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APPLICATION OF SINGLE FIRING TECHNIQUE FOR EFFICIENCY IN FUEL AND TIME

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Introduction

For thousands of years ceramic bodies have been developed and fired to a varying range of temperature using a variety of kilns, firing fuels and techniques. During these periods, the priority of firing ceramic wares was principally the attainment of either bisque or gloss firing temperature with little or no attention paid to firing efficiency, fuel consumption or the issues of environmental protection. With the rising issues of sustainability however, fuel efficiency and sufficiency, climate change and the protection of the fast eroding ecosystem taking the center stage as topical issues for discussions in conferences, seminars and workshops globally, it is not surprising that, ceramic processing and firing is no longer business as usual. In view of this, researches in ceramics material science, fuel and firing technology are now streamlined to reflect these issues as well as other emerging concerns as they relate to sustainable ceramic practice (Abubakar & Sadiq 2018a; Abubakar & Sadiq 2018b: Englund, 1995). The thrust of this study therefore, is to develop a single fired (once fired) ceramic body and glaze with a view to making ceramic processing efficient in time and fuel usage.

Literature Review

Ceramic Glaze and Bodies

Humans by nature are inclined to add beauty to everything they make. This is illustrated by the primitive decorations found on pottery shards and metals in ancient times (Englund, 1995). Of significance to the decorative aspect of ceramic was the discovery of burnished shards in the Anatolian plateau, of Catalhoyuk Turkey dating about 7500BC to 5700BC and the application of the Egyptian white slip on red ceramic body to reduce the porosity of the ware (Englund, 1995). Although, burnishing can be done before or after firing, there was however no indication at what temperature the Anatolian Burnish or the Egyptian slip was fired to. The Fuji people have also been known to solve the problem of porosity by the use of resin; where a piece of pot is removed from open bonfire while still hot and resins are applied to the inner part of the ware (Englund, 1995). The melted resins do not only seal the porous surface of the earthen ware body but also provided lustre to its surface. It however appears that, salt glazing which involves the introduction of salt into a kiln at a high temperature, resulting in the release of sodium fog and the coating of the ceramic ware by the sodium fog has some semblance to the Fuji technique, which involve the application of resin on a hot ware. Given the similarity between the Fuji and the salt glazing technique and the fact that, Fuji technique predates salt glazing technique, it is then possible that, the Fuji technique is a precursor to the development of modern glazes.

The discovery in about 5500BC of a blue-green glaze in Egypt is believed to be the first attempt at what can now be referred to as modern glaze (Jamieson, 2003). This type of glaze, which was also known as Mohammedan blue was dominantly used in Middle Eastern ceramics. Since the discovery of primitive glazes and development of the earliest modern glazes, numerous studies have been conducted using a variety of ceramic materials to develop an array of glaze recipe for a wide range of temperature. For example Ajala (2009) reports on the development of earthenware glaze using eucalyptus leave and cullet. Isa (2018) reports on the use of cullet, maize cob ash, feldspar and kaolin for development of earthenware glaze. Similarly, Datiri (2015) develops a glaze recipe using volcanic ash, while Umar (2000) works on the production of high temperature glazes using Alkaleri kaolin in Bauchi State.

Earthenware Ceramic Body and Glazes

The earliest ceramic wares produced, which are now known technically as earthen ware fall within the temperature range of 1150^{0}C -1160^{0}C. Unglazed earthen ware bodies are usually porous in nature, and characterized by brittleness. They were also known to chip or break easily leading to reduced functionality and lifespan. Despite these shortcomings, earthenware has been the dominant feature of the early years of ceramic production in both individual potteries and industries across the world. With the development and application of glazes to earthenware, issues of porosity were eliminated with a significant increase in strength and life span of the ceramic ware. Examples of glazed earthenware produced in Europe include the Palence of France, the Majolica of Spain, and Italy, and the Delft of Holland (Englund, 1995).

Middle fired Ceramic Body and Glaze

This class of body and glaze falls within the temperature range of 1100^{0}C-1200^{0}C (Englund, 1995). Studies on this range of glaze temperature appear to be scanty when compared with earthenware glaze and high temperature bodies and glazes such as stoneware and porcelain. An example of studies conducted on the development of middle fire ceramic body and glaze is the one reported by Englund (1995) where glaze and body were developed and fired to1100O^C and 1200^{0}C.

High Fired Ceramic Body and Glaze

Glazes classified under this category fall within the temperature range of 1260^{0}C - 1300^{0}C (Segar cone 8-10). Beginning from the lower end of the temperature range (1260^{0}C) and fired upward, bodies and glazes that vitrify within these temperature ranges are technically regarded as high temperature bodies and glazes. Stoneware and porcelain body and glazes fall within this temperature range. The characteristic feature of this type of body is its high verification, which tends to close all the pore spaces within the body particles. The earliest record of stoneware ceramics was traced to the Ann- yang Honan province of China. Although, the exact period when these wares were produced is debatable, with some authors reporting 3200BC- 2900BC; 2500BC-2000BC and 1800BC, it is however clear from the carbon dating of pottery shards that, at the time pots were produced under earthenware temperatures in Europe and the Middle East, the Chinese were producing 'hard baked' and "hard white pottery" which was believed to be stoneware (Peterson, 1992, Englund, 1995)

Two Stage Firing

Two stage firing was believed to have been pioneered in Europe as a remedy to the problems of breakages and waste experienced during the firing of tin oxide (D'Souza, 2019) and Majolica (Smith, 2001). Ever since it was introduced, the two stage firing has grown in popularity and acceptability across the ceramics world. The first stage of firing is what is commonly known in the ceramic profession as bisque or biscuit firing. This firing which falls within the temperature range of 500^{0}C-900^{0}C or in some cases 1000^{0}C is done with the sole aim of transforming the leather hard ceramic into hard and porous material. Once the ceramic is successfully bisque fired, it is then ready for the second stage of firing, where slipped glaze is applied to the hard porous ceramic and fired to a vitrification temperature.

Two stage firing, particularly the second part of the firing, which involves the application of glaze to a porous ceramic ware and fired to a vitrification temperature was in the researchers' opinion made more prominent by the concept of division of labour, resulting from the industrial revolution of Europe which emphasized the breaking and specialization of the pottery firing process as well as the domiciliation of gloss firing technique across European pottery canters and studios.

Once / Single Glaze Firing Technique

Once/single firing technique is not a recent development as potters around the world have been practicing it for centuries (D'Souza, 2019; Smith, 2001 & Englund, 1995). Examples of the use of 'once fired technique' include the Raku, Bonfire, Saw dust and pit firing techniques. Ceramic wares produced from once fired techniques include plant pots, tiles and sanitary wares. This class of ceramics forms the bulk of wares produced globally (Englund, 1995). Given that the once firing technique eliminates bisque firing from the firing equation, the following benefits can be accrued to the ceramicist: the removal of first stage of firing (Bisque) could result in savings in terms of the cost of fuel (reduced fuel use) and reduction in firing time (D'Souza, 2019). The elimination of bisque firing means that, time spent on setting the kiln, firing, unloading and off loading the bisque kiln could now be channelled into other productive endeavour such as the production of more ceramic wares. Once firing is also profitable to the environment; this is because as less fuel/energy is consumed, less carbon dioxide ($C0_2$) is released into the environment. Once /single firing also enhances the carbon foot print of ceramics processing by contributing less greenhouse gas emission into the climate system.

Efficiency of Fuel and Time in the Context of Ceramic Firing

Two stage firing has been reported above to be a time, energy and resource consuming process. For example, depending on the size of the kiln, up to 12 hours or more could be expended in a bisque firing cycle. Similarly, up to 24 or more hours could also be expended in glaze firing cycle (D'Souza, 2019). There is also the reported issue of fuel consumption and green house gas emission. This is based on the fact that, the longer the firing time, the more energy is consumed; the more $C0_2$ is emitted to the atmosphere and vice versa. With the current global clamour for efficiency in production and consumption which revolves around reduction in carbon dioxide ($C0_2$) emission, the sustainable use of natural resources as well as savings in energy usage, it is not out of place to rejuvenate and sustain the "once firing" technique by exploring the suitability of ceramic materials from Bauchi and Numan for the development of body and glaze materials capable of firing once to gloss temperature.

Aim of the Study

The aim of this study is to develop body and glaze materials suitable for once/single firing to a cone temperature of 1200^{0}C using ceramic raw materials from Adamawa (Numan) and Bauchi States.

Materials and Method

Materials

White ball clay and Siltstone used for this study were dug along the upper bank of river Benue in Numan, Adamawa State, while granite and grog were collected from the Sahel quarry site in Gudum Hausawa and the Department of Industrial Design, Abubakar Tafawa Balewa University Bauchi in Bauchi State. Prior to their use, the raw materials were washed, ground and sieved with a 200-micron meter sieve to remove stones, metals, glass shards and other impurities that may hinder the process. Other materials used in the study were digital weighing scale, 45 CF downdraft kerosene kiln, kerosene burner, thermocouple thermometer model 434 and a plastic bucket.

Methods

Chemical Analysis

The red silt stone, white ball clay and granite used for the study were analysed using Atomic absorption spectroscopy (AAS). The procedure which is based on the ability of free metallic ions to absorb light is used to quantitatively determine the volume of elements in a sample by the optical (light) radiation of free atoms in gaseous state.

Batch Formulation

The materials used for the development of body and the slip glaze recipe for once firing were formulated using trixial glaze blends of 21 titles (figure 1) as recommended by Umar (2001). From figure 1, trixial blends of tile 1, comprising 60% clay, 30% granite, and 10% siltstone were selected and used for the body while tile No 81 which comprises of 10% clay, 60% granite and 30% siltstone were used for the glaze formulation. Once firing has been attributed with flaking, the presence of high clay content in the body formulation has the tendency to eliminate this problem (Hill, 1986). Similarly, to increase the dry strength of the green ware (body) grog was added as also recommended by Hill (1986).

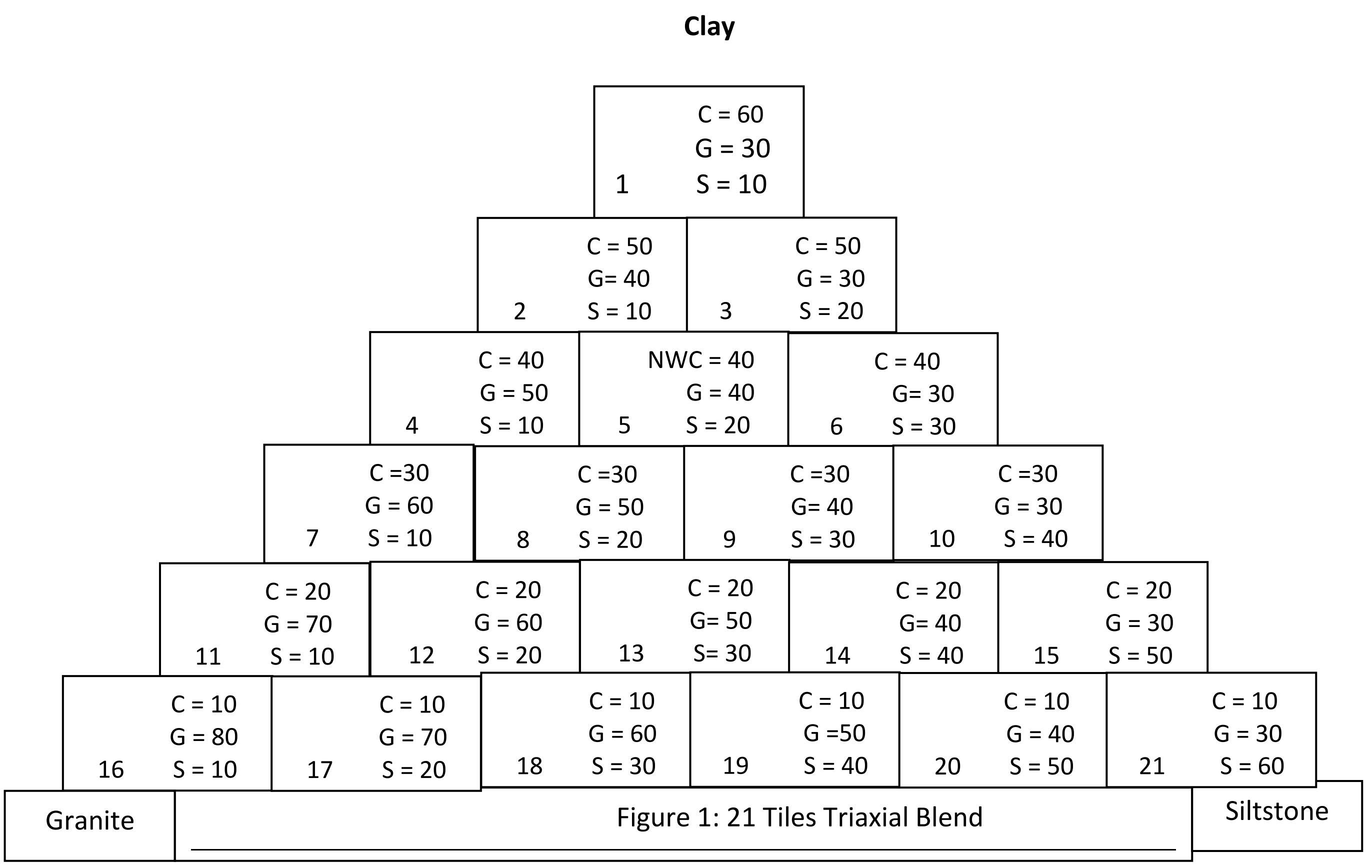

Figure 1: 21 Tiles Triaxial Blend

Glaze Application

The thrown body was allowed to bone dry before glaze is applied to it using the dipping technique. This was done to eliminate the possibility of the thrown ware crumbling due to water absorption and explosion during firing (D'Souza, 2019 and Hill, 1986).

Firing

The developed wares (body and glaze) were fired once in the reduced kiln atmosphere **(**Plate 1). Firing started slowly and made to increase progressively. This was done to allow for soaking of the ware and the prevention of shattering (Hill, 1986)

Plate 1: Body and glaze fired to 1200^{O}C

Results and Discussion

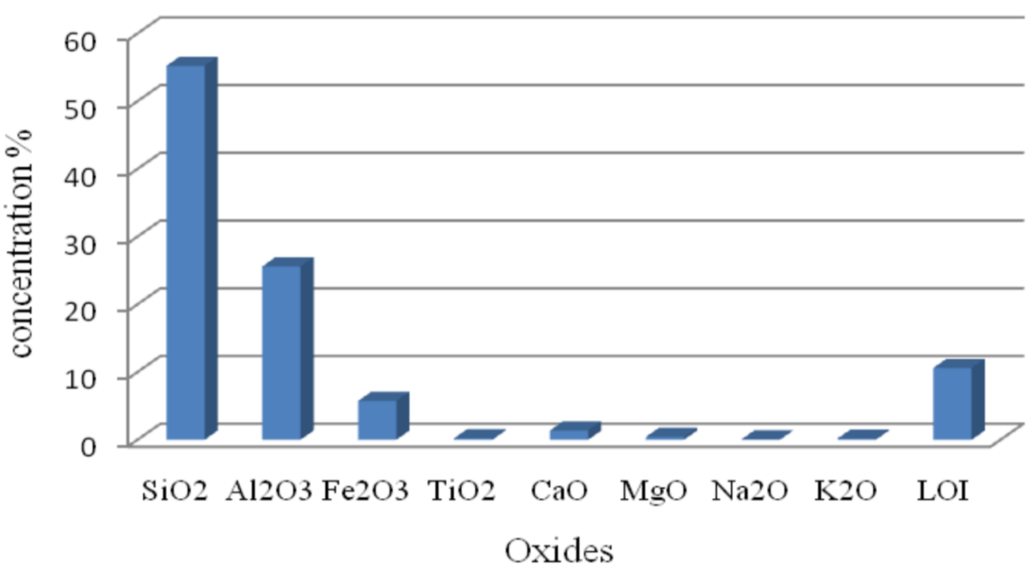

Figure 2: Chemical analysis of Numan white Clay

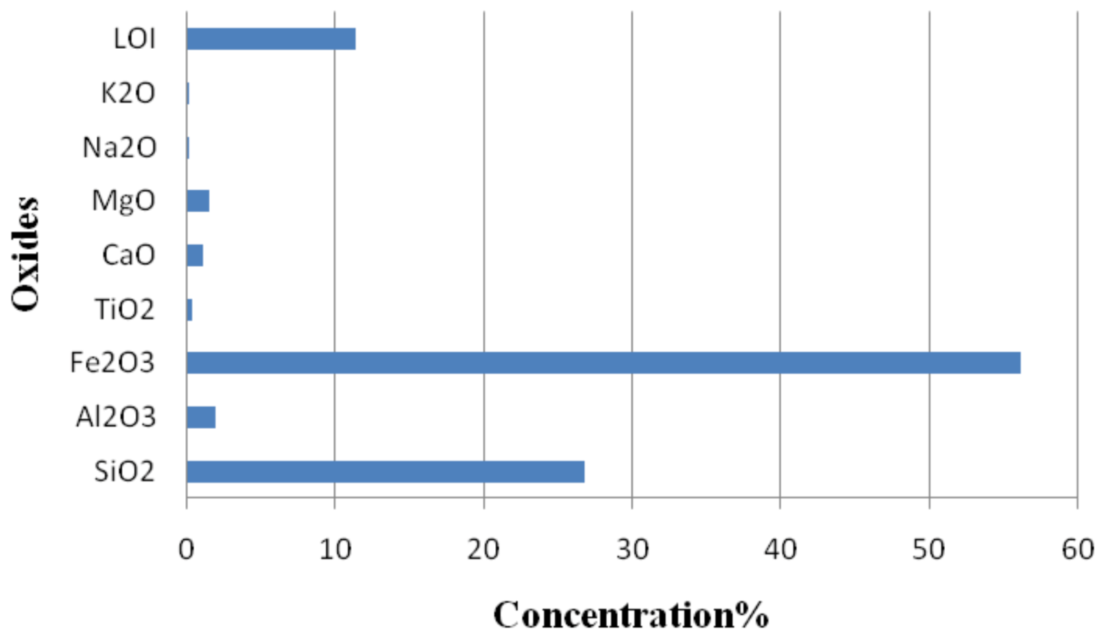

Figure 3: Chemical analysis of Numan Red Siltstone

The result of the chemical analysis indicated high percentage of SiO_2 (55.20%) followed by Al_20_3 (25.58%) (Fig, 3). These values are a strong indication of the binding capability of the ball clay. There was the presence of other fluxing oxides such as, CaO, MgO, Na_2O and K_2O in the Numan red siltstone. The high percentage of iron oxide however, made it a dominant fluxing agent and responsible for the reddish appearance of the fired ware.

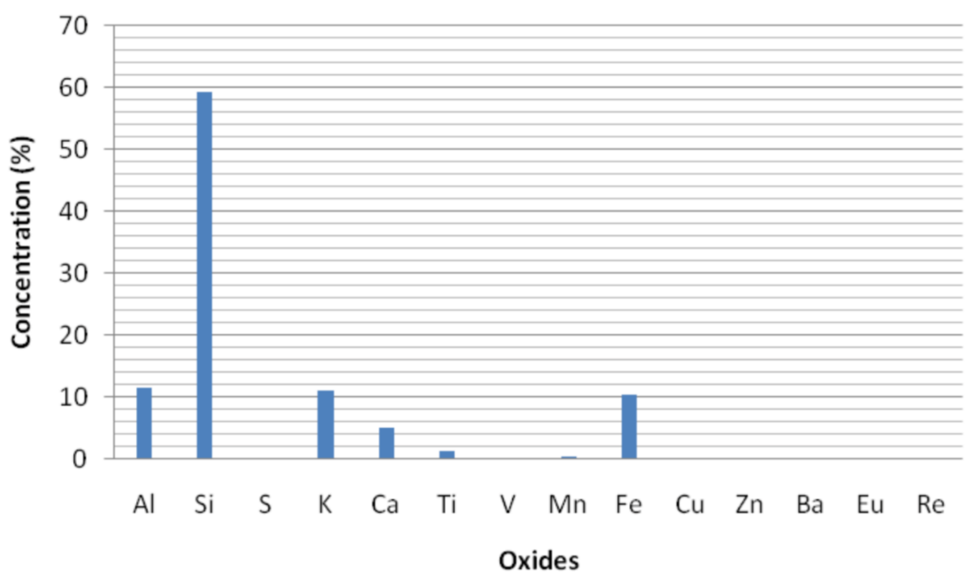

Figure 4: Chemical analysis of Sahel granite of Gudum Hausawa Bauchi

The result of the chemical analysis for Gudum Hausawa granite indicated high percentage of SiO_2 (59.10%) and Al_20_3 (11.3%) (Fig, 4). The high content of alumina is believed to be responsible for good coefficient of expansion and contraction between the body and the glaze; hence helping the glaze to fit into the body without problems. Though, high content of flux is required to meet up with the high content of silica (59.10%) for the formation of silicates in high temperature glazes, the low content of flux in the granite does not seem to have affected the firing of both body and glaze to 1200^{0}C. The ability of the body and glaze to adhere was attributed to the fact that both body and glaze were formulated from the same constituent raw materials.

Firing

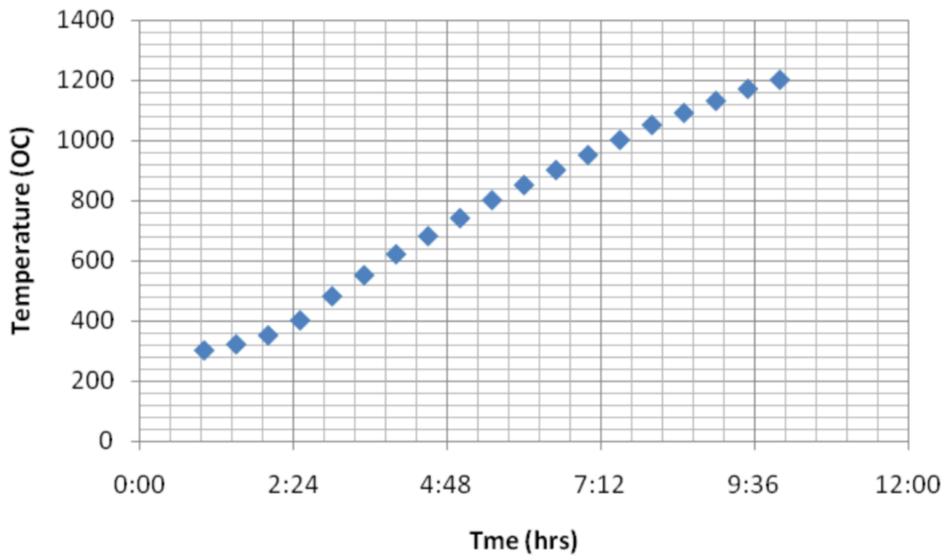

Figure 5: Firing Time and Temperature Relationship in Double Firing

In the two-stage firing, 30 litres of kerosene was used to attain bisque firing temperature of 900^{0}C in 4 hours while in the second phase of firing, 45 litres of kerosene was used to attain gloss temperature of 1200^{0}C in 6 hours. This therefore, means that, a total of 75 litres of kerosene put at the cost of N1,340 firing was expended to attain a firing temperature of 1200^{0}C in a total time of 10hrs (Fig. 4). In the single phase firing (once firing), 45 litres of kerosene was used to attain gloss temperature at 1200^{0}C in 8 hours. This clearly shows a reduction in the volume of fuel consumption from 75 to 45litrs, which translates to a saving of 30 litres of kerosene. A 2- hour savings in time of firing was also recorded with a reduction in firing time from 10 to 8 hours. Nonetheless, it suffices to state that, apart from the tiring and demanding nature of the two-stage firing, which involves loading, preheating, bisque firing, off loading, loading and glaze firing, the entire process could take up to 60 or more hours, depending on the size of the kiln. This is aside the requirement for raw materials, energy and manpower.

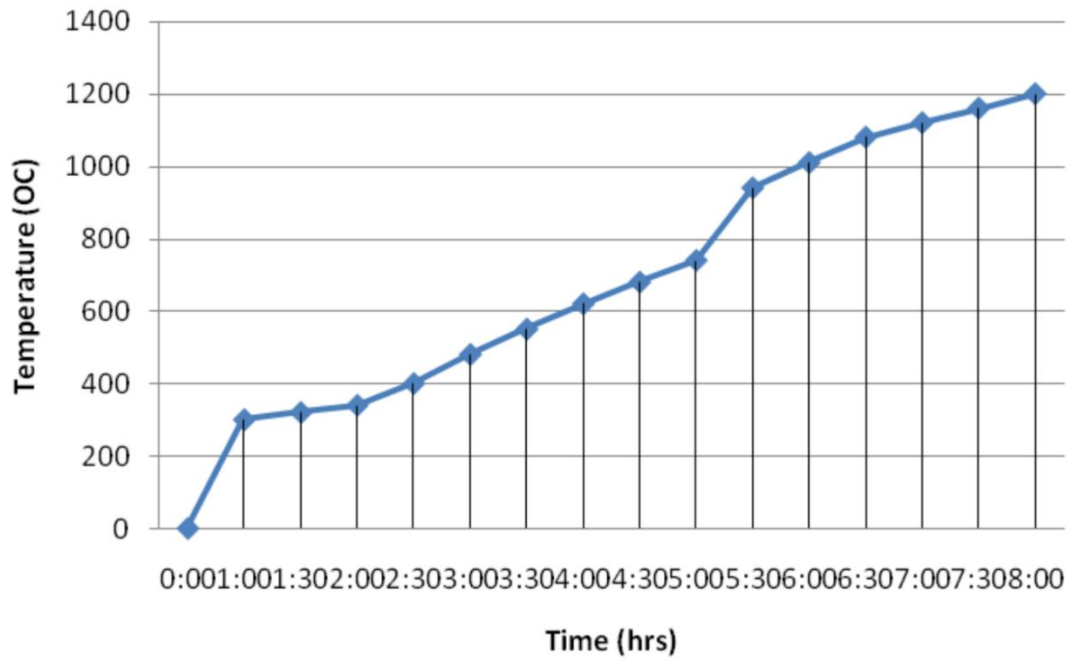

Figure 6: Firing time and temperature Relationship in Single Firing

Conclusion

The application of once firing has been shown to reduce the duration of the firing cycle and the amount of time expended in the firing process. The reductions in firing cycle and fuel usage have significant impact on reducing the emission of greenhouse gases and enhancing green credentials of ceramic firing. Similarly, the material and time spent on the 2- phase firing (Bisque and Gloss) can now be channelled into other aspects of social and economic development. In spite of the possibility of having some problems such as flaking, cracking, breaking and even explosion during the single firing when not handled carefully, the advantages seem to out-weigh the disadvantages.

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