3D Printing of Self-Glazing Ceramic Materials: An Investigation Inspired by Ancient Egyptian Technology

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Abstract

The inspiration and background research for this project is based upon Egyptian Faience because there is an interesting and coincidental synergy between the material properties of ancient Egyptian Faience and the material requirement for the successful 3D printing of ceramic powders. Originating in the 5th Millennium BC, Egyptian Faience was not made from clay, but instead composed of quartz and alkali fluxes and is distinct from Italian Faience or Majolica, which is a tin, glazed earthenware. In its original Egyptian context Faience was a versatile material, used in a variety of ways and in a number of different forms, to create objects such as sculpture, vessels, funeral figurines, tiles, boxes and body ornamentation – all with a highly coloured lustred glaze. In contemporary terms Egyptian Paste has visual qualities desirable to many crafts practitioners.

This paper will chart the progress of the project to date and detail the technical development of 3D printed self-glazing ceramics. The potential of the process will be demonstrated by the production of ceramic artworks using the techniques developed during the project.

Introduction:

The Centre for Fine Print Research has over five years continuous experience in the 3D printing of ceramic materials for artists, designers and the ceramic industry. This particular research project aims to create a set of functional ceramic 3D printable materials through a process based upon the historic Egyptian Faience techniques, which will allow ceramic artists, designers and craftspeople to 3D print directly from a 3D CAD file an actual object in a ceramic material that can be glazed and vitrified in one firing; a breakthrough for ceramic design and manufacture.

Historical Background:

The inspiration and background research for this project is based upon Egyptian Faience. “Faience was the first glazed ceramic material invented by man.”[1], Egyptian Faience is a silica based, glazed ceramic first produced in Egypt and the Near East around the 4th millennia BC The composition is based on a powdered quartz or sand body, containing traces of lime and an alkali obtained from natron or plant ash. The body was coated in a soda-lime-silica glaze that was most commonly bright blue-green in colour due to the addition of copper [2]. The main advantage of Faience was that it could be glazed, something that was not done to clay pottery until Roman times. [3]

The bright colours of Egyptian Faience reminded early travellers to Egypt of ‘Fayence’ a colourful tin- glazed earthenware produced in Faenza (northern Italy) around the 16th century [4]. Presently this material is more commonly known as Majolica. It is important to note that the ceramic ware produced by the ancient Egyptians is completely different in composition to Majolica, as well as the mechanisms used for glaze application.

The Egyptians referred to Faience as ‘tjehnet’, meaning that which is brilliant and scintillating like the sun, moon and stars [3] To the ancient Egyptians, the sun was a symbol of resurrection, and its link to Faience explains why this material was used to create funerary figurines (shabti) to accompany the dead. The turquoise blue colour associated with the earliest Faience is also thought to be symbolic of rebirth and fertility. [4]

Figure 1. *Egyptian Faience Shabti British Museum*

Glazing techniques:

It is now generally accepted that Egyptian Faience was glazed using 3 techniques; efflorescence, cementation and application. These techniques are not mutually exclusive and could have been in combination to produce a single object. Efflorescent glazing is a self-glazing technique that occurs when soluble salts mixed in with the body migrate to the surface upon drying to form a crust on the outer surface. Upon firing, the ‘efflorescent layer’ melts to form a glaze [5]

Cementation glazing is also a self-glazing technique. After an object has been formed and left to dry, it is buried in a glazing powder composed of alkalis, copper compounds, calcium oxide or hydroxide and/or quartz. During the firing process, a glaze layer is formed on the outer surface of the object only. Research conducted by [6] Mehran, M. and Mehran, M. showed that one of the mechanisms at work in this process was the diffusion and migration of alkalis in the glazing powder to the siliceous Faience body, followed by subsequent reactions between them to produce glass phases which not only cover the object in a layer of glaze, but also penetrate the body to produce glass between the fine grains of quartz. [5]

After firing, the friable glazing mixture can be crumbled away to reveal the glazed object inside.

The third glazing method used by the ancient Egyptians was application glazing. Similar to techniques used by potters today, this method involves coating the Faience object in a paste or slurry. The slurry was composed of alkalis derived from plant ash or natron and copper compounds such as malachite, which was applied to a fired object by dipping, pouring or brushing the slurry onto the body. [7]

When fired the slurry melts to form a glaze on the surface of the object.

The Project:

True Egyptian Faience is notoriously difficult to work with, the low plasticity of the Faience bodies makes it a very difficult material shape, if too little water is added, the material will not bend and tends to break when forming objects and if too much water is added the material becomes sticky and has a tendency to slump under its own weight. The possibility of 3D printing this type of material offers the opportunity of opening up the area of self-glazing ceramics to artists and craftspeople, the intention of the project to offer low cost routes and methods to accessing 3D technologies will benefit all interested in this fascinating material.

Methodology:

Starting with ancient Egyptian recipes, 3D ceramic printing body powders will be developed, using modern materials and firing techniques to give a wider palette of colours and more consistent and reproducible results. The aim of the project is to develop a series of self-glazing, low firing temperature bodies for 3D printing. This paper will describe the development of an effloresing glazing type body suitable for 3D printing.

The investigation has started by taking four examples of Egyptian faience recipes, one currently used by craft potters and three ancient Egyptian recipes discovered by researching the available archaeological literature.

Examples of these bodies have been produced by conventional wet forming methods, the ceramic powders and silica were dry mixed with anhydrous soluble salts (sodium carbonate and sodium bicarbonate) and various ceramic stains including copper carbonate, cobalt carbonate, cobalt oxide and manganese dioxide to attempt to replicate the traditional Egyptian Faience colours. The efficiency in producing an effloresced glaze surface has been analysed and measured, to determine the best ratio of soluble salt addition and the optimum drying conditions along with a series of tests to determine the ideal firing regime and temperature for each particular body. Tests have been performed to determine the fired shrinkage and fired porosity and mechanical properties of each.

The best performing ancient Egyptian body has then been re-formulated to use currently available ceramic materials of consistent grain size and quality to improve their properties

Preliminary Investigations:

Early experiments have resulted in success with an Egyptian Faience body recipe produced by conventional ceramic forming techniques; with a self-glazed copper carbonate stained body being fired at 950 deg. C.

Figure 2. *Egyptian Faience test body with copper carbonate stain*

Having had success in consistently reproducing the efflorescent glazing effect using a conventional ceramic body a series of trials were performed using the 3D printable ceramic body developed at the CFPR. By 3D printing the base form, firing and then applying by dipping onto the top of the fired 3D print an efflorescence slip derived from the trials with conventional forming materials on the ancient Egyptian recipe body it has proved possible to reproduce the turquoise glaze effect exhibited by the ancient Egyptian process, although this is at this stage a two fire procedure it can be considered to analogous to the application glazing techniques described in the archaeological literature and provides a route to reproducing Ancient Egyptian artefacts by using modern 3D technologies.

To demonstrate this technique it was decided to try to 3D print and glaze a classic Faience object, the Nile hippopotamus examples can be found in museums all over the world.

Figure 3. *Faience hippopotamus Metropolitan Museum New York*

In ancient Egypt, the hippopotamus was a threat to farmers' crops and became associated with chaos and evil, the first pharaohs hunted them in the marshes. Small sculptures of hippos were placed in tombs as reminders of the Egyptians' love of hunting. At least one leg was broken on each tomb hippo in order to render the animal harmless in the afterlife.

It seemed appropriate to attempt to reproduce a 3D printed model of a hippopotamus as an example of the process. To pursue on of the aims of the project to investigate low cost alternative to accessing 3D technologies to generate the 3D model of the hippopotamus it was decided to trial a new 3D capture system 123D Catch from Autodesk. This is a web-based system that can generate a 3D model from a series of photographs taken around a physical model. The photographs are uploaded to the 123D Catch website, processed and then the 3D model suitable for printing can be downloaded. One of the barriers for artists in accessing 3D technologies is the substantial cost to acquire the equipment and many companies are experimenting with low cost routes to utilise the technologies. While the model does not possess the high resolution of a laser or white light scanned 3D model it is sufficient for the 3D printed Egyptian faience, the process is free and can be accessed by anyone with a camera.

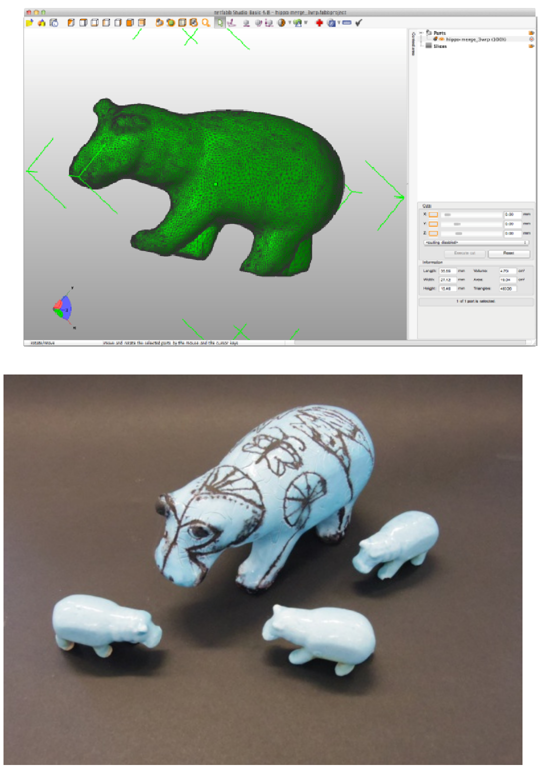

***Figure 4.** 3D scanned model of hippopotamus and 3DP Faience models*

A model of a faience hippopotamus bought from the Metropolitan Museum of Art was obtained, photographed and uploaded. The subsequent 3D file was processed to produce a watertight 3D computer model, this was 3D printed in ceramic, covered in efflorescent glaze slip stained with copper carbonate, decorated with manganese dioxide stain and fired.

Current Work:

The work to this point has involved using the 3D print ceramic body developed at CFPR UWE and coating it with an efflorescence glazing slip based on ancient Egyptian recipes, current and ongoing work has involved the development of a 3D printable ceramic body containing soluble salts that will effloresce upon drying to form a glazed surface when fired. The 3D printers used for this project are the Z Corporation model Z310 powder/binder printers. In the CFPR UWE 3D printed ceramic process the standard Z Corporation plaster based powder material is replaced by a specially developed ceramic body that is activated by jetting the standard Z Corporation ZB60 binder onto the build bed to form the model layer by layer. The conventional efflorescence glazing material chosen from the original trials and used for the efflorescence slip glazing of the hippopotamus model was re-formulated to use the calcined alumino-silicate materials and organic binders developed during the previous CFPR UWE 3D ceramic printing projects. This has been a difficult balancing act to accomplish, as the requirements of a 3D printable material are in many ways incompatible with the requirements of a self-glazing ceramic body. To get a sufficient amount of water via the binder into the faience body mix to generate the soluble salt transfer to the surface during drying can cause layer shifting during printing and careful control of the binder saturation levels is necessary, but it has proved possible to successfully 3D print an Egyptian Faience ceramic body.

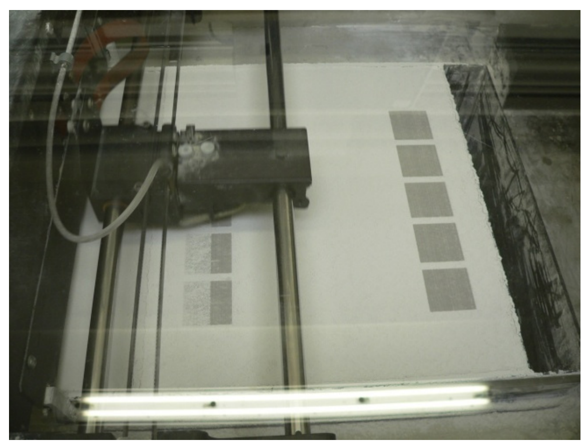

***Figure 5.** 3D printing Egyptian Faience body*

By adding to this 3D printing Egyptian faience body a 50/50 mixture of a sodium carbonate and sodium bicarbonate, containing finely ground manganese dioxide stain it has proved possible by increasing the liquid binder saturation level to 3D print sample tiles of Egyptian Faience body which can be removed safely from the build bed and which effloresce on drying.
When fired to 950 deg. C a black glaze surface is developed on the outside of the tile due to the migration of the salts and the stain.

Figure 6. *Efflorescence glazed 3D printed tile*

Figure 7. *Section showing glaze surface*

Summary:

This is the first year of a three year project to investigate 3D printed self-glazing ceramics and work to date has demonstrated the viability of applying ancient Egyptian glazing techniques to modern 3D printing technologies to develop a new type of ceramic material which has great potential for ceramic artists, designers and craftspeople as well as in the field of ceramic education. Work to date on the project has demonstrated the viability of these techniques to 3D print self-glazing ceramics. Trials on the cementation glazing process are scheduled for the end of the first year of the project. It is envisaged that there will be a series of workshops and a symposium that will be held will be held to disseminate the results of the project. Artists will be invited to submit 3D files to be produced by the process.

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Author Biography

David Huson is a Senior Research Fellow in the Centre for Fine Print Research at the University of the West of England in Bristol.

Having worked for over 25 years in the U.K. ceramic industry, he is currently researching 3D printed ceramics, photo ceramics and the use of digital fabrication techniques for Art/Crafts, Designer/Maker ceramics and industrial applications. In 2011he was awarded the Saxby medal by the Royal Photographic Society for his work on 3D imaging.