EXPERIMENTAL ANALYSIS OF TRANSIENT HEAT CONDUCTION FOR DIFFERENT ALLOYS AND TRANSIENT CFD APPROACH

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Abstract

Alloy is a metal made by mixing two or more metallic elements, or by mixing a metal with a nonmetal. For example, bronze is a mixture of copper and tin, and steel is a mixture of iron and carbon now days the quality of engineering designs are increasing sophisticatedly in every field. To satisfy these demands more efficient and responsive metals or alloys in terms of structural, thermal and electrical properties ect., has to be invented. In this paper, mainly focused on rate of heat gain capacity and heat dissipation capacity among copper metal and Al+Pb, Zn+Sn+Sb, Cd+Pb alloys. These copper metal and alloys are casted as cylindrical bars (Dia. 40 mm and Length 40 mm) for experimental analysis. Initially these bars are heated in hot castor oil reservoir for 120s duration. Temperature of each bar is recorded for each 10s interval. Then metal bars are cooled in atmospheric air for 120s duration. As mentioned above temperature of each bar recorded for each 10s interval. Transient CFD analysis of copper bar is carried out for 120s duration to validate experimental analysis by comparing copper bar experimental results.To this point, it is considered that conductive heat transfer problems in which the temperatures are independent of time. In many applications, however, the temperatures are varying with time, and require the understanding of the complete time history of the temperature variation.

Keywords: **Copper, CFD analysis, independent of time, metals or alloys, cylindrical bars, heat dissipation.**

I INTRODUCTION

An alloy is a mixture of metals or a mixture of a metal and another element. Alloys are defined by a metallic bonding character An alloy may be a solid solution of metal elements (a single phase) or a mixture of metallic phases (two or more solutions). Inter metallic compounds are alloys with a defined stoichiometry and crystal structure. Zintl phases are also sometimes considered alloys depending on bond types (see also: Van Arkel-Ketelaar triangle for information on classifying bonding in binary compounds).

Alloys are used in a wide variety of applications. In some cases, a combination of metals may reduce the overall cost of the material while preserving important properties. In other cases, the combination of metals imparts synergistic properties to the constituent metal elements such as corrosion resistance or mechanical strength. Examples of alloys are steel, solder, brass, pewter, duralumin, bron ze and amalgams.

The alloy constituents are usually measured by mass. Alloys are usually classified as substitutional or interstitial alloys, depending on the atomic arrangement that forms the alloy. They can be further classified as homogeneous (consisting of a single phase), or heterogeneous (consisting of two or more phases) or intermetallic.

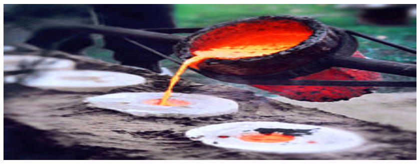


Fig: 1 Liquid Bronze, Being Poured Into Molds During Casting.

An alloy is a mixture of chemical elements, which forms an impure substance (admixture) that retains the characteristics of a metal. An alloy is distinct from an impure metal in that, with an alloy, the added elements are well controlled to produce desirable properties, while impure metals such as wrought iron, are less controlled, but are often considered useful. Alloys are made by mixing two or more elements, at least one of which is a metal. This is usually called the primary metal or the base metal, and the name of this metal may also be the name of the alloy. The other constituents may or may not be metals but, when mixed with the molten base, they will be soluble and dissolve into the mixture.

The mechanical properties of alloys will often be quite different from those of its individual constituents. A metal that is normally very soft (malleable), such as aluminum, can be altered by alloying it with another soft metal, such as copper. Although both metals are very soft and ductile, the resulting aluminum alloy will have much greater strength. Adding a small amount of non-metallic carbon to iron trades its great ductility for the greater strength of an alloy called steel. Due to its very-high strength, but still substantial toughness, and its ability to be greatly altered by heat treatment, steel is one of the most useful and common alloys in modern use. By adding chromium to steel, its resistance to corrosion can be enhanced, creating stainless steel, while adding silicon will alter its electrical characteristics, producing silicon steel.

Although the elements of an alloy usually must be soluble in the liquid state, they may not always be soluble in the solid state. If the metals remain soluble when solid, the alloy forms a solid solution, becoming a homogeneous structure consisting of identical crystals, called a phase. If as the mixture cools the constituents become insoluble, they may separate to form two or more different types of crystals, creating a heterogeneous microstructure of different phases, some with more of one constituent than the other phase has. However, in other alloys, the insoluble elements may not separate until after crystallization occurs. These alloys are called inter metallic alloys because, if cooled very quickly, they first crystallize as a homogeneous phase, but they are supersaturated and unstable with the secondary constituents. As time passes, the atoms of these supersaturated alloys separate from the crystal lattice, becoming more stable, and form inter metallic (within the crystal lattice) phases that serve to reinforce the crystals internally.

Some alloys, such as electrum which is an alloy consisting of silver and gold, occur naturally. Meteorites are sometimes made of naturally occurring alloys of iron and nickel, but are not native to the Earth. One of the first alloys made by humans was bronze, which is a mixture of the metals tin and copper. Bronze was an extremely useful alloy to the ancients, because it is much stronger and harder than either of its components. Heat transfer heterogeneity is related to the local velocity and turbulence intensity, which influences the heat transfer coefficients in food processing (Verboven et al., 1997; Verboven et al., 2006). The measurement of local heat transfer coefficients for a complex geometry is difficult, and values associated with the different geometric shapes, surfaces and package space arrays have not been determined. For the freezing of foodstuffs in boxes, buckets and drums, the literature values show that the surface heat transfer coefficients vary when the measurements are made in different locations in the stacking. Thus, the values of the coefficients are different between the layers of product in the stack; therefore, studies that ignore these variations should be used only with due care (Mannaperuma et al., 1994a, 1994b; Verboven et al., 2006; Kondjoyan, 2006). Proper methods of cooling may ensure the temperature uniformity of products stacked in a cold store and improve the heat transfer efficiency between the products and air, improve the cooling performance of cold stores, number of studies modeling the airflow pattern and temperature distribution have demonstrated the effectiveness of various methods (Nahor et al., 2005; and Goswami, 2007; Konishi et al., 2009).) Developed a transient three dimensional computational fluid dynamics model to investigate the cooling performance of a partially loaded cold store in the cooling process.

II CASTING

Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Metalworking, casting means a process, in which liquid metal is poured into a mold that contains a hollow cavity of the desired shape, and then allowed to cool and solidify. The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process. Casting is most often used for making complex shapes that would be difficult or uneconomical to make by other methods.

Fig: 2. Liquid metal pouring

III HEAT TRANSFER ANALYSIS

Heat transfer in engineering consists of the transfer of enthalpy because of a temperature difference. Enthalpy is the name for heat energy, to distinguish it from other sorts, such as kinetic energy, pressure energy, useful work. There has to be a temperature difference, or no heat transfer occurs.

The temperature difference is called the driving force. Other things being equal, a greater temperature difference will give a greater rate of heat transfer.

IV TEMPERATURE

Temperature is an intensive property: that is it does not depend on the amount of substance. Thus one kilogram of copper at 80 °C and 12 kg of copper at 80 °C both have the same temperature. Note that unless we are dealing with radiated heat, it is not normally necessary to ange these values to the Absolute Temperature scale. The Celsius temperature is simply defined as the number of kelvin above 273.15 K. If we wish to calculate heat transfer from these blocks of copper to water at 20 °C, it is quite adequate to say the temperature difference is 80 °C - 20 °C = 60 K. We get the same answer with more effort by saying it is 353 – 293 = 60 K. (As I am working to the nearest degree, I have omitted the 0.15 K). Temperatures may be given on the Absolute or Celsius temperature scales, but temperature differences should be given in kelvin.Temperature is also defined as the degree of hotness. It plays important role in the subject of thermodynamics and heat transfer (i.e.in Thermal energy).

V ENTHALPY

Enthalpy is a measure of the total energy stored in a thermodynamic system. It includes the internal energy, which is a function of temperature, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure.

VI HEAT TRANSFER MECHANISMS

There are three modes of Heat Transfer: Conduction, Convection, and Radiation. Conduction is concerned with the transfer of thermal energy through a material without bulk motion of the material. This phenomenon is fundamentally a diffusion process that occurs at the microscopic level. Convection is concerned with the transfer of thermal energy in a moving fluid (liquid or gas). Convection is characterized by two physical principles, conduction (diffusion) and bulk fluid motion (advection).

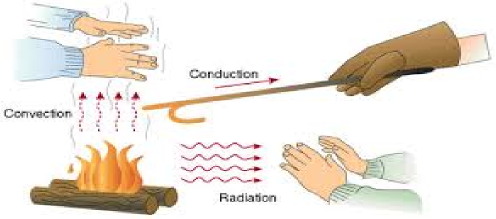


Fig: 3. Heat Transfer Mechanisms

VII STEADY-STATE CONDUCTION

Steady state conduction is the form of conduction that happens when the temperature difference(s) driving the conduction are constant, so that (after an equilibration time), the spatial distribution of temperatures (temperature field) in the conducting object does not change any further. Thus, all partial derivatives of temperature with respect to space may either be zero or have nonzero values, but all derivatives of temperature at any point with respect to time are uniformly zero. In steady state conduction, the amount of heat entering any region of an object is equal to amount of heat coming out (if this were not so, the temperature would be rising or falling, as thermal energy was tapped or trapped in a region).

For example, a bar may be cold at one end and hot at the other, but after a state of steady state conduction is reached, the spatial gradient of temperatures along the bar does not change any further, as time proceeds. Instead, the temperature at any given section of the rod remains constant, and this temperature varies linearly in space, along the direction of heat transfer.

In steady state conduction, all the laws of direct current electrical conduction can be applied to "heat currents". In such cases, it is possible to take "thermal resistances" as the analog to electrical resistances. In such cases, temperature plays the role of voltage, and heat transferred per unit time (heat power) is the analog of electric current. Steady state systems can be modelled by networks of such thermal resistances in series and in parallel, in exact analogy to electrical networks of resistors. See purely resistive thermal circuits for an example of such a network.

VIII TRANSIENT CONDUCTION

In general, during any period in which temperatures change in time at any place within an object, the mode of thermal energy flow is termed transient conduction. Another term is "non steady-state" conduction, referring to time-dependence of temperature fields in an object. Non-steady-state situations appear after an imposed change in temperature at a boundary of an object. They may also occur with temperature changes inside an object, as a result of a new source or sink of heat suddenly introduced within an object, causing temperatures near the source or sink to change in time.

When a new perturbation of temperature of this type happens, temperatures within the system change in time toward a new equilibrium with the new conditions, provided that these do not change. After equilibrium, heat flow into the system once again equals the heat flow out, and temperatures at each point inside the system no longer change. Once this happens, transient conduction is ended, although steady-state conduction may continue if heat flow continues.

Fig: 4. Experimental Setup

New external conditions also cause this process: for example the copper bar in the example steady-state conduction experiences transient conduction as soon as one end is subjected to a different temperature from the other. Over time, the fields of temperatures inside the bar reach a new steady-state, in which a constant temperature gradient along the bar is finally set up, and this gradient then stays constant in space. Typically, such a new steady state gradient is approached exponentially with time after a new temperature-or-heat source or sinks, has been introduced. When a "transient conduction" phase is over, heat flow may still continue at high power, so long as temperatures do not change.

The analysis of non steady-state conduction systems is more complex than that of steady-state systems. If the conducting body has a simple shape, then exact analytical mathematical expressions and solutions may be possible (see heat equation for the analytical approach).However, most often, because of complicated shapes with varying thermal conductivities within the shape (i.e., most complex objects, mechanisms or machines in engineering) often the application of approximate theories is required, and/or numerical analysis by computer. One popular graphical method involves the use of Heisler Charts.

Occasionally, transient conduction problems may be considerably simplified if regions of the object being heated or cooled can be identified, for which thermal conductivity is very much greater than that for heat paths leading into the region. This is due to their far higher conductance. During transient conduction, therefore, the temperature across their conductive regions changes uniformly in space, and as a simple exponential in time.

IX COMPUTATIONAL FLUID DYNAMICS ANALYSIS

CFD stands for “computational fluid dynamics”. CFD was started in the early 1960’s but came into prominence in 1980. The first major industries using CFD were stared in 1990’s. CFD is predicting what will happen, quantitatively, when fluid flow, often with the complications of

Simultaneous flow of heat,

Mass transfer (e.g. perspiration, dissolution),

Phase change (e.g. melting, freezing, boiling),

Chemical reaction (e.g. combustion, rusting),

It is concerned with obtaining numerical solution to fluid flow problems. The basic difference between CFD and other conventional methods is that in CFD computers are used for calculation part. The advent of high-speed and large-memory computers has enabled CFD to obtain solution to many flow problems including those that are compressible and incompressible, laminar or turbulent, chemically reacting or non-reacting.

CFD is the art of replacing the differential equation governing the fluid flow, with a set of algebraic equations (the process is called discretization), which in turn can be solved with the aid of a digital computer to get an approximate solution.

GOVERNING EQUATION SOLVED IN CFD

Navier stoke's equation

$\rho[u\ ((\partial v)/\partial x)+v\ (\ \partial v/(\partial y)]= -(\partial p/(\partial x))+\ u\ (Uxx+Uyy))$

………………… Navier Stokes in X direction

$\rho[u\ ((\partial v)/\partial x)+v\ (\ \partial v/(\partial y)]= -(\partial p/(\partial x))+\ u\ (Vxx+Vyy))$

………………… Navier Stokes in Y direction

Continuity equation

$((\partial u)/\partial x)+(\partial v/(\partial y)= 0)$

Momentum equation

$U\ ((\partial T)/\partial x)+V(\partial T/(\partial y)]= (k/(\rho Cp))+ [Txx+Tyy])$

X PROCEDURE FOLLOWED IN CFD

Solving a particular problem generally involves first discretizing the physical domain that the flow occurs in, such as the interior of turbine engine or the radiator system of a car. This discretization is straight forward for very simple geometries such as rectangles or circles, but is a difficult problem in CAD for more complicated objects. Currently automatic "mesh generators" are simply not adequate, requiring extensive investment of time on the part of the scientist or engineer. This leads to problems in human-computer interfaces (HCI) and CASE tools, as well as fundamental problems in graph theory since the resulting discretization gives a mesh.

On the discretized mesh the Navier-Stokes equations take the form of a large system of nonlinear equations; going from the continuum to the discrete set of equations in a problem that combines both physical and numerical analysis; for example, it is important to maintain conservation of mass in the discrete equations. At each node in the mesh, between 3 and 20 variables are associated: the pressure, the three velocity components, density, temperature, ect.

XI OBJECTIVES OF CFD

To describe the basic features of computer-based numerical methods for predicting fluid flows, heat and mass transfer, which falls under the collective name of computational fluid Dynamics (CFD) .To, use the methods to perform computer simulations of a range of thrmo-fluids problems as an aid to understanding. To experience of the use of CFD codes as design tools.

XII LIMITATIONS OF CFD

CFD-based predictions are never 100% reliable, because:

The input data may involve too much guess work or imprecision. The scientific knowledge base may be inadequate.

XIII CFD ANALYSIS PROCEDURE

Transient CFD analysis is carried out for a Copper cylindrical cross section bar (Dia. 40 mm) and length (40 mm) for following 2 cases.

1. For investigating temperature gain in copper bar due to heat transfer from castor oil to copper bar, when copper bar dipped into hot castor oil.
2. Also for investigating temperature loss in copper bar due to heat transfer from copper bar to atmospheric air, when copper bar is placed in atmospheric air (wind speed 1.5 m/s provided by small electric fan).

These transient CFD analysis results are matched with experimental results which are conducted for 130 seconds duration. After comparing results we find good correlation between experimental and CFD analysis results.

XIV DISPLAY GEOMETRY

•Press 'Display' – set 'Edge Type' to 'Feature', press 'Display' and then 'Close'

•Adjust the view if you like

Drag left-mouse-button Rotates

Drag middle-mouse-button Zooms (to zoom in, drag down and right)(to zoom out, drag up and left)

Click middle-mouse-button centre origin on click

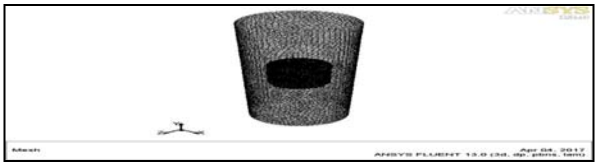


Fig: 5.Oil Reservoir with Copper Bar Mesh

XV ACTIVATE MODELS

Expand the Models branch in the Tree and Double-click (or click and press 'Edit...') the following models:– Viscous model: 'k-epsilon (2-eqn)'

Turbulence modeling is a complex area. The choice of model depends on the application. Here, the Standard k-epsilon model is used. Enhanced wall treatment is selected from near wall treatment options for adding thermal effects due to viscous heating. Keep remaining all values as their defaults.

Table-I Material Properties

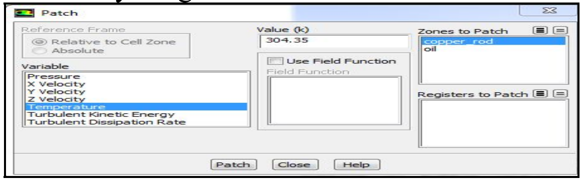
Sl No	Property	Copper	Air	Castor oil
1	Density (kg/m^3)	8978	1.225	956.1
2	Specific heat (J/kg-K)	381	1006.43	1800
3	Thermal Conductivity (W/m-K)	386	0.0242	0.18
4	Viscosity (kg/m-s)	-	1.7894e-05	

XVI. BOUNDARY CONDITIONS

For copper bar heating case, we have to assign initial temperatures of oil (364.15 K) and copper bar (304.35 K) as shown in below

For copper bar cooling case, In 'Boundary Conditions', select the zone called 'air inlet' then 'Edit'. Set the following under the Momentum tab.

– Velocity Magnitude 1.5 m/s.



Value (k): 304.35

Variable:
- Pressure
- X Velocity
- Y Velocity
- Z Velocity
- Temperature
- Turbulent Kinetic Energy
- Turbulent Dissipation Rate

Zones to Patch:
- copper_rod
- oil

Fig: 6 Assigning Initial Temperature For Fe Models

In 'Boundary Conditions', select the zone called 'air outlet' then 'Edit'. Set the following under the pressure outlet.– Gauge pressure (pascal) 0 Pa

XVII COPPER BAR HEATING TRANSIENT ANALYSIS RESULT CONTOURS

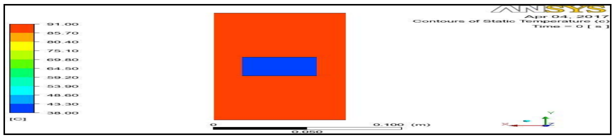


Fig:7. Temperature Distribution (Initial Temperatures)

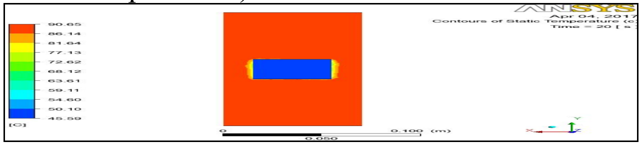


Fig: 8.Temperature Distribution (At 20 Seconds)

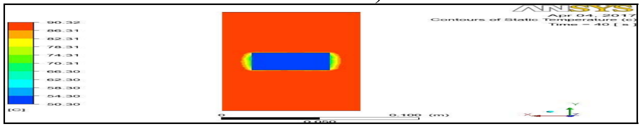


Fig: 9. Temperature Distribution (At 40 Seconds)

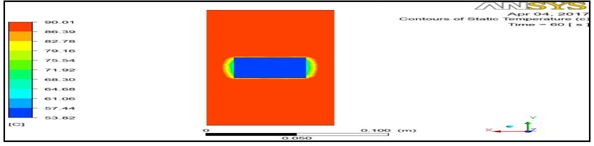


Fig: 10. Temperature Distribution (At 60 Seconds)

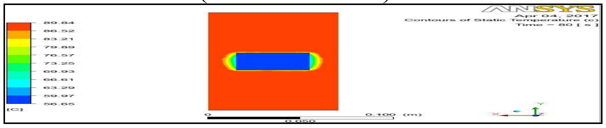


Fig: 11. Temperature Distribution (At 80 Seconds)

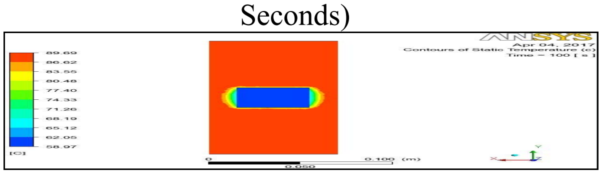


Fig: 12. Temperature Distribution (At 100 Seconds)

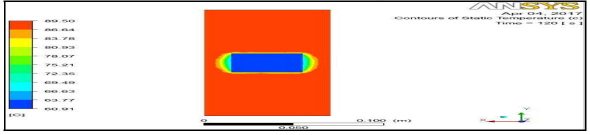
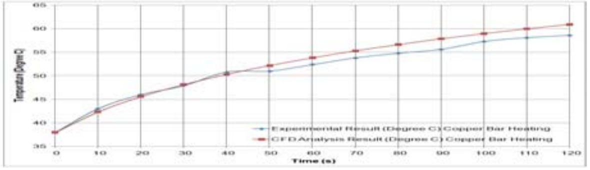


Fig: 13. Temperature Distribution (At 120 Seconds)



Graph 1. Experimental and CFD Results Comparison (Copper Bar Heating)

COPPER BAR COOLING TRANSIENT ANALYSIS RESULT CONTOURS

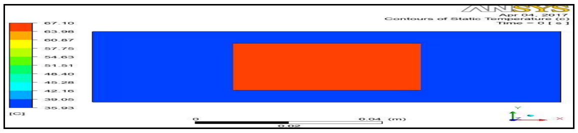


Fig: 14. Temperature Distribution (Initial Temperatures)

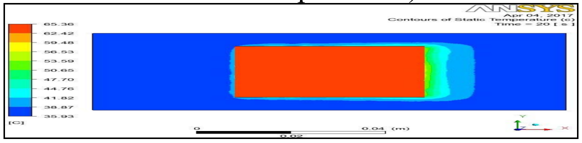


Fig: 15. Temperature Distribution (At 20 Seconds)

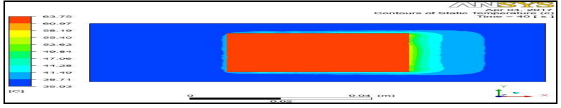


Fig: 16. Temperature Distribution (At 40 Seconds)

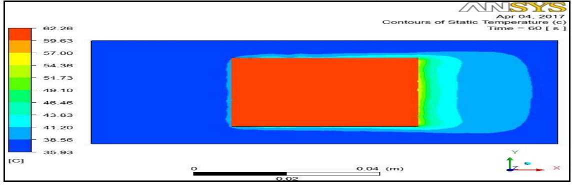


Fig: 17. Temperature Distribution (At 60 Seconds)

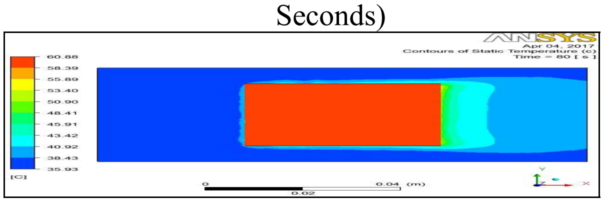


Fig: 18.Temperature Distribution (At 80 Seconds)

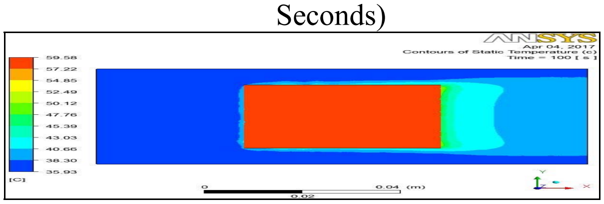


Fig: 19. Temperature Distribution (At 100 Seconds)

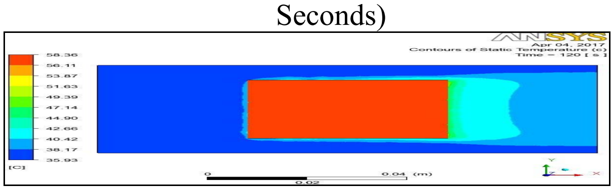
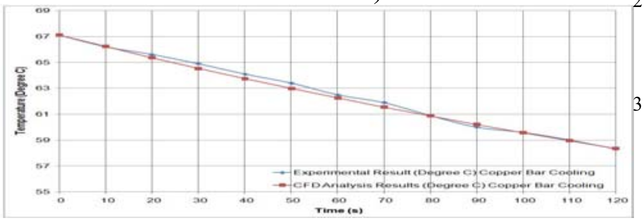


Fig: 20. Temperature Distribution (At 120 Seconds)



Graph: 2 Experimental and CFD Results Comparison (Copper Bar Cooling)

Table 2: Comparison of experimental and CFD results

S.No	HEATING (Degree C)		Time (s)	COOLING (Degree C)	
	Experimental Result	CFD Result		Experimental Result	CFD Result
1	38	38	0	67.1	67.1
2	43	42.35	10	66.2	66.22
3	46	45.59	20	65.6	65.36
4	47.9	48.14	30	64.9	64.53
5	50.8	50.29	40	64.1	63.74
6	51	52.16	50	63.4	62.98
7	52.4	53.82	60	62.5	62.25
8	53.8	55.3	70	61.9	61.55
9	54.8	56.64	80	60.9	60.87
10	55.6	57.86	90	60	60.21
11	57.3	58.97	100	59.6	59.57
12	58.1	59.98	110	59	58.95
13	58.6	60.9	120	58.3	58.34

XVIII CONCLUSION

In this paper, mainly focused on rate of heat gain capacity and heat dissipation capacity among copper metal and Al+Pb, Zn+Sn+Sb, Cd+Pb and Al+Mg+P alloys. Transient CFD analysis of copper bar is carried out for 120s duration to validate experimental analysis by comparing copper bar experimental results. CFD results are slightly deviating with experimental results along temperature increment; it can be avoided by considering transport properties of fluids (considering temperature dependent fluid properties). Both experimental and transient CFD analysis results have got excellent correlation. Time v/s Temperature plots of both heating and cooling cases are generated for all alloys. By comparing these results with copper it can find that alloys have highest heat gain capacity and heat dissipation capacity.

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