MOULD ENGINEERING SOLUTIONS FOR SMALL SERIES PRODUCTION

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ABSTRACT

Solutions that require a closed mould and high pressures for plastic injection are usually put aside to produce large polymeric parts in small quantities, due to the inherent costs of the required mould. A direct consequence of this fact is the potential constrain of product design issues like weight saving, aesthetic freedom, high dimensional precision and surface finishing. To overcome these difficulties new approaches are needed regarding low cost mould solutions for the injection moulding process. One of the possibilities, on the technology field, is the use of metal spraying technologies for the construction of the core and cavity of the mould. Using a case study, this paper presents the investigation work that has been made regarding the development and demonstration of using this technological process to the production of the injection mould. The results are compared with the more conventional technologies and materials, normally used for similar design and production requirements.

1. INTRODUCTION

There is currently a great demand towards the use of polymeric and composite materials due to several factors [1], such as weight reduction, ergonomic and aesthetic improvement. One of the sub-sectors that are increasing along this trend is the production of large products manufactured in very small series. The real constraint limiting the use of polymeric and composite materials in this sort of products is, essentially, the high cost of the mould [1]. Since they are used for the production of small volumes of parts the high cost of the conventional moulds is translated in costly parts.

To cope with these necessities, current production processes resort to a multiplicity of technological solutions, from soft material moulds [2], like epoxy resins and silicone, in which manufacturing chain several rapid prototyping based processes can be used, to light injection moulds made of soft steels and aluminium alloys, manufactured by conventional subtractive technologies. In fact, tooling for low production requires a low-cost tool in a reasonable timeframe. Amongst the most recent developments, two classes of approaches should be highlighted [3]:

- New materials allowing an easy and quick conformation (resins with metallic charges, metal powders, sintered components and light alloys);
- New design and production procedures, entailing the Reverse Cost Engineering and targeting simplification, modularization, and re-use of the tool, its sub-systems and components.

Amongst the several indirect tooling processes spray metal tooling appears as a high potential technology for cost efficient tools. This process applies a zinc/aluminium alloy with an arc spray over a pattern forming a metal shell with a few millimetres of thickness. The sprayed metal shell can then be reinforced with an aluminium-filled epoxy resin producing a finished mould. This process allows an excellent machinability to support the finishing operations, targeting the required accuracy and surface quality, and the assembly of inserts with detailed features not possible to reproduce with spray metal, and has a low manufacturing cost.

Based on the previous experience [3,4], a comparative study of the application of different technologies in cavities and cores of moulds for the production of small volumes (up to a few hundreds) of thermoplastic parts with a significant dimension was perform. The user interface cover for the new car wash machine from Brisa, was used as a demonstrative part, but the concepts, technologies and know-how obtained, can be easily transferred to other applications and industrial sectors, from the large equipments to the aeronautics industry.

2. CASE STUDY

Brisa – Auto Estradas de Portugal SA is a reference company among European toll highway operators, because of its network extension and technological innovations. The company is looking for new aesthetic image and added functionalities for the user interface on its equipments. A frontal cover panel for one of such equipments was selected as pilot project.

Till now this kind of parts have been made in sheet metal, bended, welded and painted, which deeply constrains design freedom regarding free forms and functional feature issues (Fig. 1). Manufacturing technologies like polymers injection moulding are seemed like having a great potential for the reduction/elimination of these problems. However, the market requirements point to an expected production volume of a few hundreds for such panels. So, technologies involving injection mouldings have been set aside due to difficulties in accommodate the mould cost in the panel final cost. An innovation breakthrough is required to support the injection moulding penetration in small volumes market niches.

Fig. 1. – Current control box of car washing machines

So, the objective of the case study is to perform a systematic evaluation of two alternative manufacturing chains based on light aluminium and spray metal moulds. The evaluation is performed considering the functional requirements of the part within the objective of manufacturing lead time and cost reduction. In fact considered the starting part already used in Brisa equipments (Fig. 1) the new part should be redesigned to be produced in Polycarbonate through injection moulding. Based on this technology the part can take advantage of free forms, have an appealing image and be ergonomic. It must have impact and weather resistance and must be easy to assemble and disassemble, allowing and easy access to the interior devices. The expected production volume is around 200 parts (it could become higher if the market for the control box of car washing machines enlarges but Brisa only assumes an order for 200 parts). The target price for the cover was defined based on the price of the current part considering the improved aesthetics possible to achieve with injection moulding – 90€ per part.

3. WORKING METHODOLOGY

The working methodology followed is presented in Figure 2. The first step was the analysis of the original metal sheet part proposed by BRISA. Based on the specifications and functionalities for the desired plastic part a new part design was made (Fig. 3). The second step involved the design and production of two alternative moulds: one made of aluminium the other made of a spray metal shell backfilled with resins. The third step was the production of the 200 parts using each mould. Finally the parts were evaluated and the manufacturing costs and manufacturing lead times were compared.

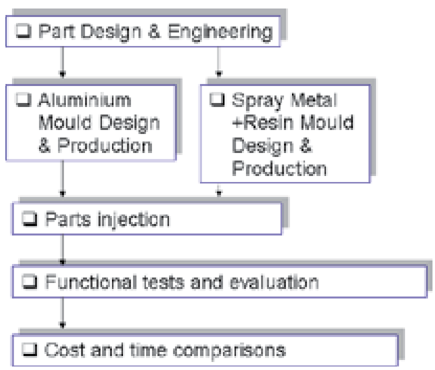

Fig. 2. – Working methodology

Fig. 3. – New design of the cover of the control box

Within this framework and according to the innovation drivers the design and manufacturing solutions can be structured within the followed principles:

- Use of low cost / easy to machine materials;
- Systematic questioning of the need of any mould functional sub-system (elimination / simplification, new solutions);
- Use reusable and shared mould components / sub-systems;
- New technologies in mould manufacturing (casting, additive technologies, among others);
- Simultaneous part and mould design for effective design for manufacture and assembly;

4. MANUFACTURE PROCESSES

The first mould produced was the conventional machined aluminium approach, normally followed by mould makers when dealing with moulds for small production volumes. The simplicity of the tool engineering was considered one of the fundamental criteria for the cost reduction. Each tool feature and component is only included if and only if it is strictly necessary to an adequate tool functioning and to the required quality of the moulded parts. The cooling channel circuit was very simplified and tubular ejectors were used to support 4mm screws that were incorporated in the plastic part during injection. As the part design was made following design for manufacturing principles expensive and long processes like EDM were avoided.

FIG. 4. – Core and cavity of aluminium mould

To reproduce the core and cavity in Spray Metal a master was machined in polyurethane. A multi-layer material approach providing customized properties in specific areas of the mould was use, improving mechanical, machining and thermal properties. The mould shell was produced using Spray Metal technology and it was reinforced through backfilling the shell with layers of a high temperature epoxy resin (Fig. 5) mixed with aluminium powder, silica powder and aluminium grains.

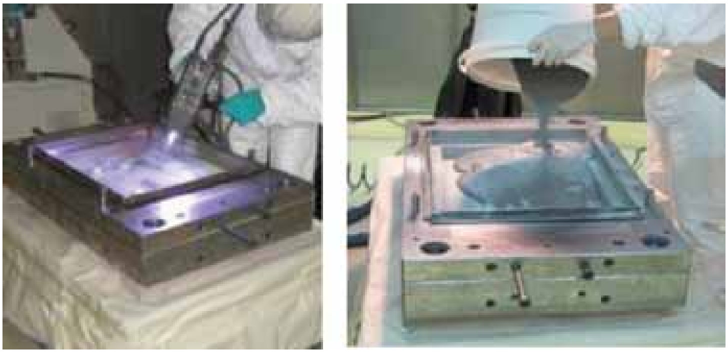

FIG. 5. – Spray metal deposition and resin filling

The introduction of aluminium powder in the first layers intends to improve the thermal conductivity and mechanical resistance. The second layer with silica, besides resistance, aims the cost reduction. The last layer targets the easiness of the machining operations (Fig. 6).

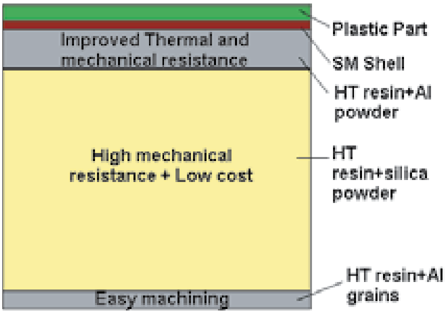

FIG. 6. – Layers of backfilling material

Two types of thermoplastic materials were considered for the injection tests of the spray metal mould: Polypropylene (PP) and Polycarbonate (PC). The first tests were carried on with the material easier to process (PP) through a production of 200 parts. After this first series the condition of the mould was analysed and more 30 parts in PC were injected. In the aluminium mould only PC was injected.

FIG. 7. – Injected parts

Table 1 presents a snapshot of the injection parameters used. The injection cycle for the spray metal mould is superior to the aluminium solution, especially because of the required cooling time.

Tab. 1. – Injection parameters

Spray metal mould						
Part material	**Cooling time**	**Injection time**	**Injection speed**	**Injection pressure**	**Clamping force**	**Nozle temperature**
PP	100 s	1.5 s	27 mm/s	70 bar	1800 Mpa	245°C
PC	120 s	2.0 s	40 mm/s	90 bar	1800 Mpa	300°C

Alluminium mould						
Part material	**Cooling time**	**Injection time**	**Injection speed**	**Injection pressure**	**Clamping force**	**Nozle temperature**
PC	50 s	1.5 s	65 mm/s	118 bar	1800 Mpa	290°C

5. RESULTS EVALUATION

The produced parts were analysed relatively to geometric stability and dimensional accuracy. Through visual inspection the finishing aspect (roughness, flow lines, color changes,Ö). Parts made in both moulds were considered to fulfill the quality levels required for the application.

Considering that for the specific application both technological alternatives are capable to meet the quality requirements, their further evaluation should involve economic aspects, like cost per part and time to market. In addition the evaluation should regard the competitiveness of companies designed for the injection of plastic parts in very small volumes.

5.1. ECONOMIC EVALUATION – COST PER PART

The spray metal solution is economically competitive when compared with the conventional aluminium mould. In fact the spray metal mould (including the master production) is approximately 27% less expensive than the aluminium one (Fig. 8). In fact both materials cost and process cost (including machine and labour costs) are significantly lower for the spray metal mould. It should be noted that the materials cost is highly dependent on the layered approach used for the backfilling mixed resins.

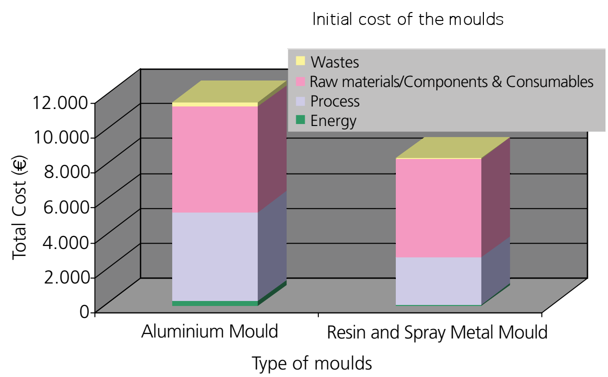

Fig. 8. – Moulds manufacturing cost

In the present case study a production volume of 200 parts was envisaged. For that volume both moulds were capable of moulding all the parts. However, at the end of the envisaged production the spray metal mould presented damaged zones due to wearing mechanisms, especially near the injection gate. In fact, the life of an aluminium mould can be considered as infinite as regarding small series, but the mould based a spray metal shell filled with a loaded resin has a very limited life. After the injection of around 200 parts, a new core and cavity for the spray metal mould must be re-made and re-assembled.

Figure 9 presents the evolution of the cost per injected part with the production volume using both mould alternatives. The cost discontinuities arising at 200 and 400 parts for the spray metal case are due to the need of producing a new core and cavity, which results in a cost increase. The cost comparison shows that for very small volumes the spray metal is a less expensive solution but for not so small volumes (> 400 units) an aluminium mould becomes preferable.

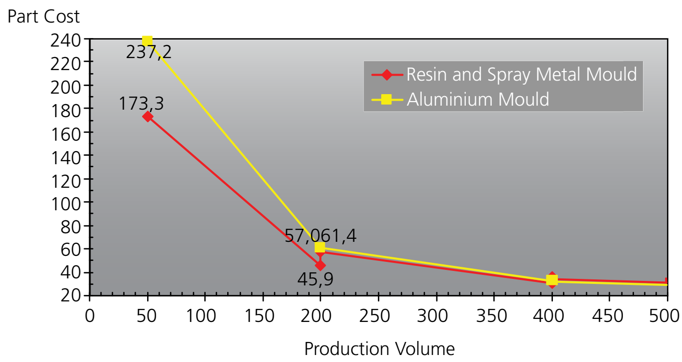

Fig. 9. – Evolution of part cost with production volume

5.2. ECONOMIC EVALUATION – TIME TO MARKET:

Besides cost issues, competitiveness also results from the capacity to provide parts in a narrow time frame. So, the manufacturing steps required to build the moulds were registered and the time spent was measured (Fig. 10).

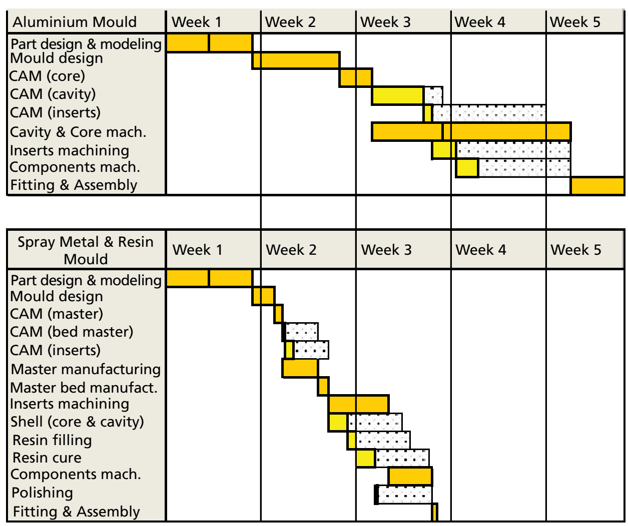

Fig. 10. – Time sequence of manufacturing operations

The execution of the spray metal mould involves more steps and is more dependent on skills and human labour. However, the spray metal mould is available to produce parts in 18 working days, while the production of the aluminium mould takes 25 days. Major differences arise from the mould design, which is quite simple in the spray metal mould (an indirect process is used to reproduce the shape of the shell), and from the long machining of the aluminium mould.

5.3. Competitive Economic Scenarios

A simple benchmarking analysis was prepared to assess the potential of creating a company targeting the production of injected parts in small series. Four scenarios were considered:

- Scenario 1 (Baseline) – A mould company using technologies and design methods typical for medium series production.
- Scenario 2 – A company specialized in the production of simplified aluminium moulds for small series [1].
- Scenario 3 – A company specializing in the production of moulds using metal spray technology and loaded resins.
- Scenario 4 (Hybrid solution) – A company using a mixed approach: spray metal and aluminium moulds depending on the production volume and part geometrical and technological complexity.

Table 2 shows the major core investments for each scenario and the minimum number of direct workers. It is assumed that all the scenarios have the same structural costs and that the injection of parts is subcontracted. Based on the work content of a standard mould (the mould of case study) and on the available machine resources it is possible to calculate the annual capacity measured by the maximum number of standard moulds.

Core Investments	Value (€)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
CAD	10.000	✓	✓	✓	✓
CAM	17.500	✓	✓	✓	✓
Milling (CNC-HSM)	250.000	✓	✓		✓
Milling (CNC)	100.000	✓	✓	✓	✓
Spray Metal	36.500			✓	✓
Minimum direct workers		3	3	2	3
Annual capacity (# of standard moulds)		16	21	28	18Al + 9SM

Tab. 2. – Core investments and annual capacity
(Al – Aluminium mould, SM – Spray Metal mould)

Scenario 4 assumes that only 1/3 of the demanded moulds have suitable characteristics for spray metal. In all the scenarios a standard mould produces 200 parts (market demand) sold at 90 € each. One should note that when small production volumes are considered the mould business is designed to provide parts and not to sell moulds.

Table 3 presents a short forecasted income statement, which allowed the calculation of some economic indicators, like the value added per employee, the return on capital employed, the cash flow and the cash flow per employee. Scenario 1, a company designing and producing moulds for small series following the conventional principles of mould making, does not present a sustainable profitability. Note that the cost data for the standard mould regarding this scenario was achieved based on a preliminary mould design request and on a cost inquiry in a company specialised in aluminium moulds. Although scenario 3 offers the higher economic profitability, one should consider that the niche market of small production volumes for this scenario is clearly smaller as far as spray metal technology is not suitable for complex or very accurate parts.

Income statement	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Turnover (1)	288.000	378.000	504.000	486.000
Variable costs (2)	231.224	209.942	225.979	235.711
Added Value (1-2)	56.776	168.058	278.021	250.289
Overheads (3)	43.200	56.700	75.600	72.900
Depreciation (4)	52.916	52.916	26.228	57.478
EBT (1-2-3-4)	-39.340	58.443	176.193	119.911
Indicators				
Added Value per employee	18.925	56.019	92.674	83.430
ROCE	-10,4%	15,5%	107,4%	29,0%
Chas-Flow	13.576	111.358	202.421	177.389
Chas-Flow per employee	4.525	37.119	67.474	59.130

Tab. 3. – Economic indicators

CONCLUSIONS

The production of moulds for cost-efficient small production runs of an increasing variety of customizing products prevails as an important industrial and economic challenge. New mould, materials and engineering concepts need to be developed and adapted for the production of small quantities of highly sophisticated and customized products. The basis of the previous work converges towards its fundamental objective: to lay the foundations for a new mould making business sector: injection moulding for small series production. Innovative tooling approaches based on "shell + substratum" principles were demonstrated, establishing a close comparison with machined aluminum moulds.The case study presented gives a very encouraging expectation relatively to the part injection trials. It also verified the potential of creating a new market slot, specialized on the conception and production of moulds for small series plastic parts. The use of a mixed solution, producing moulds by spray metal technologies and aluminium moulds was considered the most realistic approach.

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