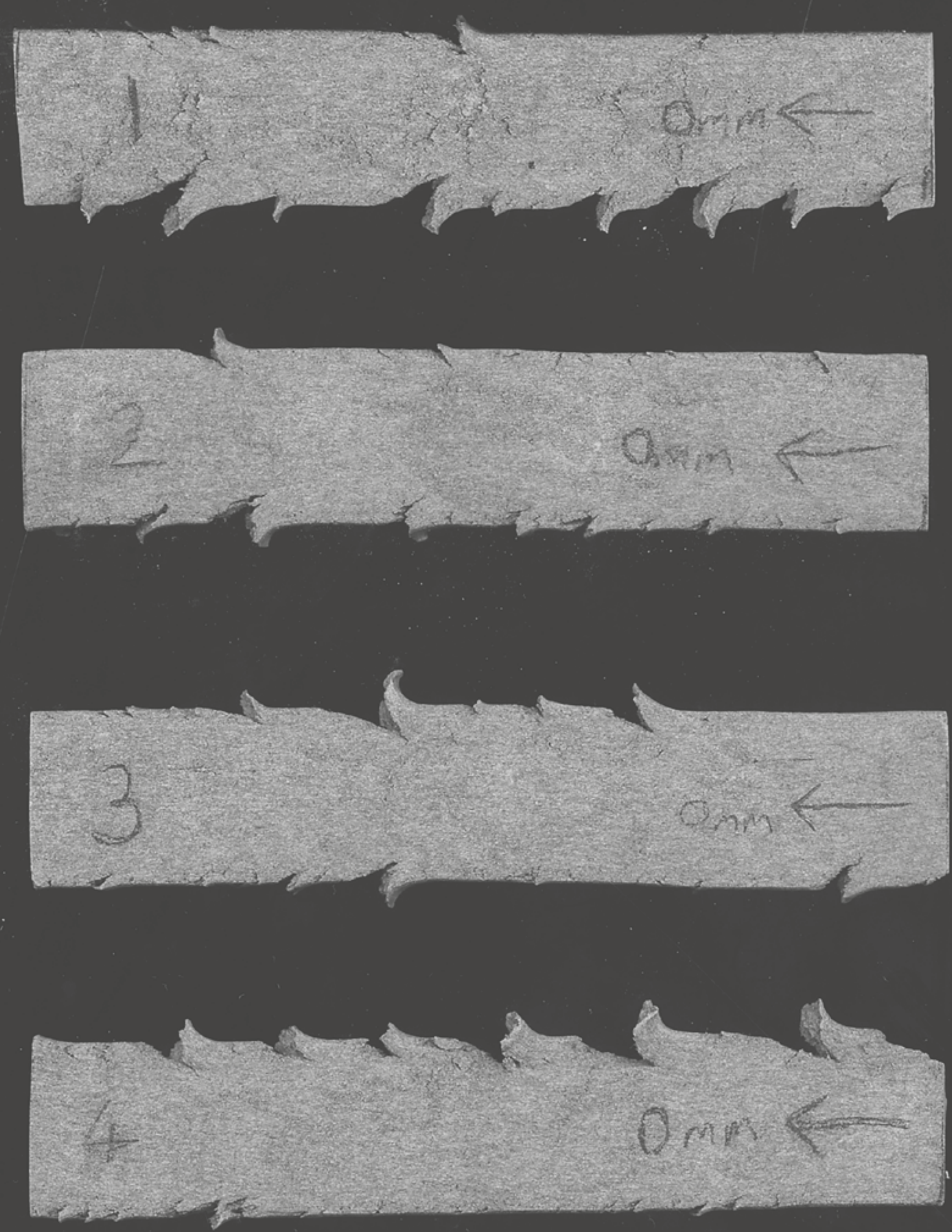
Innovation with Impact: Interdisciplinary Approaches and Empirical Research with Ceramic Extrusion

Dr Tavs Jorgensen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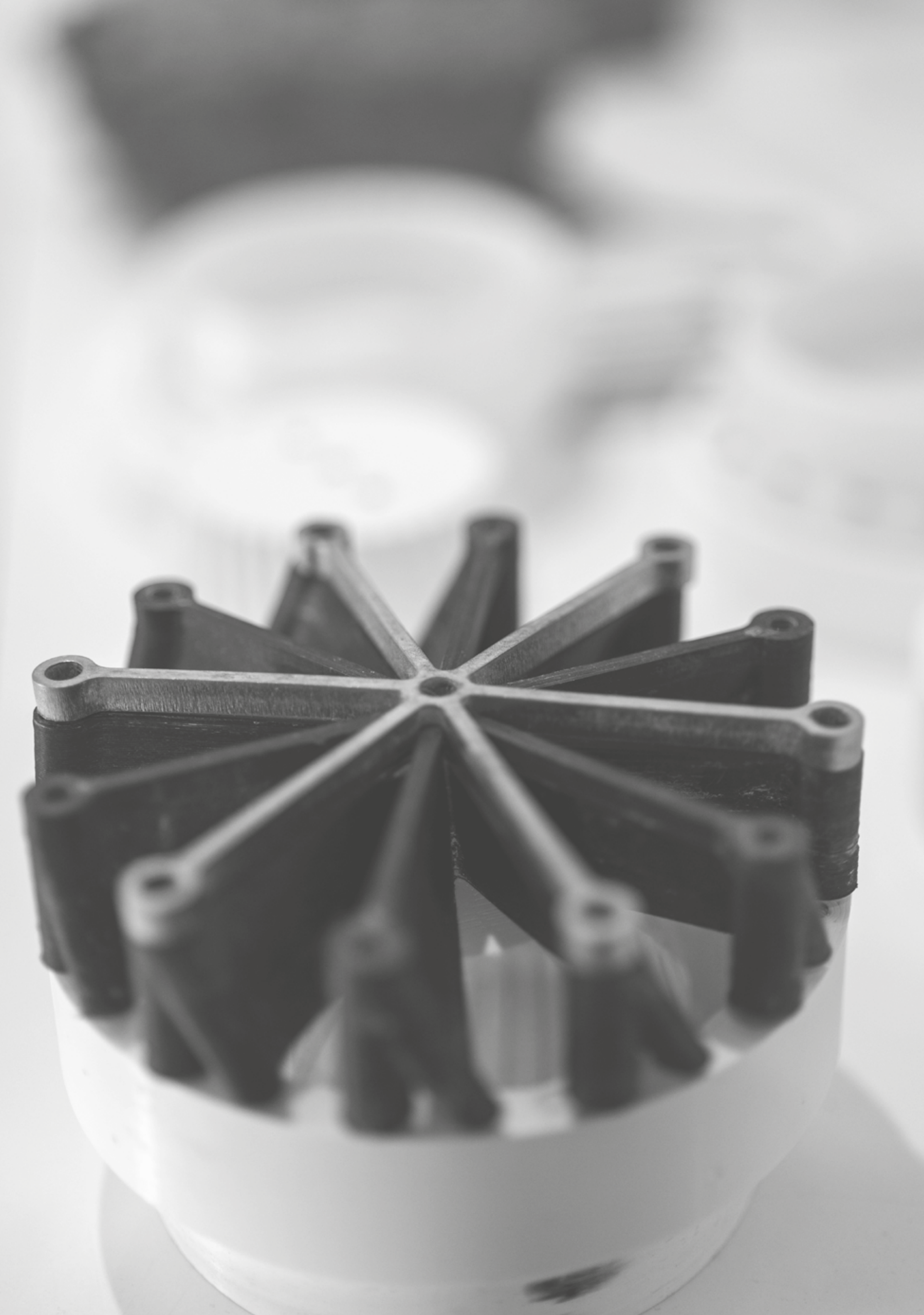

This booklet covers research exploring innovative approaches with the ceramic extrusion process. The research was carried out from October 2021 to April 2024 and led by Dr Tavs Jorgensen, Associate Professor at the Centre for Print Research (CFPR) at the University of the West of England (UWE Bristol). The project was funded by the Arts and Humanities Research Council (AHRC) through a Leadership Fellow Award.

This is the second publication covering the outcomes of the research, focussing specifically on phase two. Just like the previous booklet, *Through the Die: An Exploration into Clay Extrusion*, which covered phase one of the research, this edition conveys the results of the enquiry through a pictorial journey with accompanying text outlining key aspects of the research process.

The research was carried out at the CFPR, a centre of research excellence with a unique, multidisciplinary group of experts combining knowledge and skills across traditional and digital techniques and technologies to reflect, innovate and find creative solutions for the future of print. The material properties, artistic medium and practical applications of ceramics is one of the many focal points for the Centre.

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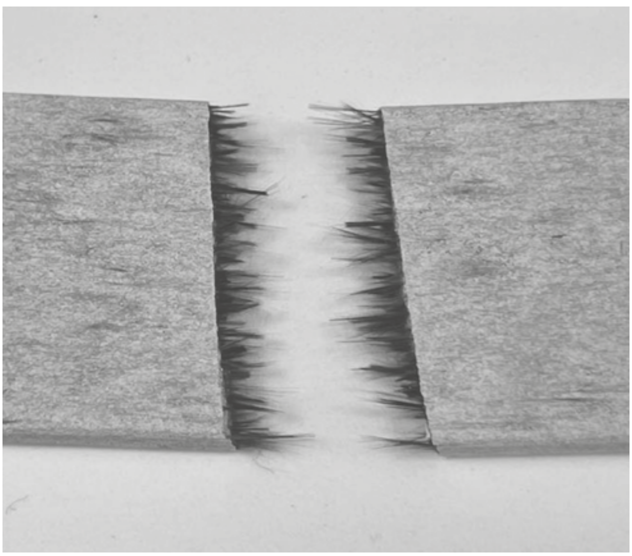


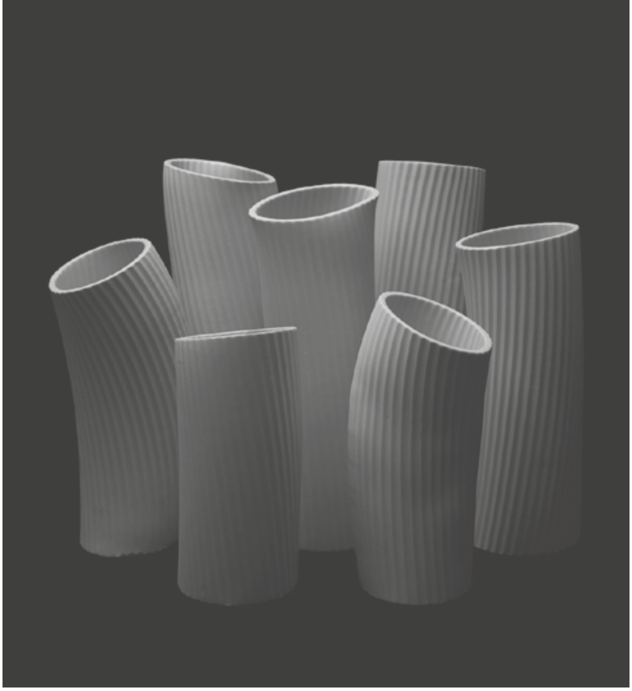
Front Cover: Scanner-grams of Ceramic Matrix Composites (CMC) tests.

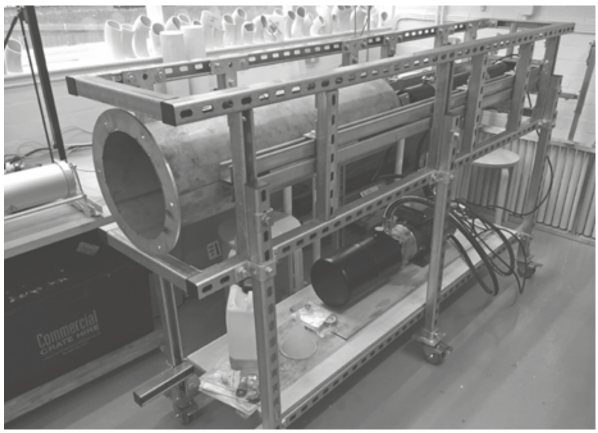
Opposite: 3D printed extrusion die for creative research into twisted porcelain vases.

Above: Extruded earth brick tests.

Left: Extruded CMC tests.

All Images: Frank Menger 2024.





___Utilize the innovative knowledge developed in the first period to explore new directions for the body of research, in particular, to exploit the potential for innovation in unexpected applications and diverse sectors___

Research aim as submitted to the Arts and Humanities Research Council (AHRC)
Leadership Fellow Award scheme

Phase Two Research Enquiry: Knowledge Foundations, Aims and Objectives

The first phase of the research established some core research capabilities. A new, low-cost concept design for a ram extruder was developed at the start of phase one and this machine facilitated the practical research tests carried out in both phases. Crucial knowledge of developing the use of low-cost filament 3D printers to carry out the toolmaking of extrusion dies was also established in the first phase. These, and many other knowledge gains, provided the foundation for expanding the explorations in this subsequent research enquiry.

The second phase of the research sought to expand the applications of the innovations from phase one into new areas where extrusion had previously not been used, essentially to explore how knowledge generated in one discipline could be harnessed in completely different contexts. This interdisciplinary approach was a fundamental basis for the latest research, and the overall aim was articulated in the AHRC funding application as quoted left.

This broad aim was divided into several individual enquiries to crystallise the project objectives. One of these was to explore the use of extrusion to produce a particular ceramic product known as Ceramic Matrix Composites (CMC). CMC is a composite that consists of ceramic oxide fibres combined with ceramic paste and parts made from this material are used for high performance applications, such as jet engines.

CMC is typically produced through the layering of woven mats – just like the common approach with fibreglass and resin. There are, to date, no known examples of CMC being produced via extrusion, however work in the latest phase of the research was successful in delivering a proof of concept that this manufacturing process is possible. This booklet reveals further insights from the research into this application.

Another objective in the second phase of the research was to explore new creative possibilities presented by the approach of 3D printing the extrusion dies. This was carried out through Tavs' creative practice in ceramics with the output in the form of a series of visually and texturally compelling twisted porcelain vases.

An equally significant objective was the exploration of the extrusion process to manufacture cob building components. Cob is a traditional building material consisting of subsoil and fibre (usually straw). The current climate crisis has meant that cob is being re-evaluated as an extremely low carbon building material. The use of extrusion to produce cob bricks has previously been significantly under researched, however this project successfully generated promising new approaches in this area particularly aided by the transfer of findings from other parts of the research, specifically the exploration into extrusion of the fibrous CMC material.

The creative explorations, the investigation with CMC and the experiments with extruding cob are all further detailed in this booklet.

02

Opposite Top Left: Extruded porcelain vases by Tavs Jorgensen 2022. Photo Frank Menger 2024.

Opposite Bottom Left: Hydraulic extrusion machine constructed during the first phase of the extrusion research. Photo Tavs Jorgensen 2020.

Above: 3D printed extrusion dies for Ceramic Matrix Composites (CMC). Photo Tavs Jorgensen 2022.

Right: Extruding a CMC pipe. Photo Tavs Jorgensen 2022.

Researcher Profile: Background, Development and Leadership

This research project was conceived and led by Dr Tavs Jorgensen. Tavs was a designer for the ceramic industry before forging a career in academia. He joined the CFPR at UWE Bristol in 2017 having previously worked for the University of Plymouth. Prior to this post he taught for more than 10 years at the Royal College of Art and was also a Research Fellow at the Autonomatic Research Cluster at University College Falmouth, which is widely recognised as pioneering the use of digital tools in design and craft practice.

His ceramic extrusion research has been funded through two consecutive AHRC Leadership Fellow Awards. These awards are intended not only to provide funding for the actual research topic but also to advance the research leadership capabilities of the recipient. An integral part of the funding application was a development plan to enhance Tavs' leadership skills and enable him to take increasing responsibility in the research environment at UWE Bristol and more widely. Tavs has undertaken multiple leadership growth activities including intensive 1-2-1 leadership coaching and selection for Clore Leadership's highly competitive Emerging Leaders course.

The AHRC funding has been very successful in delivering the objective of augmenting Tavs' research leadership potential with him progressing from his initial post of Senior Research Fellow at UWE Bristol to his current role as Associate Professor. In this post he has managed multiple research projects and taken on responsibility for steering the Transformative Technologies for Practice-led Design research theme, which was established as a part of the CFPR's £7.7M Expanding Excellence in England (E3) award from Research England.

Most recently Tavs has been awarded a £2.3M AHRC Capital Investment Award to establish an entirely new interdisciplinary research lab at UWE Bristol called The Bridge. The Bridge is due to open in summer 2024 and will provide 500m^2 of lab space with state-of-the-art facilities for practice-based, design-led creative research.

03

Opposite: Tavs in the CFPR at UWE Bristol's Frenchay Campus. Large format photography Frank Menger 2024.

Above: Tavs Jorgensen leading the cob experiments assisted by Research Associate Sonny Lightfoot. Photo Simon Regan 2023.

Left: Sonny Lightfoot and Research Technician Mike White working on the extrusion research. Photo Tavs Jorgensen 2022.

___The emerging climate crisis has provided a strong rationale for the material to be re-evaluated___

Extruding Cob: Developing New Sustainable Building Components

The enquiry into extrusion of cob dovetailed with experiments into Ceramic Matrix Composites (CMC) detailed later in this booklet, building on the knowledge gained from this investigation. Just like CMC, cob is a fibre composite although of a different nature. Cob is a simple mixture of subsoil and fibre – usually straw or sometimes hay. It is a natural composite that has been used for millennia in traditional house building in many cultures around the world. Cob has one of the lowest environmental impacts of any house building material and the emerging climate crisis has provided a strong rationale for the material to be re-evaluated.

Extrusion is already used extensively for fired ceramic architectural components such as bricks and tiles. However, in terms of cob, the use of extrusion is largely unexplored. This part or the research sought to address this knowledge gap. The CobBauge project team at the University of Plymouth has over the last few years developed new cob compositions which enhance the thermal and structural performance so contemporary cob buildings can be constructed that meet the current, strict building standards. This research used the cob 'recipes' developed by the University of Plymouth as a starting point, but alterations to the compositions were needed to make them extrudable. Specially designed geometries for the extrusion dies also had to be developed for the particular material characteristics of the cob composites.

Overall, this part of the research has delivered a concept for a complete cob fabrication system that, excitingly, enables researchers, architects and builders to experiment with new cob brick designs at incredibly low cost, unprecedented speed and with almost no environmental impact.

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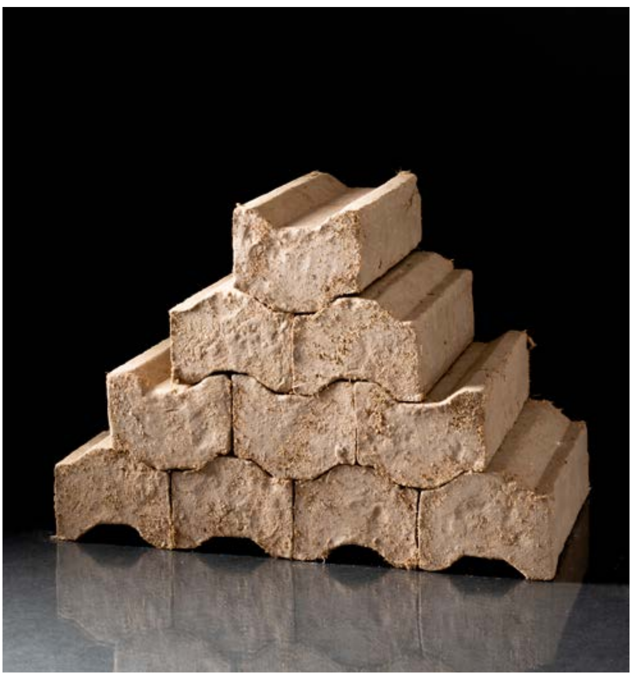


Opposite: Extruded light earth bricks. Photo Frank Menger 2024.

Above: 3D printed extrusion die for light earth and cob bricks. Photo Simon Regan 2023.

Left: Extruded structural, interlocking cob bricks. Photo Simon Regan 2023.

Opposite Top Left and Bottom Left: Extruded interlocking, structural cob and light earth bricks in structural and thermal concept combinations. Photos Simon Regan 2023.

Top Right and Bottom Right: Samples of extruded earth bricks. Photos Frank Menger 2024.

Fibrous Composites: Interdisciplinary Collaboration with Advanced Industrial Applications

Ceramics have myriad and diverse applications, including traditional uses such as tableware, tiles and bricks. However, ceramics are also increasingly being used for advanced technical applications, including aerospace engineering. One type of ceramics used in this sector is Ceramic Matrix Composites (CMC). CMC is a highly advanced material developed for very challenging environments such as high temperature situations in jet engines. CMC closely resembles fibreglass but is made purely of ceramic material, with parts that have very high material strength combined with being temperature resistant to over 1200ºC.

The production of CMC has so far been limited to particular geometries that can be produced by conventional CMC manufacturing approaches – usually in the format of layered woven mats. This phase of the research developed a new approach of producing CMC parts through the process of extrusion, which in the context of CMC is entirely novel. The extrusion process offers the potential of producing entirely new geometries with the CMC material, and, when using 3D printed extrusion dies, also a very rapid, low-cost tooling process.

Access to CMC material was one of the initial hurdles with this investigation. CMC is very costly and there are restrictions on its use, but collaboration with the National Composites Centre (NCC) resulted in a donation of CMC material from Rolls-Royce that enabled the study. One of the significant challenges with this research was to extrude parts with the fibrous CMC medium that had a high surface fidelity without the surface and edge tearing. It took many experiments with the geometry of the extrusion dies' design to achieve this objective.

Following the proof of concept research to this innovative approach to CMC production, a number of extruded samples were investigated for their structural performance though modulus of rupture tests, which formed part of the empirical testing carried out in this study that is further outlined later in this booklet.

05

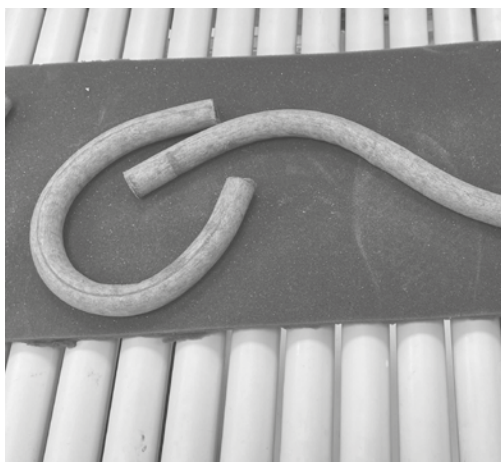
Opposite Top Left: Extruding Ceramic Matrix Composites (CMC) tests.

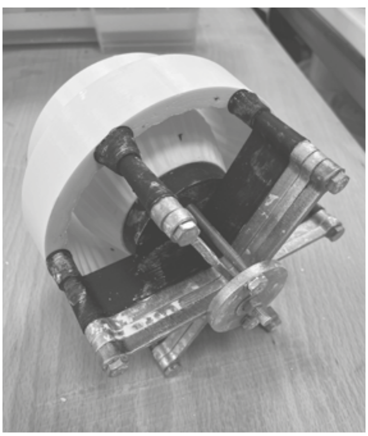
Opposite Left: 3D printing extrusion dies for CMC tests.

Above: Woven CMC mats sponsored by Rolls-Royce.

Right: Curved extruded CMC pipes.

All Images: Tavs Jorgensen 2022.





Twisting Clay: Creative Research to Explore the Complex Rheology in Ceramic Extrusion

A complimentary objective in the second phase of research was to further delve into the creative potential of the technical discoveries. Explorations of this had been started in phase one through collaboration with other artists at the CFPR, however phase two facilitated time for Tavs to personally examine the technical findings through his own creative practice as a maker.

The aim of this creative practice-based research was to produce a series of porcelain vases which represented the natural, and sometime unpredictable, outcomes of the extrusion process. In this research extrusion dies were developed to facilitate the making of twisting, faceted forms.

The movement of plastic clay in the extrusion process is governed by very complex forces under the branch of physics known as rheology. It is near impossible to accurately predict how clay will react during extrusion, but knowledge of some of the theories that are involved proved to be very useful in guiding the design of the extrusion dies used by Tavs. The multidisciplinary environment at the CFPR was key to assisting with this aspect.

The CFPR has had several trained physicists as members of staff. Dr Damien Leech and Dr Paul Worgan both contributed to the research with in-depth knowledge of theoretical physics which helped to guide the practical experiments used as part of the creative investigations. The use of low-cost 3D printers to facilitate the production of extrusion dies for rapid, iterative creative explorations, with die designs informed by theorical knowledge of clay extrusion rheology, was also of huge benefit to Tavs' research.

The porcelain clay material chosen for this element of the research proved particularly challenging. Porcelain clay has beautiful aesthetic qualities when fired, but it also has inherently low levels of plasticity which is the fundamental requirement for extrusion. This made the production of the vases extremely difficult, but the challenging nature of the porcelain clay also helped to generate enhanced technical knowledge gained from the process.

An initial series of porcelain vases produced from the research was first shown in 2022 at the Artful Craft exhibition at the acclaimed MAKE Southwest arts space in Bovey Tracey, Devon, which considered the impact of new technologies on craft, art and design.

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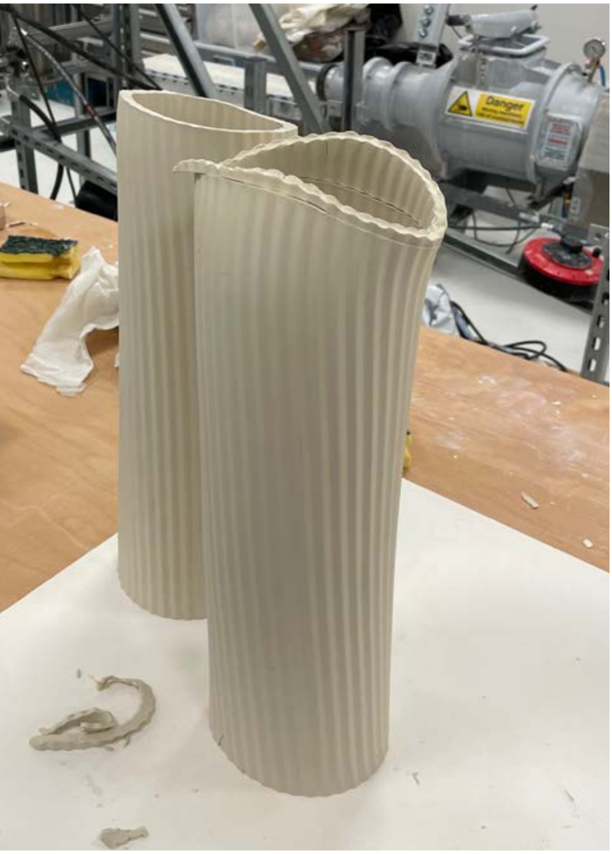

Opposite Top Left: Porcelain vase in the process of being extruded.

Opposite Far Left and Left: 3D printed extrusion dies in the process of being used for creative research.

Above Left: Freshly extruded porcelain vases.

Above Right: Laser cut stainless steel reenforcement bars for 3D printed extrusion dies.

All Images: Tavs Jorgensen 2022.

Empirical Testing: Modulus of Rupture, Compressive Strength and Thermal Conductivity

One of the key methodologies of this research has been to explore and experiment freely supported by rapid physical prototyping. This way of problem solving and developing original solutions through designing and making is closely associated with a craft research approach. This approach has several advantages when it comes to delivering innovation in itself, but when it comes to providing proof of real innovation potential, other, more structured, research styles are needed.

In this research phase a far greater emphasis was placed on gathering testing data to quantify the performance of extrusion applications developed during the project. This data could potentially be produced by theoretical mathematic modelling, but with the many variables in natural materials inherent to cob composites in particular, data recorded from practical tests was considered the relevant approach.

Adopting an approach where data is derived from observation of test recordings is known as empirical research. Particularly, the results of the enquiry into Ceramic Matrix Composites (CMC) and cob brick making were subjected to structured empirical testing methods. These included modulus of rupture (also known as flexural strength) tests. This is where samples are placed on two bars and pressure is applied and measurements are then taken to determine how much force the samples can take before breaking and how much they flex before this happens. Other tests include compressive and shear strength tests.

The cob bricks were tested for their insulating capabilities through a process called a thermal conductivity test using a Heat Flow Meter that determines the R (thermal resistance) and U (thermal transmittance) values critical for building standards certification.

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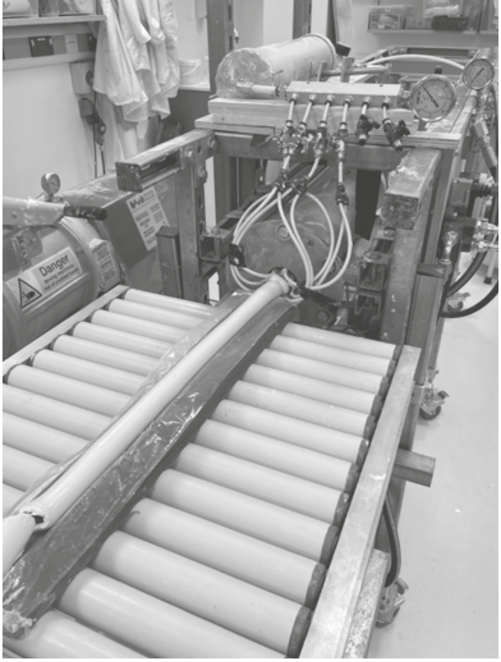

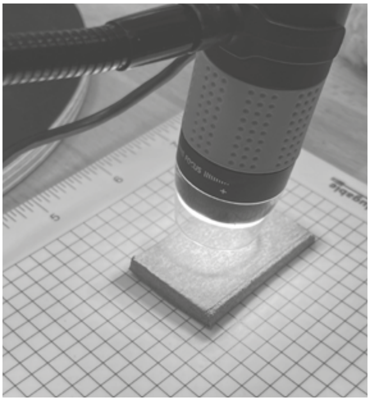

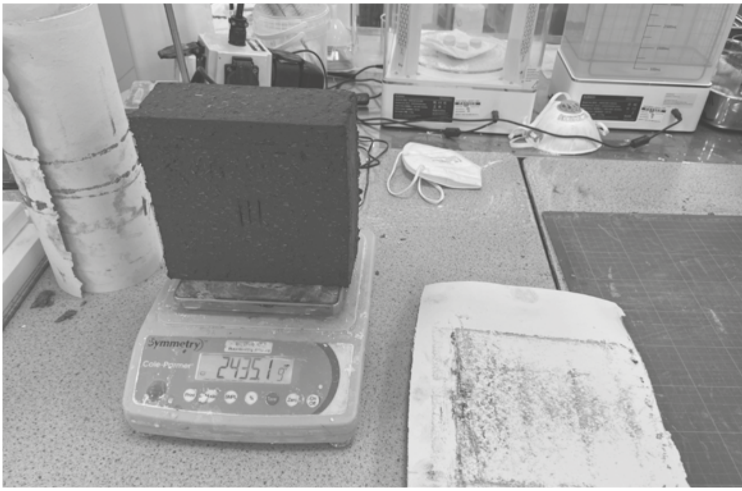

Opposite Top Left and Left: Extruded porcelain vases by Tavs Jorgensen. Photos Frank Menger 2024.

Above Top Left: Structural testing of extruded cob composite. Photo Tavs Jorgensen 2022.

Above Top Right: Microscope investigation of fibre alignment in Ceramic Matrix Composites (CMC) tests. Photo Tavs Jorgensen 2023.

Above: Monitoring the drying of earth bricks through weighing of test samples. Photo Tavs Jorgensen 2024.

Above: General CFPR lab at UWE Bristol's Frenchay Campus. Photo Tavs Jorgensen 2024.

Right: Research Associate Rosy Heywood working in the ceramic lab at the CFPR. Photo Tavs Jorgensen 2022.

Inside Cover: Ceramic Matrix Composites (CMC) tests. Photo Frank Menger 2024.

Back Cover: Scanner-grams of CMC tests. Photo Frank Menger 2024.

Research Environment: Research Centre, Funder, Collaborators, Contributors and Credits

The extrusion research has been carried out at the CFPR, one of the UK's leading research centres. The work of the CFPR is internationally recognised and the Centre has won numerous significant research grants, most recently a £7.7million Expanding Excellence in England (E3) award from Research England. The CFPR is an integral part of the research environment at the School of Arts at UWE Bristol with labs located at the University's Frenchay Campus.

This research has been funded by the Arts and Humanities Research Council (AHRC) through two consecutive Leadership Fellow Awards. The research has been supported by sector-leading industry partners including Arup, Wienerberger UK and the National Composites Centre (NCC). Collaboration with the CobBauge project team at the University of Plymouth was critical in extending the cob extrusion aspects of the research.

The core research has been carried out by Dr Tavs Jorgensen (Principle Investigator) and Sonny Lightfoot (Research Associate). However, many others have contributed to the research. There have been significant contributions from CFPR staff Mike White, Dr Damien Leech, Dr Poul Worgan and Farzad Farzadnia. Atul Vadgama, from UWE Bristol's Construction Materials Lab, was a major help with the testing and characterisation of the cob extrusion samples with vital assistance from student interns Hazel Luff and Max Tillotson.

08

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