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Industrial Ceramic Form Profile Control through High Degree Vitrification Firing Process

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Abstract
In ceramic, firing is the most crucial stage of the whole production process. It's influencing the successfulness of ceramic profile. The successful ceramic profile refers to the delicacy of that particular shape which is the quality of being beautiful and delicate in appearance. However, the mechanical behaviour of clay body during the sintering process affecting the designed profile. Therefore, this study associates the use of Setter as a potential mechanism to systematically controlling ceramic profile; thus, reducing warpage to its designed form during firing.

Keywords: Ceramic, Setter, Design, Vitrification

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1.0 Introduction

Firing is the process of using kiln to turn raw clay or castware into ceramic through high temperature heating. It is the very last stage of ceramic production process. During heating, minerals in the clay body will undergo a complex set of thermal modifications (Jorda ́n et al., 2001; Pardoet al., 2011) which the final properties of the ceramic products will be determine. The limitation for ceramics, either in its green- or sintered-form, are known for being hard yet brittle which limits further shape reconfiguration. (Zhang et al., 2019). These final body properties can sometimes affect the visual profile of a specific product design, especially for pieces with unstable profiles. When there is a high degree of vitrification for the body itself or an unstable shape or profile, warping occurs during the firing of ceramic ware. Most clay bodies will soften as they approach their melting point. Predicting phase changes in fired ceramic clays is difficult due to complex relationships between the structural and chemical properties of the fired ceramics (Ouahabi et al., 2015). As a result, the only way to ensure that the product retains its intended form is to avoid any possibilities that could affect its profile change. The success or failure of the production process is determined by several key factors, so it is critical to ensure that each stage of the cycle is fully completed before the next phase begins Gliozzo (2020). As a result, this research focuses on a potential mechanism that can be used as a systematic control, particularly for high-risk ceramic profiles. In general, the method used to avoid clay profile change is to use warp-resistant wall thicknesses or product shapes. However, it will limit the designer's or artist's ability to go beyond the standard design.

Thus, for vitreous bodies, a balancing understanding is required, firing as high as possible to achieve the most dense and strongest body possible while employing ware shapes and wall thicknesses that are resistant to warping. During firing, clay bodies soften as they approach their melting point. During heating, clay minerals undergo a complex set of thermal modifications that determine the final properties of the ceramic products (Jordan et al., 2001; Pardoet al., 2011). Predicting phase changes in fired ceramic clays is difficult due to complex relationships between the structural and chemical properties of the fired ceramics (Ouahabi et al., 2015). When there is a high degree of vitrification or an unstable shape, warping occurs during the firing of ceramic ware. However, warping is to be expected in translucent ware; it is simply a factor that must be considered when designing.

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Several key factors may determine the success or failure of the manufacturing process, so it is critical to ensure that each stage of the cycle is completed before moving on to the next (Gliozzo,2020). This is interpreted as the result of reduced water fugacity caused by the combustion of organic matter (Maritan et al., 2006). The behaviour of these ceramic bodies during the manufacturing cycle is largely determined by the raw material composition and firing temperature, but the shaping technique and thermal gradient also play important roles (Fabbri and Dondi, 1995a, Jordan et al., 1999). Ceramics, whether green or sintered, are known for being hard but brittle, limiting further shape reconfiguration (Zhang et al., 2019). The improvement of ceramic body strength in sanitary ware has become a critical situation in order to achieve new design development. This design evolution is directly related to the investigation of the current manufacturing process, which included forms, materials, and techniques. Anwar and colleagues (2011) Traditional industrial ceramic design investigation encountered numerous challenges, particularly in terms of design methodology. The designers' ambiguous design approach leads to technical difficulties when introducing a new product design (Anwar et al., 2014). The mechanical strength of traditional porcelain is a result of the ceramic processing that formed the piece, followed by raw materials and their characteristics, forming process, firing atmosphere, time, and temperature. These parameters determine the complexities of microstructure and phase development, which are difficult to control and make predicting porcelain final properties nearly impossible. Many theories have been developed to explain the strength of porcelain over the last century, and some have recently been revised and improved due to the development of new analytical techniques. 2004 (Braganca and Bergmann)

2.0 Body Reaction During Firing

Anorthite is a calcium aluminosilicate that forms as a result of a reaction between calcium oxide and a byproduct of clay minerals breaking down during firing. The thermal and moisture vaporising process tends to pressurise the body profile during the early phase of 550 oC. This activity can sometimes result in uncontrolled profile contraction and expansion. Calcium oxide consumed amorphous phases in this reaction, forming crystalline phases that are resistant to moisture expansion. Dehydroxylation of kaolinite is the name given to this stage (please refer Fig. 1)

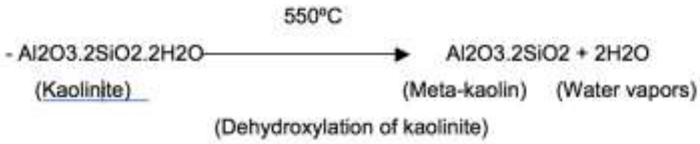


Fig. 1: Example of Graph firing curve of dilato for porcelain body (Vermol, 2010)

At high temperatures, the formations also avoid the breakdown structure of metakaolin. Around 800oC, the decomposition of limestone process begins, releasing gases while also creating pores within the body (please refer Fig. 2).

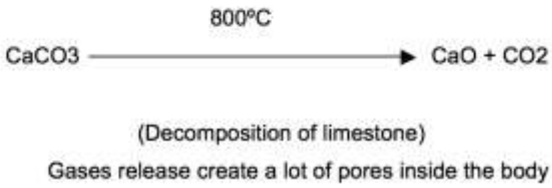


Fig. 2: Example of Graph firing curve of dilato for porcelain body (Vermol, 2010)

Meta-kaolin decomposes around 900oC-1000oC to form mulite and release amorphous silica. Silica begins to dissolve and form a liquid (glassy) phase at high temperatures; if meta-kaolin is consumed, this reaction does not occur (please refer Fig.3)

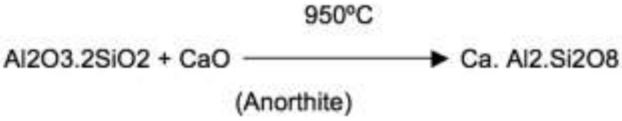


Fig. 3: Example of Graph firing curve of dilato for porcelain body (Vermol, 2010)

The glassy phase is also susceptible to moisture expansion. The formation of pores as a result of calcium carbonate decomposition, the formation of anorthite, and less formation of glassy phase reduces body shrinkage. The overall firing heat work of an entire firing process can be detailed using the firing graph shown in Figure 4.

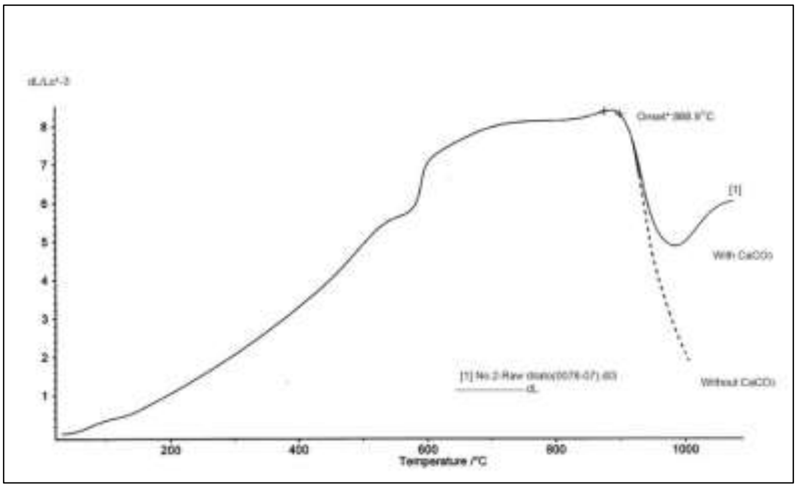


Fig. 4: Example of Graph firing curve of dilato for porcelain body (Vermol, 2010)

2.1 Warpage in Ceramic

Clay is a sensitive material with a memory. It tends to reflect from its memory and deform according to the stress during firing due to pressure and stress during the forming process in a green condition. Ceramic warping can be caused by clay particle orientation caused by physical/ionic properties. This is because when clay particles dry out, they tend to revert to their original orientation. Understanding what causes memory is one thing; understanding how to reduce its impact is quite another. The first thing to realize is that high-plasticity clays frequently have a high memory. Memory problems are more common in porcelain, but any highly plastic clay body is susceptible. The second issue is water. The more water added to a body during formation, the more likely memory issues are. The heavy slip that appears when you throw indicates that you are washing out fine particle plasticizers on the inner and outer walls, softening them and changing the ionic charge they carry. You've created surface tension, ionic charge, and particle alignment differences between the inner cavity and outer walls.

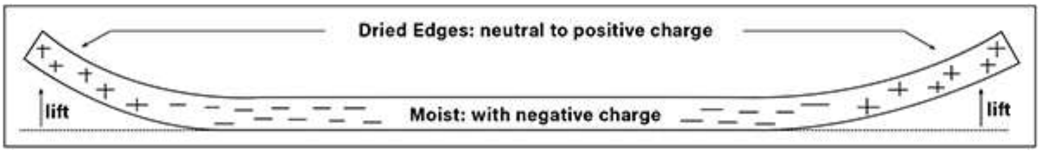


Fig. 5: Slab cross section. Plasticity comes from a negative charge in the clay/water film. As the clay dries, the ionic charge reverts back to its original neutral or slightly positive charge, creating tension (Source was taken from: https://ceramicartsnetwork.org/daily/article/Great-Advice-for-Preventing-Ceramic-Warping

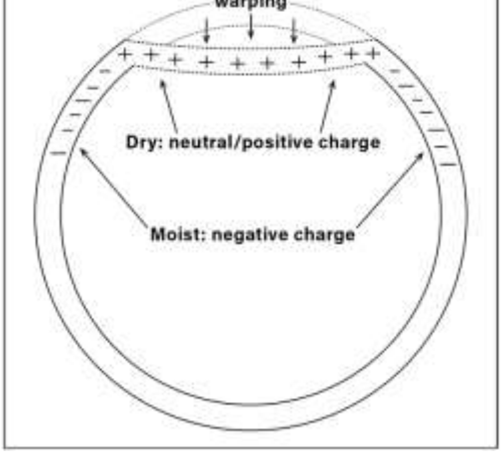


Fig. 6: Rim cross section. The extent of warpage on bowls and cups is related to diameter and wall thickness. Plasticizers can absorb excess water used in throwing or forming, and compound warping issues.

(Source was taken from: https://ceramicartsnetwork.org/daily/article/Great-Advice-for-Preventing-Ceramic-Warping

Warping is most common in slab and tile work. Prevention begins with the rolling of slabs. Roll in more than one direction. Smaller pieces can be flipped halfway through the process. Large slabs formed on a slab roller should be rolled in both directions, forward and backward. Rolling in one direction stretches the slab as much as it compresses it. Unequal compression can exacerbate memory issues and make the slab more susceptible to quartz inversion stress during firing. Cut pieces from the centre of the slab, avoiding the outer 2 inches around the perimeter if possible. Storage on drywall ware boards is the preferred method for handling ceramic tiles after they have been rolled. While this method is effective, I prefer 1/2-inch Sande plywood because it absorbs and releases moisture more slowly and does not flex when lifted. To avoid additional clay handling, I roll and cut tile on plywood. A second piece of plywood placed over the tile adds just enough weight to lightly compress the tiles and prevent warping. Tiles and slabs will shrink while drying, so use enough weight to keep them flat while drying, but not so much that they drag. Memory is a clay property that must be managed during the forming process.

3.0 Design Issue

Cracks and warps are both caused by the same phenomenon: a buildup of stress in the clay that exceeds the inherent strength of the clay. When this happens, the clay will first try to deform in order to relieve the stress buildup, i.e. warp. If the piece is prevented from warping due to geometry or other factors, it will eventually crack when the stress buildup exceeds the strength of the clay at a specific point in time, such as during drying or firing. Clay strength must be increased to eliminate stress buildup in order to solve these problems (particularly non-uniform stress buildup). The removal of stress caused by ceramic artists or designers changing the composition of their clay body, which is a necessary step if we are to increase the strength of the clay slip. There would be no cracking or warping if it were possible to completely eliminate stress buildup in clay as it goes through the various processing steps on its way to becoming a finished piece of pottery (there still might be distortion due to sagging, but this is a different type of problem).

3.1 Non Uniform Drying

Non-uniform drying is possibly the most common cause of stress buildup in pottery. Because clay shrinks as it dries, a partially dry piece is drier on the outside than it is in the centre. The faster it dries, the more the outside shrinks compared to the centre, and the more stress accumulates. Of course, non-uniform drying from one side of the pot to the other can cause stress. These stresses may not immediately cause cracking or warping, but they will be present during firing. When the clay reaches maturing temperature and becomes a little "softer" or weaker, a stress buildup caused by non-uniform drying may be relieved by a crack or a warp. This is especially likely if the firing is also non-uniform. Several underlying issues can cause non-uniform drying. The most obvious is excessive drying time. If all other factors remain constant, a pot that is dried quickly will experience greater stress buildup and is more likely to crack or warp than one that is dried slowly. If cracking/warping is causing you problems, you should ask yourself the following questions: Has the weather changed? n the winter, a dry, heated studio will dry much faster than an open studio exposed to summer humidity.

3.2 Uneven Thickness

Uneven clay thickness is another underlying cause of non-uniform drying. Crack most likely caused from uneven drying as a result of uneven clay thickness. There are areas in the foot that are three times the thickness of the wall and nearly twice the thickness of the bottom. Again, all else being equal, thin sections of a pot will dry faster (and shrink or try to shrink more quickly). If they are restrained by a thick section that is slowly drying, a crack is almost unavoidable.

3.3 Non-Uniform Drying

The physical configuration of the drying environment and how you process pots through it is a third source of non-uniform drying. Changing from a plywood ware board to a plastic coated ware board may also affect the drying rate, especially at the bottom of the pot. A damp pot will absorb a significant amount of moisture, whereas a painted or plastic-coated ware board will not. Are you exposing the bottom of the piece to air by turning it over from time to time, or do you just put it on a shelf and forget about it? Maybe drying your pots on a screen is preferable to drying them on a ware board. Tiles are an especially difficult type of piece to dry uniformly and without warping. Giorgini (2001) suggested drying tiles between layers of sheet rock or wallboard in his book Handmade Tiles. This method provides relatively uniform removal of water from both the top and bottom of the tile at the same time. Using this technique, the drying process can take 1-3 weeks, but being in a hurry may be the best way to describe, in a single phrase, the primary cause of cracking and warping. If your tiles do not have a flat surface, wrapping them in plastic for 12-18 hours per day and exposing them to air on a screen for a few hours per day can slow the drying process enough to prevent warping.

3.3 Uneven Firing or Cooling

Another cause of cracking or warping is too rapid or uneven firing or cooling. This is very similar to the clay drying too quickly or unevenly. The risk of developing unacceptable levels of stress, as well as the resulting cracking or warping, is the same. During the firing process, the clay emits water and/or shrinks. Rapid fire would probably not be a big deal if it didn't result in uneven firing. Of course, uneven firing can be caused by more than just firing too quickly. An element in an electric kiln may be failing. In gas kilns, it could be anything from a poorly designed kiln to incorrectly adjusted burners. Uneven loading can cause uneven firing in all types of kilns. If you notice cracks or warpage during firing, this is the first place to look for an answer. Slowing down is the most obvious thing to try. Increase the firing time to see if there is a noticeable difference. However, don't dismiss other possible causes of the problem. Stresses accumulated during drying may not manifest as cracks during drying or even bisque firing. They may only become visible during glaze firing or cooling.

3.3 Air Bubles

Air bubbles in a pot can cause cracks, but they are unlikely to be involved in warping. As previously stated, stress accumulates during the drying and firing processes due to the inherent non-uniformities in these processes. Bubbles cause weak spots in the pot structure. They also result in stress concentrations. As a result, stress accumulation that might be tolerated in a bubble-free pot can result in a crack in the area where a bubble is present. Because the bottom of the pot is usually the most vulnerable, special care should be taken to avoid bubbles in this area. Even if the clay has been wedged to a bubble-free state, it is possible to trap an air bubble between the wheelhead and the clay when it is placed on the wheel. This bubble will then work its way into the pot's base and may even remain after trimming. If you have a cracking problem, be very careful to make bubble-free pots, but also take advantage of the opportunity to examine cracked pots for evidence of bubbles. This is one of the possible causes of cracking. Break the pot as carefully as possible along the crack, and inspect the chards for a void larger than the crack would have caused.

3.3 Non-Uniform Orientation

Non-uniform orientation can also be a major issue when slip casting a tile. If a one-piece mould is used, there will be a significant difference in platelet orientation across the tile's thickness because the interaction of the clay with the plaster orients the platelets while the side exposed to air receives no orientation. A tile cast in this manner will almost certainly warp. The use of a two-sided mould significantly alleviates this issue.

4.0 Research Methodology

4.1 Ceramic Mullite Setters

Ceramic Setters are kiln furniture items that are shaped (generally on their upper surface) to conform with the undersurface of plates and dishes in the ceramic tableware industry and serve to support ware and maintain its shape in the kiln during firing. Overall, ceramic setters were developed to reduce stress or support product weight during the firing process. The process flowchart is as shown in Fig.7 after designing the formulation parameters for the setters.

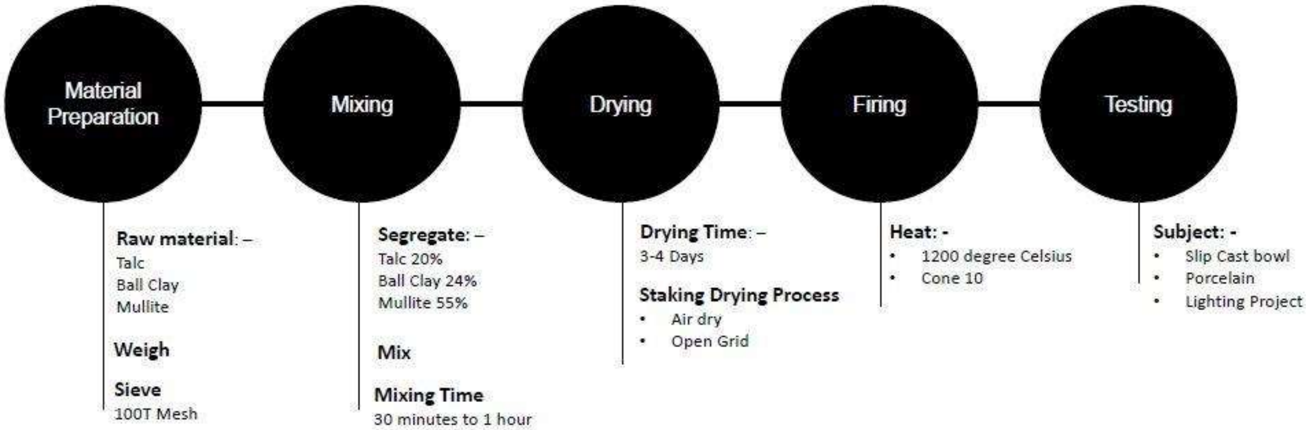


Fig. 7: Flowchart of process in preparing Ceramic Setters

4.2 Mixing the Mullite Recipe

It is critical to determine the minimum amount of water for the dry mix so that the final product is not too wet (2). Begin by combining a 4545-gram batch of Mullite Setters dry mix (recipe on page 11) with 32 ounces of water. When measuring and mixing dry ingredients, always wear a properly fitted respirator. Allow it to slake for one day before mixing with a power drill equipped with a paddle mixer. To make the mixture more workable, add small amounts of water as needed. Rolling a small ball of the body in your hands is a good test to see if it has enough water; if it cracks around the edges, it needs more water. When the mixture is combined and ready to use, place it in a bucket for a few days to allow all of the particles to fully saturate.

Setters	
Cone 10 Oxidation/ Reduction	
Talc	20%
Ball Clay	25%
100 Mesh Mullite	55%

Fig. 8: Ceramic Mullite Setters Recipe

Source: https://ceramicartsnetwork.org/pottery-making-illustrated/pottery-making-illustrated-article/In-the-Studio-Make-Your-Own-Kiln-Setters#

4.3 Working with the Mixture

Compress a slab, then cut out a shape with the template. After that, wedge the clay (3) and roll it with a slab roller. This body behaves much more like cement than clay, and it's wet enough to be slightly jelly-like. It helps to let it dry a little bit between drywall boards after it's been rolled out in this wet state (30 minutes to an hour) so that it's a little stiffer when you cut it. Because each size setter has a different thickness, start with the largest slab and then readjust the slab roller for each smaller type. The clay is so short (non-plastic) that keeping the edges from slightly cracking is difficult. To prevent edge-cracking, beat the slab with a paddle to compress it. Repeat this process until it's close to the desired thickness, then pass it through the slab roller again.

4.3 Drying the Setters

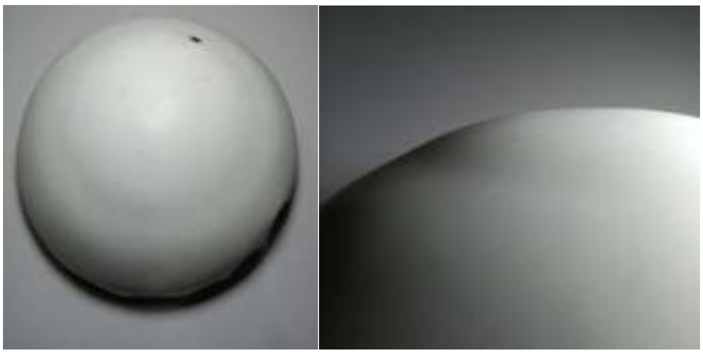
The drying process is now a little more difficult. To keep the slabs from sticking to the drywall, sandwich the setters between cloth-covered drywall boards (6). The cloths must be completely smooth so that they do not leave marks on the setters' surfaces. You'll have to stack the drywall boards if you don't have a lot of them. They should be flipped every 12 hours on the first day—a total of two times—and then once a day after that to ensure even drying. The drywall board tends to get very wet at first, so using fresh drywall boards after the first day speeds up the drying process. After 3 or 4 days, remove the setters and dry them on an open grid (7). I use an egg-crate diffuser, which is commonly found in drop ceilings and can be purchased at any building supply store. The grid must be raised off the table to allow air to circulate beneath it. I propped it up with kiln furniture and placed it on the most level surface I had, the floor. You can bisque fire them once they are completely dry.

4.4 Firing and Using the Setters

When it came time for my next cone 10 firing, I treated them as if they had already been high fired, placing pots on them and stacking them as I would in a regular kiln loading. This was a HUGE ERROR. Unfortunately, they stumbled in their first attempt. I assumed that because the setters we've been using for years don't move during a cone 10 firing, the bisque-fired ones would, too. I was mistaken. I had to make a new batch, cut it out, and dry it. I bisque fired and high fired this batch while standing on edge, and they did not warp. Your setters are now ready to be used in your next firing (8). After the shelves have been fired, I recommend applying kiln wash to them. My Grolleg porcelain pieces became stuck to the shelves without kiln wash. This did not occur with stoneware.

5.0 Results and discussion

Small & medium form - Maintain its profile



Larger / bigger form compared to setter size - Warped and profile slightly change

Form without setter - Warped and bottom profile change drastically

6.0 Conclusion and Recommendation

In conclusion, based on the findings of this study, we can clearly see that using a setter during firing will help to reduce the risk of profile changes in ceramic products. However, it will also depend on the size and profile of the setter used with the product. Another factor to consider is the economic side, as the setter for this specific type of form is only suitable for a single use due to the shrinkage factor for the setter. As a result, it is strongly advised to find another method that is not limited to the size of the form or the number of times it has been fired. It is thus critical to use gas-permeable ceramic setter plates; for example, an integral ceramic setter plate with cavities may be used, and this ceramic setter plate is manufactured from two ceramic setter plate compacts prepared by subjecting a ceramic powder raw material to press working in such a way as to form undulations on one surface thereof, and by joining the ceramic setter plate compacts together at their profile. Alternatively, ceramic setter plates can be made by firing the ceramic setter plate compacts with undulations on one surface as described above. When the thus ceramic setter plates are used to fire a laminate of ceramic green sheets, two fired ceramic setter plates are placed on each side of the laminate and joined together at the convex surfaces to form cavities over it. Fresh air is introduced, and decomposition gas is released through the cavities.

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References

John Hesselberth, Ron Roy (2020) Mastering Cone 6 Glazes: Improving Durability, Fit and Aesthetics, Echo Point Books & Media. United States.

Abidin, S. Z., Bjelland, H. V., & Øritsland, T. A. (2008). The embodied mind in relation to thinking about form development. Proceedings of NordDesign 2008 Conference (pp. 265-274). Tallin: Design Society.

Adams, F. M. and Osgood, C. E. (1973) A cross-cultural study of the affective meaning of colour. Journal of Cross-Cultural Psychology 4(2) 135-156

Ernst Eder, W.(2010) 'Engineering design science and theory of technical systems: legacy of VladimirHubka', Journal of Engineering Design,, First published on: 19 November 2010

Lawson, B. (2006). How Designers Think: The Design Process Demystified (4th ed.). Oxford; Burlington, MA: Elsevier/ Architectural Press.

Lovegove, K. (2000) Airline Identity, Design, and Culture. London, Laurence King.

"Painting versus Polishing of Airplane Exterior Surfaces". Aero Magazine. Boeing. January 1999

Anwar, R., Abidin, S. Z., & Hassan, O. H. (2016). In-vitro design protocol: Artificial situation strategy uses to comprehend designers' thought. In EDP Sciences: MATEC Web of Conferences, Vol. 52.

Smith, Glenn (2019). "An Interview with Frieder Nake". Arts. 8 (2): 69. doi:10.3390/arts8020069.

Thurlow, A. and Aiello, G. (2007) National pride, global capital: a social semiotic analysis of transnational visual branding in the airline industry Visual Communication 6(3) 305-344.

Verly Veto Vermol (2021, September 2). *"Verly Veto Vermol, Malaysian Painter"*. Asian Art Association Singapore. - https://en.artassociation.asia/master/verlyvetovermol/

Yarwood, A. 2000. British Airways World Images Farewell Airliners 13(6) 25- 43