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Thermal Behavior of Ceramic Cup Filled with Coffee

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Abstract: The goal is to predict transient thermal behavior of a ceramic cup filled of coffee. Ceramic cup with exterior temperature of 22^0 c is initially filled with coffee at high temperature of 45^{0}C. 3D numerical model has been developed to understand the thermal behavior of ceramic cup, MASS71 element will be used to take into account the thermal capacitance of the coffee. The internal thermal resistance will be neglected. SURF152 element will be used for convection between coffee and cup. Transient analysis has ran for about 10 min and plotted fluid temperature evolution with time. Further approach has been modeled to get Optimized designed.
Keywords: ceramic, fluid temperature, transient, surf 152, mass 71

I. INTRODUCTION

Ceramics are a solid non-metallic and inorganic substance, which can consist of metallic, non-metallic, or metallic atoms that are mainly kept in ionic or covalent bonds. Known for its brittle properties, the porcelain is solid, strong in pressure, and weak in shearing and stress. It also resists chemical corrosion and high temperatures. Ceramics are part of our daily life without realizing it; We are surrounded by it, from home and industrial building products, cutlery and the arts to medical devices and microchips. Traditionally, the raw materials used in ceramics were clay-like minerals, such as kaolinite. Recently, aluminum oxide, also known as alumina, has been widely adopted. Advanced ceramics contain materials such as silicon carbide and tungsten carbide, both of which are famous for their corrosion resistance, which makes them useful in crushing equipment and mining operations. Advanced ceramics can also be found in the medical, electrical and electronic industries. Since the raw materials are subject to depletion, the creation of artificial sand has been developed for use in ceramics. Artificial sand is an incomplete mud sand, mixed with bentonite or other clay-like materials to make it suitable for molding.

Research studies indicate that the first ceramic pieces appeared in Dolni Vestonice (Czech archaeological site) around 26,000 BC. Siberia followed in 12000 A.D. Jim, China in the year 11000 A. C. And Mesopotamia in 8000 A.D. And in Asia, the Middle East and Europe in the late Neolithic period between 7000 and 6000 BC [1-4]. Increasing the thermal efficiency of drying and releasing ceramic products plays an important role for industries that want to remain competitive in the market. (We, this work aims to assess the effect of the type and thickness of thermal insulation, applied to the outer side walls of a disconnected ceramic furnace, on heat transfer, temperature distribution in insulating materials, and the temperature of the maximum external surface and energy gain compared to the furnace without thermal insulation. All installations are based The proposed math to energy conservation, and mathematical measures are performed in Microsoft Excel Four types are tested here: thermal insulators: fiberglass, rockwool, calcium silicate and ceramic fibers The results indicate that the higher the thickness of the thermal insulation, the maximum external surface temperature decreases Energy gain increased compared to the furnace without thermal insulation, in addition to that the fiberglass is the insulation material, among the four types of ados analysis, which provides a greater increase in energy and a decrease in the maximum temperature of the outer surface [5]. In drying, a large amount of thermal energy is used to evaporate the water that was added to the part during the formation period and to provide the mechanical resistance necessary to reduce the possibility of failure during the cooking process. If the drying process is not done properly, it may cause material defects, lose productivity and increase energy consumption. According to the literature [6-15], the operating parameters that influence the drying process are temperature, relative humidity, air drying speed, time, shape, thickness, area / volume ratio, particle size, initial moisture content and properties. It is made of ceramic. After the drying stage, the molded part is exposed to high temperatures (ignition) to provide rigidity and mechanical resistance. (The burning of the ceramic materials in the furnaces must follow a predetermined firing curve. (The burning curve connects the temperature of the piece to the processing time, indicating the rate of heat transfer at which the piece must be heated. Or it cools and cools at the operating temperature at every moment of time. Figure 1 shows a typical release curve for ceramic products. For each material, there is a critical rate of heating and cooling so that if it is exceeded, it is certain that product quality losses occur.

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Improving the burning curve for a particular material means knowing the critical heating and cooling rates at each temperature and type of product, and it can be defined The furnace as a structure in which the materials can be heated to high temperatures. Temperatures, that is, the equipment where the drying and burning steps of the casting part are made of ceramics, many of the equipment is made of refractory materials, which is a ceramic that is able to maintain its strength Its physical integrity is at a high level H. The temperatures (above 3000 ° C) are classified into two main groups: intermittent or continuous furnace (tunnel type) Five major stress ratios are considered (13%, 17%, 32.4%, 41%, 50%) For experiment. The image is processed suck The sample is guided by "Adobe Photoshop CS2" and "Image J" is applied to estimate the average grain size. The annoying process was simulated with the finite element action code, ANSYS ver11.0. Al-Zinc / fly ash /SiC-supported compounds are manufactured by the vortex method using a casting path. The incorporation of fly ash the tensile properties, such as tensile and yield strength are improved. Reinforcement mechanisms to improve the properties of wear and corrosions are discussed [16-18].

II. INTRODUCTON TO DESIGN OF COFEE CUP

Control of heat flow and temperature are important topics in chemistry and chemical engineering. Analysed the cooling curve of hot water in an insulated cup as an example of a first-order process. Although not explicitly stated, it was assumed that the hot water in the bowl loses heat to the surroundings according to a pure conduction model. In this project, we use hypothetical models and tests to show that conduction followed by convection is the correct form of hot fluid cooling in a mug. We'll start by showing that the pure conduction model predicts that the hot water in the insulated mug will cool much faster than was found experimentally. We assume that the water temperature in the bowl is T which is attached to the outer surface of the bowl is T_{Room}, room temperature. According to the law of conduction of heat in Fourier, the rate of heat flowing from the cup is equal

$$\frac{\Delta Q}{\Delta t} = mC\frac{\Delta T}{\Delta t} = -\kappa\frac{A}{d}(T - T_{room})$$

In this equation, ΔQ is the amount of heat that flows from the cup over a short period of time, Δt. We use one minute intervals in our model. Thus =t = 1.00 min = 60.0 seconds. In equation (2), a is the surface area of the cup, d is the wall thickness and the cup cover, m is the mass of the liquid in the cup, c is the specific heat capacity of that liquid and K is the thermal conductivity of the cup material. The thermal conductivity constant contains units of the second joule -1 m -1 ° C. The use of oC is allowed in place of K because equation (2) involves temperature differences instead of absolute temperatures. T is the temperature of the liquid in the cup, and TRoom is the room temperature. Again, it should be clear that the pure driving model assumes that the outer surface of the cup is at room temperature. For simplicity, A will be assumed to be the full surface area of the cup. Most of the cup comes into contact with the liquid in the cup, and heat escapes from the cup from the air area above the liquid level as well as below the liquid level. Remember that there is a lid on the cup of the same material, so there is no cooling due to evaporation. The base is not in contact with the air, but we will assume that the heat is lost here at the same rate as through the walls and ceiling. This is definitely not the case, but the space is small, so the error is small.

III. TRANSIENT THERMAL ANALYSIS OF COFFEE CUP

This simulation project analyses the temperature distribution and heat flux of coffee mugs made of five types of ceramic materials and as two different simulation runs. A steady state heat transfer problem is simulated with convective heat transfer phenomena between coffee, coffee mug and surrounding air. The physical data of the appropriate fields have been referred from Internet and experimental data references. In this project we are chosen the low thermal conductivity ceramic materials. Surrounding temperature was maintained at 22^0C, the transient condition was adopted that initial time is 1s and end time 600 s was maintained. And convection takes place on surface of the cup was given as 25W/m²·°C as shown in Fig1.1

Table I

Properties of the ceramic materials

Material	Thermal Conductivity W/mC^0	Density (kg/cm^3)
Ceramic	1.45	2000
Ceramic-1	1.4	2100
Fly ash	0.505	1000
Siliceous sand	1.36	2500
Clay (dry)	0.15	2300

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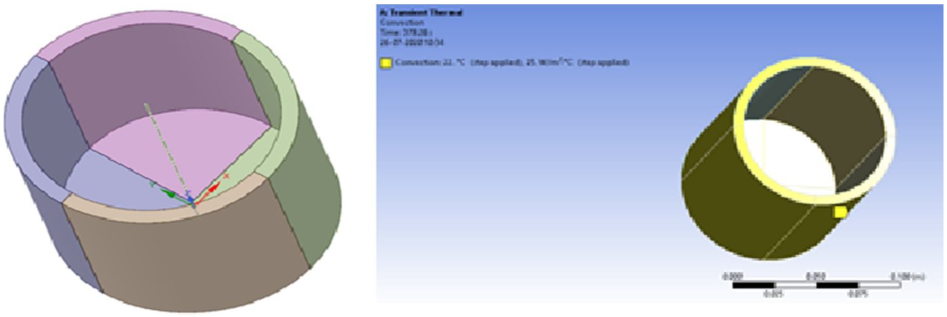

Fig 1.1 shows Geometry the boundary conditions of the mug

ANSYS Parametric Design language program was developed in this project as given in the below. Fluid is usecd as hot coffee or tea for this volume, density and specific heat of the fluid is play a important role for this surface element on the fluid creation is needed for enhancement of the temp and heat flux.

```
!   Commands inserted into this file will be executed just prior to the ANSYS SOLVE command.
!   These commands may supersede command settings set by Workbench.

!   Active UNIT system in Workbench when this object was created:  Metric (m, kg, N, s, V, A)
!   NOTE:  Any data that requires units (such as mass) is assumed to be in the consistent solver unit system.
!                See Solving Units in the help system for more information.


FINISH
/PREP7                                    !enter the model creation preprocessor

!********SURF152********
*GET,maxnode,NODE,0,NUM,MAX               !find the maximum number of nodes and put it in the parameter maxnode
N,maxnode+100,0,0,0                       !create a node with coordinates (0,0,0)which will be the SURF152 extra node
*GET,maxtype,ETYP,0,NUM,MAX               !find the maximum number pf types and put it in the parameter maxtype
ET,maxtype+1,152                          !define a SURF152 element with an element type maxtype+1
KEYOPT,maxtype+1,8,2                      !change the keyoption 8 to 2 of the SURF152 element
KEYOPT,maxtype+1,5,1                      !change the keyoption 5 to 1 of the SURF152 element
TYPE,maxtype+1                            !activate the surf152 type

CMSEL,S,Nodes_Fluid                       !select the nodes of the nameds selection Nodes_Fluid
ESURF,maxnode+100                         !generate SURF152 elements on the selected nodes and specify that xnode is the extra node
ALLSEL,ALL                                !select all the nodes and elements

ESEL,S,TYPE,,maxtype+1                    !select  the SURF152 elements
SFE,ALL,1,CONV,0,200                      !apply a convection with a film of coefficient of 200 W.m-2.K-1
ALLSEL,ALL                                !select all the nodes and elements

!********MASS71********
ET,maxtype+2,71                           !define a MASS71 element with an element type maxtype+2
KEYOPT,maxtype+2,3,1                      !change the keyoption 3 to 1 of the MASS71 element

VOLUME=6.9944e-004                        !parameter that defines the volume of the fluid
SPECIFIC_HEAT=4200                        !parameter that defines the specific heat of the fluid
DENSITY=1000                              !parameter that defines the density of the fluid
R,maxtype+2,VOLUME*SPECIFIC_HEAT*DENSITY  !defining the thermal capacitance of the fluid as a real

TYPE,maxtype+2
REAL,maxtype+2
EN,maxtype+2,maxnode+100                  !define a MASS71 element and connect it to the extra node of SURF152

FINISH
/SOLU                                     !enter the solution processor
IC,maxnode+100,TEMP,45                    !specify an initial temperature of 45 C on the extra node
```

The max temperature, heat flux, temp probe and cooling curve graphs are shown in fig 1.2 to 1.3 for the five different materials of the plane coffee cup. The results show that clay cup having good temperature distribution around the surface, after fly ash cup also gives the good temp results than other materials.

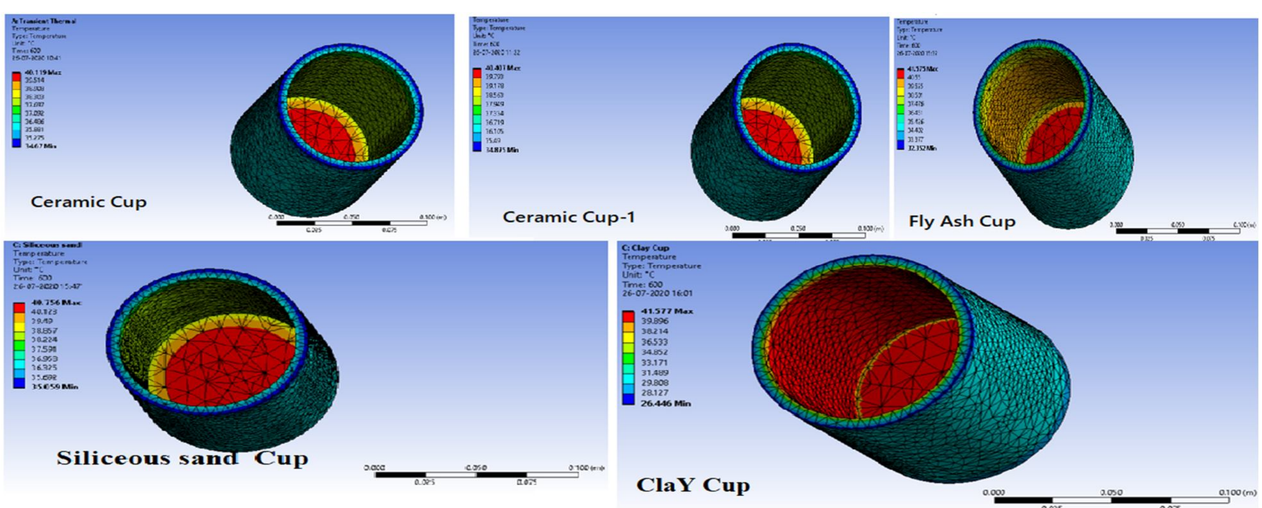

Fig 1.2 Max temp distribution of different materials of coffee Cup

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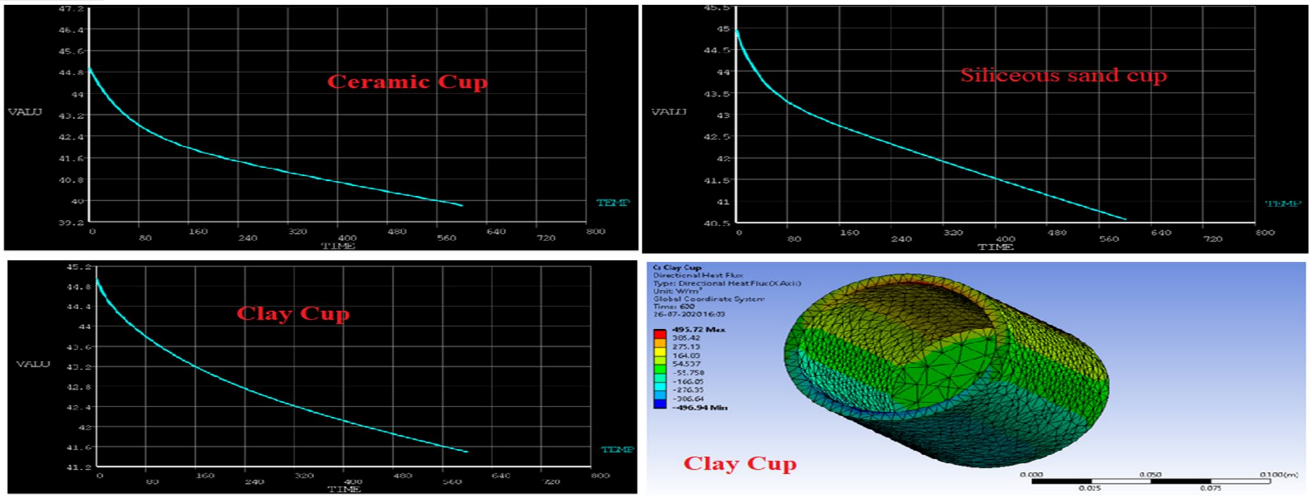


Fig 1.3 Cooling Curves of different materials of coffee Cup and max heat flux of clay coffee cup

IV. TRANSIENT THERMAL ANALYSIS ON OPTIMIZED DESIGN

This simulation project analyses the temperature distribution and heat flux of coffee mugs with handle made of five types of ceramic materials and as two different simulation runs. And also an optimized model was developed to consider the ergonomics conditions of the human usage. A steady state heat transfer problem is simulated with convective heat transfer phenomena between coffee, coffee mug and surrounding air. The physical data of the appropriate fields have been referred from Internet and experimental data references. In this project we are chosen the low thermal conductivity ceramic materials. The geometry and meshed structure of the coffee mug is directly obtained from ANSYS space claim software as shown in Fig 1.4 In the x,y, and z direction lengths are taken as 0.1,0.1 and 0.12m respectively. The picture below shows the CAD geometry used for this analysis. Total number of nodes and elements on the entire body are 14758 and 7563was mashed. Surrounding temperature was maintained at 220C and convection takes place on surface of the cup was given as 25W/m²·°C as shown. The transient condition was adopted that initial time is 1s and end time 600 s was maintained.

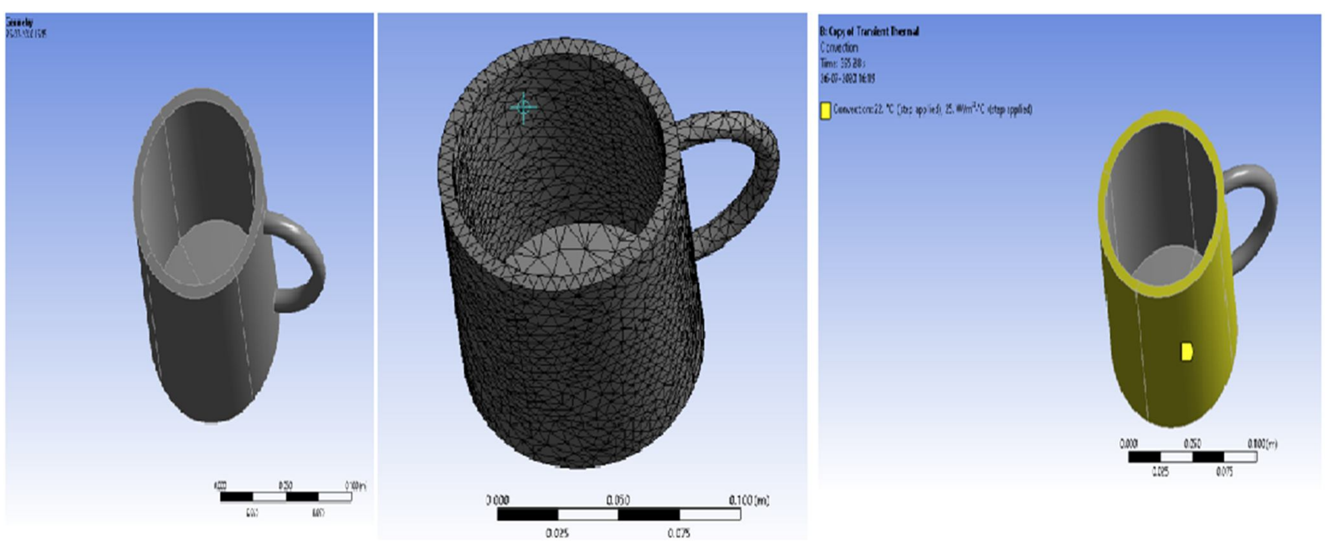


Fig 1.3 geometry and meshed structure and boundary conditions

Fig 1.4 shows the max temp, heat flux and cooling curve of the ceramic and clay materials. The clay cup gives the better temp than others and the temp on the handle is 22^0c ie room temp was given. For handling the clay cup with new design given the better results in the ergonomics point of view. The fly ash cup handling temp was 22.929 ^{0}C it was later better than clay cup in the ergonomics point of view.

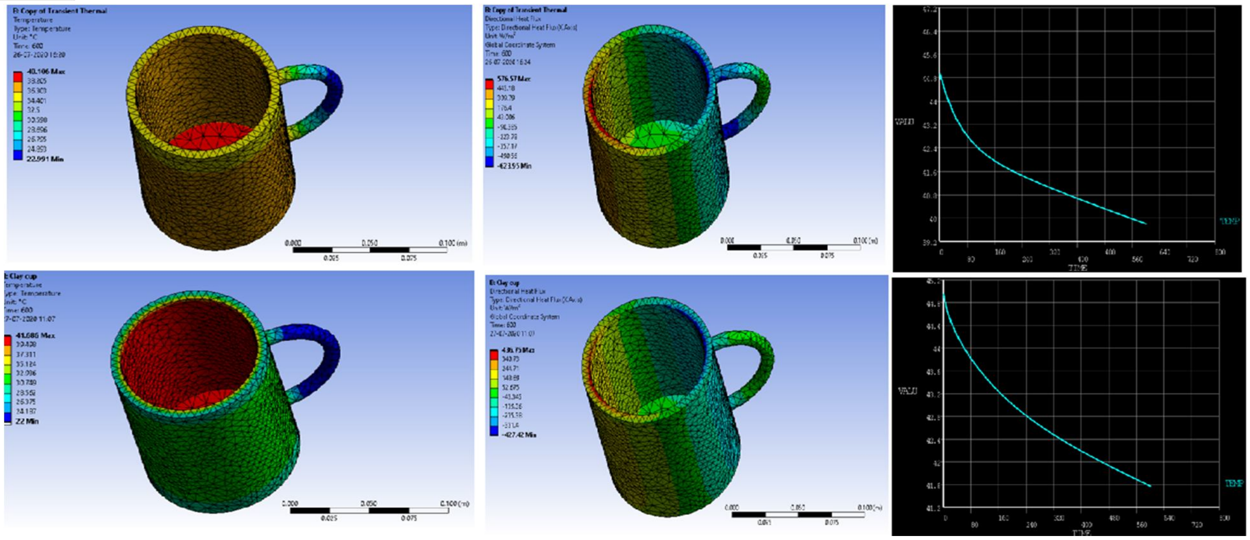


Fig 1.4 shows the max temp, heat flux and cooling curve of the ceramic and clay materials

V. RESULTS AND DISCUSSIONS

The 3D digital model of the ceramic cup at 220 ° C is designed filled with coffee at 450 ° C and the outer surface exposed to surrounding conditions and heat transfer due to heat load in a simulated transient for about 600 seconds. Case 2 was optimized with the handle, and the case of Case 1 was compared to each other. It was observed that the transient behavior of the ceramic cup after 10 minutes reached 400 ° C and 350 ° C min. From case 2, it has dropped to a minimum temperature of about 230 ° C. The evolution of fluid temperature is drawn taking into account mass 71 that provides a convenient means of modeling the effects of convection when the bulk temperature is unknown. Surf 152 provides additional flexibility in determining the temperature used to determine film coefficients based on temperature, surface temperature, fluid temperature, average temperature, and the absolute value of the differential temperature. Case-1 Plane Cup Results: Table II show the temp at the inner and outer surface of the plane cup and III show the directional heat flux of the cup with different materials. The results show that clay cup having good temperature distribution around the surface, after fly ash cup also gives the good temp results than other materials.

Table II

Thermal results of the different materials of the cup

Material	Temp(c^0) at inner surface	Temp(c^0) at outer surface
Ceramic	40.119	34.67
Ceramic-1	40.407	34.875
Fly ash	41.575	32.352
Siliceous sand	40.756	35.059
Clay	41.577	26.446

Table III

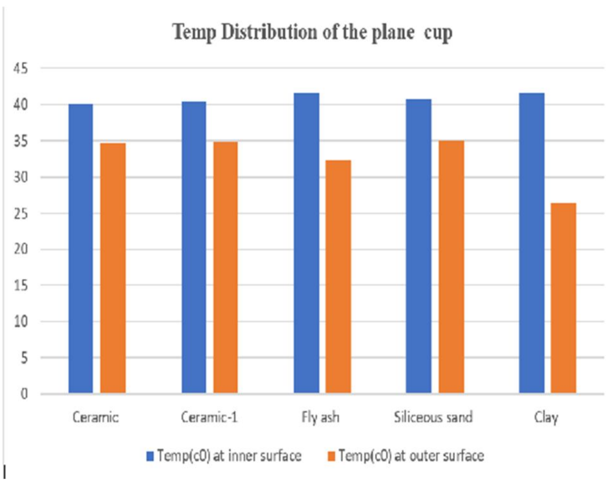
Directional Heat Flux of the different materials of the cup

Material	Directional Heat Flux(W/m^2)
Ceramic	594.6
Ceramic-1	611.82
Fly ash	647.83
Siliceous sand	633.65
Clay	495.72

Case-2 Cup with handle (optimized) Results: Table IV shows the temp at the outer surface and temp at the handle of the optimized cup of the five different materials. The optimized clay cup gives the better temp results than others and the temp on the handle is 22^0c ie room temp was given. For handling the clay cup with new design given the better results in the ergonomics point of view. The fly ash cup handling temp was 22.929 ^{0}C it was later better than clay cup in the ergonomics point of view

Table IV
The comparison of temp

Type of Material	Temp(c^0) at outer surface	Temp(c^0) at handle
Ceramic	34.67	22.991
Ceramic-1	34.875	23.96
Fly ash	32.352	22.929
Siliceous sand	35.059	23.365
Clay	26.446	22



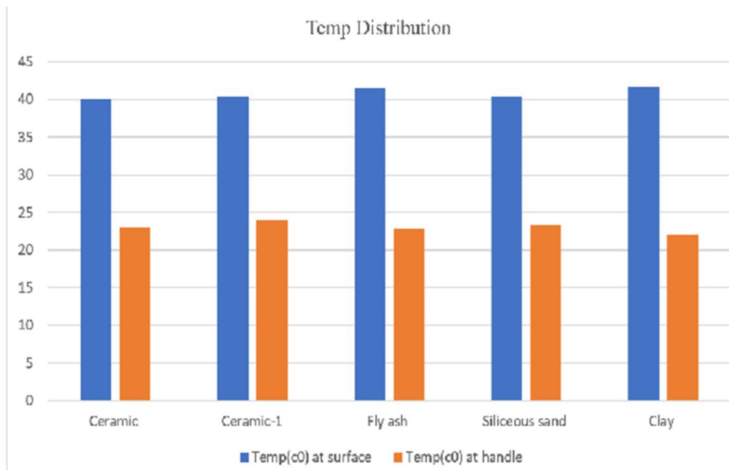


Fig 1.5 Temp at inner and outer surface of the of plane cup and temp at inner surface and at handle of the cup (new design) with different materials

Fig 1.5 the temp at the inner and outer surface of the cup with handle and show the directional heat flux of the cup with different materials. The results show that clay cup having good temperature distribution around the surface, after, fly ash cup also gives the good temp results than other materials.

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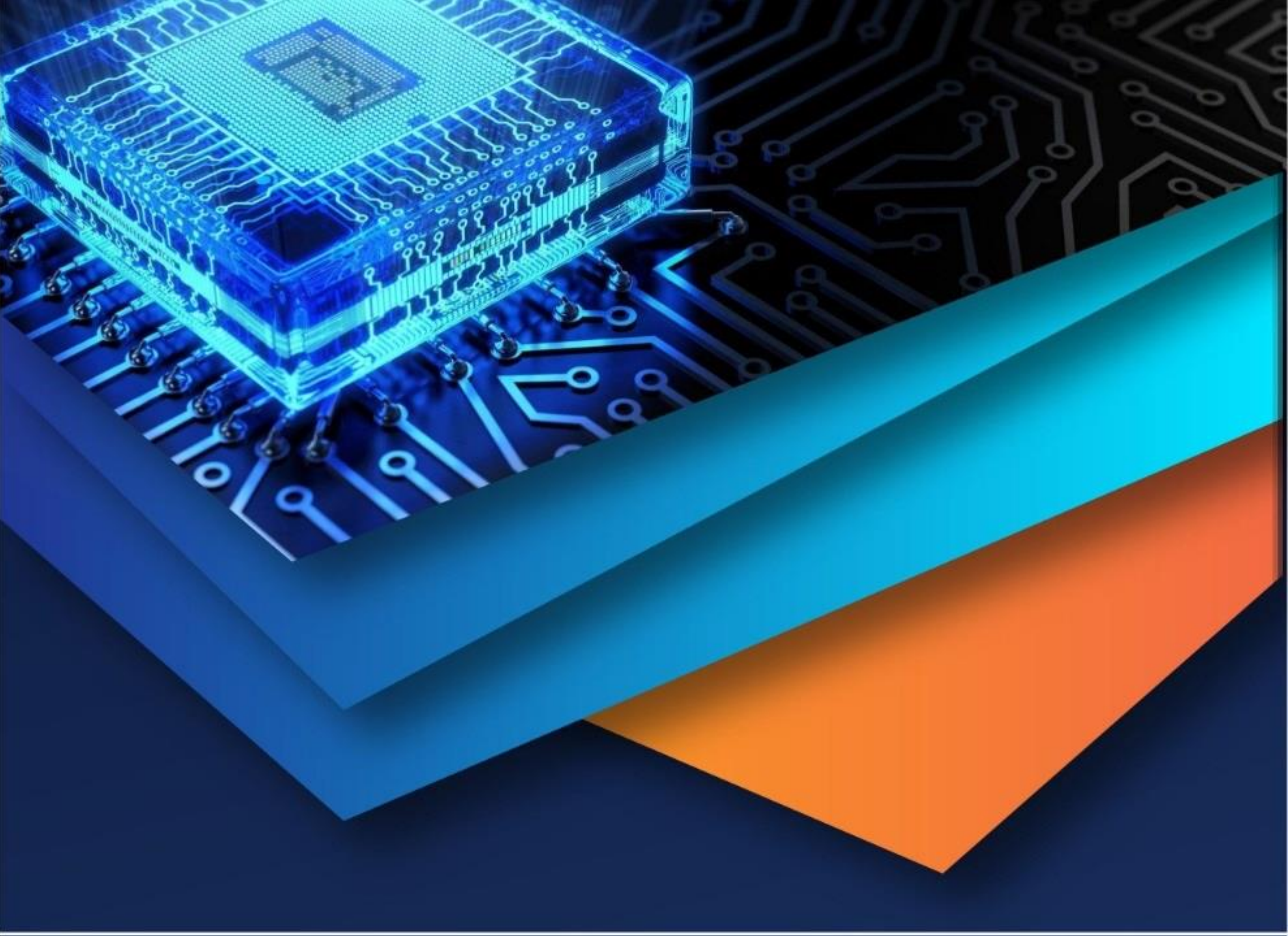

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