3D Printed Durable Flexible Memory Thermo Plastic Copolymers for Packaging of Optical Components

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Abstract: Embedding fibre Bragg gratings (FBGs) in memory retaining flexible thermo plastic copolyester is assessed. (john.canning@uts.edu.au). © 2020 The Author(s)

1. Introduction

Optical components, such as Fibre Bragg gratings, need packaging for field use. FBGs are of particular interest because they are an excellent in-line sensor. This demands rugged and long-term reliability. However, their packaging has not been trivial. In telecom this has led to a substantive cost factor around stabilising and isolating the sensor from the environment [1,2]. In sensing, the opposite is often required - sensitivity to the environment but this sensitivity needs to be reproducible and durable. That too can place demands on packaging since it needs to survive dynamically harsh environments [3]. Here, I assess our recent work in embedding FBGs within 3D printed flexible plastic insoles produced by fused deposition modelling for gait measurements from this packaging perspective. This is to emphasize the significance of one set of plastics: thermo plastic copolyesters (TPCs) as an ideal absorbing flexible package for fibre grating and optical components and sensors generally.

2. TPCs

There is a simple reason why plastics or polymers of various sorts are attractive packaging materials. The volume expansion is higher in the liquid state than in the solid state, which leads to instant compression on any embedded object as the plastic solidifies. With supporting design, no adhesives or special preparations are required. For this reason, embedding optical fibres and optical components and sensors in plastic works well, with the quenching and annealing rates highly tuneable to control the imparted pressure if one so desires.

In the insole work [3], plastic used was a thermo plastic copolyester (TPC). They are a class of thermoplastic elastomers (TPEs) that combine many of the properties of both thermoplastics and rubbers, demonstrating thermoplastic behavior and structural strength whilst exhibiting elasticity and resistance to impact and flex fatigue. This is important because at low strains, these materials have a low hysteresis, behaving like a perfect spring with ideal elasticity. Their shore hardness, or resistance to indention can readily exceed 60D (the higher the value the more resistant and durable but less flexible or soft). They recover quickly and effectively. In addition, these materials possess excellent resistance to temperature, UV exposure, oils and chemicals and have high service temperatures making them ideal for long term, external field applications.

Such properties combined with their amenability to injection molding, mean TPCs have replaced metal, general rubbers, composites of rubber with metal, glass, and fabrics without reinforcement. They are used predominantly in automotive parts/components (an estimated 45–46% of total world consumption in 2016 and 2017), hose and tubing (17–18%), medical uses (10–11%), and wire and cable (8–9%). In other words, this is a very well-developed industrial plastic making it extremely attractive for sensor applications. The ability to 3D print these into any arbitrary shape is literally transformative.

In order to explore these properties, I focus on that available for 3D printing that we reported previously: commercially available Flexfil [4]. Like most TPCs, it retains a so-called “flexural memory” that allows full recovery of a plastic after an applied strain, allowing objects to return to their original position or shape after being bent. This memory comes with a slightly reduced shore hardness of 45D. The environment, external or indoors, of an application is also an important factor when selecting a packaging design for an FBG sensor. Their UV resistance and high fire rating (IEC 60695-11-10 Flammability classification: HB) makes them ideal for 3D fused deposition printing (FDM) rather than photopolymerized approaches which tend to produce less stable plastics. Given plastics also have significant environmental concerns (a growing consideration in engineering), it is interesting to note that Flexfil claims to have a 43% renewable bio-based content.

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3. Insole response and sources of measurement error

The introduction of an FBG (direct written through a phase mask with 193 nm from an ArF laser) into the Flexfil format was relatively straightforward with 3D printing (transformative from a packaging perspective). However, this may be misleading if grating writing is not optimised for the packaging process – high intensity 193 nm pulsed light used to accelerate grating writing leads, through two step photoexcitation and enhanced absorption, to asymmetric index change across a fibre optic core [5]. This needs consideration when mounting within the plastic rubber – applied load is also geometry dependent with chirping and short wavelength shifts influenced by the orientation of the FBGs (those facing out of plane and those facing in-plane). Because of the applied load, $w \sim (5.5 \pm 0.1)$ g, the FBG spectra of the gratings shifted to short wavelengths by more than $\Delta\lambda_B \sim 10$ nm and their bandwidths increased to over $\Delta\lambda \sim 8$nm. This arises from compression effects along the FBG, which is influenced in part by the direction of FDM printing as well as the applied load. The plastic compression upon solidification is important because it fixes strongly the FBGs within the TPC enabling reliable and repeatable measurements as reported earlier.

This was not exactly the same for each because of the FBG orientation during 3D printing overlayers of the insoles – orientation and penetration across the core also impacts contributing polarisation and varying amplitudes, also seen across the seed gratings. Consequently, the four embedded gratings varied in terms of induced chirp. This variation contributed to the monitored response because there was an interrogation variation in tracking arising from the FBG bandwidth. The reported results are reproduced in Figure 1. More information about chirping can be found in [3]. These various contributions along with amplitude differences in the seed gratings, appears to be the main source of difference and variation between sensors observed experimentally.

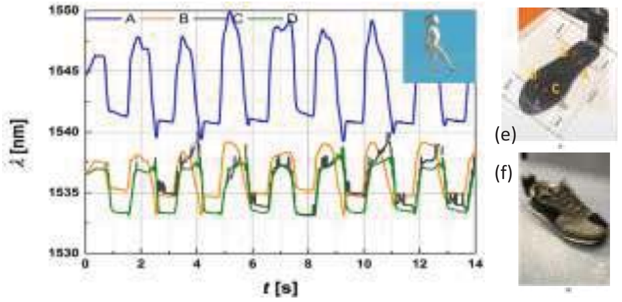

Figure 1. Example of the reported results in [3]. Four sensors in the insole are affected by different loads from the Student Under Test (SUT - Z. Hao [3]). The four sensors are showing the data gathered by a walking on the spot adopted by the SUT. Signals for the back-heel sensors (A), (B) and front end foot sensors (C & D) show an asymmetric load bearing on the insole. What is of particular note is the signal response of senor (C) – the Micron Optics interrogator was struggling to keep track of the peak, arising from too much chirping on this FBG [6].

4. Conclusions

TPC polymers, the bridge between rubbers and plastics, are ideal for grating packages offering reliable long-term performance for FBG sensors. Sources of variation in the previous work can be explained by complications in the grating writing process and grating insertion during 3D printing rather than a materials property. Effectively, considering grating asymmetry along with removing chirp, will significantly improve results to a point where the technology is ready for commercial applications. This is suggestive that TPC polymer plastics are a useful packaging material for field-testing.

5. References

[1] G.W. Yoffe, P.A. Krug, F. Ouellette, D.A. Thorncraft, "Passive temperature-compensating package for fiber gratings," Appl. Opt. **34**, 6859 (1995)

[2] D.C. Psaila, H.G. Inglis, "Packaging of optical fibre Bragg gratings", *IEEE Proc. 51st Electron. Components & Tech. Conf.* (2001).

[3] Z. Hao, K. Cook, J. Canning, H. Chen and C. Martelli, "3-D Printed Smart Orthotic Insoles: Monitoring a Person's Gait Step by Step," in *IEEE Sensors Letters*, **4** (1), 1-4, (2020). Art no. 5000204.

[4] https://www.formfutura.com/shop/product/flexifil-natural-223

[5] M. Janos, J. Canning, M.G. Sceats, "Incoherent Scattering in Optical Fibre Bragg Gratings", Opt. Lett., **21** (22), 1827, (1996)

[6] A. Ziyani, J. Canning, "Using Additive Manufacturing to Package and Chirp Fibre Bragg gratings", CLEO PR, Australia (2020)