

Properties of Injection Molded Bioresorbable Glass Fiber Reinforced Composites

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Introduction

Silica based bioresorbable glass fibers remarkably increase the strength properties of PLA based composites [1]. In the past, both continuous and chopped fibers have been used as reinforcements. This study was focused in analysing injection molded PLA composites reinforced by chopped bioresorbable glass fibers.

Experimental

Interference screw shaped ($\varnothing 6 \times 20$ mm) implant prototypes were injection molded from dried raw materials (96L/4D PLA + 20wt-% GF) using Engel e-motion 170/50 TL machine, equipped with custom made raw materials feeder. 96L/4D PLA polymer was derived from Corbion Purac (PURASORB PLD) and glass fibers (GF) were manufactured at Arctic Biomaterials. The injection molding process was optimized using full factorial DOE (Minitab® 17.3.1) in order to optimize the manufacturing process. The adhesion between PLA matrix and bioresorbable glass fibers as well as distribution of fibers in molded samples were analysed by means of scanning electron microscopy (Hitachi TM30303). Fiber distribution was further analysed using micro CT (Zeiss Xradia MicroXCT-400 at TTY / Biomaterial Sciences and Engineering research group). Degradation characteristics were analysed by incubating samples at 37°C in SBF solution [2] for 16-20 weeks. Pull-out resistant force was measured from samples inserted to saw bone blocks (20pcf) with simulated tendon. Inherent viscosity was measured using Ubbelohde viscometer.



Figure 1. Process optimization according to DOE predictions for inherent viscosity (LEFT) and residual monomer content (RIGHT)

Results and discussion

DOE analysis was found to be a feasible tool in optimizing injection molding process. Processing parameters which yield to maximized inherent viscosity and minimized residual monomer content were predicted using the DOE analysis (Figure 1). According to DOE modelling, the samples with initial inherent viscosity of approx. 2.0 dl/g and 2.8 dl/g (prototype 1 and prototype 2) were injection molded. Residual monomer content of all manufactured samples was below 0.1 wt-%.

SEM analysis indicated strong adhesion between PLA matrix and bioresorbable glass fibers (Figure 2). The fiber distribution was shown to be dependent on sample geometry (Figure 3). The fibers on screw thread followed the thread geometry, while the fibers near the driver hole followed the longitudinal axis of the sample. The varying fiber distribution within the samples was deduced to be caused by flow characteristics of the used material during the injection molding process. This was further proven in flow analysis conducted by using Moldex software (Figure 4).

2D Micro CT graphs showed similar results as SEM analysis. Micro CT analysis was also found to be a powerful tool to analyse 3D fiber distribution within samples (Figure 5).

The degradation analysis using simulated bone-tendon-implant combination showed that the both analysed implant prototypes retained the pull-out force above 300N over 16-20 weeks degradation (Figure 6). The reduction of inherent viscosity proved that the degradation process in vitro occurs (Figure 6).

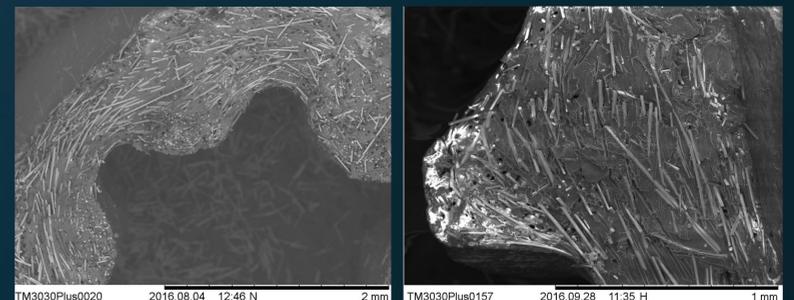


Figure 3. Varying glass fiber distribution analysed using SEM

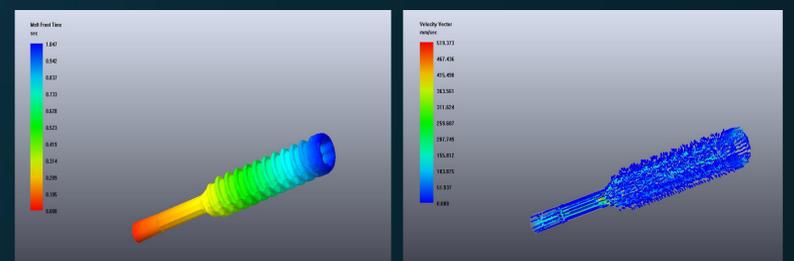


Figure 4. Melt flow analysis according to Moldex simulation. Melt front time (LEFT) and filling velocity factor (RIGHT)

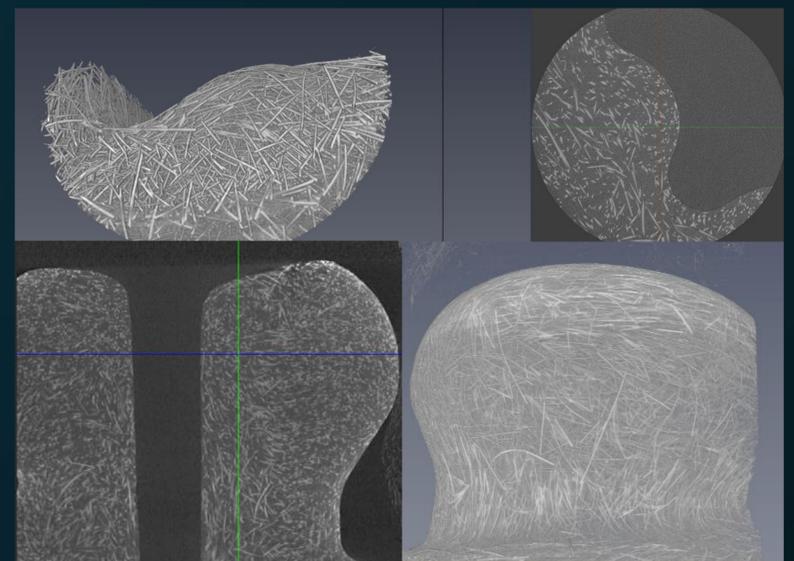


Figure 5. Micro CT imaging showing the 3D distribution of glass fibers

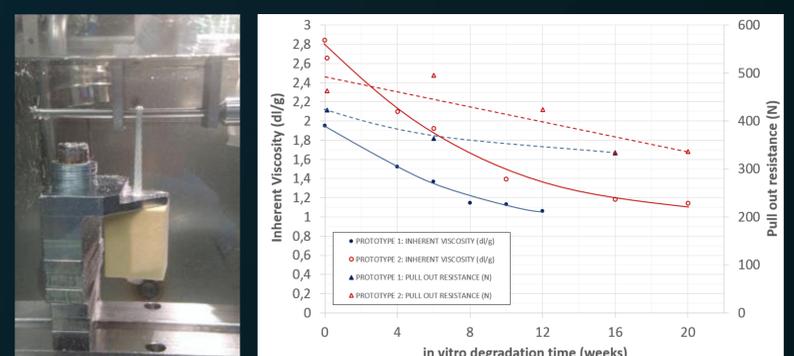


Figure 6. Pull-out test set-up from saw bone (LEFT) and degradation characteristics of injection molded implant prototypes

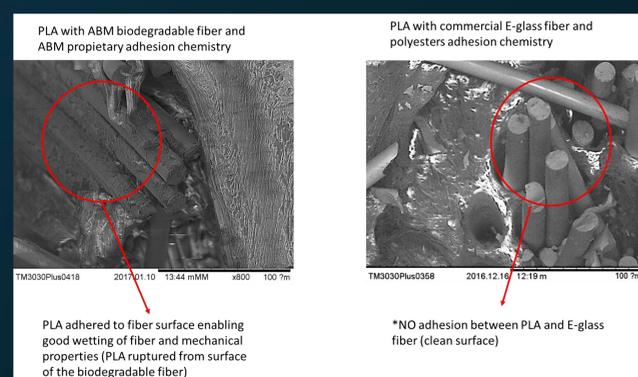


Figure 2. Adhesion of PLA matrix and glass fibers.

Conclusions

Investigational implant prototypes were successfully injection molded from 96L/4D PLA matrix and silica based bioresorbable glass fiber reinforcement. The adhesion between fibers and matrix was visible from SEM micrographs, which also revealed variable distribution of fiber reinforcement. In vitro degradation analysis revealed that in simulated conditions the studied composite and implant design combination retained pull-out force above 300N over 16 – 20 week follow-up.

References

- [1] Lehtonen T-J, et al Acta biomaterialia, 9(1): 4868-4877, 2013
- [2] Kokubo T., Takadama H., Biomaterials, 27, 2907-2915, 2006