Refractory concrete: A material that offers new ceramic opportunities.

Dr Alasdair Bremner and Mr Fahad Alkandari

E-mail: Abremner@uclan.ac.uk
Research Associate
University of Central Lancashire, Silicate Research Unit

www.silicateresearchunit.org

Abstract

Refractory concretes (RC) are industrial materials used most commonly in high temperature applications, primarily in the steel and glass industries. In most cases they are a mix of refractory aggregate's chosen for specific hot engineering applications combined with a cement binder. RCs are known to ceramicists largely only for their insulating properties for which they are used in the manufacture of kilns as hot face lining. However, currently very little information is available regarding the structural and aesthetic possibilities that RC can offer to the artist and designer. Refractory concrete displays novel handling properties that include: increased green and fired toughness and strength, thermal shock resistance, ceramic glaze compatibility, thixotropic effects and rapid setting. These properties offer the opportunity to achieve the creation of objects that do not conform to some of the traditional limitations of conventional clay and yet are able draw upon the vast array of ceramic surface decoration available to the ceramicist [1]. This paper seeks to inform readers on the possibilities of RC and the potential for their use by smaller scale manufacturers in architectural applications through some practical advice and instruction on their use. The paper goes on to discuss how RC has been used in a recent PhD project to create contemporary Islamic ceramics that draw upon the rich history of ceramics in Arab states. The paper questions specifically how the cultural sustainability of Islamic architectural ceramics can be fostered in the face of western globalization and modernization and how RC might offer part of a solution.

Keywords: Design, Refractory Concrete, Silicates, Ceramics, Architecture, Islamic, Identity

1. Introduction

Refractory concretes have been used extensively in high temperature industrial applications for over 60 years. RCs are commonly used in the steel, glass and chemical industries where their ability to operate at high temperatures while maintaining their structural strength are the desired properties. Monolithic scale products are cast to very high specifications in terms of material and form, with individual RCs designed for very specific jobs and environments. Figure 1 shows the scales possible within industry.

Figure 1 Monolithic RC products from DSF Ltd

However, their application in the sphere of craft, design, and in particular the field of ceramics has been limited to the purely functional; primarily in the construction of kilns and kiln furniture. One exception is Dr Anja Bache. Her work over a number of years has explored the possibilities of Compact Reinforced Composite (CRC) a material very similar to refractory concrete for use in architectural applications and in public sculpture. [2]

This paper begins by highlighting the qualities that RCs offer the ceramic artist and designer. It briefly outlines methods of working with these materials normally associated with heavy industry, in a studio-based environment. RCs offer novel structural properties in comparison with conventional ceramic materials such as:

- RCs will typically shrink less than 0.5% compared with up to 12% for some clays.
- RCs will not suffer from warping due to uneven drying and firing.
- Clay is brittle and easily damaged at a dry or green state making handling difficult while many RCs are as tough when fired as conventional concrete.[3]
- Ceramic is inherently weak in tension, RCs are substantially stronger in tension and can be used for wide spans, impossible with conventional ceramics.
- There is no need for extended drying times or very slow firing as RC is specifically designed to cope with extreme temperature variance.

It is important to note that these perceived advantages of using RC over clay are not universal; indeed there remain many cases where using RC will not be suitable. Professional ceramic artists and craftpersons are capable of amazing feats of manipulation using clay, however this paper gives two examples of the potential of these materials in situations that would be considerably more challenging if made in clay, using existing and known processes.

It should also be noted that RCs also present a number of disadvantages: RC is not a malleable plastic body and therefore cannot be moulded in the same way as plastic clay can, resulting in the need for moulds to aid forming. RCs are tougher than many ceramic bodies as the aggregates within the body are designed to prevent crack propagation. However, they share the same brittleness. Finally, the different composition of RC means that in some cases existing ceramic glazes behaving differently on RC bodies.

2. Working with Refractory Concrete

Most refractories are made up from three main constituents: Aggregates, Modifiers and a Bonding agent.

Aggregates

Aggregates form the bulk of refractory concretes. In the same way that conventional concretes function, the aggregates provide the strength within the concrete and serve an important function in the resistance to crack propagation. Careful consideration is taken to ensure that a range of different sizes are represented. The goal is to generate a good packing and particle distribution within the body of the refractory after casting.

Modifiers

Modifiers are added to refractories primarily to adjust the handling properties of refractories, for example; the addition of clay materials will create a plastic mix that is suitable for ramming; Silica fume also referred to as micro silica, a by-product of the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys, is added to increase both the strength of the material green and sintered and adjust the rheology, allowing vibration and self-flow refractories. Polyester and synthetic fibres are also often added to give increased green strength similar to ceramicists adding paper fibres to clay.

Bonding Agent

The most common bonding agent used in refractories is calcium alumina cement (CAC). CAC is by no means a recent invention. It was discovered as early as 1865 in France and was first commercially produced by La Farge using a fused mixture of alumina and lime. [4] CAC exhibits high strength in a short period of time, after 24 hours CAC is stronger than Portland cement after 28 days. In industry today the vast majority of refractories are used in the furnace and metal sector where their high compression strength and resistance to chemical attack at high temperature is utilised. Generally the higher the proportion of alumina in CAC results in higher operating temperatures and a whiter appearance.

The strength of CAC decreases as it is heated, however above 1000°C ceramic bonds are formed resulting in a concrete with higher compression and tensile strength than Portland concrete. Once CAC concrete has been sintered it does not suffer from loss of strength and will retain its properties indefinitely. For the ceramicists this temperature range puts a vast majority of ceramic glazes and surface treatments in reach whilst, at the same time, allowing forms to be constructed without some of the traditional ceramic barriers.

Industrial refractory concrete producers will adjust these three main constituents to give different properties for different applications. While there are lots of different brand name concretes (approximately 5000 globally) in reality many of these will be based on three different types of concrete. Low Cement, Castables and Insulating concretes.

Low cement self flow type materials

These materials generally have a very low water to material ratio. Thus the amount of energy required when mixing these refractory concretes is very high therefore standard rotary concrete mixers are unsuitable and a high intensity mixer is required for large scale pieces. For these materials mixing any more than 1-2kg of material by hand at one time is very difficult without dramatically increasing the water to material ratio. Low cement concretes are generally stronger than other types at the green stage.

Castables

Castables will normally have higher water to material ratio in comparison with self-flows and can therefore be more easily mixed by hand. For any moderately large-scale objects mixing machinery will be required. For high to moderate water to material refractories it is possible to use standard rotary mixers. Certain castables will require vibration during casting such as vibrate able refractories. For small-scale pieces manual vibration will be sufficient.

Insulating refractories

Insulating RC’s are generally much easier to mix, as they will have smaller or often lighter weight aggregates and a much higher water to concrete ratio. They can be mixed by hand or in a mechanical mixer. By their very nature insulating refractories are softer and not as durable as other RC’s.

Mixing Machinery

In the refractory industry the standard machinery used is capable of outputting up to a ton of concrete in one mix. For small-scale manufacture this type of machinery will be prohibitively expensive and impractical for ‘one off’ objects or short run batches. As such, one of the objectives of the research was to establish methods and materials that would be suitable for small-scale manufacture.

The mixer used in this project was a Hobart AE 200 planetary mixer with a 10 quart capacity bowl. Using the paddle attachment 10kg can be mixed in around 5 minutes. Single-phase mixers can be obtained for around £300.

Water

Water is very important in the preparation of any refractory concrete. Water added should be, where possible, as close to the recommended amount suggested by the manufacturer. The amount of water added has a direct bearing on a number of important structural and handling properties: Water controls the setting and dispersion of aggregates within a mix, affects the strength and density of pre and post fired refractory and directly influences the flow and thixotropic properties of refractories.

Hand mixing of refractories will in some cases (particularly with self-flows and low water ratio refractories) require additional water to enable mixing. Increasing the percentage of water by 0.5% increments is recommended until the desired consistency is achieved.

Casting

Obviously design requirements will define the construction of moulds. However, some general rules should be noted:

Moulds can be made from any number of materials E.g.: plastic, wood, polystyrene, RTV (Room Temperature Vulcanising) rubber or silicone, or plaster. However moulds must be watertight and waterproofed. Porous materials should be sealed.

Installation should be carried out as soon as possible after mixing. Ideally moulds should be filled in one mix. However, multiple mixes are possible provided each layer is disturbed to create a solid bond and avoid the possibility of lamination between layer.

Setting and Drying

Once cast the mould should be kept at an ambient temperature ideally at temperatures above 60°F (15°C) to set for 24 hours before firing. At lower temperatures setting times will increase and additional time should be allowed. De-shuttering of moulds should ideally be carried out after 24 hours when the material has gained its maximum green strength.

Finishing

The majority of RC's will set hard in 48 hours therefore consideration should be taken in reducing the amount of finishing required. Rough cutting can be carried out using an angle grinder and diamond cutting discs. Extraction should be used at all times while dry grinding.

Firing

Published and recommended firing schedules as provided by suppliers are often specifically designed to reduce the risk of spalling or problems caused by escaping gasses and water from large scale monolithics. In many cases on a small scale these over cautious firing schedules with regular soaks at certain temperatures are unnecessary and can be substituted with more aggressive firing schedules. It is important to note that some materials can generate hazardous gasses during firing so specific industry advice where hazardous gasses are involved should be followed.

Refractories are very resilient materials and firing cycles can be faster than normally recommended for ceramic materials.

2. Contemporary Islamic ceramics

This research acknowledges that while there are a wide range of issues that impact on countries' economies and trade, politics, media, cultural exchange, customs and traditions. These can have a profound effect on the way that countries design their buildings and architecture. There is no doubt that this phenomenon has had a negative impact on the culture and identity of the Middle East. Indeed, globalization as a social force has homogenized the world by gradually erasing the cultural traditions of the other non-Western regions of the world, and especially that of the Islamic civilization and its culture. This is most visible, in the fading nature of the traditional Islamic arts, design and architecture. Today, as a result of the burgeoning impact of globalization, and through the transfer of visual images and architectural designs from the West, most Arab states have been transformed in the last few decades to be seen almost as replicas of the major cities of the West.

> The Arab city has lost, whether intentionally or unintentionally, its local image, with architectural development mainly following the prevailing international trends without addressing the Arab tradition. This has resulted in a loss of identity and a separation between the Arab city's past and present, as well as a concern for its future [6]

Ceramics and tiles are considered as one of the greatest manifestations of Islamic visual culture. Islamic ceramics are a source of fertile beauty, that when linked artistically to the Islamic heritage, can provide a level of creativity that is unmatched by any other art form. However this legacy has been eroded through the diminishing identity of Islamic visual culture is particularly evident through current architectural development occurring in the Arab states. The building revolution in the Gulf countries has increased momentum dramatically since the onset of the 'oil economy' and reinforced by the current process of globalization. There is an apparent desire for Arab states to be seen as modern and forward thinking. However, this is not seen as compatible with retention of traditional imagery and techniques, Khattab states:

> The use of traditional local building materials and techniques, which are often considered archaic and obsolete, have been unfortunately abandoned in favour of modern imported materials and construction techniques [6]

In looking to address these concerns and offer a sustainable and practical solution to what is both a problem of supply of contemporary Islamic ceramic surface materials and one of cultural perception and arguably education. The examples form part of a practice based PhD research project currently being conducted which seeks to address these concerns. Refractory concrete was used to create large scale Islamic tiles and a series of deep relief fret work pieces that both acknowledge the rich traditions of Islamic ceramics, yet would are appropriate for application within the context of contemporary Islamic architecture detailing. – blending contemporary aesthetic and technical thinking with traditional Islamic design.

Figure 3 Glazed relief refractory concrete

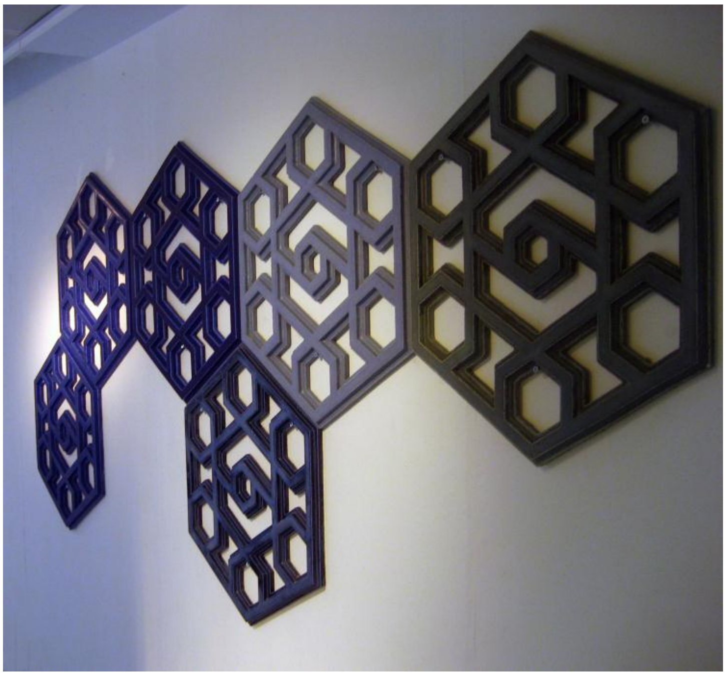

Figure 4 Geometric fretwork Glazed refractory concrete

3. Conclusion

RC can offer flexibility in the creation of forms on a scale that is prohibitive when using clay materials, The paper shows how RC could allow smaller manufacturers and artists to influence architectural aesthetics in a local, more culturally relevant way. While this paper has focused on the impact of western styles of architecture on Arab states, the phenomenon of cultural erosion is not limited or restricted to this region the research therefore has resonance globally many cultures have lost a rich architectural ceramics history through the importation of western styles and materials.

The two examples of RC used in architectural applications demonstrate the strength of refractory concrete on large-scale textured forms and also shows the possibilities of creating fretwork and deep relief forms, primarily designed for retrograde fitting to existing buildings. The green strength of RC allows the creation of these forms without the technology that is required in other alternative ceramic methods, where the fragility of conventional clay would render these forms impossible. The creation of the large format sheets and the relief fretwork pieces are a further demonstration of the capabilities of the material.

The examples show that RC can put bespoke and small run architectural products within reach of small studio makers using low tech and inexpensive machinery, also demonstrating the potential for commercial application and industrial mass manufacture. The intended application for this project was architectural cladding, and of a functional nature, however it could also be employed for more expressive projects. Importantly, the nature of both the material and methods developed allow for a great deal of flexibility in generating surface decoration and relief pattern.

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