Rapid Prototyping: An Explorative Study on Its Viability in Pottery Production (Sub-Theme:17)

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ABSTRACT

This paper seeks to explore further on findings from previous research work which experimentally investigates the viability of digital and rapid prototyping in small and medium scale ceramic industries. The findings from the research revealed that digital and rapid prototyping are viable in reducing development time and improving prototype accuracy; however, based on the rapid technology (Fused Deposition Modeling) used for the research, the research shows that rapid prototyping is an expensive approach. Therefore, based on these findings, this concept paper seeks to explore and propose other available rapid technology (Laminated Object Manufacturing and CNC) for small and medium scale ceramic industries. The paper illuminates generally on rapid prototyping and technology; review the application of Laminated Object Manufacturing (LOM) in ceramic product development based on the research carried out by Jorge, Rui, Ricardo, & Ana at Institute of Mechanical Engineering and Industrial Management, Portugal. And finally, proposed the use of Computer Numerical Control (CNC) in ceramic product development.

Keywords: Ceramics, Digital Prototyping, Pottery, Prototyping technology, Rapid Prototyping.

Introduction

Physical prototyping can be a major bottleneck, slowing down the product development process and seriously constraining the number of design alternatives that can be examined (3D Vision Technologies, 2008). Gary Hawley, a designer in Denby Pottery Company said, “Despite the prodigious skills of the company’s carvers, some having more than 25years experience; the process of physical prototyping was time consuming and never produced 100 percent accurate models”. As a result, it was hard for the clients to fully understand the concepts being proposed. Also, the fact that their prototypes take as long as four weeks to be created made them too careful about introducing new products (Gary, 2012).

Therefore, many manufacturers easily accept that eliminating physical prototypes equates to shorter or shortened product development cycle time and also a competitive strategies for reducing development cycles and getting products to market faster. However, despite the fact that many industries have moved to virtual prototyping to prove out design concepts and validate design decisions, there is still a huge reliance for many industries on the physical testing of a prototype to validate product function (3D Vision Technology, 2008). Most especially for new designs in ceramic production, a physical prototype is necessary to verify proper functionality, create mould and also to ensure that the product is built the way the designer imagined it.

So, while the use of physical prototypes is still a necessity for many ceramic product developers, replacing more and more physical prototyping and testing with digital methods, and better coordination of physical test and measurement with digital modelling and finally linking with rapid technology to produce prototype from CAD data is seen as an approach that can reduce development costs while slashing months off product development schedules. According to Jennifer (2010), the application of computer aided design can help reduce draftsmen significantly, especially in small and mid-size companies.

With respect to this, this paper seeks to explore further on findings from previous research work which experimentally investigates the viability of digital and rapid prototyping in small and medium scale ceramic industries. The findings from the research revealed that digital and rapid prototyping are viable in reducing development time and improving prototype accuracy; however, based on the rapid technology (Fused Deposition Modeling) used for the research, the research shows that rapid prototyping is an expensive approach. Therefore, based on these findings, this concept paper seeks to explore and propose other available rapid technology (Laminated Object Manufacturing and CNC) for small and medium scale ceramic industries. The paper illuminates generally on rapid prototyping and technology; review the application of Laminated Object Manufacturing (LOM) in ceramic product development based on the research carried out by Jorge, Rui, Ricardo, & Ana at Institute of Mechanical Engineering and Industrial Management, Portugal. And finally, proposed the use of Computer Numerical Control (CNC) in ceramic product development.

Rapid Prototyping Technology

There are three basic ways of creating prototypes: conservative, subtractive, and additive (Fig. 1). Conservative approach involves applying the needed forces to deform material to the required shape, without either adding or removing material, i.e., material is conserved (Venuvinod & Ma, 2004). However, the disadvantages of this approach are that it consumes a lot of energy. Also, it focuses on form generation without providing means for controlling material composition. This approach is applied in many industries processes such as extraction, forging, casting and sheet metal forming.

(Insert Fig. 1 about here)

In subtractive approach, unwanted segments are chipped away from a block of material. In modern industry, CNC machines works on the subtractive principle. According to Venuvinod & Ma (2004), an advantage of CNC is that it can utilize information embedded in a CAD model of the part. Some of the challenges of this approach are that; it waste materials, only those form features accessible by the subtractive tools can be created and lastly, like the conservative approach, it focuses on the form generation without providing means for controlling material composition (Venuvinod & Ma, 2004).

The additive approach starts with nothing and builds an object incrementally by adding materials (Venuvinod & Ma, 2004). The materials added each time can be the same or different. Thus, problems of form generation and composition can be addressed at once through the same process (Venuvinod & Ma, 2004). The advantage of this approach is that any solid 3D freeform can be generated without the aid of external tooling, so most of the problems associated with the conservative and subtractive methods are totally sidestepped (Venuvinod & Ma, 2004). The first commercially available equipment based on this principle was StereoLithography Apparatus-1 (SLA-1) released by 3D System, Inc. in 1987. There are now numbers of Solid Free Form (SFF) technologies that uses additive principles; these include: Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Layered Object Manufacturing (LOM), 3D Printing (3DP) (see Table 1).

Rapid prototyping is the automatic construction/fabrication of physical objects directly from computer aided design (CAD) data sources. Rapid prototyping is often the best manufacturing process available for small production runs and complicated objects. Most prototypes require from three to seventy-two hours to build, depending on the size and complexity of the object (Williams, 1998). This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining. These dramatic time savings allow manufacturers to bring products to market faster and more cheaply. According to Steven (1995), in 1994, Pratt & Whitney were able to achieved cost reduction and time savings of 70 to 90 percent by incorporating rapid prototyping into their investment casting process.

There are different rapid prototyping techniques, each with unique strengths. However, because RP technologies are being increasingly used in non-prototyping applications, the techniques are often collectively referred to as solid free-form fabrication; computer automated manufacturing, or layered manufacturing (William, 1998). These systems add and bond materials in layers to form objects. With this additive technologies, object can be form with any geometric complexity or intricacy without the need for elaborate machine setup of final assembly (Venuvinod & Ma, 2004). Also, rapid prototyping systems reduce the construction of complex objects to a manageable straight forward and relatively fast process. This has result in their used by engineers as a way to reduce time to market in manufacturing, to better understand and communicate product designs, and to make rapid tooling to manufacture those products.

Surgeons, architects, artist and individuals from many other disciplines also routinely use the technology. Table 1 illustrates the different prototyping technologies and their base materials.

(Insert Table 1 about here)

Selective Laser Sintering (SLS) was developed by Carl Deckard for his master's thesis at the University of Texas, selective laser sintering was patented in 1989 (William, 1998). The technique uses a laser beam to selectively fuse powdered materials, such as nylon and metal into a solid object. Parts are built upon a platform which sits just below the surface in a bin of the heat-fusible powder. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete. Excess powder in each layer helps to support the part during the build.

Fused Deposition Modeling technique extrudes filaments of heated thermoplastic from a tip that moves in the x-y plane. The controlled extrusion head deposits very thin beads of material onto the build platform to form the layer. The materials are heated to semi-liquid state, fed through the extrusion tip and precisely deposited onto the modeling base in extremely fine layers. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction.

Stereolithography technique builds three-dimensional models from liquid photosensitive polymers that solidify when exposed to ultraviolet light. The model is built upon a platform situated just below the surface in a vat of liquid epoxy or acrylate resin (William, 1998). A low-power highly focused UV laser traces out the first layer, solidifying the model's cross section while leaving excess areas liquid.

Application of Laminated Object Manufacturing (LOM) and CNC in Pottery Production

Laminated Object Manufacturing

In Laminated Object Manufacturing developed by Helisys of Torrance, CA, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. Next, a heated roller applies pressure to bond the paper to the base and a focused laser cuts the outline of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype) (Williams, 1998). Cross-hatching breaks up the extra material, making it easier to remove during post-processing (Fig. 2). During the build, the excess material provides excellent support for overhangs and thin-walled sections. After the first layer is cut, the platform lowers out of the way and fresh material is advanced. The platform rises slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. However, because the models are made of paper, they must be sealed and finished with paint or varnish to prevent moisture damage (Williams, 1998).

(Insert Fig. 2 about here)

Jorge, Rui, Ricardo, & Ana (2004) carried out a research at Institute of Mechanical Engineering and Industrial Management, Portugal on the viability of rapid prototyping & tooling in product development of ceramic components (decorative ceramics). The researchers used an experiment approach by first designing new 3D CAD components using different software's, like Allias, Solid Works, Solid Edge and Unigraphics. After these, Laminated Object Manufacturing (LOM) rapid prototypes were manufactured. This prototypes where used to evaluate the success opportunity of using LOM for new product development. The advantage of LOM as stated by Jorge et al (2004) is that, the prototype production based on LOM rapid prototyping offers important time and money savings. One of the reasons for this is because of the material used by LOM (paper) is less expensive compared to ABS-plus used by FDM. However, the disadvantage of LOM is that; the models are less durable because of the material used (paper), but the durability can be enhanced through the application of seal or finishing with paint or varnish to prevent moisture damage (Williams, 1998).

Computer Numerical Control (CNC)

Computer Numerical control (CNC) is a method of controlling machines by the application of digital electronic computer and circuitry. In CNC, machine movement that are controlled by CAMs, gears, levers or screws in conventional machines are directed by computer and digital circuitry. This technology is seen has a viable tool in pottery product development. The application of CNC is more viable in direct production of mould in ceramic production (see Fig. 3). However, the process of generating mould using CNC technology involves three stages has illustrated in Fig. 4 below.

(Insert Fig. 3 about here)

(Insert Fig. 4 about here)

Creation of CAD Model

The process of producing physical prototypes using CNC machine starts with the digital prototyping. Digital prototyping involves creation of 3D CAD model using CAD software such has AutoCAD, Solidworks, Solid Edge etc (Fig. 5). Digital prototyping (using CAD) enables product developers to design, iterate, optimize, validate and visualize their products digitally throughout the development process (Autodesk, 2013). Apart from creating 3D CAD models, computer aided design can also be used to test evaluated design so as to identify possible fault at the early stage of product development.

(Insert Fig. 5 about here)

Creation of CAD Mould

After creating the 3D CAD model using CAD software (Solidworks), the CAD model can then be use to develop 3D CAD mould (Fig. 6).

(Insert Fig. 6 about here)

Building the Mould (with CNC)

The CAD data of the mould created can then be sent to the CNC machine to build the mould from the CAD data (Fig. 7). One of the advantages of using CNC machine is that it can build on different materials such as wood, Plaster (POP), plastic etc. Therefore, this will give product developers opportunity to explore various available materials to know the most suitable for their product.

(Insert Fig. 7 about here)

Casting Model from the mould

For visualization purpose, and to verify proper functionality, most manufacturers still insist on physical models. Therefore, the model can be casted from the mould built with CNC machine. This will help to visualize, evaluate and test the model to see how it will function and its manufacturability.

(Insert Fig. 8 about here)

Conclusion

Based on the previous findings that revealed that Fused Deposition Modelling rapid technology is an expensive approach in small and medium scale ceramic industry; Laminated Object Manufacturing (LOM) and Computer Numerical control (CNC) are seen as an alternative for small and medium ceramic industries. This is because, the two rapid technologies uses less expensive and readily available materials (LOM uses paper; CNC uses wood, plaster etc). Also, CNC technology allows the use of different material such as wood, Plaster of Paris (POP) etc; this will give manufacturers opportunity to explore various materials in product development process. However, future research one LOM and CNC will be to practically develop product using the two technologies and then compare them with the traditional method based on development cost, time and the product quality. This will give a clear view of the viability of the technologies (LOM & CNC) in enhancing small and medium scale ceramic industries.

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Table 1: Prototyping technologies and their base materials (Olalere, Aziz, & Ramli, 2012)

Prototyping Technologies	**Base Materials**
Selective Laser Sintering (SLS)	Thermoplastic & metal powders
Direct Metal Laser Sintering (DMLS)	Alloy metals
Fused Deposition Modeling (FDM)	Thermoplastic, eutectic metals
Stereolithography (SLA)	Photopolymer
Laminated Object Manufacturing (LOM)	Paper
Electron Beam Melting (EBM)	Titanium alloys
3D Printing (3DP)	High performance composite

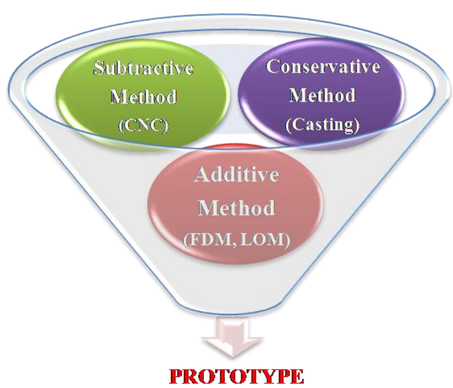

Figure 1: The three different ways of creating prototypes

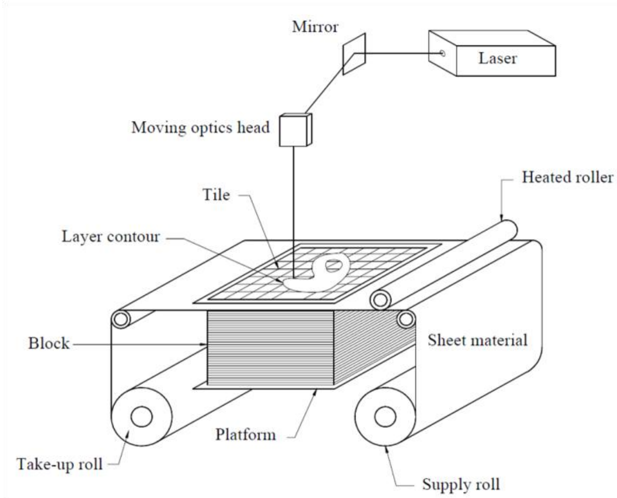

Figure 2: Illustration of the working principles of LOM
Source: http://blog.nus.edu.sg/u0804594/files/2011/10/LOM-Process.png

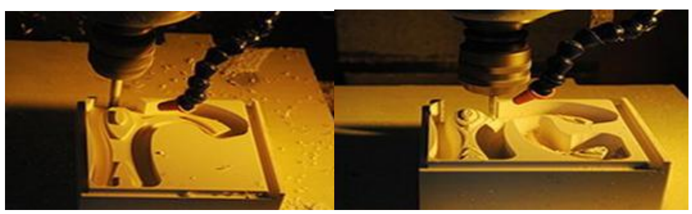

Figure 3: Plaster Moulds created with CNC
Source: ELANTAS Company

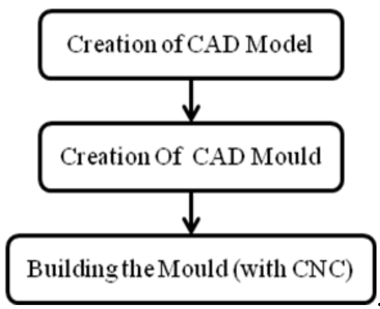

Figure 4: Four stage in product development using CNC

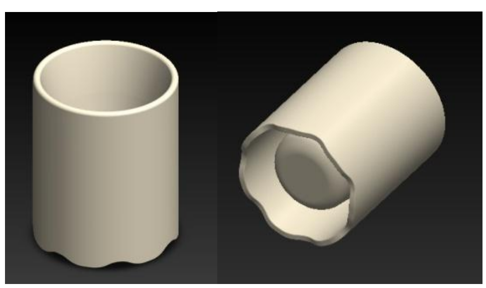

Figure 5: 3D CAD design of handle-free mug

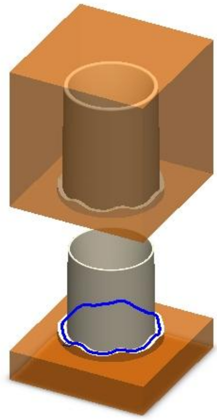

Figure 6: CAD Mould created with Solidworks

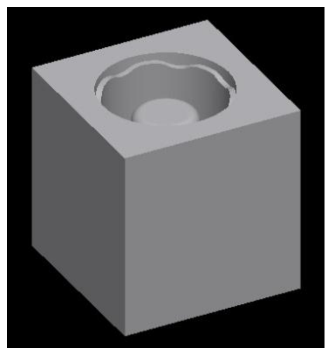

Figure 7: Plaster Mould