METALLIC PROTOTYPES FOR THE PRESSURE DIE CASTING INDUSTRY

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Abstract

Very useful engineering models for product development can be rapidly available using Rapid Prototyping technologies. A diversity of industrial sectors can benefit from the use of these technologies, through speed improvement in the product development phase and consequently minimising the time to market.

Rapid Prototyping technologies also allow the direct or indirect production of metallic prototypes to be used in the development of fully or semi-functional products, like house ware, kitchen and bathroom taps, sand castings, die castings and components to be produced by pressure die casting for the automotive industry.

It is the aim of this work to describe a 3 years experience in the development of metallic conversion techniques, to supply functional metallic prototypes for different national companies. The advantages and the disadvantages of some possible complementary technologies to obtain functional prototypes of products that will be produced by pressure die casting are presented. The “lost model” technique using LOM, Thermoject, SLA “Quick Cast”, and the “lost wax” will be compared in terms of accuracy, speed and costs, with techniques that use silicone and the resin filled moulds, considering the production of pre-series of 3 to 50 prototypes.

Introduction

Over the last decade, a radical change in the project field have been witnessed, with the traditional 2D processes progressively replaced by CAD systems, which are able to generate three-dimensional models.

In systems with parametric modelling capacities, it is possible to start by conceptualising the project, and developing different options with simplicity and quickly. Photo-realistic presentations and computer animations help to change the client’s attitude towards prototypes and to avoid costly investments. Therefore, this first step makes it possible to prevent defects, which otherwise, would only be detected at a later stage of the process [1 2]. However, the design process does not end just because a three-dimensional model was created; these programmes can and should interact with other specialised applications to create a global solution to design and manufacture a product. This is the case of the Rapid Prototyping (RP) and Rapid Tooling (RT) technologies, which enable to create prototypes and pre-series with highly reduced response time to market demands [2-6].

In the development phase of new products to be pressure die casted, there is an absolute necessity in producing functional prototypes, which are obtained with a non-final manufacturing process. These prototypes allowing the simulation of the assembling and functionality of the final parts minimize errors that if detected in a later stage, would produce loss of profits and enlarge the time to market.

Traditionally, in worldwide, the most defended process for prototypes materialization is the sand casting in green sand and core sand. This methodology implies two simultaneous projects, the project of the die casted part, with the parting lines, sliding cores, and rational thickness distribution, and the project of the foundry tools in sand, with other drafts, parting lines, core prints and core boxes. This fact creates the problem of compromising the parts qualification, the prototypes delivering time, the injection moulds execution and the delivery of die casted parts [2].

With the introduction in the market, in 1987, of the Rapid Prototyping technologies, with the stereolitography being the first system to be commercialised, other systems like selective laser sintering (SLS), fused deposition modelling (FDM), laminated object manufacturing (LOM) and thermoject, were developed and used in many industrial sectors to reduce the time to market [2, 7]. Nowadays, RP is becoming more or less standard in product development, with prototypes being used for demonstration purposes, visual aid, simple tests, etc. However, many times the prototype has to be manufactured in the same material of the final part, in order to perform functional tests. Although direct production of functional metallic prototypes can be performed using the direct metal laser sintering (DMLS) or SLS metals processes [2, 7], the prototypes can only be obtained in the patented alloys developed by these equipment manufacturers, and are very expensive, significantly limiting their use. For this reason, there is a tremendous interest in converting the RP models into metal models, which can be done combining the RP and the investment casting technologies.

The big advantage of these new methodologies is based in the speed and in the possibility of obtaining casted parts with dimensional, geometric and surface characteristics, similar to the ones obtained by pressure die casting. The cost associated to the production of these prototypes and pre-series are more elevated than with the conventional processes like sand casting. However, the delivery time is much shorter.

From the exposed one can conclude that there are two big classes of alternatives for functional or semi-functional metallic prototypes production, the direct and the indirect processes.

Direct Processes

In the direct processes, instead of a traditional wax model injected into a mould, prototypes obtained by different RP processes are directly used [2, 7], namely:

Hollow stereolitography:

- Quick Cast from 3D Systems
- Skin and Core from EDS

SLS in wax infiltrated polystyrene, Cast Form from DTM

Wax FDM

Wax Thermoject

Paper LOM.

These models, eventually without defined parting lines and without draft angles, but with machining allowances, are welded to the wax gating and feeding systems. In the next step, using the shell ceramic moulding process or block plaster moulds, the assembly suffers a calcining cycle of 1-2 hours for the wax, or 12-24 hours for the paper, epoxy resins (3D Systems and EOS) or plastics (DTM). Finally, the metal is cast into the ceramic cavities. The great advantage of this process is the speed, and the major disadvantage is the total prototype price, and the risk that the cast part is not in conformity. These processes are only used for the production of 1-3 metallic prototypes and allow metallic parts manufacturing with a total delivering time of 3-7 days.

Indirect Processes

In this case, the models obtained by RP processes, such as SLA, SLS, FDM, LOM or others [1, 2], are used to manufacture one mould for wax injection.

The wax injection moulds can basically be of two types:

- Flexible, in silicone or polyurethane elastomers
- Rigid in epoxy or polyurethane resins.

The flexible moulds can be used even in the cases where the parts still do not have the parting lines and draft angles defined. Usually, they can be obtained in 1-2 days with little human labour. Although the wax can be injected in these moulds with a 1-3 bar pressure, the injection pressure produces parts distortion, compromising the dimensional and the geometric tolerances. For a better process efficiency, the wax should be cast in vacuum chambers designed for this purposes. With the single gravity effect, the wax models precision obtained is much better than in the previous case. From a ±2mm accuracy, values of ±0.5mm can be achieved. However, without pressure, the parts can have air bubbles. The solidification and the wax cooling time in the elastomeric moulds is very elevated, i.e. around 1-3 hours, which only allows, in some cases, the production of 2-3 parts per day. Because of these reasons, these technologies are currently used for the production of 1-5 prototypes, with delivering time of 4-8 working days, competing with the direct conversion processes already referred.

In order to use rigid moulds it is necessary that the part to be manufactured have already defined the parting lines, specific draft angles for the injection wax process and the bases for parts positioning. In this case, the project of the mould for the wax injection has great similitude with the project of the mould for metal injection, requiring a detailed CAD 3D work with very specialized human labour.

The mould is manufactured in a number of steps correspondents to the number of mobile parts of the mould (stationary mould + moving mould + number of sliding cores) and normally it takes, for complex moulds, 3-7 days to be manufactured. This mould is usually manufactured with aluminium powder filled resins, which is used to increase the thermal conductivity of the mould. This allows the injection of 12-30 parts per day. This process allows a dimensional accuracy higher than the one obtained with silicone moulds, with ±0.2 mm susceptible to be achieved with original stereolitography models.

Experimental Work

Since 1998, our research group has been dedicating a great effort to develop the direct and indirect conversion processes, in order to guarantee a large technological offer in this interesting services area. Considering this, the following technologies were developed:

Manufacturing injection moulds,

Manufacturing ceramic shells (investment casting), Lost models, calcination of paper, wax, thermoplastics and thermosettings.

The development of these technologies was possible due to an enrolment in the following activities:

- RNPR project, National network of rapid prototyping,
- DECOPOFI project, Cooperative development for high quality prototypes for die casting industry,
- Selling services to companies.

In this context, more than 2000 parts of 100 references were obtained by the investment casting process. Around 20 parts were produced for partners and costumers by the lost models processes, namely Lost LOM, “Quick cast” and Thermoject.

Results

Direct Conversion

The direct conversion process used lost models in paper (LOM), Quick Cast (SLA), and wax (Thermoject).

The results were obtained using lost models in LOM, using two types of paper [8]. The paper from Helysis (LOM equipment manufacturer) is nowadays commercialised by the American Company Cubic Systems Inc. The other paper is commercialised by the German Company BMT (Buss Modelling Technologies).

The BMT paper is almost impossible to use, because it has an anti ignition mineral product, which after 24 hours of calcinations at 1100ºC, produces an enormous ashes quantity, generating great defects in the metallic casted parts. These defects disable the use of this type of paper in direct conversion.

The Helysis paper does not have mineral fillers. However, if the prototypes walls have a thickness less than 4mm, they tend to produce parts with defects. In some cases, like oil pumps, gas carburettors and water pumps, good results were obtained. Figure 1 shows the aspect of some metallic prototypes obtained by lost LOM. These metallic prototypes have a dimensional accuracy of ±0.4mm.

Lost models in SLA (Quick Cast) were converted in metallic oil pumps, engine supports and filter boxes. This process produces better results than the ones achieved with the lost LOM process. The prototypes have a quality that allows their industrial use with a ±0.2 mm accuracy. Some of the prototypes obtained by this process are indicated in figure 2.

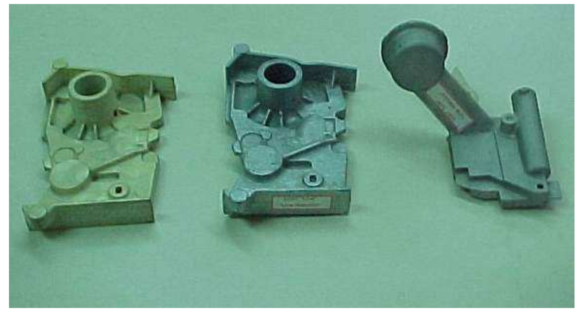

Fig. 1. LOM model and prototypes in an aluminium alloy, obtained by the lost LOM process.

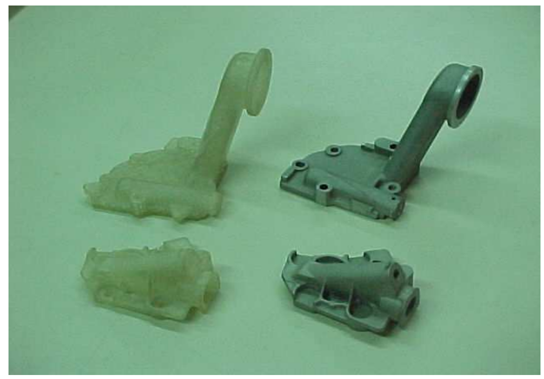

Fig. 2. SLA models and prototypes in an aluminium alloy, obtained by the lost Quick Cast process.

Thermoject prototypes were directly converted in one serie of metallic prototypes of a body and covers of an oil pump. Figure 3 shows some of these prototypes. The conversion results were excellent, but the prototypes have a low dimensional accuracy (±0.6-0.8mm), and the support regions have an inadequate finishing.

Fig. 3. Wax model (Thermoject) and aluminium prototypes obtained by the lost wax process.

Indirect Conversion

The development of the indirect conversion processes was centred fundamentally in the use of two different types of moulds;

- Wax injection moulds in silicone (fig. 4)

- Wax injection moulds in aluminium filled resins (fig. 5) [9-11].

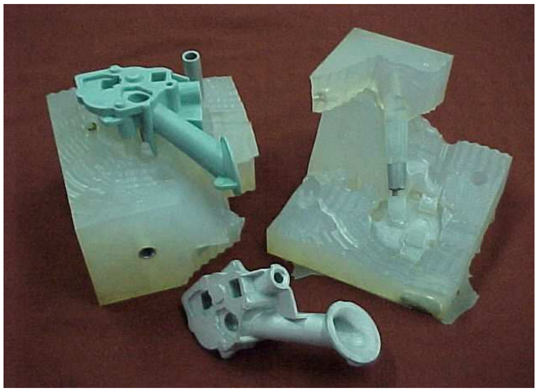

Fig. 4. Wax injection mould in silicone. The figure also presents the wax model and the aluminium prototype.

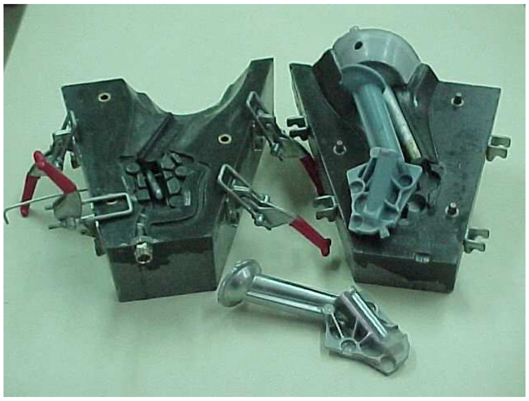

Fig. 5. Wax injection mould in an aluminium filled resin. The figure also presents the wax model and the aluminium prototype.

Using silicone moulds, oil pump covers, bodies of electronic lockers, oil filters boxes, and artistic sculptures were obtained.

With the oil pump covers and the electronic bodies lockers the dimensional precision obtained with wax injection at 3 bars was only ±3mm. This is due to the injection pressure influence on the moulds distortion. This fact disables the use of this process to manufacture technical prototypes.

With the part oil filter boxes the dimensional precision increased to ±0.5mm, due to the fact that the wax casting was performed by gravity in a vacuum chamber.

With the artistic sculptures parts, the dimensional precision problems are not important.

The silicone moulds process seems particularly adapted to the vacuum casting and pre-series of 1-5 parts. This is based in technical and economical questions and in the risk and the delivering time.

In figure 6 one can see, for the oil filter box, the economic advantages of this conversion process relatively to other processes.

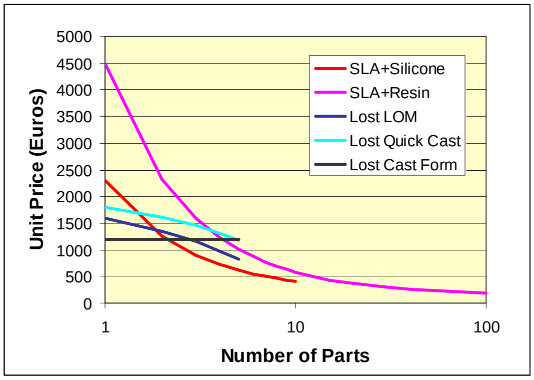

Fig. 6. Costs comparison for metallic prototypes production using different processes.

Using the aluminium filled resins, 20 pre-series of 10, 20, 50, 70 and 150 parts, namely oil pumps bodies, oil pumps covers, water pumps, gas injectors, gas valves, gas distributors, boilers exhausting systems, and many other products, were produced (see fig. 7).

Fig. 7. Different metallic prototypes produced.

With an adequate control of the resins, wax and metal shrinkages, it is possible to get dimensional tolerances of ±0.2mm and eventually ±0.1mm (in 100mm). As a general rule, for this type of parts it is possible to subcontract the original model in stereolitography (1 week), and deliver pre-series of 10 parts in 3 weeks or 20 parts in 4 weeks with repeatability, and metallurgical and dimensional quality consistency.

Figure 6 shows that for the great majority of the cases, i.e., pre-series of 10-50 parts, this is the only tested process really competitive, and which have a great acceptation. As an alternative of this process, eventually with a significant price reduction, but with larger delivery time, the only competitive processes use moulds in low melting point alloys, like Sn-Bi, or eventually integral aluminium machined moulds. Although we never used these processes, they are current manufacturing processes for large series, in normal production investment casting companies.

Conclusion

Rapid prototyping, associated with the lost wax process clearly opened new potentialities to speed up the developing phase of new products for the die casting sector.

The lost models process, particularly the Quick Cast and eventually the Cast Form, although expensive, are the only processes that allow the manufacturing of single metallic prototypes almost functional, in short periods of time, 3-4 days.

The lost wax process with silicone moulds can be more advantageous than the previous one, but for 2-5 prototypes and not for a single prototype. The time increase and the costs reduction are the disadvantage and the advantage, respectively, relatively to the lost models process.

For 5 parts pre-series and particularly for 10-50 parts, the more interesting process is the aluminium filled resin moulds.

Keywords

Die casting, direct conversion, indirect conversion, rapid prototyping, moulds, metallic prototypes.

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