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ELASTOMER OVERMOLDING OVER RIGID 3D-PRINTED PARTS FOR RAPID PROTOTYPES

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Abstract: *Product designers and engineers can benefit from the rapid production of prototypes with characteristics that closely resemble those of finished products. In the case of plastic objects which include rubber-like surfaces, existing manufacturing options are either expensive or are impractical, limiting their use of rapid prototypes. This paper presents a method of fabricating rapid prototypes by combining rigid and soft materials through an overmolding process, thus providing a fast and cheap way to obtain feedback regarding form-and-feel characteristics during the design process. Functional objects can be also produced using the proposed method, enhancing part design freedom. Elastomers are injected or cast into molds attached to 3D-printed rigid parts in order to form functional soft surfaces. Several solutions of binding elastomer to parts fabricated using Fused Filament Deposition (FDM) are presented, including multiple ways to produce the bonding of materials. Chemical bonding and mechanical bonding using specifically designed geometries or exploiting the interior structure of 3D-printed parts are proposed. Objects made from rigid plastics overmolded with elastomers are produced for exemplification. A time and cost analysis is also included as reference and for comparison with other manufacturing methods.*

Keywords: *3D Printing, prototyping, form and feel, elastomer, overmolding.*

1. INTRODUCTION

One of the advantages of Additive Manufacturing (AM) technology is that it allows the validation of design concepts by making the physical prototypes of products available early in the design process [1]. However, quite often these prototypes are limited to one material even if, for a correct design evaluation, there is a need to have a multi-material model which can exactly mimic the real product. In this context, developing methods to manufacture inexpensive objects with complex geometries, combining soft and rigid materials represents a valuable support for product designers. Thus, not only the product form and dimensions can be validated, but also other characteristics such as the product feel when held or during use. Moreover, producing such multi-material objects can sustain design freedom by providing additional functionalities to different components [2]. Robotic joints made of heterogeneous material [3], compliant mechanisms [4], or multi-material prosthetics [5] are examples of functional objects that can benefit of the multi-material soft-rigid approach.

According to the International Union of Pure and Applied Chemistry (IUPAC), an elastomer is a "polymer that displays rubber-like elasticity" [6]. These polymers exhibit molecule chains which are held together by relatively weak intermolecular bonds which allow the materials to stretch under macroscopic stresses. In industry, elastomers are commonly used in the production of handles and gripping surfaces for tools and household items [7], vibration dampeners [8], or insulation for electrical and electronic components [9]. The key process used to fuse the elastomer to a rigid part is called overmolding and the material the elastomer is being molded onto is called a substrate.

In AM, two or more materials can be mixed and then used as feedstock, or added one next to another in a discrete manner [2]. Currently, prototypes which combine rigid plastics with rubber-like materials can be made through PolyJet technology, a process which uses UV-curable thermoset resins [10]. While the process can produce multi-material parts, the mechanical properties of these parts are inferior and manufacturing cost is high [11].

Another AM process, Fusion Deposition Modeling (FDM), also has the capability of using multi-material additive fabrication to create parts made of rigid plastic combined with thermoplastic elastomers, with the use of machines with multiple extruders. Such a 3D printer can alternate between active extruders in order to build the multi-material part by depositing one material at a time. However, this fabrication process presents difficulties because of material properties. Typical FDM printers use raw material in the form of standardized round section

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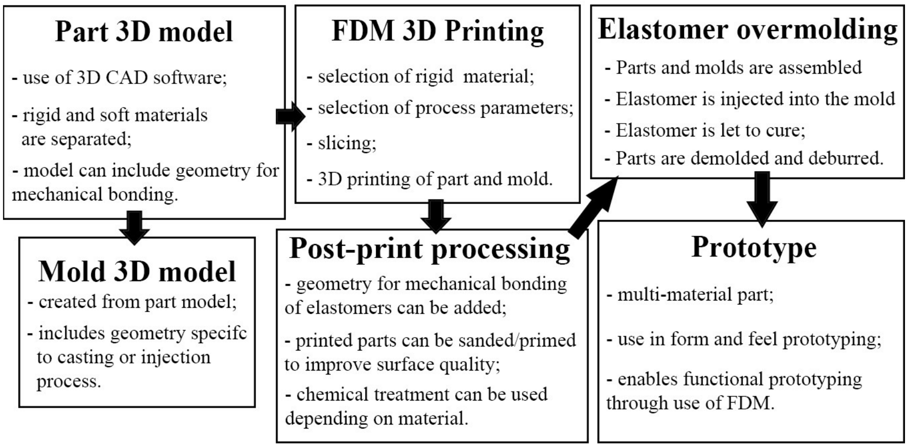

Fig. 1. Manufacturing method schematics.

filament. The low Young modulus of the thermoplastic elastomers suitable for use in additive manufacturing makes them difficult to use in the typical extrusion systems of FDM printers.

This paper looks into new solutions of creating rapid prototypes using elastomers and 3D-printed parts fabricated through an FDM process. These are based on a new manufacturing method (Fig. 1) that can be applied to different types of objects and in different fields. Several case studies consisting of prototypes made with FDM-fabricated substrates from common rigid materials such as PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene), and overmolded with various elastomers are presented.

2. METHODS OF BONDING ELASTOMERS TO RIGID FDM 3D PRINTED PARTS

In order to create multi-material parts, a method which bonds these materials together is needed. There are two distinct possibilities: chemical bonding, when the materials adhere chemically to one-another, and mechanical bonding, where geometry of the substrate is used for locking the elastomer in place. In overmolding applications, one of these methods, or a combination of both, is used.

Chemical bonding is feasible when the chosen elastomer can chemically react with the type of plastic the substrate body is made of, or if an adhesive can be applied on the surface of the rigid material before the part is overmolded. In this case, if the mold (or mask) is made of the same material as the part, a release agent needs to be used for the 3D-printed mold. This drives up production costs and labor needs and is one additional source of errors. The advantage of chemical bonding is that the elastomer can be bonded directly to the 3D-printed part without any special geometry added to the model [12]. Figure 2,*e* shows a 3D-printed prototype of a pair of ski goggles which includes a rigid frame with an overmolded soft and flexible padding suitable for skin contact. The substrate consists in the frame of the ski goggles and was manufactured out of PLA (Fig. 2,*a*). A half mold has been designed and 3D-printed using the same material (Fig. 2,*b*). Designing the half mold for overmolding was done starting from the digital 3D model of the rigid frame. A layer of mold release agent (Polydimethylsiloxane 350 cSt) was applied to the mold piece before fixing it to the rigid frame (Fig. 2,*c*). Adhesive was applied to the rigid surface and an RTV (Room Temperature Vulcanizing), condensation-cured silicone rubber was injected into the mold. After curing, the mold was removed, leaving a 5 mm thick band of soft material bonded to the frame (Fig. 2,*d*).

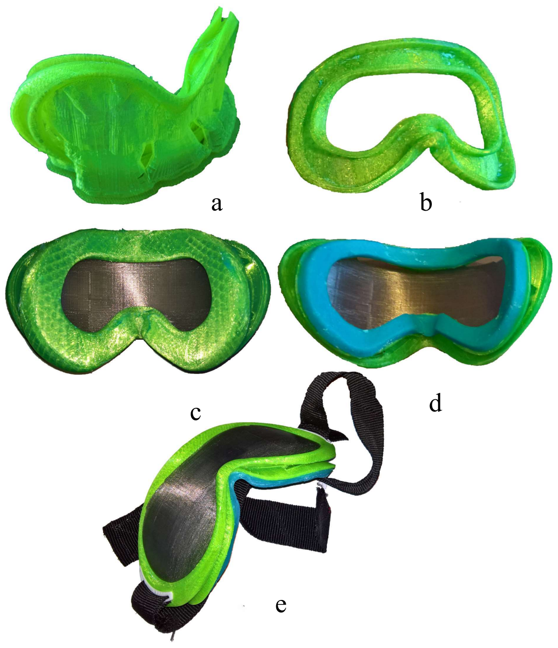

Fig. 2. Ski goggles prototype: *a* – 3D printed goggles frame; *b* – 3D printed half mold; *c* – half mold mounted on the frame; *d* – silicone band after demolding; e – ski goggles prototype**.**

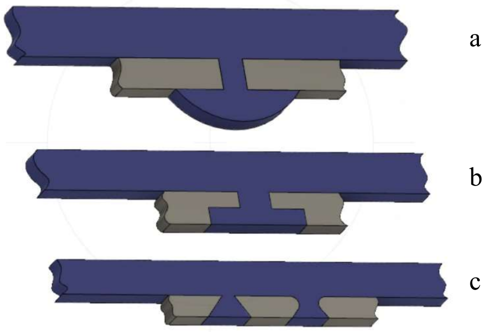

Fig. 3. Joint types for mechanical bonding.

Mechanical bonding is used when the chemical bonding is insufficiently strong or when the bond would deteriorate in time under operating conditions and mechanical stress. Figure 3 shows several types of geometries used for mechanical bonding which can be integrated into the design of the prototype. Overmolded elastomer can protrude through the substrate and fix itself on the other side of the substrate, a method which can be applied when the back surface does not have a functional role which can be impaired (Fig. 3,*a*). For parts with thicker substrates, the mechanical joint can be embedded within the substrate (Fig. 3,*b*). For thin parts, the overmolded material can be fixed to the substrate using dovetail joints (Fig. 3,*c*).

3. DESIGN OF MECHANICAL BONDING JOINTS FOR OVERMOLDING OF FDM 3D - PRINTED PARTS

FDM has the advantage over other manufacturing techniques of being able to fabricate overhanging surfaces, thus allowing the creation of internal voids in the finished part. For form-and-feel prototypes, before the stages of design for manufacturing, various geometries can be embedded in a substrate material to create mechanical joints for elastomer.

Figure 4,*d* shows a 3D-printed prototype of a handle for a ratchet screwdriver. A rigid core contains embedded channels which form the mechanical joints for elastomer overmolding (Fig. 4,*a*). The dimensions of these channels should be sufficiently large to allow the elastomer to flow inside under pressure and to fill them. In the case of the screwdriver handle, 3 mm diameter channels provide sufficient bonding. The core was 3D-printed from PLA/PHA (Polyhydroxyalkanoates) (Colorfabb). The two-piece mold was fabricated using the same process and material (Fig. 4,*b*). After printing, the core was inserted in the two mold halves which were aligned and fixed together using screws. Thermoset silicone rubber was then injected into the mold. No mold release application was necessary, as no chemical bonding occurs between the silicone and PLA. After curing, the part was demolded (Fig. 4,*c*).

Figure 5,*c* shows the prototype of a tape measure with a rubber outside shell. A two-piece mold (Fig. 5,*b*) was used to inject silicone rubber around the substrate (Fig. 5,*a*). The substrate and the mold were 3D-printed from PLA (Filamentum) material. No mold release was used as there is no chemical bonding occurring between the silicone and the substrate. No specific geometrical features have been designed in order to create mechanical bonding joints. After demolding, the two materials are held together by the tension created by the elastomer, whose volume reduces after curing [13], [14]. For this prototype, the section of the elastomer wrap can be as thin as 1 mm.

Figure 6,*c* shows a 3D-printed prototype of a swivel caster wheel used in office furniture. The rim and the body of the caster were 3D-printed from PLA material. A soft RTV silicone rubber was overmolded onto the rigid rim to form a soft surface that does not damage the floor. Overmolding was done through material injection in a 3D-printed two-piece mold made from PLA (Fig. 6,*a*). After curing and demolding, no chemical bonding occurs with the two materials being joined together through two mechanical means. The first means is through a series of dovetail holes embedded in the rigid rim model. The second means is through the elastic tension created

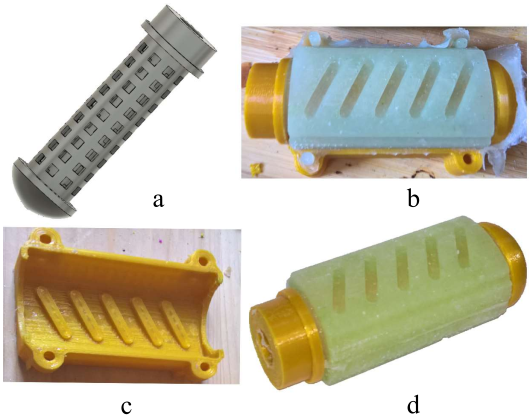

Fig. 4. Screwdriver handle prototype *a* – handle geometry; *b* – 3D-printed mold; *c* – part after curing; *d* – handle prototype.

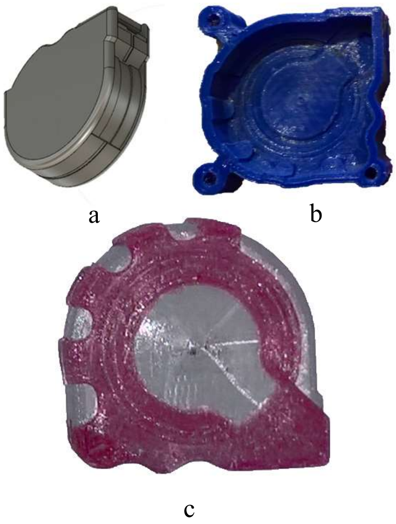

Fig. 5. Tape measure prototype: *a* – tape measure body; *b* – 3D-printed mold, 1 of 2; *c* – finished tape measure prototype.

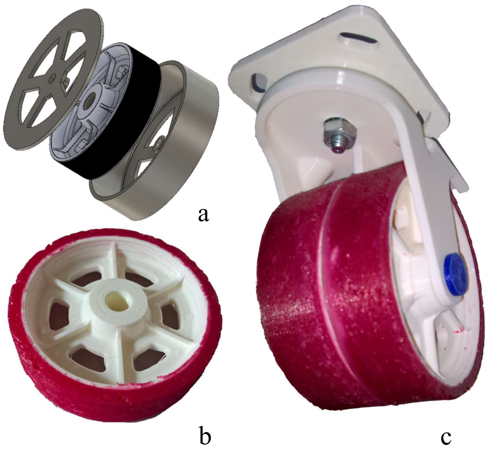

Fig. 6. Caster wheel prototype: *a* – mold and wheel rim; *b* – wheel with rubber tire; *c* – finished caster wheel prototype.

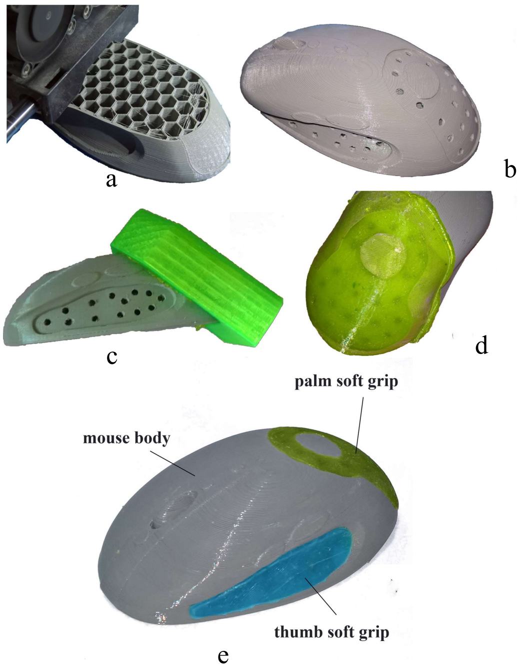

Fig. 7. PC Mouse: *a* – cellular structure of 3D printed body; *b* – drilled surfaces for mechanical bonding; *c* – substrate with attached half mold for palm grip injection; *d* – part with soft palm grip material after demolding; *e* – finished mouse prototype.

by the tire when the silicone rubber shrinks as a result of curing. Together, these two methods ensure the rubber tire stays firmly around the rim (Fig. 6,*b*).

The process of overmolding can also be accomplished using multiple elastomer materials and molds for the same rigid substrate. Figure 7,*e* shows a prototype of a PC Mouse fabricated with two different overmolded materials. RTV silicone rubber was used for creating a soft surface which functions as a palm grip. For a surface which functions as a soft thumb grip, condensation-cured silicone rubber was used. The mouse body and two half molds were fabricated with a 0.25 mm layer height from PLA material.

In this case a different approach was used to bond the different materials together and no geometric features have been designed in the part to function as mechanical bonding. Instead, the property of FDM processes to build parts which have partial infill has been leveraged after the part has been printed. The partial infill structure used to build the part forms a cellular structure (Fig. 7,*a*). By drilling the outer surface of the part (Fig. 7,*b*) several cells are connected to the outside volume and allow the injection of elastomer, forming mechanical joints for material bonding. Silicone rubber was injected into these open cells, then a snap-fit half mold was attached (Fig. 7,*c*) and more elastomer was injected. The FDM fabrication process precision of 0.1 mm can create slight misalignments between the part and the mold. This will result in the presence of burrs after curing and demolding (Fig. 7,*d*). The burrs are significantly thinner than the thickness of functional surfaces and can be easily trimmed off.

Figure 8 shows a prototype of a toothbrush with a rigid handle made out of ABS and three separate overmolded surfaces which are made with different elastomers. The molds were fabricated from the same material as the rigid substrate. Surface quality was increased by slicing the part into very thin, 80 µm layers. The quality of elastomer surfaces can be improved by post-processing the 3D-printed molds. While part exterior surfaces can be sanded to remove layer lines and to obtain good surface finish, mold surfaces are complex and difficult to grind down. An alternative is to use a chemical vapor bath to partially melt and smoothen the mold surface.

Figure 9,*e* shows the prototype of a tool casing for a corded drill with an overmolded soft surface which serves as padding on the handle. The drill casing was printed in an inclined position (Fig. 9,*a*) in order to reduce the amount of required support material. Similar to the previously shown mouse and toothbrush models, no geometry was generated prior to 3D-printing to serve as mechanical bonding joints with overmolded elastomer. The 2.4 mm thickness of the part in the handle region was sufficient to drill holes for accessing the internal cellular geometry created by part infill (Fig. 9,*b*). For increased surface quality, the rigid part has been sanded and primed. A one-piece mold was designed and fabricated using the same process and material. The mold was attached to the drill case prototype using screws through mounting holes designed to match the functional screw holes on the casing (Fig. 9,*c*). After curing and demolding, any resulted burrs (Fig. 9,*d*) can be removed using a sharp tool.

Overmolding of elastomers on 3D-printed models is not limited to producing prototypes, but may be feasible for the production of functional parts as well. A potential application of thermoplastic material 3D-printing in the medical field is the production of braces for restricting the movement of injured joints. Various techniques have been approached by researchers, including digital optical scanning of patients in order to create 3D models which would subsequently be 3D-printed [7], or generating 3D-printable models for braces from a set of measurements taken from the patient [8].

Overmolding elastomer material on such a brace would provide a soft surface that comes in contact with skin and result in lower risk for developing pressure sores. Figure 10,*d* shows a functional arm brace 3D-printed from PLA material with an overmolded silicone

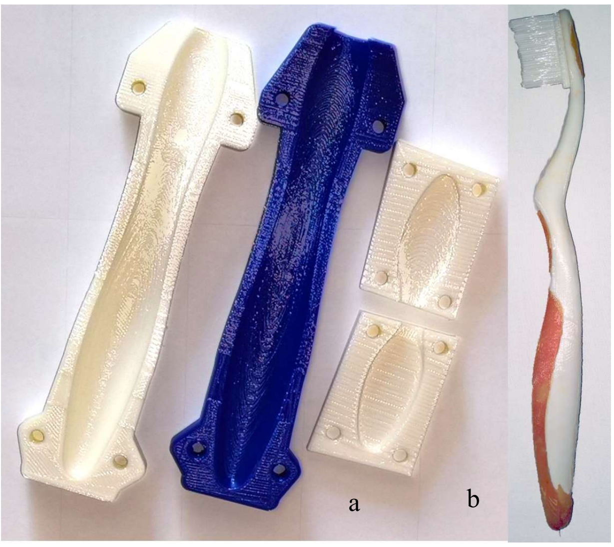

Fig. 8. Toothbrush prototype: *a* – Mold for toothbrush prototype; *b* – finished toothbrush prototype.

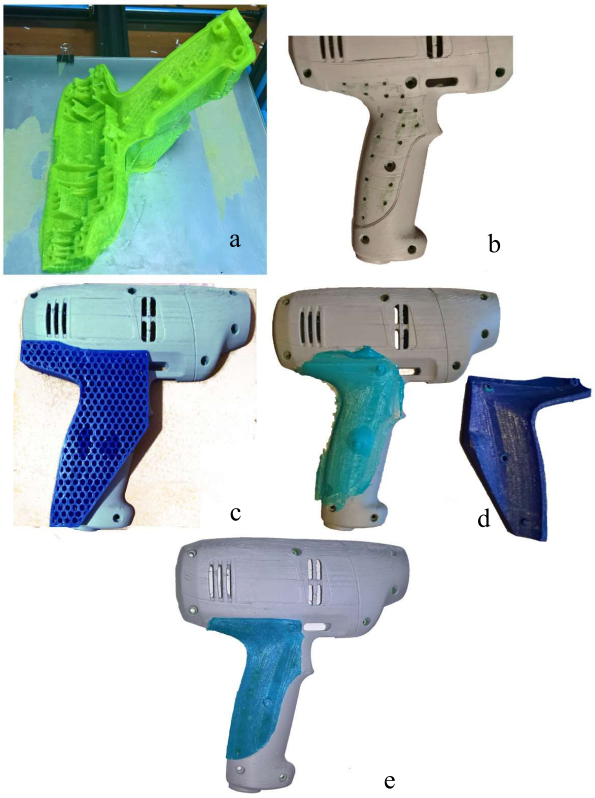

Fig. 9. Prototype of drill case: *a* – 3D-printed drill case; *b* – holes for mechanical bonding; c – drill case with attached mold; *d* – drill case with soft grip handle after demolding; *e* – finished drill case prototype.

surface. A 3D-printed mold was produced in order to form the silicone surface onto the inner side of the arm brace (Fig. 10,*b*). The elastomer was mechanically fixed to the substrate through a series of channels embedded into the brace. The FDM process can use an extrusion nozzle with a large diameter of 0.80 mm and a layer height of 0.50 mm to produce the plastic parts for the arm brace in less than 1 hour, with a similar fabrication time needed for the mold. After printing, silicone was injected into the channels and into the 3D-printed mold, the two parts were clamped together and the elastomer was allowed to cure. Following curing and demolding from the mask (Fig. 10,*c*), the brace was thermoformed to gain its functional shape.

Table 1 shows the time needed to fabricate the prototypes presented in this paper, as well as an estimated production cost for these prototypes. The time needed to fabricate the components and the molds are for parts fabricated with a 0.20 mm layer height, 2 outer perimeters, 30% infill and a maximum printing speed of 45 mm/s. Part orientation was optimized for shorter fabrication time. Support structures were used where necessary and the production time includes the time needed to remove them, as well as the time needed to cure and demold the elastomer. The estimate for the time required for production considers all parts are made on the same printer.

These values can be further reduced if the workload is split over multiple printers. Four hours are required for elastomer curing, with the exception of fast-curing elastomers.

All the parts and molds have been fabricated on consumer-grade FDM machines with a market value ranging from USD 400 to USD 2,000. The cost per hour of printing includes thermoplastic material costs, energy and machine costs and has been set at $1.5 per hour. The costs of the elastomers used range from USD 12 per 1000 cm^3 to USD 70 per 1000 cm^3.

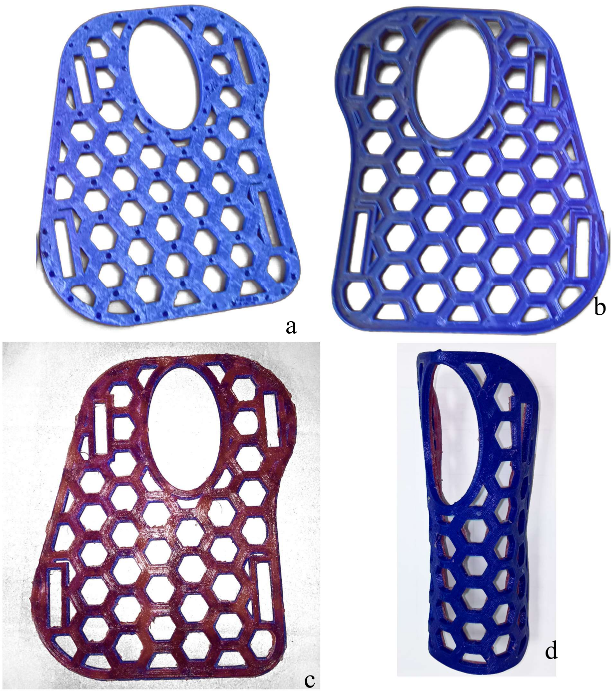

Fig. 10. 3D-printed, overmolded arm brace: *a* – arm brace substrate; *b* – half mold; *c* – de-molded arm brace; *d* – thermoformed arm brace.

Table 1

Prototype production–time and cost analysis

Prototype	Component fabrication time [hours]	Mold fabrication time [hours]	Elastomer Vol. [cm^3]	Est. prod. time* [hours]	Est. cost ** [USD]	PolyJet Quote [USD][17]
Ski goggles	13.5	5.5	100	23.5	30.5	250.2
Tape measure	2	3.7	40	10.2	9	63.9
Caster wheel	20	8	80	34	43	448.2
Drill case (half)	16.2	3.6	40	24.4	31.1	213.5
Toothbrush	2.5	4	120	12	11.2	52
PC Mouse	8.5	7	80	20	24.9	217.6
Screwdriver handle	3.2	3.1	60	10.8	11.25	135
Arm Brace	0.9	1.1	40	1.5- 2	5.8	-

*Production time estimate does not include any additional finishing such as sanding, priming, painting, etc.

**Cost estimate does not include cost of labor.

4. CONCLUSIONS

This paper presents a method of fabricating rapid prototypes of multi-material parts which combine rigid thermoplastics with flexible elastomers. Such parts can be used during a design process to provide accurate feedback regarding product fit, form and feel.

Various solutions of bonding the materials together have been presented. These include chemical bonding, mechanical bonding through the use of purposefully designed geometries, or mechanical bonding through exploiting the interior structure of 3D-printed parts. Several case studies have been presented displaying the wide range of potential use for this manufacturing method.

Parts resulting from FDM printing have a lower surface quality and are less detailed than parts fabricated using other AM techniques, such as PolyJet. However, their surface finish can be improved using post-processing operations such as sanding, priming and painting or through chemical baths (acetone vapor bath in the case of ABS). An advantage of FDM compared to resin-based processes is the use of thermoplastic polymers, giving designers the possibility to approach multi-material functional prototyping.

A time and cost analysis has been made. Time and cost for parts made using this method are relatively proportional to their total volume. For the prototypes considered for case studies, a cost comparison has been made against quotes received from 3DHubs manufacturing services provider for PolyJet printing showing the investigated method is considerably more affordable.

REFERENCES

[1] B. Ahuja, M.C.H. Karg, M.Schmidt, *Additive Manufacturing in production: challenges and opportunities*, Proc. of SPIE Vol. 9353, 2015, p. 935304.

[2] I.D. Gibson, W. Rosen, l.B. Stucker, *Additive Manufacturing Technologies Rapid Prototyping to Direct Digital Manufacturing*, Chapter 17 The Use of Multiple Materials in Additive Manufacturing, 2010, pp. 423–436.

[3] R.R. Ma, J.T. Belter, A.M. Dollar, *Hybrid deposition manufacturing: design strategies for multimaterial mechanisms via three-dimensional printing and material deposition,* Journal of Mechanisms and Robotics, 2015, p. 021002.

[4] A.T. Gaynor, N.A. Meisel, C.B. Williams, J.K. Guest, *Multiple-Material Topology Optimization of Compliant Mechanisms Created Via PolyJet Three-Dimensional Printing*, Journal of Manufacturing Science and Engineering-Transactions of the Asme, Vol. 136, No. 6, 2014, p. 061015.

[5] S. Bijadi, E. de Bruijn, E.Y. Tempelman, J. Oberdorf, *Application of Multi-material 3D printing for improved functionality and modularity of open source low cost prosthetics – A case study*, Proceedings of the 2017 Design of Medical Devices Conference DMD2017 April 10–13, 2017, Minneapolis, Minnesota, USA, pp. V001T10A003-V001T10A003..

[6] R.G. Jones, *Definitions of terms relating to the structure and processing of sols, gels, networks, and inorganic-organic hybrid materials* (IUPAC Recommendations, 1801),2007.

[7] J.A. Brydson, *Thermoplastic Elastomers*: *Properties* and *Applications*, Rapra Review Report No.81, Vol. 7, No. 9, Rapra Technology, Shrewsbury, UK, 1995.

[8] C. Lewitzke, P. Lee, *Application of Elastomeric Components for Noise and Vibration Isolation in the Automotive Industry.* SAE Technical Paper, (No. 2001-01-1447), 2001.

[9] S. Amin, M. Amin, *Thermoplastic elastomeric (TPE) materials and their use in outdoor electrical insulation*, Rev. Adv. Mater. Sci., Vol. 29, 2011, pp 15–30.

[10] R. Singh, *Process capability study of PolyJet printing for plastic components*, Journal of Mechanical Science and Technology, 2011, Vol. 25, No. 4, pp. 1011–1015.

[11] F. Fischer, *FDM and PolyJet 3D printing; determining which technology is right for your application*, Stratasys Inc. White Paper, retrieved from `http://www.stratasys.com/resources/search/white-papers/fdm-vs-polyjet` , accessed: 30.04.2018;

[12] A. Banerjee, X. Li, G. Fowler, S.K. Gupta. *Incorporating manufacturability considerations during design of injection molded multi-material objects*. Research in Engineering Design, Vol. 17, No. 4, 2007, pp.207–231.

[13] M. Braden, *Dimensional stability of condensation silicone rubbers*, Biomaterials, Vol 13, No. 5, 1992, pp 333–336;

[14] V. Fano, PU. Gennari, I. Ortali, *Dimensional stability of silicone-based impression materials*, Dent. Mater., Vol 8, No. 2, 1992, pp. 105–109.

[15] A.M.J. Paterson, R.J. Bibb & R.I. Campbell, *A review of existing anatomical data capture methods to support the mass customisation of wrist splints*, Virtual and Physical Prototyping, Vol. 5, No. 4, 2010, pp. 201–207.

[16] I. Poortinga, *Local fabrication of a custom finger splint using parametric design and additive manufacturing*, Master thesis, University of Groningen, 2016, available at: `https://waag.org/sites/waag/files/media/publicaties/local-fabrication-of-a-custom-fit-finger-splint.pdf`, accessed: 30.04.2018;

[17] `www.3dhubs.com`, accessed: 01.05.2018.