Using Additive Manufacturing with Blow Moulding to Facilitate Accurate Consumer Testing

Abstract

A South African entrepreneur needed a fast and accurate route to consumer testing for a design of phlegm collection bottle for long-distance runners. Vaal University of Technology was presented with an initial product concept which had to be developed into a fully functional prototype required for field trials. The idea was converted into a practical product proposal and modelled using a 3D computer aided design (CAD) system. The CAD data were used for laser sintering of polyamide to produce an initial prototype for appearance and ergonomic evaluation. For product testing in the field, a short run of fully functional prototypes in thin-walled low density poly-ethylene (LDPE) was required. This required a further design iteration and the production of tooling for the blow moulding process. A novel hybrid modular approach to tool manufacture was followed, where the outer frame of the tools were machined in aluminium and the tool inserts were laser sintered in Alumide^{TM}. Blow moulding trials were undertaken in LDPE which revealed a number of positive and negative issues. The rough surface of the tool inserts produced a desirable textured surface in the resultant blow-moulded bottles but also prevented a clean "shut-off" between the two halves of the tool. This allowed air to escape from the cavity along the split plane, creating unwanted holes in the bottles. In addition, the low thermal conductivity of Alumide^{TM} resulted in an unwanted overheating of the tools. Strategies were identified to overcome these issues and these are explained in the paper.

Keywords: Consumer testing, Additive manufacturing, Hybrid Tooling, Blow Moulding

1. Background

Consumer testing plays a vital role in the new product development (NPD) process. At various stages in NPD it can be used to evaluate alternative concepts, to determine product performance levels and for final verification of a design before full-scale production. It is beneficial to use prototypes for testing that bear a close resemblance to the final product, both in terms of appearance and functionality. This will help to ensure accurate results are obtained from consumer tests (Campbell et al, 2007a). The ability of additive manufacturing (AM) models to meet both aesthetic and functional requirements was one of the reasons for its early adoption by product manufacturers as a means of "rapid prototyping" (RP). Never-the-less, the range of materials available with AM processes is still rather limited and so fully representative prototypes (faithfully representing aesthetics and function) cannot always be obtained from a single AM technique. In an attempt to remedy this, some researchers have been investigation multi-material AM systems (Espalin et al, 2012) and of course, the Objet Connex systems also available. Never-the-less, direct fabrication of the prototype may not be suitable with any AM technique and so a secondary processing stage is required. So-called rapid tooling (RT) is one such process, where AM is used to produce tooling that is then used to manufacture the prototype(s).

Rapid tooling has been used for many years with the aim of providing earlier and sometimes cheaper tools in comparison to using computer numerical controlled (CNC) machining. There are a variety of strategies for using RT (Campbell et al, 2007b) including “bridge tooling” to enable advanced production of final parts until the production tool becomes available (de Beer et al, 2005) and “prototype tooling” where the tool is used only for production of prototypes (Booysen et al, 2006). Various claims have been made as to the benefits of RT, including lower costs, reduced lead-times (and even better performance through conformal cooling (Dalgarno and Stewart, 2001, Ferreira and Mateusb, 2003, Norwood et al, 2004). However, there has also been debate as to whether the quality of parts coming from RT is comparable to those coming from production tools (Segal, 2001). The popularity of RT (especially around the turn of the century) has led to several researchers offering advice on how best to design these tools. Rosen et al (2003) investigated the use of Group Technology to support design of rapid tooling. Volpato and Childs have proposed shelling strategies to reduce the material usage and build time for rapid tools (Volpato and Childs, 2003). Booysen (2006) has described eleven tooling design considerations for another specific RT process, namely 3D System’s SLS process using LaserForm™ A6 steel. Such advice was consulted when designing the prototype tools used during this case study.

The work reported here used a combination of RP and RT to provide a range of prototypes that met various requirements for consumer evaluation. Such a combination has been used before (Chiang et al, 2005) and the benefits of RT in bringing earlier and more meaningful consumer feedback have also been reported (King and Tansey, 2002). Additive manufacturing has previously been applied to blow moulding tools, but only for metal inserts (Houtekier et al, 2008). The novel aspects of this work were the use of RP in combination with hybrid tooling (made through a combination of additive and subtractive processing) and the application of Alumide™ material to blow mould tooling. The literature does not report previous use of this material for blow moulding tools. Such an approach was necessary to achieve the design and cost requirements of the product being tested.

2. Design Brief

This paper follows a case study which began when a South African entrepreneur approached Vaal University of Technology (VUT) looking for a fast and accurate route to consumer testing. The product idea was for a phlegm collection bottle for long-distance runners. This product was devised to overcome both the environmental and psychological problems associated with runners spitting on the ground. The entrepreneur had developed an initial product concept and was directed to the Technology Station at the VUT with the aim of developing this into a fully functional prototype required for field trials. The specific requirements for the product design were as follows:

- The product had to be lightweight for carrying over long distances
- It had to fit comfortably in a range of hand sizes
- Disposable and cost effective,
- Recyclable plastic material

An experienced industrial designer took the idea and turned it into a practical product proposal, firstly through sketching and then 3D modelling using a computer aided design (CAD) system. A CAD rendering of the first iteration of the complete design is shown in Figure 1.

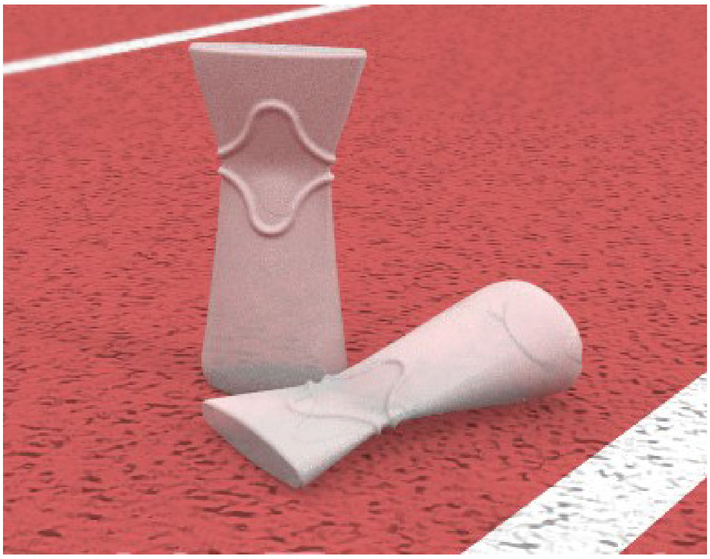

Figure 1: CAD rendering of first iteration of complete product design.

3. Appearance and Ergonomic Prototype

The first prototype requirement was for a model that showed the overall shape of the product and that could be assessed for ergonomic suitability, i.e. was it comfortable to hold over extended periods of time. It was necessary to produce a model that looked like the final product and that a similar weight. It was intended to make the final product in an injection moulded thermoplastic and so a plastic prototyping process was chosen. Therefore, to arrive quickly at the initial physical prototype, the CAD data were converted to the STL format and used for laser sintering in polyamide material on an EOS P390 machine. Figure 2 shows this prototype (built with and without a sacrificial top which would be removed after blow moulding). This prototype was useful for appearance and ergonomic evaluation but had neither the wall thickness nor material properties to provide full functionality.

Figure 2. First prototype made from laser sintered polyamide

4. Prototype Tooling

The decision was taken to create a short run of fully functional prototypes in thin-walled blow-moulded low density poly-ethylene (LDPE). This was in line with the likely material and production process to be used for the final product. A further design iteration was required to incorporate the features required for blow moulding, such as a split plane with associated draft angles. The high cost and long lead-time of CNC machining complete tools suggested that AM should also be used for production of the required tooling for the blow moulding process. The use of laser sintered RT had proved to be very effective in previous projects. Building on past experience, a hybrid modular approach to tool manufacture was followed, where the outer frame of the tools were machined in aluminium and the tool inserts were laser sintered in Alumide™ . This material is essentially a composite mix of polyamide and aluminium powders (ratio 50/50 by volume) that can be used in several of the LS machines sold by EOS. The partially disassembled tool is shown in Figure 3 with one of the laser sintered inserts on the right. The fully assembled tools are shown in Figure 4.

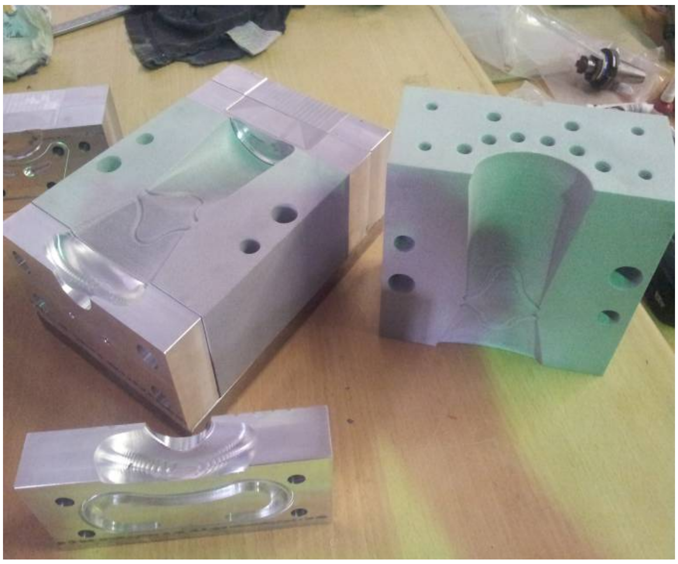

Figure 3. Partially disassembled tools.

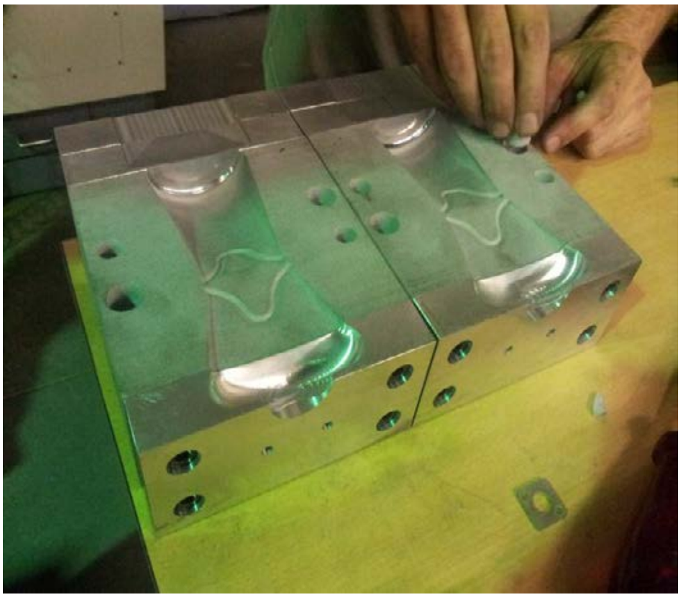

Figure 4. Fully assembled blow moulding tools.

5. Blow Moulding Trials

Using the hybrid tools, blow moulding trials were undertaken using LDPE, which revealed a number of positive and negative issues with the approach. Firstly, the use of LS gave the tool inserts a textured surface which translated to a desirable grip and opacity in the resultant blow-moulded bottles (see Figure 5). Secondly, the rougher surface of the inserts prevented a clean "shut-off" between the two halves of the tool. The blow moulding process requires a continued blowing of air to form and cool the polymer in order to obtain the intended shape. When the two halves of the tool were clamped together, air was able to escape from the cavity along the split plane, creating unwanted holes in the bottle (see Figure 6). Thirdly, the thermal conductivity of Alumide™ proved to be much lower than what was expected, i.e. 0.5 to 0.8 W/mK (EOS, 2013) as compared to 205 to 250 W/mK for solid aluminium (Engineering Toolbox, 2013), and this resulted in an unwanted overheating of the tools. This meant that the quality of parts from successive shots would deteriorate unless substantial cooling with high pressure air was used between shots. As a result of these issues, only a small number of satisfactory parts were obtained from the trials.

Figure 5. Desirable textured finish on the bottles.

Figure 6. Unwanted “blow holes” along the bottle split plane.

6. Resolving the tooling issues

The two tooling issues that needed to be resolved were the lack of clean “shut-off” and unwanted overheating of the tools. Regarding the first issue, manual polishing of the interface surface of both tool inserts to give a smoother surface was considered. However, this posed two problems. Firstly, the thickness of material removed was both difficult to control and variable across the tool. Secondly, an equivalent thickness of material would also need to be removed from the outer aluminium frame of the tool. Therefore, to give precise control of the removal of material and to maintain uniformity with the surrounding frame, the decision was taken to “skim” machine the assembled tool to a depth of 0.7 mm. To avoid unwanted modification of the bottle geometry, this would have to be preceded by addition of a machining allowance to the original tool frame and insert designs. The sharp “shut-off” edge created by machining the surface of the assembled tool is shown in Figure 7.

Figure 7. Skim-machined shut-off edge.

Regarding the second issue of unwanted overheating, two strategies were considered. The first was the introduction of conformal cooling channels closer to the internal surface of the Alumide™ inserts. The original tool design did use water cooling but this was by means of simple straight channels. However, with the thermal conductivity of Alumide™ being so low, it was calculated that the channels would have had to be so close to the surface of the inserts that the minimum acceptable wall thickness would not be maintained. Therefore, a second strategy was investigated, application of an aerosol cooling spray to the internal surfaces of the inserts between shots. This is a technique that was applied successfully for Stereolithography tooling which also had a very low thermal conductivity (Rahmati, 1997). A number of cooling sprays are available but one that also acts as a release agent would be preferable.

7. Conclusions

The work reported in this paper indicates that it is sometimes necessary to use a combination of AM techniques and materials to satisfy the needs of an NPD project. This confirms the findings of a previous review (Campbell et al, 2012) and is typified by the different materials used in the hybrid blow moulding tools that were produced. It would be unwise for any design team to rely totally upon a single AM machine, despite the fact that their price is decreasing. This leaves room in the market place for bureaus and other service providers who have access to multiple platforms. In this case, AM was used for RP during initial stages and for RT at later stages. Despite the high degree of research focus upon AM as an end-use part production process, its application in the older areas of prototyping and tooling should not be neglected. There are still plenty of research issues to be addressed in these areas, particularly as low-cost AM systems become more available and accessible as prototyping technologies. The paper has also shown that a combination of additive and subtractive technologies proved useful for the production of blow moulding tools. This hybrid approach could also be applied to the manufacture of end-use parts, particularly when there is a need for some features to have high accuracy. Although the full quantitative benefits of this approach have not yet been fully assessed, it is possible to say that the development time for the functional prototypes was reduced by around 50% compared to previous projects undertaken. Finally, the work has demonstrated that there are still many opportunities for materials development within the field of AM. A greater range of engineering plastics is needed (e.g. including LDPE) for prototypes and end-use parts.

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