Injection molding of degradable interference screws into polymeric mold

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Injection molding of degradable interference screws into polymeric mold

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Abstract. Nowadays the need for faster development cycle can be found all over in the industry. Rapid prototyping has become a common tool in product development, but available materials in these technologies can not always substitute the materials needed for product. Rapid tooling makes it possible to produce a small series of a product with the same technology and materials as that of the final product. In our work we have used the Polyjet technology (Objet Geometries Ltd.) to produce mold for the injection molding of biodegradable interference screws. Our goal was to produce enough quantity of interference screws for biomechanical measurements, with a technology that is more cost efficient than selective laser sintering (SLS). Two types of mold materials were tested. The first mold was prepared from Fullcure720, an acrylic based, UV curing resin on an Object ALARIS machine. The second mold was prepared with resin casting from AH-12/T-58 (100:40) epoxy resin filled with 25 m% Al_2O_3 powder. For injection molding Natureworks 3051D polylactide (PLA) was used. After injection molding the weight and the geometry of the screws were measured. The results showed that the molds can withstand 5-10 injection cycles, and the screws manufactured meet the requirements for biomechanical tests on porcine knees.

Introduction

Interference screws are used for graft fixation in anterior cruciate ligament (ACL) reconstruction. They can be both manufactured from titanium alloys and biodegradable polymers such as polylactide. Differences in screw geometry can have a significant effect on fixation strength, although mainly length and diameter were studied [1]. It has been shown that screw tapering has a positive effect on pullout strength, but the effect of thread has not been studied yet [2]. With rapid prototyping technologies (RPT) it is possible to manufacture screws with different type of threads, but they would not be suitable for *"in vivo"* investigations. With injection molding it is possible to produce sterilized biodegradable implants, but tooling costs must be also taken into consideration [3]. When rapid tooling (RT) technologies used, mold making time can be considerably reduced compared to the conventional mold making techniques. Metallic based RT technologies have lower accuracy than commonly needed in the industry, need finishing procedures and costs are much higher than in substractive technologies [4]. Although production time of a mold suitable for 10000-100000 shots can be reduced from 8 weeks to 2 weeks [5].

Techniques involving stereolitography (SL) for the production of injection molds are becoming increasingly popular among manufacturers. Parts made with SL can be either used as the model for casted molds, or as the shape giving part of the mold with a backfilling.

Injection molds from metallic powder filled epoxy resin are used with success for injection molding, but these methods require a preliminary model of the final part. Dependent on the RPT technology used for fabricating the model, finishing by hand might be also needed. The molds are made by casting metallic powder filled resins over the finished models into a metallic frame. Cooling channels can be also implemented into the mold, for conformal cooling. With this method

30–1250 parts can be produced, dependent on the part geometry and the material used for injection molding. [6].

Stereolitography can be also used rapidly to produce injection molds themselves. The disadvantage of the technique is that it is capable of producing only a small number of parts before failure. SL parts can be used as injection molds, despite of the low glass transition temperature (~65–70°C) of its materials and the high melt temperature above 200°C during injection molding. Longer cooling period is also needed prior to injection, and after the cycle the mold should be allowed to cool down before the next cycle. Most techniques involving SL use the backfill material in the mold, and steel frame around it. Only the shape giving part of the mold is produced with SL [7, 8]. It must be also noted that the shrinkage for crystalline polymers (PA) in an SL mold can double compared to an alumina mold. Such differences were not demonstrated for amorphous polymers (ABS) [9].

The Polyjet technology from Objet Geometries Ltd. was not developed for rapid tooling, but for rapid prototyping. It uses UV curing acrylic based resins with different material properties for building up the models. There is a wide variety of materials available for Objet machines some mimicking the properties of polypropylene, others having rubbery like behavior. Layer thickness may vary from 16 to 32 μm, depending on the machine used [10].

Experimental

After conceptual screw designs the geometry of the interference screw was finalized. Diameter and length were determined after consulting with practitioner surgeons, performing ACL reconstruction. Thread profile was designed so that it would not copy any of the existing screw. The length of tapering at the screw end was chosen to be ~1/3 of the total screw length. The screwdriver recess (socket) was chosen to be hexagonal, because of manufacturing considerations. The respective dimensions of the interference screw are illustrated on Fig. 2. After finalizing geometry practitioners received prototype screws made with Polyjet technology for verification.

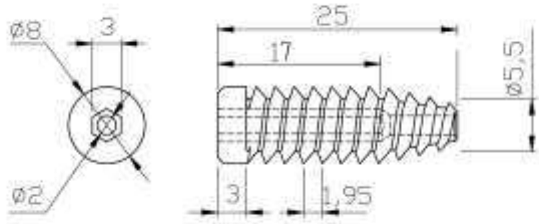

Fig. 2 Main dimensions of the interference screws in mm

Before injection molding simulation were carried out with Moldflow Plastics Insight 6.2 to investigate the possible problems during molding. Filling time, temperature distribution, cooling time, shrinkage and warpage of the screw were investigated. For the metallic insert displacement was calculated. Results showed that maximal volumetric shrinkage would occur in the screw head, but shrinkage of the screwdriver socket would be less than 0.01 mm, which is acceptable.

For injection molding Natureworks 3051D polylactide was used. The material was dried for 8 hours, at 80°C.

Two molds were prepared for injection molding from two materials. FullCure720 resin from Objet Geometries Ltd. was used for the Polyjet technology. After printing the mold a silicone rubber tool was made from it with silicon casting. In the silicon rubber tool the other injection mold was produced by resin casting from AH-12/T-58 (100:40) epoxy resin filled with 25 m% Al_2O_3 powder. For the screwdriver socket and borehole a metallic insert was manufactured with turning from a hexagonal rod having 3 mm diameter. The mold was designed so that two screws could be produced in one cycle, this way the mold would be balanced. No ejector pins were designed into the mold, so the screws had to be removed by hand. Mold closure has to be done with two additional clips, made of sheet metal. The moving plate of the injection molding machine is responsible only for assuring the clamping force needed during molding. Injection molding parameters were kept constant during molding.

The manufacturing process of the screw is shown in Fig. 1, starting from the initial concept to the final part.

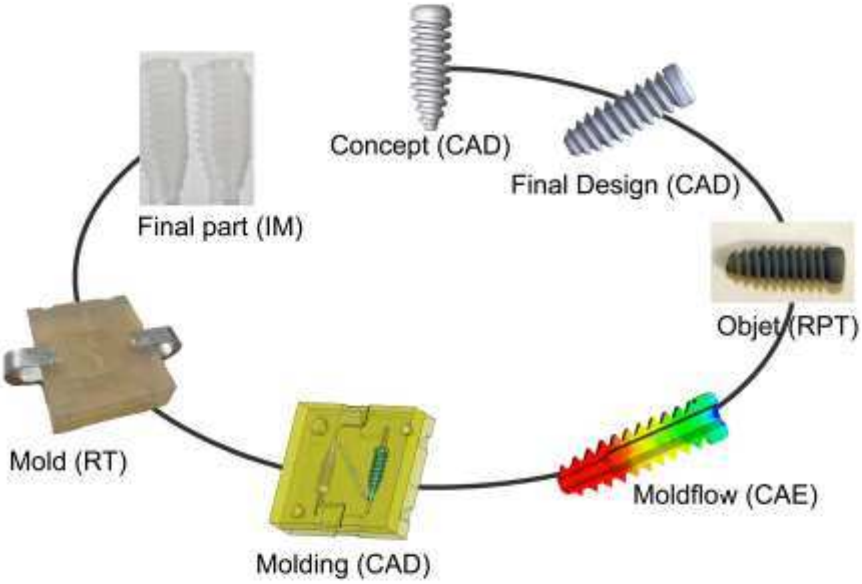

Fig. 1 Manufacturing process from concept to part

Results and discussion

Diameter of the screws was measured with a digital caliper. The caliper was calibrated with a measuring block collection by OMH (Hungarian National Measuring Association). Screw weight was measured on an OHAUS E01140 scale, with 0.1 mg precision.

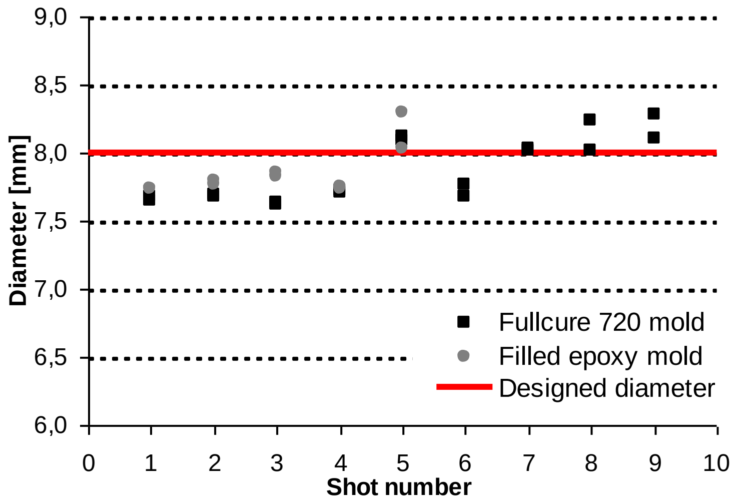

Fig. 3 Diameter of injection molded interference screws

Results showed that transversal (diameter) shrinkage was much higher than anticipated from the Moldflow simulations (Fig. 3), but it showed the similar results as experienced by others in SL molds [9]. Both type of molds showed growth in diameter before breaking. In case of the filled epoxy mold growth in diameter could be noticed only in the cycle before breakage.

Calculated weight of the screw from the CAD model and material datasheet was 0,769 g. Deviation from the calculated mass was different for the filled epoxy mold and the Polyjet mold

(Fig 4.). Weight of the screws was always above the calculated value for the filled epoxy mold, in contrast to the Polyjet mold. Weight started rising during the final cycles which suggest that it is caused by the same process that is responsible for mold brakeage.

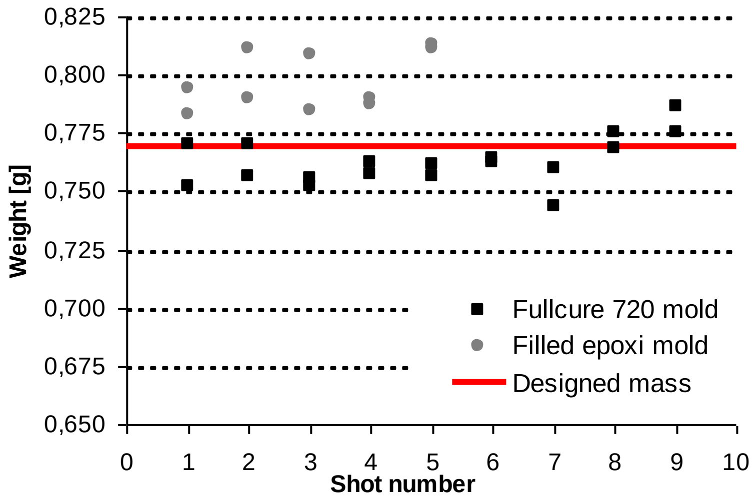

Fig. 4 Weight of injection molded interference screws

Compression tests showed that both materials have similar compressibility modulus at room temperature, but the modulus of the filled epoxy resin drops faster as temperature rises. The lowered modulus of the epoxy resin is responsible the bigger deformation of the mold cavities in the epoxy mold, that lead to heavier screw than calculated (Fig. 5). These results show that, recommendations of SL mold users that suggest enough cooling time for the mold to cool down between cycles, should be taken into consideration for these materials also.

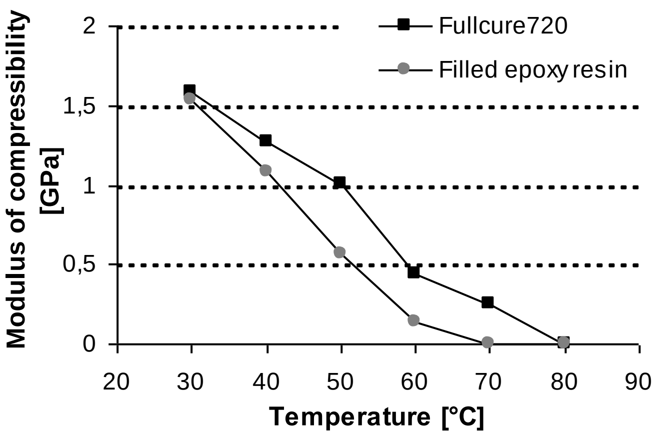

Fig. 5 Compressibility modulus of the mold materials
in the function of temperature

Summary

In our study/work we have demonstrated that it is possible to manufacture injection molds with Polyjet technology from Objet Geometries Ltd for small series. Results also showed that molds made of 25 m% Al_2O_3 filled epoxy resin can be also used, but product mass will be higher than in the Polyjet mold. Since both molds had two cavities a total number of 30 screws were manufactured, 10 in the epoxy mold, 20 in the Polyjet Mold. Processes responsible for mold brakeage should be further investigated, in order to achieve higher shot numbers.

Acknowledgements

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