3D Printing of Ceramics for Design Concept Modeling

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Abstract

David Huson and colleagues at the Centre for Fine Print Research in the Department of Art and Design at the University of the West of England have recently obtained funding from the Arts and Humanities Research Council to continue their research into the 3D printing of ceramic materials.

Many ceramic manufacturing companies use 3D CAD software and 3D printing technologies to produce design concept models for evaluation, although their value to the design process is limited due to the type of materials that can be printed, conventional modeling and processing methods still need to be used to achieve a design concept model in a real material.

In collaboration with Denby Pottery a leading UK domestic tableware manufacturer the research project will refine and enhance the 3D ceramic printing process already developed at the University. This collaboration will enable he production of concept models of new design ideas in a real ceramic material that can be printed directly from CAD data, fired, glazed and decorated.

This paper will detail the progress of the research project and use examples of new designs to illustrate how these novel techniques can show great advantages in terms of time, cost, design flexibility and functionality when compared to existing 3D printing and conventional modeling techniques.

Introduction

The Centre for Fine Print Research was first introduced to 3D digital technologies and rapid prototyping techniques during an earlier AHRC (Arts and Humanities Research Council) funded project to investigate photo-ceramic tiles. A subsequent project, again funded by the AHRC, "The fabrication of Three Dimensional art and craft artifacts through virtual digital construction and output" was used to investigate the use of 3D rapid prototyping and digital fabrication techniques in the areas of Art/Craft and Designer/Maker Ceramics. This project successfully demonstrated that 3D printing with ceramic materials was a viable method for the production of ceramic artworks and a series of works were produced for several artists. During the course of the project it was realised that there may be other commercial applications for this process, although the physical properties and characteristics of 3D printed ceramic tableware bodies are not yet comparable with ceramic bodies produced by conventional forming techniques and would not be able to withstand the rigours of daily use in terms of chip resistance and dish washer suitability, one area where the process could find an immediate application would be in concept modeling for new design shapes. In collaboration with Denby Pottery, a leading UK ceramic manufacturer a successful bid application for follow on funding was made to the AHRC to investigate the viability of using this technology to produce design concept models for the tableware industry.

3D Ceramic Printing

The appearance of relatively low cost 3D powder printers from Z Corporation gave rise to the idea that these technologies could perhaps be used to print ceramic artworks. Fundamental to the concept of 3D printing of ceramic powders is the Z Corporation 3D printer, the purchase of a Z 310+ model at the start of the project allowed development work to begin. The Z Corp system uses two moving beds of powder traversed by a carriage consisting of a roller to move a precise thickness layer of powder from the feed bed to the build bed and an ink jet head that moves north and south on the same carriage. The printer software slices a 3D virtual model into layers 100 microns thick and sends each layer to the print head sequentially; each layer represents a cross section of the model. The ink jet head prints binder onto the powder build bed in the pattern of the layer cross section, the build bed drops down by a layer thickness, the roller mechanism moves across to the feed bed which rises by a layer thickness, the roller then sweeps the layer of powder from the feed bed across onto the build bed and the process is repeated until the model is built, After allowing about one hour for the model to set, the model can be removed from the build bed and the excess powder is removed.

Over the course of the previous project a ceramic body was developed that could be used in Z Corp printers to replace the proprietary plaster based material used by a new type of ceramic body that performed in a similar way to the recipes used for tableware manufacture.

In conventional ceramic forming processes a clay body is used that is composed of a mixture of different material that react together to form a fired ceramic, an industrial ceramic body will contain clay minerals which exhibit plastic properties when mixed with water and this allows the ceramic body mix to be shaped or formed into mould and provide the green (unfired) strength to the mix. Other components such as feldspathic fluxes are added as they form a glass like structure during firing to bind the materials together, the final ingredient is silica in the form of flint or a ground sand that acts as a filler and is vital to obtain the correct thermal expansion of the fired body to ensure a good glaze fit.

The selection of different types of raw materials and the adjustment of the ratios of these materials in the blend allows the fired characteristic of the final ceramic body.

Concept Model Design Process

Tableware and whiteware companies already use 3D CAD and computer numerical control (CNC) models to produce tooling that feeds into traditional mould making methods. Some companies have advanced further and use 3D printing machines such as Z Corp and Objet to print out 3D visualisation design models. The positive model produced from this process can then be used to continue the process by traditional techniques.

Denby Pottery are at the forefront of these developments in the UK using 3D printing in their design studio to aid in the development of new design concepts. They are extremely positive

about these technologies and cite great advantages in terms of time, cost and design flexibility.

The traditional ceramic design method involves transcribing dimensions for a design from a drawing, turning it on a lathe or modeling it in solid plaster then turning and adjusting the design as the model develops. From this a mould is made in potter's plaster from which a slip cast clay model is made which is then fired and glazed. The disadvantage is this method can be a very slow and labour intensive process requiring a great deal of skill. The model is difficult to alter and modification often means starting again to adjust the shape. CNC milling uses 3D CAD software to create a virtual model that is then machined using a CNC miller out of a modeling material. The model has a potters plaster mould cast from it, it is then slip cast with clay and fired. This is a much faster process allowing the designer to make design iterations, speeding up the modeling process. The Z Corp printing method used by Denby Pottery employs the 3D CAD software to develop designs, which are directly printed in using standard Z Corp material. The design process allows multiple iterations to take place and creates a model with the same shape and section as the final piece but in a plaster material that cannot be fired or take glaze, decoration or be tested for its functionality.

3D Printed Ceramic Concept Model

Denby Pottery are seeking a concept model process that looks and feels like the final product which can be fired, glazed and decorated and can be fully tested for functionality.

Several researcher teams have investigated the Z Corp 3D printing process (which normally prints with plaster based powders) to fabricate ceramics including the original inventors of the process, Yoo and Cima at MIT [1]. More recently the CFPR at the University of the West of England, Hoskins and Huson [2], Bowling Green University, Balistreri [3] and University of Washington, Ganter [4], have undertaken research replacing the standard plaster-based composite material with a ceramic body material. Ganter has concentrated on producing a low cost open source system to reduce the cost of prototyping in an educational context. Balistreri has used the process to make ceramic artworks.

Common characteristics displayed by all 3D printed ceramic forms compared to conventionally formed ceramics are that they exhibit a high firing contraction and distortion, a high porosity and low strength. These disadvantages can be allowed for in the production of one off artworks but can cause serious problems when attempting to reproduce a commercially acceptable tableware shape.

Conventionally, highly vitrified thin section bodies such as bone china and porcelain used in tableware require profile setters during firing to maintain the integrity of the shape. Profile setters are purpose built ceramic supports that have a similar expansion and contraction rate to the object they are supporting. So when fired, the plate, will not warp unduly because it is supported by its profile setter. However these support systems would not necessarily be suitable or available for new concept shapes.

Work to date

Denby Pottery use a standard test cup shape to as base for monitoring the performance of their production glazes and as a comparison for new glaze finishes that are under development.

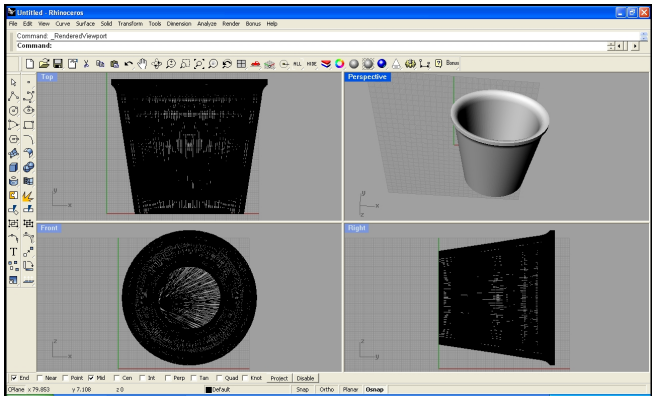

Figure 1 Denby test cup

It was decided to use this shape to investigate the suitability of the 3D ceramic printing body for concept models and to develop a support to prevent the distortion of the concept models during the initial bisque firing. One of the advantages of the 3D printing process is the possibility to print a custom support setter within the 3D printer at the same time as printing the ceramic object.

A support was generated in Rhino 3D CAD software that would support both the base of the cup and the rim during the firing cycle. A series of test cups and supports were built on a Z Corp 310 3D printer using standard ZB 150 binder and the UWE Standard Porcelain ceramic body specially developed for the process. This body still has a relatively high porosity of 30% on a four hour water absorption test, the dry to fired shrinkage is 15% which compares suitably to the dry to fired contraction of a typical porcelain body.

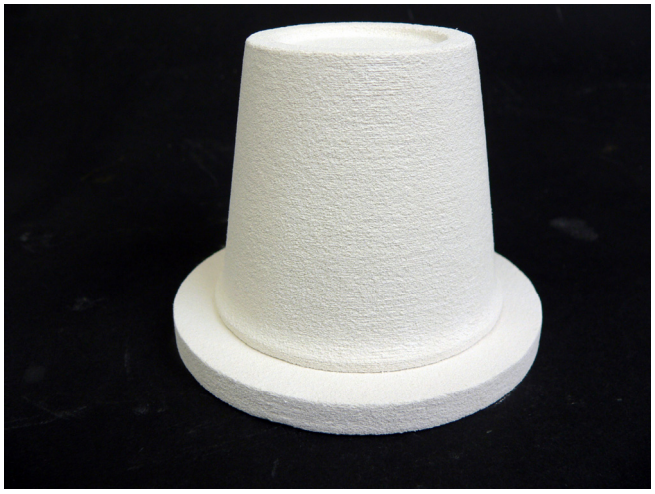

Figure 2 3D printed test cup on firing support

Figure 3 Test cup and firing support

The cup and support were bisque fired together at a temperature of 1225 degrees C. with a dwell of 30 minutes. After bisque firing the cups we glazed with a transparent lo-sol glaze and the fired again at 1050 degrees C.

Figure 4 Fired glazed test cup

Having successfully recreated the Denby Pottery test cup by 3D ceramic printing it was decided to attempt to produce a fired, glazed 3D printed concept model of a sugar bowl and lid that was being developed by Denby Pottery.

A 3D CAD file was obtained from the Denby design studio and a model was 3D printed in the Standard Porcelain material. This was bisque fired to 1225 degrees C. and the glazed with a transparent lo-sol glaze and fired again at 1050 degrees C.

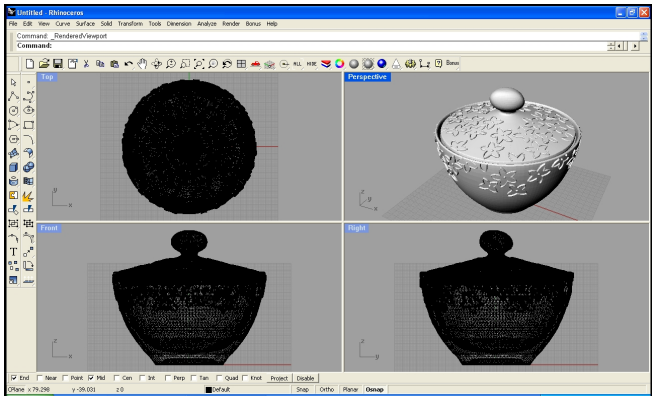

Figure 5 CAD drawing of sugar bowl and lid

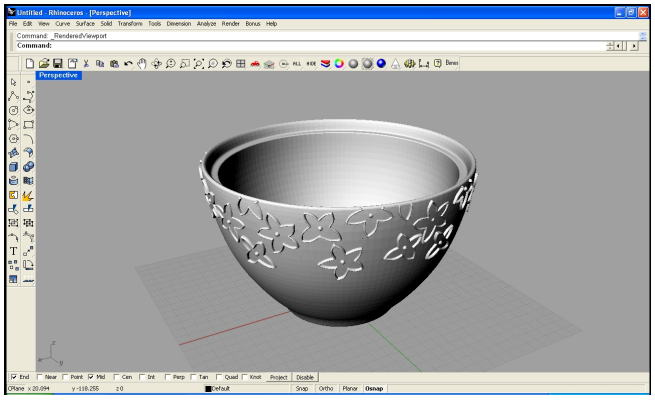

Figure 6 Rendered sugar bowl

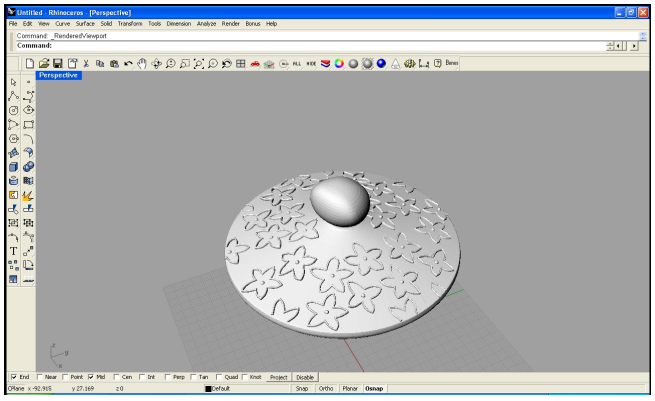

Figure7 Rendered sugar bowl lid

Figure 8 3D printed unfired ceramic sugar bowl and lid

Figure 9 Fired, glazed sugar bowl and lid

Figure 10 3D printed ceramic concept models

Summary

The work to date has shown that although the project is in its early stages it is possible to produce real ceramic concept models by 3D printing. With further refinements to the ceramic body formulation and particular emphasis on the type and design of support structures for firing there is great potential for 3D ceramic printing to be a useful and productive tool for a ceramic design studio.

References

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Author Biography

David Huson is a Research Fellow at the University of the West of England. Previously he has worked in the ceramic industry, holding positions of Research and Development Manager, Technical Manager and Works Manager. He also ran his own business for five years producing commercial ceramics. He is currently researching photo ceramics and the use of digital fabrication techniques for Art/Crafts, Designer/Maker ceramics and industrial applications.