The Digital Fabrication of Ceramics by 3D Powder Printing

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Abstract

David Huson and colleagues at the Centre for Fine Print Research in the School of Creative Arts at the University of the West of England have recently successfully completed a three-year Arts and Humanities Research Council funded project into the use of Digital Fabrication techniques in the area of Art/Craft ceramics. The research project has developed a methodology for the 3D printing of ceramics by replacing the proprietary powder in a commercially available powder/binder 3D printer system with a specially formulated ceramic powder. This process has been shown to be a viable procedure for translating 3D computer generated models in to physical ceramic forms that can then be fired and further processed. This paper will detail the progress of the research throughout the project and use examples from current artwork projects to illustrate how these novel techniques have been developed and refined to allow artists and crafts persons to investigate and implement ideas and concepts that were unattainable by conventional forming methods.

Introduction

The Centre for Fine Print Research at the University of the West of England in Bristol has recently been awarded a substantial grant from the United Kingdom Arts and Humanities Research Council (AHRC) to fund a three year project “The fabrication of 3Dimensional art and craft artefacts through virtual digital construction and output“ to investigate the use of 3D rapid prototyping and digital fabrication techniques in the areas of Art/Craft and Designer /Maker Ceramics.

The CFPR has had much experience in working with industry to incorporate unique and useful fine art based paradigms into industrial research partnerships and commercially successful developments. This integration of industrial needs and academic research has formed the basis of a number of the Centre’s previous AHRC grants and Knowledge Transfer awards.

3D Printed Ceramics

A major strand of the research project was to investigate the potential of using 3D printing technologies to directly form ceramic artworks. The intention was to attempt to replace the proprietary plaster based powder in a Z Corporation 3D printer with a ceramic body in powder form. If successful this would allow one off or short runs of bespoke ceramic artworks to be produced directly from a 3D virtual model that had been designed in a 3D computer aided design (CAD) software without the need for the traditional intermediate steps of modeling and mould making.

This paper will detail chronologically the route taken to achieve the aims of the project, to develop a viable 3D printing process for art and craft ceramics, from the first trials with ceramic powders through to the final outcomes. It will show the problems encountered on the way and the solutions derived to overcome these problems. To illustrate the process studies of artworks developed by Brendan Reid the PhD research student on the project will be used along with test pieces developed by other members of the Centre for Fine Print Research (CFPR) research team.

The CFPR was first introduced to 3D digital technologies and rapid prototyping techniques during an earlier AHRC funded project to investigate photo-ceramic tiles. This project successfully managed to reproduce by using digital technologies a 19C method of generating a continuous tone photographic image onto the surface of a glazed ceramic tile by using a combination of a tinted glaze overlying a relief map of the image. When early attempts to produce the reliefs by using photomechanical techniques prove unsuccessful a method of generating the relief by using a combination of 3D software and a computer numerical control (CNC) rapid prototyping machine was developed. This technique enabled a series of photo-ceramic tiles based on images supplied by invited artists to be produced and exhibited at the City Museum of Stoke on Trent alongside the original 19thC tiles.

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 and funding was obtain from the AHRC to investigate.

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 ids 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.

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 for general use 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 to be achieved .ceramic clay bodies can be bought from suppliers ready prepared or can be mixed from the basic ingredients. In industrial ceramic production one form that be bought is spray dried material, this is a fully prepared and pre-mixed ceramic body that is in granular form. As a starting point for the 3D ceramic printing experiments spray dried material was sourced and introduced into the feed bed of the Z Corp printer.

Some simple geometric shapes were drawn in Rhino 4, a computer aided design (CAD) software package and loaded into the Z Corp printer driver software. The first indications were that although not as good as the native Z Corp material the spray dried body had reasonable flow properties and printed reasonably well, unfortunately on trying to remove the printed forms from the build bed the green strength was seen to be inadequate as they crumbled back to dust. The procedure was repeated but this time much more care was taken in removing the printed forms and prior to handling they were carefully dried to remove any moisture remaining from the binder. After drying the printed forms were fired in a kiln at 1150 deg C and examined, as can be seen from the following photographs some distortion had occurred. The fired forms had a very low density and were quite friable; in some respects they resembled a "ceramic sponge". Nevertheless the first 3D printed ceramic object had been made.

While it had proved possible to 3D print simple geometric shapes in a ceramic material, because of the poor green strength it would be very difficult to print a more complicated form, to circumvent this problem a two stage firing regime was investigated. The maturing temperature of the ceramic body mix being used was 1150 deg C, it was thought that by printing a more complex form and removing it from the build bed still encased in the unbound powder it would be possible to pre-fire or sinter the ceramic material to a point that the printed model could gain sufficient mechanical strength to retain its form while the supporting powder would be loose enough to by removed from around the model by brushing it away. Firing trials were carried out and a temperature of around 990 deg C was discovered to be the optimum for this particular body.

In terms of ceramic production the unique property of a 3D printing system means that it is possible to produce complex forms that could not be realised by conventional forming methods, freed from the constraints of moulds and tooling, to demonstrate this property a 3D model was constructed in Rhino 4 CAD software of a lattice sphere containing a ball, this model was to be printed out and processed using the two stage firing method.

The two stage firing process combined with the spray dried ceramic body had been shown to be able to be used to form 3D printed ceramic objects but while it had the advantage of the prepared body material being readily available and of the correct thermal expansion, the coarse grain size and the poor green strength which necessitated the two firing approach limited its attraction as a process worth further investigation.

It was decided to investigate a different material to see if some of the disadvantages could be overcome.

Ball clay is sedimentary clay that is used in ceramic bodies for its contribution to green strength, it is highly plastic with a fine particle size and when fired to around 1100 deg C is self fluxing and will produce a dense body. A commercially available ball clay was obtained and a series of printing trials were carried out on a range of models.

Using the ball clay gave a useful insight into how the 3D printing process operated with ceramic materials, because of its high green strength it became possible to print out models that could be remove from the build bed without breaking and could be de-powdered and fired in without having to follow a two firing pre-sintering route. The fine particle size particle size of the ball clay while contributing to the superior green strength also gave a much improved surface finish. On the downside the properties that showed what was needed to solve some of the problems in the original spray dried body system also caused difficulties. The high plasticity that helped the unfired body strength caused problems with cracking of the model when drying (the binder used in the process contains a high percentage of water which is absorbed by the powder) and the same action causes the individual layers of powder to curl and shift causing distortions in the model. From a ceramic point of view using a single ball clay type material is not a viable route to produce ceramic objects as well as the above detailed problems the thermal expansion characteristics means that it would be very difficult to find a glaze to fit. However the ball clay trials were extremely useful in determining the next direction for the investigation.

A widely used ceramic body, particularly in the UK ceramic industry is an earthenware body, a typical recipe for this type of material would be 25% ball clay, 25% china clay, 35% silica and 15% flux, the ratios of the components in this type of body can be adjusted to optimise the characteristics of the body. The standard method for processing these materials would be to wet mix them to and then either to de-water the mix by filter pressing to make a plastic clay body or to spray dry the material for dust pressing. The previous work carried out during the project showed that a fine particle size with sufficient plasticity to provide a reasonable green strength would be essential.

Investigations during the project and research into the details of the Z Corp 3D printing process had indicated that the addition of certain binders and supplementary materials to the powder mix would help to solve some of the problems with the previous ceramic body mixes that testing had highlighted.

It was decided to dry blend a mix of the earthenware ingredients with the addition of binders and catalysts to the powder and to run a series of tests and trials.

With the new dry blended earthenware recipe body the same set of models as in the earlier trials were produced to provide a comparison. The performance of this ceramic body was far superior to the original trials; it was possible to remove the green printed ceramics from the build bed and fire in one process. Adjusting the orientation of the models in the build bed helped to reduce the incidence of layer shifting but did not completely eliminate it.

Although the fired contraction, porosity and surface finish were not yet comparable with ceramics formed by conventional processes it was thought that attempting to produce a one off ceramic artwork using the 3D printing ceramic process would be a useful exercise.

Brendan Reid, the PhD research student working with the team, had been using 3D CAD design techniques allied to the 3D scanning of found objects to construct 3D virtual models, by printing these models in the new ceramic powder it would be possible to determine the viability and desirability of the new process.

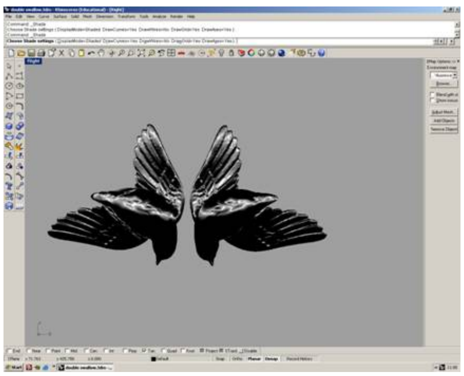

Figure 1. *Dead Swallows*

Creating the Dead Swallows concept in 3D printed ceramic material showed that a viable reproducible process had been developed but that it still had serious limitations; from an aesthetic point of view the surface quality and definition of the finished work could be improved. Looking from a technical perspective there were four areas that needed to be improved, these were layer shift, too high fired porosity, too high fired contraction and variable surface quality.

To realise these aims it was decided to take a two track approach, research had indicated that by applying the new powder binder addition and catalyst to pre-processed commercially available bodies it was possible by careful attention to the particle size and the overall particle size distribution to create a ceramic body suitable for the 3D printing process. The reduction in particle size by ball milling gave an increase in green strength that allowed the liquid binder saturation level to be reduced. This had a beneficial effect on the layer shift problem and reduced the incidence of this to acceptable levels. By controlling the particle size distribution the high porosity and high fired contractions exhibited could be reduced to manageable proportions and were starting to approach the figures experienced with conventional ceramic bodies in conventional ceramic forming techniques. Being able to adapt any commercially available clay body by pre-processing and the powder binder/catalyst addition would increase the flexibility of the ceramic 3D printing system in the range of bodies that could be processed and the final fired appearance and characteristics. A commercial bone china body was acquired and prepared for 3D printing.

Although modifying a commercially available body had the potential to give good results it meant that the firing performance of the body was still tied in to a fixed body recipe, the exact recipe and the materials used in commercial bodies are confidential, so a second track was followed that involved using the knowledge gained from the previous trials and experiments to construct a suitable ceramic body for 3D printing from raw materials, again with careful attention to particle size distribution and with the addition of powder binders and catalysts. A porcelain type was blended and prepared for 3D printing. Both of the new bodies were used for case studies to demonstrate their properties.

Using the bone china body a case study was done using a 3D model created by Brendan Reid.

Figure 2. *Manta*

To reduce the potential for distortion in the firing process, the ability if the Z Corp Z Print software to form a support structure was used to print a firing setter alongside the model. The new bone china body demonstrated a much higher green strength and could be handled and de-powdered straight from the build bed. The Manta model was successfully fired and exhibited alongside other versions at the Impact Conference held in Bristol in September 2009.

Dr Peter Walters, a RCUK Research Fellow based at the CFPR, has been working with the team using a series of CAD generated forms to investigate the material properties of a range of 3D printing and rapid prototyping methods. To demonstrate the capabilities of the 3D ceramic printing process with the porcelain body it was decided to use one of these forms the trumpet sphere.

This object would be impossible to make using conventional ceramic forming methods and is the ideal subject to demonstrate the capabilities of the ceramic 3D printing process.

Figure 3. *Trumpet sphere*

Summary

3D ceramic printing using a Z Corporation machine has proven to be a viable method for the production of bespoke ceramic artworks and has great potential for future use in the areas of Art/Craft and industrially based ceramics.

Development is continuing with both methods of production for a 3D ceramic printing body and refinements have been made to all the relevant parameters, the layer shift problem has been eliminated and green strength, surface finish, fired contraction and porosity have all been considerably improved.

The increased resolution possible with the latest body types have meant that we have now come full circle, it is possible to print a surface relief with sufficient detail to produce a glazed photo-ceramic tile of the same type that that the CFPR originally developed over five years ago at the start of the journey into 3D digital technologies. The CNC milled tiles required up to fifteen hours of machining time to cut the relief into a plaster substrate, then several hours of mould making and slip casting. A 3D ceramic printed tile can be formed directly from a 3D file in less than half an hour, fully realising the potential of this new technology.

The following images are of the latest models made by this technique

Figure 4. *3D printed ceramics*

Figure 5. ***Skulls***

Figure 6. ***3D printed ceramic photo tile***

References

1. Bunnell, K, 'Re-Presenting Making, The Integration of New Technology into Ceramic Designer-Maker Practice', Centre for Research in Art and Design, Gray's School of Art, The Robert Gordon University, 1998. ISBN: 1-901085-28-7)
2. AHRB Aylieff F. Exploring 3D Modeling Software in the production of ceramic artworks) (Gernand B. Exploring sculptural practice and design strategies through the media of ceramics and 3D Computer Modeling
3. Rees M. Rapid Prototyping and Art, paper given at the Rapid Prototyping Conference May 1998. Facets and Fingerprints: Contemplating the Computer in Art. Paper at the International Sculpture Conference 1998 Rapid Prototyping: Realizing Convoluted Form and Nesting in Sculpture.[1] Prototipazione e Produzione Rapida 1998.
4. Marshall J. Computers and Creativity-Is CAD a useful tool for studio potters. Ceramic Review Mar/Apr 2002
5. TACTICS Aitken, P, Bunnell, K, Pirie, I, 'The Integration of New Media Technology In Craft Practice', CADE (Computers in Art and Design Education) 99 Conference Proceedings, University of Teeside, 1999 Page 192 - 2

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 an the use of digital fabrication techniques for Art/Crafts ,Designer/Maker ceramics and industrial applications.