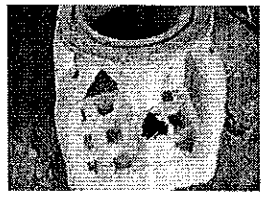


Fig. 17. Ceramic shell.

- Liquid metal (zamak) pouring into the ceramic shell cavity;
- Shake out to remove the metallic tool;
- Cut of the risers and the feeding system, and minor surface finishing operations.

The final aspect of the metallic tools is shown on figure 18. More details about all these steps of the investment casting process can be find on the reference [2].

Fig. 18. Metallic tools in zamak.

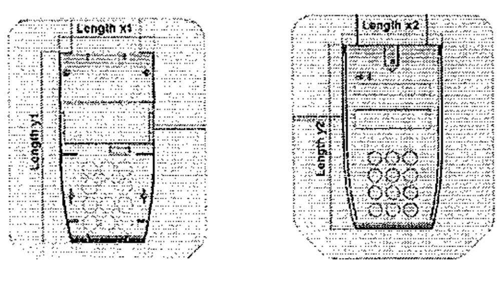
Results

Ceramic moulding

The table below presents the practical shrinkage (average values of three cores and three cavities obtained by ceramic moulding).

	Core		Cavity	
Lenght	x1	y1	x2	y2
Nominal Length	77mm	150mm	81mm	154mm
HSM - ZAMAK shrinkage	1,1% (0,9mm)	1,3% (1,9mm)	0,8% (0,6mm)	0,8% (1,3mm)

Core Cavity



- **Investment casting** process's cost, and associated risk in not getting the desired metallic tool quality:

	Core + Cavity
HSM model	€ 1 245
Silicones	€ 265
Ceramic moulding	€ 250
Pouring + Finishing	€ 125
TOTAL COST	€ 1 885
RISK (Ceramic moulding/Total cost)	13% Total Cost

Investment casting

The table below presents the practical shrinkage (average values of three cores and three cavities obtained by investment casting).

	Core		Cavity	
Lenght	x1	y1	x2	y2
Nominal Lenght	76mm	148mm	80mm	152mm
Wax - ZAMAK shrinkage	1,1% (0,8mm)	1,0% (1,5mm)	1,1% (0,9mm)	0,8% (1,2mm)

- Ceramic moulding process's cost, and associated risk in not getting the desired metallic tool quality:

	Core + Cavity
Wax model (thermojet)	€ 1 745
Ceramic shells	€ 350
Pouring + Finishing	€ 100
TOTAL COST	€ 2 195
RISK (Wax model/Total cost)	79% Total Cost

Based on both studied processes, one should conclude:

- Medium contraction was 1,0% for both processes;
- In terms of costs, investment casting presents a higher total cost, due to the higher price of the wax model. Although on this work, the above was achieved by resin moulds, the desirable would be to obtain the wax model by a thermojet, because, with a thermojet, is not necessary the production of the resin moulds. So the cost of the wax model was presented as a thermojet model one;
- In terms of the associated risk in not getting the desired metallic tool quality, investment casting presents a higher risk because the most difficult stage was to obtain the wax model. On total cost, 79% of this one relates to the above model. On ceramic moulding process, to obtain the ceramic moulds was the most difficult stage, being 13% of total cost;

Conclusions

- On ceramic moulding it was verified that the mechanical demoulding was fundamental to produce metallic tools with a higher dimensional precision, because when the manual demoulding was performed from the silicon model, ceramic moulding has similar consistence to the rubber. Therefore, if the perpendicularity between the separation plan and the demoulding direction is not guaranteed, irreversible deformations are obtained;
- The investment casting comes out more expensive due to the high price of the wax model. However, the attention must be draw to the fact that the prices of the ceramic powders employed are lower than the ones used on ceramic moulding process.
- Facing the traditional machining and/or electroerosion technologies used on the plastic injection moulds production, the studied processes have a short time production (≈ 1 week), a quite low price, but a lower dimensional precision;
- Complementary studies are necessary to check the influence of procedure parameters in the shrinkage and dimensional precision.

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