University of Huddersfield Repository

Kus, Abdil, Unver, Ertu, Jagger, Brian and Durgun, Ismail

A Study of Injection Moulding with Bismuth Alloy

Original Citation

Kus, Abdil, Unver, Ertu, Jagger, Brian and Durgun, Ismail (2013) A Study of Injection Moulding with Bismuth Alloy. In: Green Design, Materials and Manufacturing Processes. Taylor & Francis, pp. 225-232. ISBN 9781138000469

This version is available at http://eprints.hud.ac.uk/id/eprint/17274/

A Study of Injection Moulding with Bismuth Alloy

A. Kus
Uludag University, Bursa, Turkey

E. Unver & B. Jagger
University of Huddersfield, Huddersfield, UK

I. Durgun
Tofas Automotive Research and Development, Bursa, Turkey

ABSTRACT: There is a demand to produce parts in small quantities, using cost effective injection moulding processes. The emerging economic case suggests there will be advantages in producing injection moulding tools for short duration low volume production runs where the tool is rebuilt for each manufacturing cycle. CAD/CAM, Rapid Prototyping (RP) and digital technologies help to bring new products to market faster.Mould inserts are traditionally produced using expensive and time consuming CNC machining processes. This article presents development of an injection moulding tool where rapid tooling, bismuth-tin mould insert and injection moulding are used to manufacture one hundred plastic parts. It describes the manufacturing methods applied and the use of manual and 3D scanning methods. It also evaluates the surface finishes and dimensions of the parts produced in the tool.

1 BACKGROUND & INTRODUCTION.

Injection moulding is a manufacturing process commonly used for mass produced parts formed by thermoplastic and thermosetting plastic materials. The moulds or die are usually made from aluminum or steel at considerable cost to the manufacturer, which can only be offset by high volume production. Traditional tool manufacturing processes include cutting, abrading, burning, and eroding. Cutting processes involve milling, drilling, turning, planning and reaming to shear material from the workpiece. Abrading processes involve grinding, polishing or sanding. Burning and eroding processes use electricity, chemicals, heat, or hydrodynamics to shape or remove material. Until recently CNC milling machines were the only option to produce moulds. The processes are time consuming, costly and constrained by the machinery used to create the tool.

Rapid prototyping is widely used in the product, automotive, aerospace, and medical industries. RP mostly used for prototyping, rapid tooling and rapid manufacturing. RP is typically used for testing scale, fit and function, as well as providing an effective communication between design, management and marketing teams. RP includes a range of technologies which automatically construct physical prototype models from CAD data using machines recently called 3D printers. In addition to prototypes, RP techniques can be used to make tools (rapid tooling) and even production-quality parts (rapid manufacturing). There are more than six rapid prototyping techniques are commercially available, each with unique strengths.

Recent developments in Rapid Tooling (RT) have changed the design process and economic models for mass manufacture. With the advent of RT, the process can be divided into three segments. The first stage is Prototype or Soft Tooling where a mould is designed to test component functionality, appearance, size and fit. These tools produce only a few hundred parts, whereas in Bridge Tooling tens of thousands of units could be manufactured. These tooling stages facilitate early introduction of new products to the market, prior to or during the fabrication of the Production or Hard Tool. By adopting RT methodologies the manufacturer can gauge the volume of demand for the product before specification and investment in the production tool. RT can meet the needs of a customised market where an inexpensive (softer) tool is sufficiently robust to handle batch outputs. Rapid tooling either directly produces a tool with a rapid prototyping system, or indirectly utilises a rapid prototype as a pattern for the purposes of producing the tool. RT processes complement the RP options by being able to provide higher quantities of parts in a wider variety of materials and can even produce short-run injection moulded parts in the intended production material.

Currently most 3D printing technologies are better suited to the design and testing stages of manufacture, however their material properties are unsuited to RP tool printing for injection moulding where the tool materials must have sufficient hardness to retain good surface quality and accuracy in high volume manufacture. Recent advances in RP 3D metal printing technologies have enabled the production of low volume components for healthcare, aerospace and high-technology engineering and electronics sectors. The initial non-metallic plastics and powder based materials in RP have been extended to include metals such as aluminium and steel. These advances have not only changed how prototype parts are created, but have also facilitated new opportunities to create RP models for custom manufacture at the tool making stages of the manufacturing process. The concept of rapid adaptation in high volume manufacture process has been described as Mass Customization (Atkinson et al 2008).

In this study a tool insert has been created using RP to create a master for a bismuth alloy insert into a steel injection moulding tool. The process has the advantage of eliminating traditional tool making methods, but its ability to withstand the temperatures and pressures used in an industrial manufacturing setting required testing and analysis. The team chose bismuth alloy for a replaceable insert to produce a RT part as initial testing showed that the material could be cast at temperatures that would not damage the original RP master part. See Figure 1.

2 METHODOLOGY

Injection Moulding is one of the most commonly used manufacturing methods for producing plastics parts where large numbers of identical products are manufactured with relatively low unit costs. Toolmaking is an essential and costly phase of the injection moulding process where tool design, manufacturing and testing are the crucial stages of any plastic injection moulding. The tool configuration, material selection, surface finish and tolerances are important considerations in preparation for injection moulding.

Rapid tooling is the term for either indirectly utilizing a rapid prototype as a tooling pattern for the purposes of moulding production materials, or directly producing a tool with a rapid prototyping system. RT processes complement the RP options by being able to provide higher quantities of parts in a wider variety of materials, even short-run injection moulded parts in the intended production material. Dies and moulds can be produced by using RT and low melting metal alloys. This method has the advantages of reducing the time required to produce the tool, which enables further design iterations and more prototyping cycles with an overall reduction in tool development costs.

In this article, the use of low melting materials for rapid tooling is investigated for low volume production of injection plastic parts. The study describes:

- Mould tool manufacturing methods
- Use of low melting bismuth alloy for mould iserts
- Analysis of surface and dimensional changes in the plastic moulded parts (1-100)
- A comparison of traditional 2D and laser assisted 3D inspections techniques

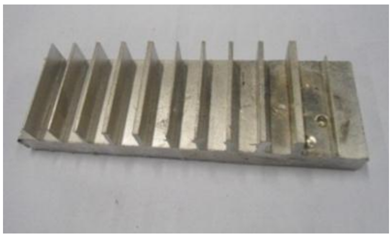


Figure 1. Initial bismuth casting

Bismuth has been known and used throughout recorded history. It has been used in pharmaceuticals as a non-toxic additive in cosmetics and in digestive medicines. Bismuth based non-ferrous alloys are used in the manufacture of solders, semiconductors, batteries, optical, and decorative products because of its distinctive properties of high density, good electrical conductance and low melting point. Typical low melting point alloys are made up from Bismuth, Indium, Lead, Tin and Cadmium. These alloys are produced by mixing two or more of the pure metals in eutectic proportions to achieve combinations that can melt at temperatures as low as hot water and re-solidify consistently even after repeated cycles. Although limited research has been carried out on bismuth alloy injection moulding processes, there are many studies where the use of RP technologies for injection moulding process are discussed and compared with existing methods. Ilyas, et al, (2010) reports on the use of indirect selective laser sintering (SLS) and machining processes to create injection mould tools where productivity improvements and energy reduction in injection moulding are discussed. Stucker, and Qu (2003), studied the use of Rapid Tooling directly in conjunction with other processes such as casting, plasma spraying etc. to create metallic or ceramic tooling for limited production and an STL-based finish machining technique for tools and parts made using RP. Pre-process algorithms and machining strategies are explored and software is assessed. Jetley and Low (1998) showed how RP techniques have been adapted to develop a low melting point metal casting alloy tool for injection moulding and compares the results with design and manufacture of mould inserts using traditional methods by examination of the 150 parts produced. Altan, et al (2001), reviewed the variety of technologies available for the manufacture of dies and moulds with particular focus on automotive applications. Dalgarno,and Stewart (2001) reported layer manufacture methods to produce injection mould tools and assesses the economic advantages over existing production methods. Sudershan, Low (2006) studied the use of Low melting alloys for insert design.

3 EXPERIMENTAL STUDY

This research was done in conjunction with Fren Sistemleri Sanayi (FSS) Ltd in Bursa, Turkey to produce a component for a clutch system. The company specialises in the production of Air Brake and Clutch Components for trucks and buses. The research team investigated the use of a recyclable material for low volume injection moulding process and testing. The team used low melting Bismuth 137 Alloy as recyclable material for initial injection tooling before manufacturing of the Steel tool for mass manufacturing.

In this paper the use of low melting materials for rapid tooling is investigated for low volume production of injection plastic parts. The study describes:

- Mould tool manufacturing methods
- Use of low melting bismuth alloy for mould inserts
- Analysis of surface and dimensional changes in the plastic moulded parts (1-100)
- A comparison of traditional 2D and laser assisted 3D inspections techniques

The team used an alloy of Bismuth (58%) and Tin known as Bismuth 137 alloy which has a hardness of 20HB for the tool insert in a steel injection mould. For consistency with the parts already in production the team used PE I20 plastic material on an industrial injection moulding machine. Figure 2 shows the CAD model of the part to be injection moulded.

Figure 2 CAD data of produced part.

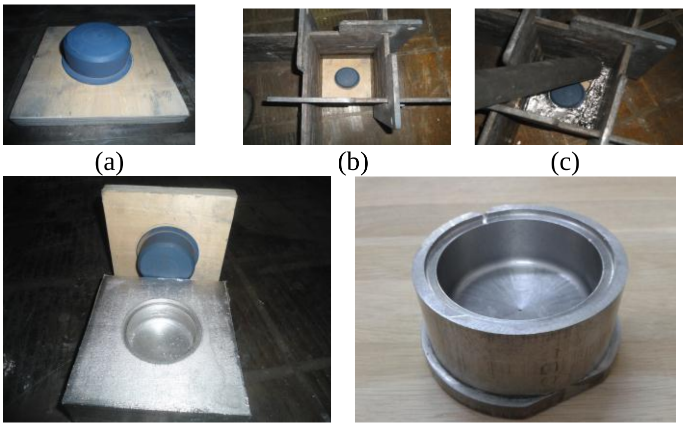
PE-I20 is a low density polyethylene thermoplastic commonly used for injection moulding of consumer and industrial products. The material is resistant to acids and is commonly used for liquid containers. Material specification is shown on Table 1.

Property		Value
Tensile Strength	(Kg/cm^2)	100
Coefficient Therm. Exp.	(for -1 ºC)	$240x10^{-6}$
Thermal Conductivity	(Kcal/mh ºC)	0.26
Density	(gr/cm^3)	0.92
Mould Temperature	(ºC)	30-50-80
Melting Point	(ºC)	165
Shrinkage	(%)	2-3

Table 1 PE I20 Material parameters

3.1 Mould and Insert Design

A master male model was created on a CNC turning machine from the Cibatool BM 1051 material shown in Figure 3a. This master model was placed on a metal plate and a frame, shown in Figure 3b. MCP 137 alloy was melted at 150 C and poured over the Cibatool shown in Figure 3c&d.

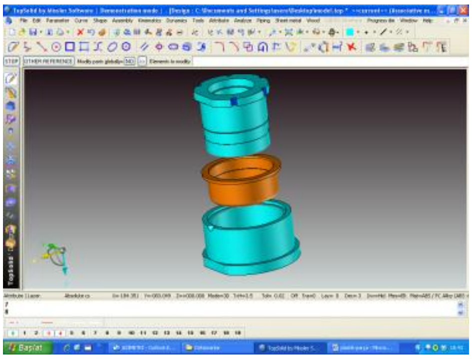


(a) (b) (c)

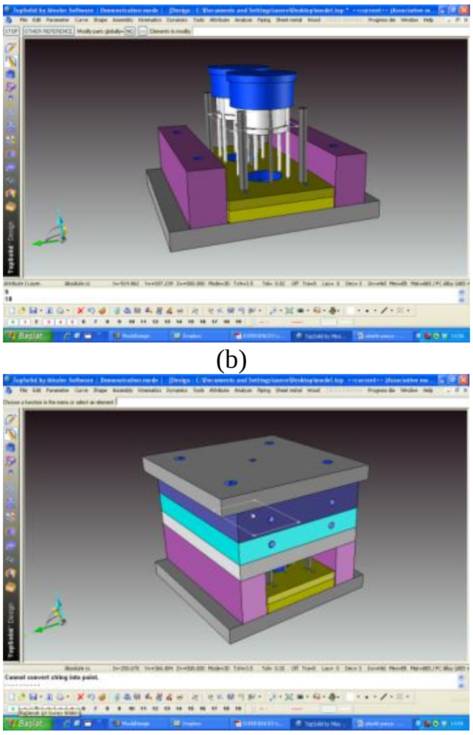
(d) (e)

Figure 3 (a) Master Model (b) Casting Frame (c) Alloy casting (d) Insert Models (e) Machined model

The male and female tools were manufactured using CNC turning and milling machines. As a result of the alloy's density of over $9.78\ g\cdot cm^{-3}$ the overall weight of MCP 137 was 20kg. The poured alloy was then allowed to air-cool in the die frame for over one hour at room temperature. The low temperature insert tool was removed and finished on a CNC lathe to the required dimensions to fit inside the steel outer mould Figure 3e.



(a)



(b)

(c)

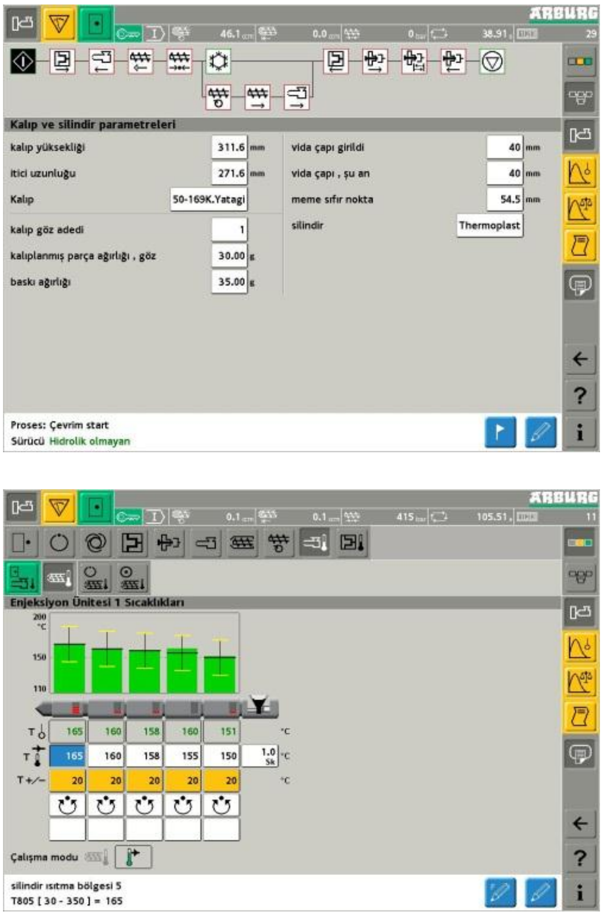
Figure 4 (a) Part and mould inserts (b) Ejectors (c) mould Set

Figure 4 illustrates the 3D design and development of the mould tool using TopSolid CAD software. The external sizes of the tools are 350 x 450 mm. Note for this test, only the male mould insert was made from Bismuth alloy (shown in orange in Figure 4a). The remaining tool parts are made of German specification Steel 1.2738 with hardness of 32 HRC. The steel is widely used in large moulds for the production of Polystyrenes (PS), PE, and ABS plastic parts. The tool was designed to accommodate a shrinkage allowance of 2.5% in PE I20. Standard parameters and features in injection mould design were included in the steel components of the mould, such as cooling channels, plastic injection nozzle location and ejector pins.

3.2 Injection Moulding Process

An Arburg Allrounder 420c plastic injection moulding machine used in this experiment is shown in Figure 5a. Figure 5b shows the steel tool and bismuth alloy insert, and Figure 5c shows the white plastic part on the steel male tool.

Figure 5 a) Steel and bismuth insert. b) Finished part and male tool



Kalıp ve silindir parametreleri

kalıp yüksekliği 311.6 mm
itici uzunluğu 271.6 mm
Kalıp 50-169K.Yatagi
kalıp göz adedi 1
kalıplanmış parça ağırlığı , göz 30.00 g
baskı ağırlığı 35.00 g
vida çapı girildi 40 mm
vida çapı , şu an 40 mm
meme sıfır nokta 54.5 mm
silindir Thermoplast

Proses: Çevrim start
Sürücü Hidrolik olmayan

Enjeksiyon Ünitesi 1 Sıcaklıkları

T	165	160	158	160	151		°C
T	165	160	158	155	150	1.0 Sk	°C
T +/−	20	20	20	20	20		°C

Çalışma modu

silindir ısıtma bölgesi 5
T805 [30 - 350] = 165

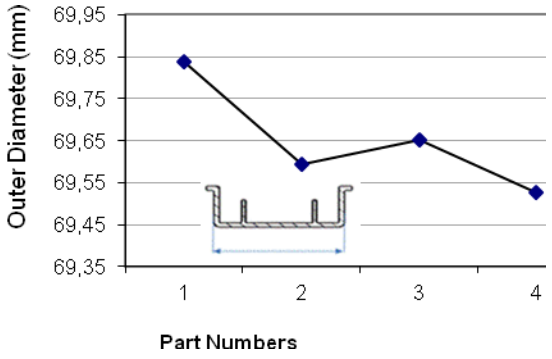
Figure 6 a) Injection moulding cycle b) Temperature parameters

Figure 6a shows parameters applied to the injection process. The tool closed at 300 mm/s, slowing to 30 mm/s, with a closing force of 40 kN. The pressure on the melted plastic is 1250 bar which delivers the material at 55 cm/s into the mould cavity. A delay of 10.5 sec was allowed to complete the plastic injection into the cavity. The pressure was reduced to 150 bar for 20 sec to allow cooling before the ejector pins parted the component from the mould. This cycle was repeated to produce one hundred components. Figure 6b shows the heater settings used in the injector chamber. During the injection sequence the temperature of the molten plastic fell from an initial temperature of 165 C to 150 C at the point of contact with the mould. After release from the moulding tool the temperature of the ejected part had fallen to 45 C due to automatic cooling of the tool. These settings ensure that the mould insert was kept below the melting temperature of the alloy and also meet the recommended cooling temperature specifications of the plastic manufacturers.

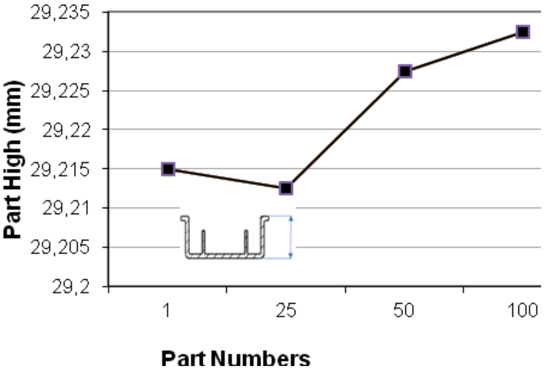
4 INSPECTION AND TESTING

Four samples were selected from the one hundred batch run at numbers 1, 25, 50 and 100. These parts were inspected to measure dimensional changes in diameter and height during the moulding run. Graph

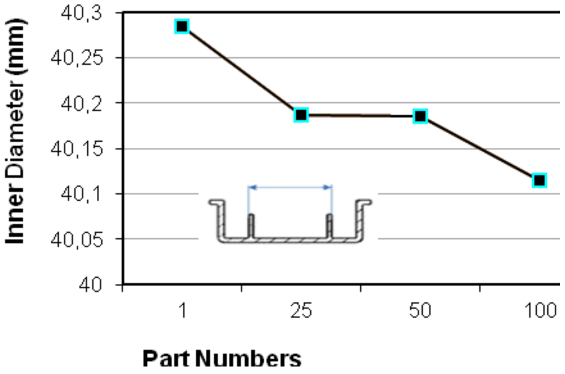
1 shows the changes measured manually with callipers on each sample part. Outside diameter, height, inside diameter, inside thickness and outside thickness were recorded for each of the four selected parts results are shown in Table 2.



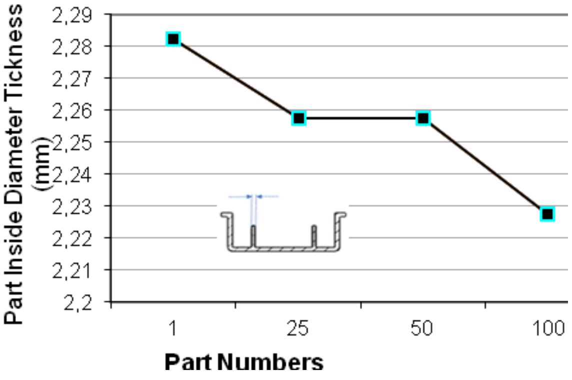
(a)



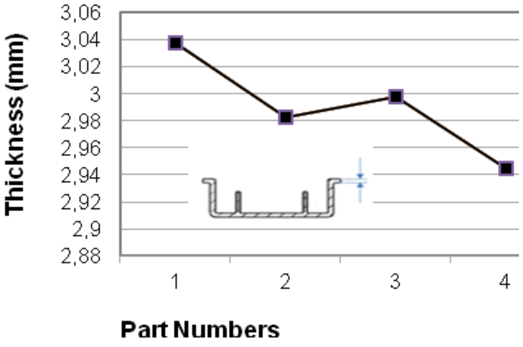
(b)



(c)



(d)



(e)

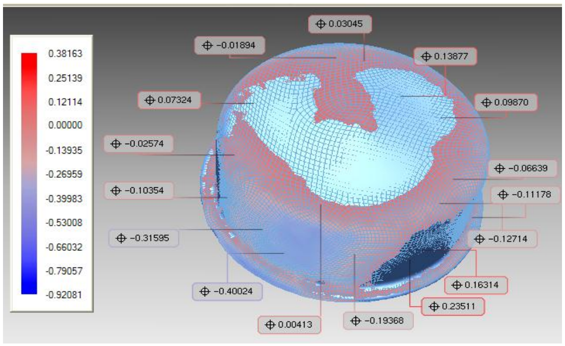
Graph 1. Measurement a) Outer Diameter b) Hight c) Inner Diameter d) Inner Thickness

Measurements	Mean (mm)	Deviation (mm)	
		Min	Max
Outer Diameter	69.66	-0.1	0.19
Hight	29.21	-0.02	-0.01
Inner Diameter	40.2	-0.1	0.1
Inner Thickness	2.26	-0.03	0.02
Outer Thickness	2.98	-0.05	0.06

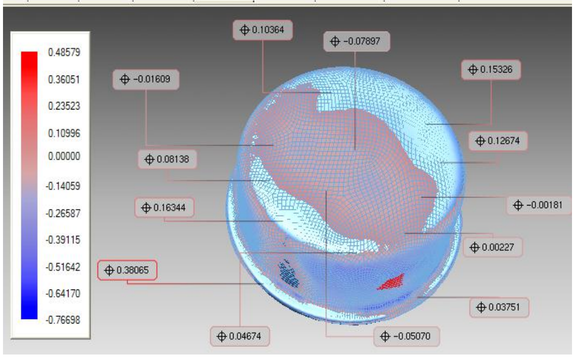
Table 2 Measurement Analysis

For digital comparison, a Breuckmann Opto-TOP HE 3D optical scanning system was used to scan the models. The measurements were then read into Rapidform reverse engineering software for analysis as shown in Figure 7. This method enables not only surface analysis, but also records dimensional changes which are listed below.

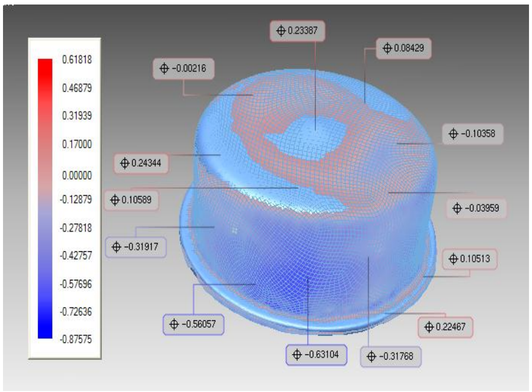
1st and 25th parts : -0.92 to +0.38mm
1st and 50th parts : -0.28 to +0.48mm
1st and 100 parts : -0.28 to +0.61mm



(a)



(b)



(c)

Figure 7. 3D scanning and automatic analysis of dimensional changes from part 1. a) part 25, b) part 50, c) part 100

The dimensional changes on the sample selection were found to be random with no correlation to increasing production cycle wear in bismuth alloy insert. The team believes this could be as a result of human error during manual measurements or the effect of material properties such as shrinkage during cooling and ambient air temperatures.

5 FINDINGS

The research showed that bismuth MCP alloys can be used as an insert for injection moulding process for low volume production with the following benefits.

- Bismuth alloys are recyclable materials. Tool manufacturing waste or worn tool inserts can be recycled with very low energy costs.
- Relatively cheap RP models can be used for insert mould making.
- The use of low melting alloy insets to adapt injection tooling will enable globalised production to meet local market demands for customised images, logos or text – Mass Customisation.
- Bismuth insert tooling could be applied to blow, silicon or other moulding processes.
- Bismuth alloy insert tooling has the potential to extend the range of units produced in the Prototype (soft)/Bridge phases of manufacture.
- In hard tooling the bismuth insert enables extended iterations of the product.

There are also disadvantages of using low melting materials in injection moulding processes.

- Low melting temperature and low surface roughness value of Bismuth limits plastic materials selection.
- Without a longer production run it is not possible to determine the maximum number of parts that can be produced with this system but it is probable that it is only applicable for low volume production, it is not a replacement for aluminium or steel mould.
- Low heat transfer co-efficiency results lower cooling time and longer injection moulding time
- The effects of using bismuth inserts on intricate surfaces and edges will require further testing.

6 CONCLUSION

The experimental process has demonstrated that tooling can be efficiently adapted to meet local consumer needs. Low melting-point alloy inserts have potential as a means of delivering reduced volume Mass Customization with the economic advantages of high volume production. More testing and funding will be required to explore and define the limitations of the process.

Although the melting point of plastic PE I20 material is 165C and exceeds the melting point of bismuth MCP melts at 137C alloy, due to automatic cooling, the mould temperature was kept around 40-45C during the production of one hundred units. The research shows that there were no significant dimensional changes during the hundred-unit production run. Further research is required to determine the upper limits of bismuth alloy insert tooling, which may be very much higher than the total units produced in this experiment. The use of manual and reverse engineering technology, employing 3D scanning of the manufactured parts was to be a more reliable system for monitoring production quality, but also requires a larger volume experiment to determine the tipping points at which either manual or electronic systems begin to measure significant falls in production quality.

At this stage the research team can confidently conclude that it is possible to use low melting-point alloy inserts in short production runs. The technique demonstrates a process that enables insert materials to be recycled efficiently at little cost to the manufacturer. The experiment also found that low cost 3D printing can be used in the manufacture of the bismuth insert tool.

ACKNOWLEDGEMENT

The authors would like to thanks FSS ltd. Bursa, TURKEY for supporting this research.

6 REFERENCES

Ilyas, I., Chris Taylor, C., Dalgarno, K., Gosden, J., 2010. Design and manufacture of injection mould tool inserts produced using indirect SLS and machining processes. *Rapid Prototyping Journal*, Vol. 16 : 429 – 440.

Jetley, S., Low, D.K. 2006, A Rapid Tooling Technique Using a Low Melting Point Metal Alloy for Plastic Injection Molding, *Journal of Industrial Technology*, (22)3.

Stucker, B. & Qu, X., (2003), A finish machining strategy for rapid manufactured parts and tools, Rapid Prototyping Journal, Vol.9, No. 4, pp 194-200

Atkinson, P, Unver, E, Marshall, J and Dean, D. T. (2008) *Post Industrial Manufacturing Systems: the undisciplined nature of generative design.* In: Proceedings of the Design Research Society Conference 2008. Sheffield Hallam University, 194/1-194/17.

Altan, T., Lillg, B., Yen, Y.C. 2001. Manufacturing of Dies and Molds, *CIRP Annals - Manufacturing Technology*, 50(2): 404-563.

Dalgarno, K.W., Stewart, T.D.,2001. Manufacture of production injection mould tooling incorporating conformal cooling channels via indirect selective laser sintering, *Proceedings of the Institution of Mechanical Engineers. Part B, Engineering Manufacture*, 215 : 1323-1332.

Sudershan J., Low D.K. 2006. A Rapid Tooling Technique Using a Low Melting Point Metal Alloy for Plastic Injection Molding, *Journal of Industrial Technology*, 22(3).