Effect of Firing Time on Properties of Clay Cups

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Green clay tea cups were made using a manual press. The effect of firing time on compression strength, water absorption, firing shrinkage, weight loss and density of clay cups was determined. For a particular clay and manufacturing technique, the compression strength and density increased exponentially in the early stages of heating and remained almost constant thereafter. Water absorption showed a rapid fall in the initial stages and thereafter remained almost constant. The results showed that the firing temperature was the important parameter to control the properties of the clay cups.

***Keywords*:** Clay tea cup, firing time, mechanical properties

1. **Introduction**

Clay utensils were extensively used by different civilizations and have been used since ages and were found during excavations by archaeological investigators [1]. Clay tea cups have been in use in India for serving tea. Natural eco-friendly clay terracotta disposable items like cups, pots, bowls, etc. are used to serve dessert, cakes, sweets, etc. These items are used in parties, marriages, gatherings, etc. They keep the taste of food intact. They are made in custom sizes also. Their advantages include light weight, wide range of sizes in customized forms, reasonable price and degradability.

The air-dried clean clay is mixed with the correct percentage of water and wedged or kneaded thoroughly in a pug mill to obtain plasticity. At this stage, known as plastic ware, clay is soft, flexible and easy to work with. Then it is allowed to dry slightly under ambient conditions for some time until it becomes leather-hard. This makes it more stiff and capable of supporting its self-weight. It can be worked on and necessary parts can be attached. During the moulding stage, the prepared clay is shaped into a cup form (frustum of a cone). This process can be done in two ways according to the scale of the project: hand moulding (batch production) and machine moulding (mass production). The cups are first dried at room temperature for three days until they are completely dry. In this condition, all physical moisture is lost and is ready to be fired. The clay feels at room temperature and slightly dusty.

The dry cups are fired (bisque fire), either in clamps (batch production) or in ovens (mass production) up to a certain temperature. In this stage, the cups will gain hardness and strength. Therefore, it is an important stage in the production of cups. The temperature required for firing is about 900°C. If fired beyond this limit, they will become brittle and fragile. If they are fired below this limit, they will not gain all the strength and there is the possibility of absorbing moisture from the atmosphere. Therefore, the firing must be done correctly to meet the requirements of a good cup.

The properties of the clay cups depend on the mineralogical, chemical and physical characteristics of the soil used [2,3]. Compression strength and water absorption are two important properties of the clay cup that are reliable indicators to prevent cracking [4]. The mineralogical properties, the type of manufacture, the firing temperature and the mechanical properties influence the compressive strength [5,2]. Water absorption is calculated as a percentage of dry weight and is a measure of the existing void space. Characteristics of the clay, type of production and degree of wedging influence absorption. The water absorption level of the clay cup affects the loss of tea, milk, lassi, yogurt, etc. that is poured into it.

Higher firing temperatures also influence shrinkage [6]. Changing the temperature influences the quality of the clay cups. Reducing the firing temperature will reduce the manufacturing cost and increase the productivity of the cup industry [1]. The main objective of this work is to explore the influence of firing temperature on compressive strength, water absorption, weight loss, shrinkage and density of clay cups.

1. **Materials and Methods**

The soil sample was taken from a brick manufacturing unit located in Tadepalligudem, West Godavari, AP, India. The plasticity index, liquid and plastic limits were determined [7-9].

Then a predetermined amount of clay was placed in the lower die of the press (Fig. 1). A cup (Fig. 2) of lower diameter 40mm, upper diameter 50mm, height 50mm and thickness 4mm was made. Drying before firing prevents swelling or bloating of cups at higher temperatures [10]. Subsequently, the specimens were heated in a muffle furnace. All samples were marked and weighed before firing in the electric furnace.

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| a) Clay cup making press | b) Clay tea cup |

Fig. 1. Organic tea cup made of clay

The firing of the clay, known as bisque firing, eliminates all water (both physical and chemical) and carbon. The fusion of the particles begins, but the clay is still porous to allow the absorption of the glaze. It can no longer be turned off and recycled. Firing at 550°C turns the cup red due to the oxidation of the ferrous silicate. Dehydroxylation takes place at this temperature and causes the carbonaceous organic matter to burn [11]. But this firing temperature (550°C) is lower than the inversion temperature of Silica quartz, 573°C. Therefore, the minimum temperature for cup firing in the present experimental work was taken as 600°C. The firing tests were carried out at 600-900°C in increments of 100°C. The rate of the firing is very important since it imparts final properties to the cup. The faster firing produces the swelling of the clay due to the creation of an impermeable vitrified outer skin that obstructs the escape of gases such as steam and carbon dioxide from the central part. Therefore, the temperature was slowly increased to the firing temperature in each test.

Once the heating was complete, the oven was turned off and the sample was allowed to cool slowly. Immediate removal of the sample from the oven after heating produces black spots on the surface of the cup. The dimensions (lower and upper diameters and height), dry weight and dry volume of all the samples were recorded. Each experiment was repeated in three repetitions. The properties (compressive strength, water absorption, shrinkage, weight loss and density) for all samples treated at different temperatures and firing times were measured for all samples. The compression strength was found using an indirect method - impact rebound method. Water absorption is expressed as a % and is calculated as the ratio of the weight of water absorbed in cup body divided by the dry weight of the cup. The water absorption was calculated by placing the cup in a water bath for 24 hours and then measuring the amount of water absorbed by the cup.

1. **Results and Discussion**

The mineral constitution of clay soil was a mixture of illite, kaolinite, chlorite, dolomite, hematite and quartz. Some physical properties of clay to make cups are: liquid limit 39.50; plastic limit 19.27 and clay material (sand 12.8, silt 44.0, clay 43.2), 43.12% and plastic index 20.23%. The clay raw material complies with the chemical and morphological properties, and compositions necessary for the manufacture of cups [12].

Table. 1. Effect of firing time and temperature on compression strength

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| Firing Temperature (°C) | Firing Time (min) | Compressive strength (MPa) | Water Absorption (%) | Firing Shrinkage (%) | Weight loss (%) | Density (g/cm3) |
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| 600 | 30 | 6 | 14.62 | 4.8 | 4.4 | 1.64 |
| 700 | 30 | 8 | 13.08 | 5.25 | 4.6 | 1.68 |
| 800 | 30 | 12.45 | 11.5 | 6.85 | 5.4 | 1.72 |
| 900 | 30 | 14.3 | 10.88 | 7.59 | 5.8 | 1.74 |

* 1. Compression Strength

The compression strength increases remarkably with the firing temperature (Table. 1). With the increase in the firing temperature, the compression strength increases as follows: 600-700°C, 33.33%; and 600-900°C, 138.83%. The increase in strength (Fig. 2) can be attributed to an increase in vitrification in the clay. The increase in compression strength is due to the decrease in porosity and the increase in bulk density with increasing temperature [2].

* 1. Water Absorption

18% is the upper limit for the average water absorption obtained by immersion in water for 24 hours. In this study, the water absorption of all the cups (Fig. 3) made at each firing temperature met the criteria given by the Turkish Standards Institute. The low water absorption values ​​found in this work show that the manufactured clay cups were highly non-porous. It is expected that the inside of the clay cup will be sufficiently dense to prevent the entry of water.

The absorption of water decreases considerably with the increase in temperature due to the formation of an amorphous phase during high-temperature firing [13]. The presence of amorphous silica formed at high firing temperatures could be the reason for the displayed result.

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| Fig. 2. Variation of compression strength  with firing temperature | Fig. 3. Variation of water absorption with  firing temperature |

* 1. Firing Shrinkage

The firing temperature is an important parameter that influences the shrinkage. Higher shrinkage causes damage to the cups during the firing and drying stages. Shrinkage occurs in cups when chemically and physically bound water is lost. A linear relationship can be seen between the firing temperature and the shrinkage (Fig. 4).

* 1. Weight Loss

At higher firing temperature, a greater weight loss was observed in the cup, which is 15% for a standard clay tile. The loss of weight when firing above 800°C is attributed to the loss of organic matter in the clay. In addition, the weight loss of the cup depends on the inorganic components present in the clay that are burned during the firing process. The effect of the firing temperature on the weight loss of the clay cups is shown in Fig. 5.

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| Fig. 4. Variation of firing shrinkage  with firing temperature | Fig. 5. Variation of weight loss  with firing temperature |
| * 1. Density   Density of clay cup is governed by specific gravity of clay type of production, and extent of firing. Density of fired objects made of clay usually exceeds 1.6 g/cm3, averaging 2.0 g/cm3 [14]. In the present work, density was considerably increased with high firing temperatures (Fig. 6).With increase in cup density, its strength and heat conductivity increase and water absorption decreased. With higher water content in the mixture, cup exhibited a larger size, result in a lower density. The density of cups varied from 1.64 g/cm3 at 600°C to 1.74 g/cm3 at 900°C (Table. 1). This observation is related to the quantity of water absorbed at this point and the decrease in porosity. | |

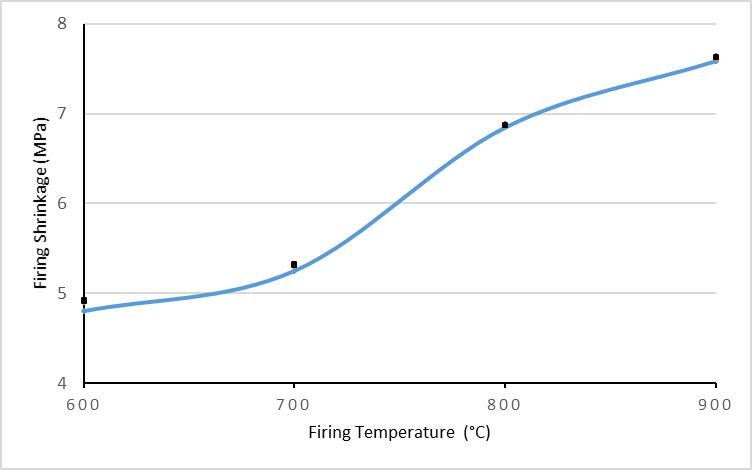
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Fig. 6. Variation of density with firing temperature

1. **Conclusion**

The strength of the cups increased and the absorption of water decreased with the firing temperature (600-900°C). The density and firing shrinkage of the cup fired at 600-900°C also increased with the increase in firing temperature. The optimal firing time essential for making long-lasting cups with specific clay should be arrived to ensure environmental safety.

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