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Robotic Ceramic Paste Extrusion for Industrial Prototyping and Production.

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Abstract:

Ceramic additive layer manufacture employs a range of different technologies including ceramic paste extrusion, powder/ binder jet and UV and daylight cure ceramic loaded resins. Each of these technologies has its own set of advantages and disadvantages. This paper investigates the possibilities of using a robot multi-axis system to enhance the capabilities of a ceramic paste extrusion process.

Introduction:

Materials and processes for additive layer manufacture have advanced considerably in the last few years and have moved the application of the technology away from prototyping to fabrication and manufacture. One area that still has little effective presence is that of 3D printed ceramics.

Ceramic materials have proved difficult to integrate with 3D printing technologies, and there is still a considerable way to go before the characteristics of most of these materials can be considered adequate. The reasons for wanting to use ceramic materials are to utilise their unique properties, but the limitations of the available processes make these properties difficult to realise by current additive manufacturing methods.

The problems experienced are high firing contractions, low density and strength and potential incompatibility with glazes. For general tableware and giftware ceramics, two main methods of 3D printing are used, ceramic paste extrusion through a syringe and fine nozzle and a powder binder process based on the original Z Corporation system that jets binder onto a powder bed containing a mix of pre-processed ceramic powders and an organic binder.

The powder/binder process gives great freedom of geometry and the ability to form complex shapes but has poor green strength and an inherent high porosity due to the burn out of the organic binders. The restrictions on the particle size range required for the 3D printing process to function correctly have a deleterious effect on the fired properties of the ceramic and reduce the fired density and strength.

The paste extrusion system has the advantage that conventional ceramic pastes and bodies can be used, solving the issues caused by using ceramic bodies that have a compromised performance by being adapted to work in a 3D printer, but there can be problems with maintaining an even extrusion of a thin bead, the main issue with this method, however, is the restriction on geometric freedom that cannot compete with other 3D printing methods.

The Centre for Fine Print Research at the University of the West of England in Bristol has a history of over ten years research into 3D printed ceramics, has developed and patented materials and processes in this area, and has collaborated with leading ceramic manufacturers and material suppliers in the U.K.

3D printed ceramic processes:

Powder Binder 3D printing

The first 3D printing process using ceramic materials was the powder binder process originally developed at MIT [1] this utilised essentially monolithic engineering type ceramic materials, it demonstrated the viability of 3D printing for ceramic materials and led to the formation of companies to exploit the technology such as Z Corporation and Specific Surface Corporation.

3D printable ceramic materials for the Z Corporation machine platforms have been developed separately by Tethon 3D and the Centre for Fine Print Research team at the University of the West of England who have available a Tri-axial porcelain 3D printing material that replicates the characteristics of conventional porcelain. Allowing both conventional designs to be produced and giving the opportunity for previously impossible to make concepts to be realised.

Figure 1. *3D printed ceramic double walled beakers produced at UWE*

Along with the previously detailed issues with powder binder 3D printed ceramics with regards to porosity and density and strength, there is the question of scale and available platforms, the legacy Z Corporation platforms are no longer supported by the manufacture and spares and components will soon begin to dry up, these platforms also have a limited build volume which can be restrictive for certain applications particularly tableware, whiteware and architectural ceramics, for this area to develop a larger more reliable build platform is needed.

Industry requirements:

The Centre for Fine Print Research CFPR at University of the West of England UWE has been developing 3D printed ceramics for over ten years during this period a patented 3D ceramic material based on the classic triaxial porcelain systems [2] has been developed and patented. Through this work, close relationships have developed with many of the major players in the European whitewares industry, (tableware sanitary ware and giftware) including major materials suppliers, manufacturers and designers. Contact has also been established with global ceramic manufacturers and ceramic equipment manufacturers.

The Centre for Fine Print Research at University of the West of England UWE 3D ceramic material is designed to allow the production of fired ceramic products directly from CAD files speeding up design origination and reducing the costs.

The material is based on the classic triaxial porcelain recipe containing kaolin, feldspars and silica that are pre proceeds and post-processed to work with the powder binder/jet 3d printing system.

Considerable work and time have gone into developing the material and system to alleviate the built-in problems of power binder/jet printing of ceramic materials, these are issues with green strength firing stability and fired strength, glaze type and fit.

Discussions with industrial partners have also bought up the issue that all of the ceramic manufacturers with interest in 3D printing have a strong requirement to have the ability to 3D print in their custom material. Factory production systems and kiln firing regimes are developed and aligned with the specific properties of the ceramic body used, and for product production validation and performance specification requirements, this is an essential requirement.

To achieve this with the powder binder/jet 3D process would be difficult due to the characteristics of ceramic bodies produced by this system. There are further processing techniques that can be deployed to move the generic The Centre for Fine Print Research CFPR at theUniversity of the West of England UWE 3D printed ceramic system and work is continuing with this ceramic 3D printing system to develop processes and bodies for specific applications that better suit the technical characteristics of this process. It would also require specific body types to be developed for each manufacturer, which would be time-consuming and expensive.

Extrusion printing

One proposed solution to this problem is to revisit the process of 3D printing ceramics by extruding a ceramic paste. This type of system has been available since low-cost FDM type printers emerged in the mid-2000s. The Centre for Fine Print Research amongst many others developed a ceramic 3 D printer using a syringe and compressed air system to extrude clay paste to produce effectively, digital coil pots; this system was one strand of a successful CFPR research project to develop a self-glazing 3D printed ceramic body.

Figure 2. *CFPR ceramic extrusion 3D print 2009*

One of the issues with clay extrusion printing is, the clay paste has to be very soft to be extruded consistently through a fine nozzle, especially with a compressed air driven feed system. This means that it is difficult to get a clean print unless a system for reducing the air pressure during certain nozzle movements can be integrated. The soft clay paste can distort easily, it is very difficult to print significant overhangs due to the risk of the model collapsing.

Many craft ceramic practitioners have worked with and developed this method, and considerable work has gone into improving the clay extrusion heads. High-pressure pugmill and ram systems have been engineered, driven by large stepper motors, with a screw auger drive in the head to dispense the clay paste through the nozzle.

In the UK this process was originally pioneered by the artist/potter Jonathan Keep using compressed air extrusion systems. He has since moved on to more sophisticated extrusion heads.

Figure 3. *Jonathan Keep 3D ceramic extrusion print*

In Belgium Unfold-fab were an early contributor to the art and have continued to develop and improve both the extrusion system and the 3D printers.

Figure4. *Unfold-fab 3D ceramic extrusion print*

Other exponents of these systems are Olivier van Herpt who is a proponent of stiff clay extruders to 3D print his designs. allowing stiffer ceramic pastes to be used.

Figure 5. *Olivier van Herpt*

Several systems have been commercialised, one of the most well-known being the WASP system.WASP are a supplier of extrusion 3D printed ceramic systems using Delta printers they have scaled the concept up to a four-metre-high printer that is capable of printing large structures.

Figure 6. *WASP Delta 3D ceramaic printer*

The main advantage with all of these paste extrusion printers is that they can use conventional ceramic materials. Decades if not Centuries of development into ceramic bodies means that conventional ceramic materials have been finely honed in terms of performance and behaviour.

The disadvantage with paste extrusion 3D printing is that the build layer thickness is very coarse compared to other 3D printing processes giving a distinctive layered appearance. It can be very difficult to extrude ceramic pastes through finer nozzles and if this was achievable there would be a corresponding unwelcome increase in build times. Geometric freedom and resolution are considerably reduced compared to powder/binder and resin/powder based 3D printing processes and fine detail and smooth surfaces are almost impossible to achieve.

The artists and potters using these systems have exploited this characteristic in their designs but for commercial ceramic prototyping this property of the process is detrimental as a perfectly smooth surface is the priority.

Hybrid Manufacture:

Considerable progress has been made in the area of Hybrid (i.e. sequential Additive and then Subtractive operations) 3D manufacture, the main driver for these processes has been in metal 3D printing and machining, companies such as Okuma are marketing integrated machines the MU-8000V system IMAGE that combines Metrology and Laser Metal Deposition IMAGE with CNC machining to both repair existing objects and to create new models.. Hybrid Manufacturing Technologies also market similar systems.

Figure 7. *Okuma MU-8000V Hybrid System*

This concept has filtered down to less expensive lab-scale manufacturing type machines , Diabase a U.S. engineering company has recently introduced their H-Series machine which has a turret system that allows FDM extrusion heads to be combined with vertical milling, rotary 4-axis milling 5-axis milling. A laser scanner can also be added to the system.

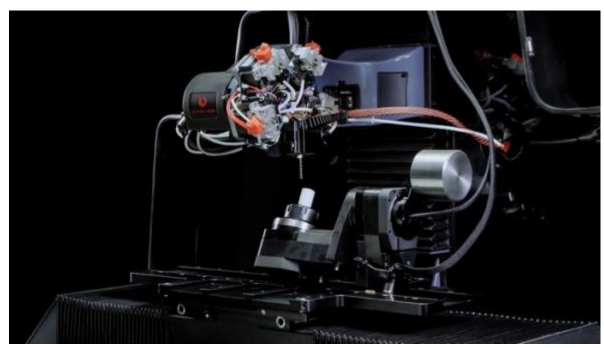

Figure 8. *Diabase H-Series*

Other manufacturers of Hybrid desktop 3D printers include Z Morph and Fabtotum.

Hybrid robotic ceramic manufacture:

The Centre for Fine Print Research at the University of the West of England has recently received a large grant to start a project to investigate the use of robot hybrid ceramic extrusion to develop a hybrid ceramic additive subtractive system to prototype commercial quality prototypes for the ceramic industry.

The aims of the project are to use a ceramic paste extruder to deposit a specially engineered ceramic paste onto a 3D printed former or mould that replicates the surface or face of the ceramic object e.g. a plate. The surfaces of the object will be machined in the green (unfired) and the machined to a smooth finish using a milling head.

Initial trials will be carried out using a Wasp Delta printer to determine the best paste formulation and stiffness and post-print machining trials will be carried out on a Roland CNC machine.

By machining the surface of the formed ceramic object it should be possible to remove the coarse layering effect of the extrusion process to give a smooth finish to the surface. The Centre for Fine Print Research CFPR University of the West of England UWE has considerable experience of direct milling of unfired ceramic tiles for the production of photo ceramic tiles in an earlier project conducted in 2003

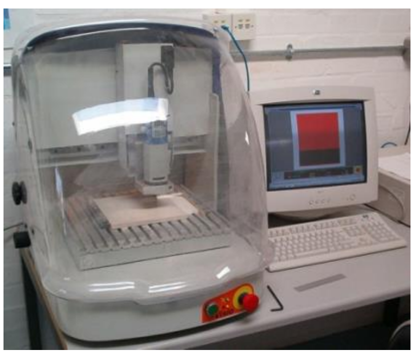

Figure 9. *CNC milling clay tile 2003*

Figure 10. *Fired Glazed CNC milled photoceramic tile*

The project will then move on to use a Mitsubishi robot to both extrude the clay paste and to mill the surface to a fine enough standard for a commercial ceramic prototype.

The project will investigate the 6-axis abilities of the robotic system to improve on the geometric freedom of simple 3-axis systems and explore the possibilities of non-layer 3D printing.

The ultimate aim is to develop a system to produce hi-fidelity industry standard ceramic prototypes and short run production of high value objects.

Figure 11. *Mitsubishi robot arm with WASP extruder*

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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 digital fabrication techniques for Art/Crafts, Designer/Maker ceramics and industrial applications. In 2011 he was awarded the Saxby medal by the Royal Photographic Society for his work on 3D imaging.