Turning technical...

diversity the key for a brighter tomorrow

Dr. Kambiz Kalantari, Innovation Manager at Lucideon UK, argues the need for traditional ceramic manufacturers to diversify their product range to include technical and advanced ceramics.

The Technical Ceramics market is growing rapidly from $5.7 billion in 2017 to $8.0 billion in 2022 [Ref 1]. This high value added market, which mainly serves electronics, healthcare and automotive sectors, has rarely been embraced by major players in traditional ceramics sector such as tableware, sanitaryware and tile manufacturers.

Ceramic manufacturers are often segmented according to their product application into technical and traditional ceramics. Traditional ceramics are derived from naturally occurring raw-materials such as clays and quartz sand. These materials are then made into familiar objects such as tableware, tile, sanitaryware and structural ceramics, e.g. bricks and clay pipes. Technical ceramics, also known as engineering or advanced ceramics, are the products of refined raw-materials that are categorized as follows:

1. Oxides such as zirconium and aluminum oxide.
2. Non-oxides such as borides, nitrides and carbides.
3. Composites that are a combination of oxides and non-oxides which are amalgamated to enhance certain performance criteria. The engineered ceramic products are exploited in various applications in respect to their performance, e.g. body armour, various coatings in turbines, multi-layer ceramic capacitors and implants.

Ceramic refractories, for example kiln linings or crucibles, is one area that does not fit the binary segmentation of the ceramic market. This is due to the diversity of the products that at one extreme includes highly engineered refractory fibres or castables and at the other extreme there are more traditional high temperature shaped products like fire bricks that are traditionally manufactured in high volumes. Cement, although classified as a traditional ceramic, is not included in the scope of this article due to its very different manufacturing process and market drivers.

The barriers...

Traditional ceramic markets rely less on cutting edge innovation than advanced ceramics markets and are mainly driven by peripheral variables that affect the cost of manufacturing. A number of these external variables have been listed below together with examples

- Governmental Policies

Swatch Bharat is one of the best examples which demonstrates the effect of rules and regulations on ceramic markets. The Swatch Bharat campaign, which was officially launched in October 2014, is a mission in India aimed at cleaning up the infrastructure through the construction of household and community toilets. The campaign has impacted ceramic manufacturing in India by increasing the sanitaryware market by up to 15% in 2017[Read further Ref 2].

- Geopolitical Factors

Since manufacturing of traditional ceramics often relies on economy of scale, any uncertainty in the market place has the potential to negatively affect the amount produced, which undermines the profitability of manufacturers. The UK Brexit, which is due in March 2019, has already raised concerns with UK ceramic manufacturers who are aiming to pre-empt any market threats from Chinese ceramic imports [Read further Ref 3].

- Environmental Policies

Ceramic manufacturing is an energy intensive process that contributes to CO_2 emissions either directly through materials reactions or the energy required for raw-materials preparation, drying and firing. For instance, in December 2017, a programme called “Measures of arranging industrial companies to retreat from the city and go back to the industrial parks” was issued by the government of Luozheng district of Linyi, China. The smaller manufacturers could not meet the demands of the environmental legislation programme, hence a third of ceramic manufacturers in Luozheng were forced into closure [Read Further Ref 4]

Published initially in the Asian Ceramics 18-9 edition; http://www.asianceramics.com

- Price of Energy

The cost of manufacturing traditional ceramics relies heavily on energy prices. Accurate prediction of the price of energy has always been a challenge for the traditional ceramic industry and has driven the manufacturing landscape of the industry. This was recently demonstrated in the ceramic industry of Indonesia. The rising energy price in ASEAN domestic markets made the production cost uneconomic in Indonesia, diminishing tile production capacity by one third. Consequently, the Chinese manufacturers took advantage of the higher energy prices for Indonesian manufacturers and increased their market share of ceramic tiles in Indonesia [Read more Ref 5].

With the ever-increasing VUCA (volatile- uncertain-complex-ambiguous) environment in the aforementioned external factors, it has been very challenging for traditional ceramic leaders to maintain their profitability. This has forced the manufacturers to diversify into manufacturing higher-end traditional ceramics. Anti-bacterial coatings, along with thinner sanitation items are the major trends in the sanitaryware market, together with design led initiatives and new business models. Tiles and tableware had a complete change of face due to ink jet printing.

However, these innovations are limited due to the defensive nature of the traditional ceramic market. Furthermore, technologies for manufacturing high-end traditional ceramic articles are rarely knowledge based and readily available for most of the players in the market, hence the diversification toward high-end customized pieces has not created a unique selling point for traditional ceramic manufacturers. Consequently, technologies were not able to secure a safe market position for traditional ceramic manufacturers leaving them to the uncertainity of the external market factors such as regulations and fuel cost.

For example, Inkjet printing is the latest technology in the traditional ceramic market (initiated in 2005). This proven technology enables manufacturers to create aesthetically superior ceramic items. The inkjet printing market has expanded year on year from 2014 to 2017 and it is expected that, in China alone, a further 4500 printers will be installed in traditional ceramic manufacturing lines in the next five years [Read more Ref 6]. In other words, there will be even more manufacturers with access to the latest technology in the traditional ceramic market and capable of producing high-end ceramic articles. Consequently, this will make competition fiercer in the high-end traditional ceramic market sector, again leaving the volatile uncontrollable external factors as the main criteria for success in the market-place.

To further emphasise the limitation for product innovation in traditional ceramic sectors, Canos and Buforn [Read more Ref 7] reviewed the innovations in the Spanish market in a quest to find the next game-changing innovation. They have identified this to be a technology that can be customised to client needs while also decreasing manufacturing costs (one such example might be a surface coating on a ceramic article that is implemented per customer request). In my opinion, by viewing the current technologies for customisation, like 3D printing, it is very unlikely that a single technology will alter the status quo of mass customisation in the traditional ceramic market. This will still leave us answering the question of how a traditional ceramic manufacturer can differentiate its products from the competitors.

Opportunity knocks

The ceramic processing similarity between technical and traditional ceramic manufacturing identifies advanced or technical ceramics as one area that traditional ceramic manufacturers could consider for diversification. One of the best examples is the Morimura Group which comprises both traditional ceramic focused companies, including Noritake and TOTO Ltd, and technical ceramic companies such as NGK which manufactures technical ceramics for automotive and electronics markets.

The main steps in manufacturing ceramic products are independent of the type of the final product, either technical or traditional. In the schematic in this article, (CERAMIC MANUFACTURING) we demonstrate the main steps of ceramic processing.

1. Raw-Materials Preparation

Traditional ceramics use common clay minerals known as plastic clays that are hydrated aluminium silicates resulting from the weathering of rocks. Advanced ceramic products are mainly based on oxides, nitrides, carbides and borides. Although the types of raw materials differ from technical to traditional ceramics, the steps of raw-material preparation and concepts are similar. Provided that the raw materials have gone through primary grindings in the quarries, the first step of the manufacturing comprises of activities (such as pre-drying, pre-blending and weathering, if required) to create a homogenised blend of raw materials. Both traditional ceramics and technical ceramics often require a secondary grinding step before shaping. Depending on the final product, this may include dry or wet milling, dry screening and spray drying. Some materials will also go through a calcination step to improve their properties. For example, dead-burning of dolomite and magnesite at 1800^{O}C is essential for manufacturing high performance refractory products. The calcination process is also applicable for fabrication of electro-ceramics, to ensure that the final phase purity is achieved prior to forming of the components.

2. Shaping or Forming of the Ware

Forming of traditional ceramics product is dominated by plastic forming; however, with the rising price of energy, a number of other forming techniques such as dry pressing and pressure casting are being increasingly used. In many cases, the aesthetic qualities are the main factor for choosing a forming technique. In contrast, the technical ceramics shaping method is selected to provide the required functional performance. Due to similar characteristics of ceramic green bodies, the majority of forming techniques are shared between technical and traditional ceramics sectors. Pressure casting, which is a variation of

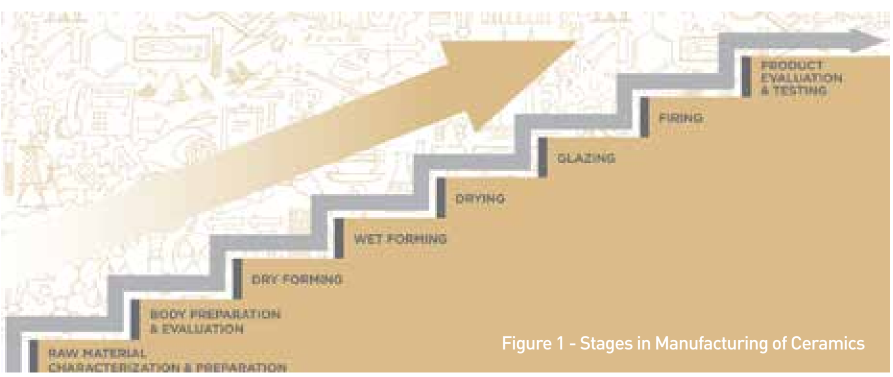

Figure 1 - Stages in Manufacturing of Ceramics

Published initially in the Asian Ceramics 18-9 edition; http://www.asianceramics.com

slip casting that uses high pressure air, is mainly driven by the sanitaryware and tableware industries. The technique that can create a more detailed ceramic article in a shorter timescale has been adopted by some of the technical ceramics manufacturers when in need of more complex shapes.

3. Drying of the Ware

Drying processes are different in traditional and advanced ceramic manufacturing because the choice of the technique depends on the sensitivity of raw materials to drying and final shape of the products which is quite different between technical and traditional products. The approaches vary from microwave drying, which is tuned to very specific applications, to tunnel drying which is well established in the traditional ceramics industry.

In contrast to the complexities of the dryer designs, the materials principles are the same in both technical and traditional ceramics manufacturing - the majority of the techniques provide an initial warming up section in a high humidity atmosphere, followed by the main drying step at higher temperatures and drier air to remove the last few percent of the water or additives. In both traditional and technical ceramics manufacturing, heat from the drying air can be recovered and reused in the process.

4. Firing or Sintering of the Ware

The key process of ceramic manufacturing is firing, which is responsible for the properties of the manufactured ware such as resistance to water and chemicals, mechanical strength, optical performance, electrical and magnetic properties. The firing cycle of traditional ceramics relies on physio-chemical changes in the raw materials as they are exposed to high temperatures. For example, a monoporosa (single firing of glaze and ceramic body) ceramic wall tile is designed to have a non-shrinkable, highly porous body. The firing process is engineered to accommodate several reactions in the ceramic body and glaze to provide an aesthetically desirable tile that can meet the performance criteria for application, e.g. water absorption and mechanical properties. The firing is controlled up to 950°C to provide time for clay reactions, and to make sure that the body is emptied of carbonates incorporated in the raw materials before the glaze has melted (to eliminate any space for removal of carbon dioxide). The maximum firing temperature and dwell time are designed to make sure that the glaze is melted in a controlled manner and results in a smooth surface finish. The cooling is carried out as quickly as possible before the temperature reaches close to 573°C, which corresponds to quartz inversion.

The same controlled process is required for technical ceramic manufacturing. This is especially the case when, for example, the final grain size of the material affects the performance and properties of the ceramic products. For example, grain size of Barium Titanate (BT), which is the main material that is used as a dielectric in capacitors, affects its electronic performance, or in the case of biomaterials such as Yttria-stabilized zirconia (YSZ), the fracture toughness is of high importance and directly relates to the abundance of grain boundaries that is controlled by the sintering process.

Either via intermittent or continuous kilns, the process of sintering or firing of ceramics must be engineered to provide a consistent atmosphere and temperature control throughout the firing chamber. The sintering apparatus designs vary but the main drivers are defined by better control of the firing process and reduction of energy and time of firing.

The similarity between manufacturing and operation of traditional and technical ceramics opens opportunities for traditional ceramics manufacturers to diversify into the production of technical ceramics. The technical ceramic sector, in contrast to traditional ceramic manufacturing, is less affected by VUCA environment and more reliant on knowledge and therefore offers, in some respects, a safer market position that traditional ceramics manufacturers.

Market drivers

Unlike the traditional ceramic market, the advanced ceramics market is highly fragmented with the presence of many small and large companies [Ref 8]. The wide product range has created a wide market space that is often dominated by the organisations which can make higher performance products. Along with capital, entering the advanced ceramic market relies on the necessary technical knowledge to create a high-performance product. A review of the key players in the technical ceramics market confirms the important role that materials engineering knowledge plays in the advanced ceramic market.

Saint-Gobain, with the turnover of EUR 39.1 Billion in 2016, comprises three main business sectors: innovative and high performance materials, construction, which includes both interior and

Lucideon Flash Sintering Technology Demonstrates a High TRL Innovative Development to Decrease Energy Consumption of Manufacturing Ceramics exterior solutions, and building distribution [Ref 9]. The corporation submitted 390 new patents in 2016 and was granted 211 US patents in the same year. This puts Saint-Gobain's ranking at number 158 of Intellectual Property Owners Association's (IPO) and highlights the importance of knowledge and expertise in the technical ceramics sector. Other ceramic manufacturers are also present on the IPO list; for example, Kyocera, who are mainly focused on manufacturing of fine ceramics and semiconductors, is positioned at number 103 in IPO list of 2016. In addition to patents that are an indicator of the knowledge of the advanced ceramics sector, the R&D budget of the companies showcase the importance of innovation in this sector. For instance, Corning Inc. (turnover of $9.4 B in 2016) is divided into manufacturing for display technologies, optical communication, environmental technologies, specialty materials and life sciences. The R&D spending of Corning in 2016 was reported to be more than $700 million. In addition other corporations like SCHOTT AG, CoorsTek Inc, Morgan Advanced Materials and RHI AG have spent a considerable budget on research and development of products for new applications as well.

Knowledge as power

Apart from a few technical ceramics manufacturers that still follow an artisan developed way of manufacturing ceramics, the majority of the high-level knowledge of making technical ceramics is available in literature. However, the basic knowledge for the fabrication of technical ceramics would not be sufficient to enter a competitive market driven by the performance of final products. In a market that is less populated by start-up companies, new experience can be acquired via established professional entities that are at the cutting edge of materials developments such as universities and research organisations.

Universities are often the go-to place for low technology readiness level (TRL) ideas. The proof of concept of a new solution or idea will be tested via students and researchers, supervised by academics that specialise in specific ceramic fields such as biomaterials, electro-ceramics, refractories and glass. Selected capable academics within universities have the potential to deliver tangible research and create innovative expertise. However, often the lack of industry experience and understanding of conditions in the manufacturing environment along with long timescales of delivery, dominated by education system timescales of awarding degrees, can create non-exploitable knowledge for the industry. Examples, such as selection of hardly available, costly raw-materials to enhance performance or advancing the materials properties via using lab-scaled processes that are not scalable, demonstrate the often less effective nature of some of the solutions provided in the academic space.

It is important to highlight the role of some of the existing programmes that have formed a close network between universities and the target industry, and that have the potential to create directed research to be applied in the ceramic industry. For instance, CDP (Center of Dielectrics and Piezoelectrics) led by the North Carolina State University, the Pennsylvania State University and the University of Sheffield (UK) aims to develop innovative solutions for industries based on capacitor and piezoelectric materials. The centre is in collaboration with the supply chain and manufacturers of electro-ceramics; hence the low TRL research is directly applicable, to be developed further into manufacturing solutions [Read more Ref 10].

In addition to universities, materials research and technology centres provide services that can create competitive knowledge for entering the technical ceramics market or diversifying within this sector to produce new high performance products. The majority of these commercial researchers are focused on higher TRLs which provide applicable solutions and required knowledge for manufacturing. The successful research organisations are driven by market needs via working in collaboration with a network of industries. The pace of development is fast in these organisations as they are operated by the professional researchers and consultants in the various ceramic industries. In addition to delivering on the low TRL research, these organisations are capable of bringing the ideas from the laboratory to the factory floor. For example, flash sintering is a flagship technology that is an innovative solution for low energy, fast firing of ceramics and was adopted by Lucideon in 2012. The technology has since been developed into a larger scale manufacturing environment that makes it much more convenient for industry to adopt and use in manufacturing, figure below [Read more Ref 11] .

The future

The traditional ceramic market is driven by external factors such as environmental policies and price of energy, making it more challenging for manufacturers to manage market threats in an ever increasing VUCA environment. Similarities of production, supply chain and processing knowledge makes manufacturing of technical or advanced ceramics a clear choice for traditional ceramic manufacturers to diversify their product range and secure a more stable market position. The main barrier to entering the technical ceramics market is the required specific knowledge and expertise required to create a distinguished market position and to meet the needs of end users. Knowledge can be acquired via universities or materials research, development and commercialisation organisations.

The future of ceramic manufacturing is promising for those organisations that are willing to look outside the factory walls to collaborate and create strong networks of customers and technology providers to enhance their competitiveness. Lucideon is facilitating this collaborative environment amongst manufacturers of technical ceramics, traditional ceramics and technology providers by creating a Ceramic Park in the UK [Read more Ref 12]. The global materials technology organisation is committed to the growth of the traditional and advanced ceramics sectors by providing its materials expertise, facilities and pioneering spirit to expedite the journey from research and development to commercial products and processes.

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Published initially in the Asian Ceramics 18-9 edition; http://www.asianceramics.com