INJECTION MOLDS BEHAVIOR AND LIFETIME CHARACTERIZATION

Concept and design of a Standard Measurement Method

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Abstract

This paper presents the concept of a standard method used to determine the durability of injection molds. In particular, some Rapid Tooling molds are less resistant to abrasive plastics than conventional steel molds. Some evidence of wear in a conventional mold is given, and a specific mold is designed for this test ; polymer materials are defined and the test methodology is outlined. Numerical simulation is utilized to show the areas of the mold subject to high shear stresses.

1. INTRODUCTION

Recent developments in Rapid Prototyping (RP) technology have brought new expectations for fundamental modifications of the development path of industrial products [1, 2, 3]. Time-to-market has been shortened, costs have been lowered, thanks to the reduced importance of prototyping time [4, 5]. RP has also supported the integration of Concurrent Engineering by providing tools and material required for rapid decision-making and fast reaction. However, tooling still had to be prepared by conventional methods.

Different Rapid Tooling approaches exist now, especially in the field of injection molding. Each process has inherent drawbacks, but each allows the fabrication of tools on the basis of a single CAD file, like in Rapid Prototyping, in very short times [6]. However, tool manufacturing is related to more specific requirements, and the mechanical specifications are much more severe than in RP. Rapid Tooling (RT) concerns various production fields, such as foundry casting, forging or injection molding. The latter is at the moment a rapidly growing market for RT vendors. This paper shall deal essentially with the characterization of tooling for injection molding.

Some of the available RT methods are based on the stereolithography (SLA) process ; according to 3D Systems' definition, these techniques can be divided into three classes : Soft, Bridge and Hard Tooling. SLA components are used as patterns for the preparation of rubber molds (silicone RTV), for investment casting (QuickCast™), as a prototype ACES epoxy mold (DirectAIM™), or for the manufacturing of the mold cavity and core (Keltool™) [5, 7]. Other commercial solutions directly generate the hard tool by "welding" metallic powders together, like 3D-printing [8] or Selective Laser Sintering [9]).

Generally, toolings made with rapid technologies have lower properties than those made conventionally, except for the Keltool™ and the RapidTool™ techniques. Especially in the case of the really Direct Rapid Tooling techniques (like SLS) [6], the raw tools surface quality is often poor, and requires time-consuming finishing. Besides, their accuracy is not sufficient and their surface is not hard enough to provide sufficient wear resistance for injection molding.

Many injection tests have been performed on Rapid Tooling molds [5, 8, 10] to assess the efficiency and the advantages of RT methods versus conventional machining, in industrial conditions. However, the test parts, the plastic materials and the injection parameters were always specific to a manufacturer or to a research institute. Little comparison can then be made between the processes, the materials and the improvements, as well as between conventional and Rapid technologies, because of the lack of common features. Furthermore, there is usually little or no information regarding the reasons why the tests were ended (insufficient precision or loss of surface quality).

2. PURPOSE

From the facts described above, it can be readily seen that performances and improvements of Rapid Tooling technologies are difficult to assess and to compare on a scientific and systematic basis, with each other and with conventional techniques. Time and cost comparisons may therefore not be valid, depending on the effective series size, tooling lead time, required surface quality and precision, cycle time, and so on. The purpose of this paper is to present the basic concept and definition of a standard test method for mold durability and quality measurement, as developed at the Swiss Federal Institute of Technology in Lausanne.

Similarly to the stereolithography users' group test part [11], the standard test method involves the design of a mold with specific wear features (describing surface roughness and tolerances requirements), the selection of processing parameters as well as the selection of abrasive plastic materials and the definition of a test methodology. In this paper, some evidence of wear on a conventional mold will first be given ; then, the mold, the material and the methodology selection will be presented, together with computer simulation to validate the choices. The first validation of the method has been made on a conventional mold made in aluminum, so that wear effects can be rapidly observed.

3. WEAR OBSERVATION

Traditionally, injection molds are manufactured by conventional methods, i. e. milling, drilling, EDM, etc., with steels such as *Werkstoff Nr.* 1.2343 or 1.2083. The properties of these molds are such that their durability should be longer than the expected life of the product on the market. However, these molds sometimes fail or present more wear than what is acceptable. For instance, figure 1 shows the worn surface of a steel mold at the injection point. About 20'000 parts in POM were injected in this tool, at an injection pressure of 900 bar and a polymer temperature of 215 °C. Figure 2 shows a surface map of the worn region, measured by laser profilometry. When the gate gets smaller, there is more wear at the runner walls because of increased polymer velocity and shear stress ; when the polymer enters the mold, its abrasive behavior erodes the steel surface. Though the wear effects are relatively small, there is a measurable difference of more than 4 μm between the nominal surface of the mold and the worn surface at the injection point.

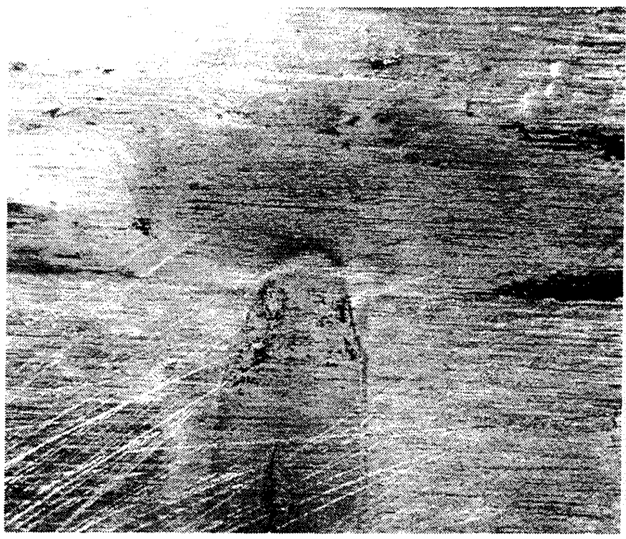


Figure 1 : micrograph of the injection point (mag. 7.5 X)

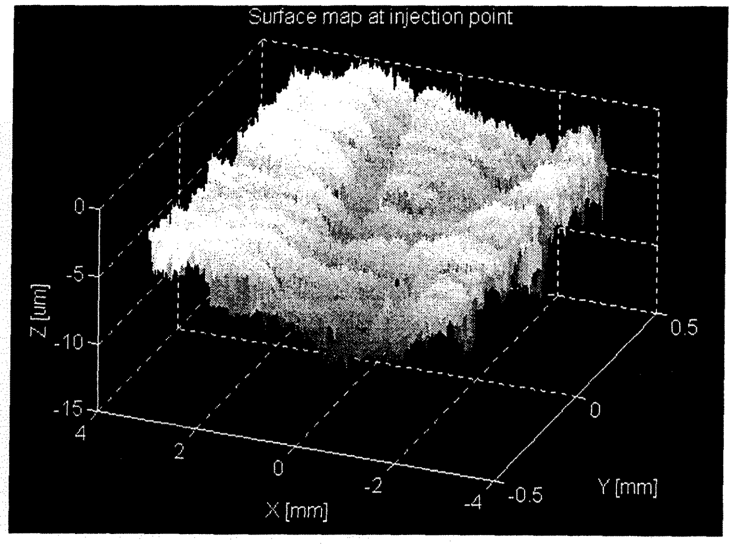


Figure 2 : laser profilometry map at the injection point.

4. STANDARD MOLD DESIGN

The design of the standard mold was made in collaboration with local moldmakers, on the basis of the following criteria : the mold has to be simple so that it can be manufactured easily, rapidly and at a low cost, either by conventional machining or by Rapid Tooling techniques. It must also comprehend typical wear features, and its size has to be compatible with generative manufacturing processes. Besides, the volume of the part has to be small enough to insure short cycle time for fast data acquisition.

Two important mold characteristics were chosen as test criteria : dimensional/angular accuracy and surface roughness. These issues are very important in plastic injection molding, since they influence the injected part functionality and esthetic aspect, as well as the ease of ejection from the mold. The mold was designed on the basis of a relatively simple part, conceived to take into account the desired wear features. The part integrates two plane areas, a slanted plane, two hollow cylinders, rectangular holes and bulges (figure 3). Two types of injection points have been chosen : a standard and a tunnel-type injection point, situated in the "fore" region of the part, so that wear can be observed on a wall directly opposite to it. In the first version of the mold, the standard injection type was chosen, as shown in figure 3. The slanted plane serves to quantify the surface roughness obtained by generative processes, and its modification during service. The holes and bulges give information on angular and dimensional accuracy in the mold.

For the first tests, a first version of the mold has been made in Fortal 60 aluminum (similar to AA7075), with an initial surface roughness CH20 (Charmilles Technologies roughness scale, $R_a \approx 2$ µm).

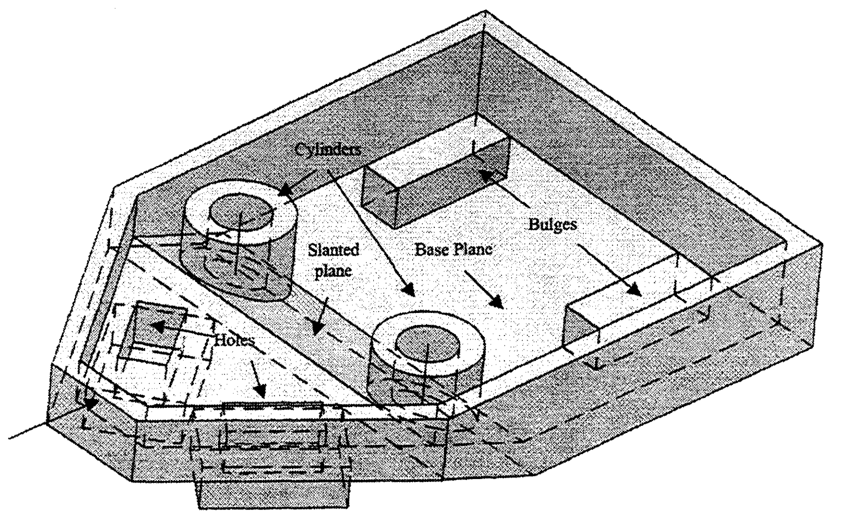


Figure 3 : preliminary version of the standard part. The arrow on the left side shows the location of the injection point.

5. PLASTIC MATERIALS

The purpose of this standard measurement method is to provide a means to view and quantify the wear of molds. Hence, in order to rapidly measure mold deterioration, several plastic materials were selected, according to their abrasive properties, and to their rate of use in industrial production, as well as availability and injection easiness. Glass fiber reinforced polyamide (PA), polypropylene (PP) and polyphenylene sulfide (PPS) comply with these requirements. The first tests were performed with glass fiber reinforced PP (Denilen M3010, similar to Hostacom G3 N01), which is easy to inject, does not require a tight mold temperature control, is readily available and can be recycled with little quality loss. The proposed processing parameters are the following : injection pressure, 900 bar ; polymer temperature, 250 °C ; mold temperature, 30 °C ; clamping force, 200'000 kN.

6. METHODOLOGY

The test methodology is simple, since data can be acquired fast and easily, with no specific equipment needed. Essentially two types of measurement are performed : first, the visual aspect of the plastic part is surveyed during production (by optical or electron microscopy), in order to determine possible mold degradation ; then, the mold is removed from the injection machine and dimensions and surface roughness are determined. A UBM laser light profilometry equipment provides surface roughness values, profiles and mapping, which are also used to determine dimensional variations.

Measurements are performed on explicit locations on the part and on the mold, particularly exposed to abrasive flow. The following measurements are specified :

- On the part : in-production changes of visual aspect, possible variation of wall thickness ;
- On the mold : surface maps and profiles of the plane in front of the injection point, surface map/profiles in the middle of the upper, lower and slanted planes, angles of the holes and bulges, inner diameter of the cylinders.

The mold will be considered “not suitable for production” if the dimensional or the average surface roughness exceed a certain value. If the visual aspect of the parts degrades too much beyond a given point (flashing, burning, etc), the production may also be ended.

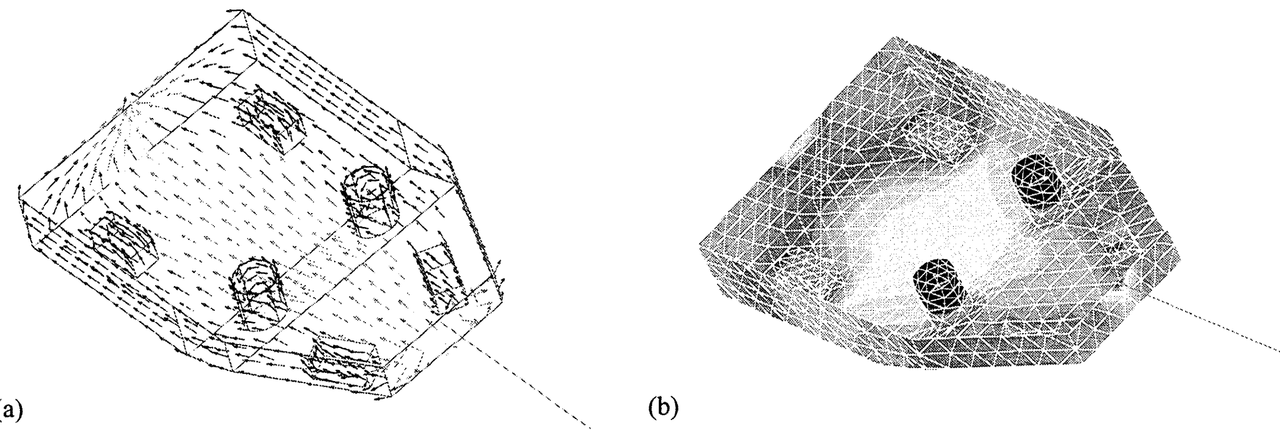
Typically, the mold will have to be removed from the injection machine after each thousand to five thousand cycles ; if visual observation reveals sudden damage, measurements will also be immediately performed.

7. SIMULATION

Recent software packages such as SDRC's I-DEAS MasterSeries 4 include powerful finite-element simulation modules, including thermoplastic or thermoset injection molding. Although simulating the injection molding process is a rather complex task, it is relatively easy to obtain results showing, for instance, the shear stresses generated during the injection of the part, and therefore to visualize the zones that are particularly exposed to the abrasive flow.

As it can be seen in figure 4a, the flow on the plane situated in front of the injection point, as well as on the middle region of the part, is more rapid than in the other areas. The representation of the shear stress generated by the polymer flow substantiates this observation (figure 4b) : the shear is strongest in the plane opposed to the injection point, in the upper plane, in the slanted plane and in the region of the lower plane close to the slanted plane.

The simulation results shows in particular that some of the specific wear features may be purposeless, since they do not seem to be submitted to extreme wear. However, one should bear in mind that finite element simulation may not really provide shear stress values at bulges or holes angles, where the wear effects can be particularly important. Together with the wear evidence presented in section 3, these results served for the definition of the measurement areas.



(a) (b)

Figure 4 : numerical simulation results. (a) Bulk flow vectors ; (b) shear stress. The lighter shades indicate higher values. The light line on the right side represents the injection runner.

8. CONCLUSIONS

This paper has presented the concept of a standard measurement method for the evaluation of injection molds durability. The purpose of this method is to provide a scientific and systematic basis for the evaluation of the different Rapid Tooling methods with each other and with traditional machining.

The surface of a conventional steel mold has been investigated, demonstrating the existence of wear. A preliminary version of the standard mold has been presented, in which wear effects of the polymer flow on specific features can be easily measured. A commercial plastic has been chosen on the basis of its abrasive properties and its rate of industrial use ; indicative processing parameters have been proposed. Finite element simulation has been used to assess the specifically worn areas of the mold, according to velocity vectors and shear stress values. The results have also revealed that some of the wear features integrated in the mold were not necessarily subjected to excessive wear, compared with the high flow rate planes.

Future work will be oriented toward improved mold design for easy wear observation and toward a standardized test and evaluation methodology. More experimental results will allow a better understanding of wear phenomena in injection mold. Finally, the results given by this test method will provide information that will serve as a basis for the definition of the exact improvements required in Rapid Tooling.

9. ACKNOWLEDGMENTS

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