THERMAL BEHAVIOUR OF HOLLOW CASTINGS CAST IN CO2-SAND MOULDS BY USING FINITE ELEMENT METHOD TECHNIQUE

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Abstract

Prediction of solidification time is one of the very important parameters used for assessing the properties of the material. Knowledge of solidification behavior of hollow cylindrical castings and the thermal behaviour of associated moulds and cores would be of immense value to a foundrymen in the production of sound castings. In the present study, experimental investigation is carried out to measure the solidification time in a cylindrical hallow casting cast in CO2-Sand moulds and the same has been compared with the Analysis made through finite element method Technique. Finite Element Analysis was carried out by using ANSYS FEM Package. Standard physical properties were taken from ASTM metal handbook. Latent heat evolution was incorporated by enthalpy method. The solidification problem for hollow cylindrical casting was assumed to be a 2-Dimensional transient Heat Conduction flow. Convective Heat losses were considered. Aluminum-4.5% copper alloy has been used. The results shows that the solidification time obtained by experimental study compares well with the one predicted by the analysis made with the help of FEM technique.

Key words: Hollow cylinder, Solidification, Material properties, Interface temperature, FEM Analysis

NOMENCLATURE

G = Euler's constant

E = Bessel's functions

K = Thermal conductivity of the metal, $\frac{W}{(m-K)}$

ρ = Density of the metal, $\frac{Kg}{m^3}$

C = Specific heat of the metal, $\frac{J}{(Kg-K)}$

L = Latent heat of the metal, $\frac{J}{Kg}$

U_m = Solidification temperature, ^0C

U_0 = Ambient temperature, ^0C

U_p = Pouring temperature, ^0C

U_1 = Specific heat of the sand (mould and core), $\frac{J}{(Kg-K)}$

ρ_1 = Density of the sand, $\frac{Kg}{m^3}$

α_1 = Mean thermal diffusivity of the sand, $\frac{cm^2}{\sec}$

ω_1 = Mean heat diffusivity of sand, $\frac{cm^2}{\sec}$

U_1 = Temperature in the mould, ^0C

K_1 = Thermal conductivity of sand, $\frac{W}{(m-K)}$

I. INTRODUCTION

Knowledge of solidification behavior of hollow cylindrical castings and the thermal behaviour of associated moulds and cores would be of immense value to a foundrymen in the production of sound castings. From the review of literature on previous work, it appears that very few analytical and experimental investigations have been carried out on this important problem. Hence in the present investigation, analysis is made with the help of ANSYS FEM package to determine the solidification behavior of hollow cylindrical castings cast in sand moulds and evaluate the thermal behavior of moulds and cores associated with the castings based on standard physical properties of the material as well as energy balance considerations. The usefulness of these analysis in practical situations has been verified by conducting experimental work in respect of Al-4.5% Cu castings cast in Sodium Silicate bonded Silica sand (CO2 –Sand) moulds.

An attempt is made to provide quantitative information on the thermal aspects of hollow castings of cylindrical configuration of solidifying in sand moulds through FEM techniques. FEM approach is well suited, in obtaining the information of solidification and its subsequent application to practical problems. A transient heat conduction problem with moving boundary as resulting from these situations has been recognized as amongst the most complex of the heat transfer problem. It is desirable to have the solution in a simple form in order to enable the application of the solution to practical problems would present difficulties in the absence of reliable thermal data in respect of both metal & mould materials. Further analysis of the solidification behavior of hollow castings is made with the help of ANSYS FEM package by using standard physical and chemical properties of the material with the help of the above analysis, solidification behavior of hollow castings, thermal analysis of casting and mould were carried out.

Although Heat transfer has been modeled, in the present study only heat conduction is considered for clarity. The representation of latent heat effects is an important feature in the modeling of solidification problems. The tracking of the phase change boundary is an important numerical problem, which is resolved in our work by use of the Enthalpy method, which incorporates latent heat in a smooth manner. A numerical analysis is carried out to find the solidification pattern under known conditions of superheat, casting geometry, and mould initial conditions. The results of numerical analysis helps in the determination of certain vital factors Such as time taken for solidification, migration rate of solid-liquid interface, cooling rate etc. These parameters can be used for prediction of Micro and Macro structures, which can further be used in determination of Mechanical properties of cast component (1,2). Simulation techniques were discussed (5) for Heat transfer modeling of Solidification problems. Although the solidification process is now well established for linear solutions involving multidimensional geometries and time dependent boundary conditions, the complexities of problems involving strongly temperature dependent thermo-physical properties have not yet been fully analyzed. Furthermore, the representation the moving boundary and the liberated latent heat, which is so characteristic of phase-change problems, can be a complicated matter. When the phase change takes place over a wide range of temperatures, the computational problems with the representation of latent heat effects are easily overcome. However, a zero width phase change interval is more difficult to deal with computationally (3,6-13).

The Solidification of alloys in metallic moulds is controlled to a significant extent by the interfacial heat-transfer characteristics. The surface irregularities of the solidifying skin results in irregular contacts between the die wall and the skin. Campbell (4) has reviewed the current limitations and future potentials of solidification modeling. Ohanka (14) has reviewed the applications of solidifications modeling to materials development. Kai-Kwong (15) has studied the effect of mould-metal interfacial heat transfer on solidification patterns for Aluminum castings with three different chills. He had clearly demonstrated the change in freezing times with the variation of interface heat transfer. He has also shown the effect of large interfacial gap that formed in dry sand moulds. Many others (16-20) have investigated various aspects of heat transfer at the mould metal interface.

II. EXPERIMENTATION

The details of the experimental study are given below:

A. Mould used

CO2-Sand moulds were used in the present work. Na2SiO3 (4%) was mixed with silica sand and used for making moulds. Moulds were hardened using CO2 gas.

Alloy Used: Al - 4.5%Cu. (Commercial)

The details of the chemical composition of the alloy are:

% COMPOSITION										
Si	Fe	Cu	Mn	Mg	Zn	Ni	Pb	Sn	Ti	Al
0.343	0.602	4.36	0.683	0.480	0.038	0.006	0.007	0.005	0.013	Remainder

B. Melting & pouring

Molten metal was prepared using a coke-fired furnace. A 10kg capacity crucible was used for preparing the molten metal. Al-4.5% Cu in the form of ingots was used as the raw materials.

The molten metal was maintained at 100 0 C above the liquids temperature. The molten metal was treated with hexachloro ethane (C2Cl6) tablet (0.5% by weight of the molten metal) for removing the dissolved gases in the metal. Then the slag was removed and molten metal was poured into the mould cavity. Using Chromel-Alumel thermocouples of 23 gauges were inserted in the mould cavity, temperature variation with respect to time was recorded and plotted for different locations (Fig. 1). The same was used for further analysis. Thermocouples were inserted at various points in the casting, in the core, and also in the mould. Heating/Cooling curves were recorded. Fig. 2 shows the solid-liquid front movement during solidification of casting.

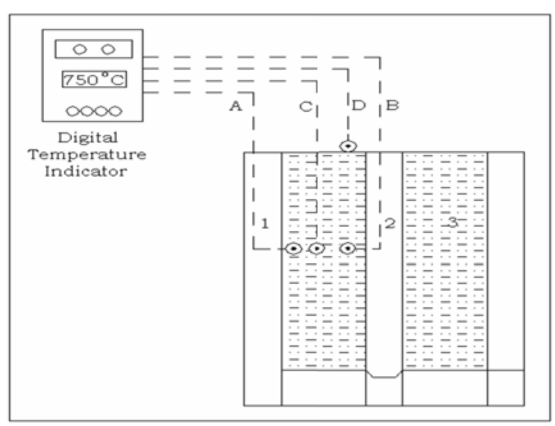

Fig. 1. Experimental Set Up Used

A → Thermocouple placed at interface of molten metal – mould

B → Thermocouple placed at interface of molten metal – core.

C → Thermocouple placed at the center of molten metal

D → Thermocouple placed at the surface of molten metal.

1 → CO_2-Sand Mould

2 → CO_2 - Sand Core

3 → Molten metal.

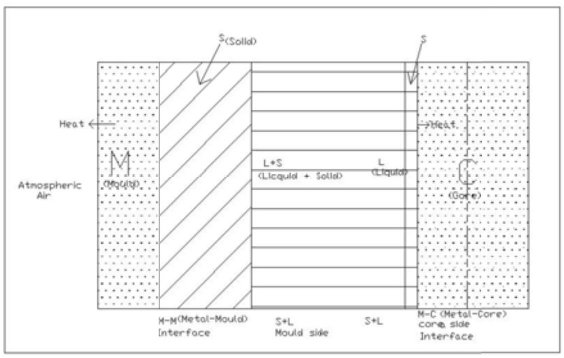

Fig. 2. Solid – Liquid Front Movement during Solidification

The experimental work was carried out for the different combination of core / mould for hollow cylindrical castings (TABLE 1).

Table 1. Dimensions of hollow cylindrical castings

Sl.No	OD D-mm	ID d- mm	Thickness t- mm	Height of Casting h-mm
1	75	25	25	250
2	125	25	50	250
		50	37.5	
3	175	25	75	250
		50	62.5	
		75	50	

Table 2. Experimental values of solidification time

Sl.No	OD D-mm	ID d-mm	Thickness t- mm	Height of Casting h-mm	Solidification Time t-secs.
1	75	25	25	250	11.563
2	125	25	50	250	16.024
		50	37.5		15.614
3	175	25	75	250	33.427
		50	62.5		23.957
		75	50		18.921

III. RESULTS AND DISCUSSIONS

Results are presented and discussed under the heads of experimental and FEM analysis.

A. Experimental

Temperatures of mould, metal and core were recorded continuously at regular intervals of 20 seconds for a total duration of 30 minutes. Graphs of Temperature Vs Time on the molten metal, mould, core and metal-air interface was plotted. Graphs were plotted for different combinations of casting diameter and thickness. Typical graphs have been shown in Figs.3-4. From these it can be seen that, the temperature of the mould decreases with time. This may be due to influence of casting thickness.

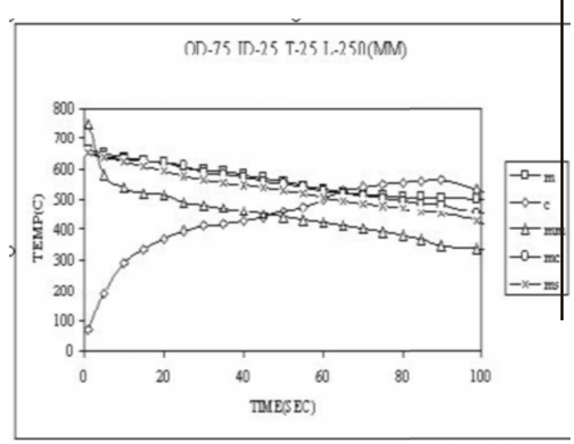

Fig. 3. Experimental Cooling Curves For 25 mm Thickness (75mm Od, 25 mm Id)

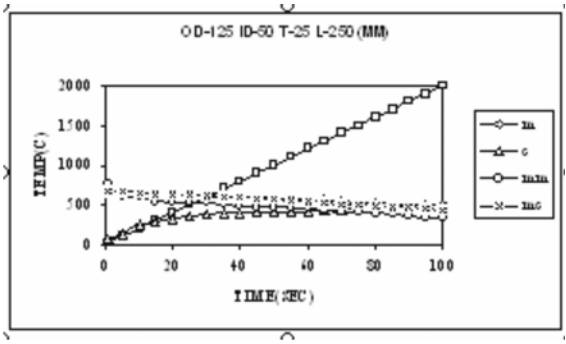

Fig. 4. Experimental Cooling Curves For 25 mm Thickness (125mm Od, 50mm Id)

The core temperature increases at a rapid rate initially, later gradually and reaches to its saturation point within 15-18 secs, which is above the solidification temperature and decreases gradually. This may be due to; initially the core was at room temperature and heats up rapidly because of convergent heat transfer. After reaching the saturation point of core, its temperature drops gradually because of reversal heat transfer.

In some cases it was also observed that at a particular point, core temperature curve and metal temperature curve meets approximately at solidification temperature of the metal. This may be due to mode of heat transfer taking place between core-metal-mould surfaces.

With the help of these figures, Solidification time can be obtained. Like wise, the heat extraction, rate of solidification and other parameters can be analyzed.

m - metal temperature

c - core temperature

mm - metal - mould interface temperature

mc - metal-core interface temperature.

B. Finite Element Analysis

(i). Thermal Analysis

Thermal analysis was carried out by using Finite Element Method. The following procedure was used.

1. Defining the properties of Aluminium-4.5% Copper alloy such as solidus temperature, liquidus temperature, thermal conductivity, density, specific heat and similarly defining the properties for CO_2 sand (used as a core and mould material).
2. A 2- D, model was developed (FIG. 5) for different configurations of hollow cylindrical Castings (TABLE 1). Meshing was done on the above Models.
3. Loads were applied to the meshing (FIG. 6) by providing various inputs (properties mentioned above). Convection losses were considered on the surfaces so as to achieve better accuracy.

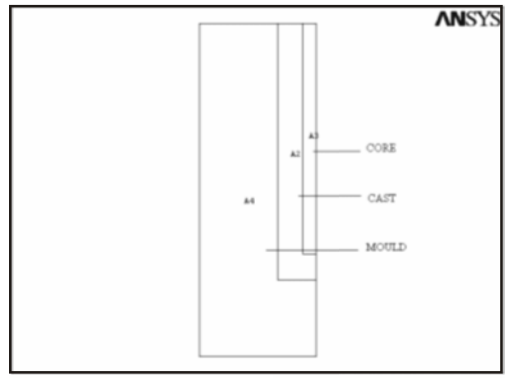

Fig. 5. Area of Simulated Model

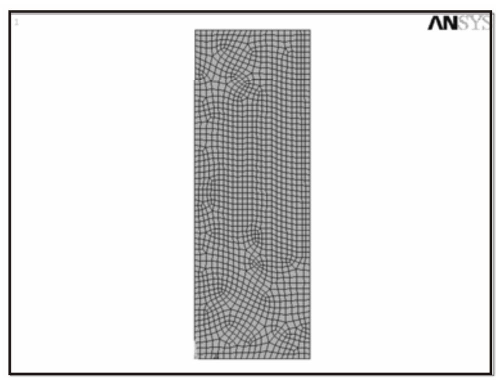

Fig. 6. Generation of Mesh and Loading on the Simulated Model

(ii) Solidification time

Solidification behavior of hollow casting for the given alloy was obtained by loading the various properties of alloy and sand, which was required for solving the problem.

Thermal Conductivity for Al-4.5%Cu. Alloy was found with the help of the formulae

$$K = \left[\left\{ .2(10^{-4}) + 4.9(10^{-9}) \right\} \frac{1}{\rho} \right] T$$

Where,

K=Thermal conductivity in W/(m-K)

r=Electrical resistance in ohm/m

T=Absolute temperature in K

Thermal conductivity value for different temperatures is given below

Table 3. Thermal Conductivity For Different

SL. NO.	TEMPERATURE °C	THERMAL CONDUCTIVITY,K W/m-k
1	0	4.036
2	400	9.9227
3	600	12.893
4	750	15.114

PROPERTIES OF Al-4.5% Cu

Solidus Temperature	549 °C
Liquidus Temperature	646 °C
Density of solid	2.52 g/cu-cm
Specific heat	1086 W/(g-K)
Thermal Conductivity of solid	192 W/(m-sec-K)
Thermal Conductivity of liquid	90W/(m-sec-K)
Density of liquid	2.38 g/cu-cm

PROPERTIES OF CO_2-SAND

Density	1.58 g/cu-cm
Thermal Conductivity	15.2 W/(cm-sec-K)
Specific heat	1045 W/(g-K)
Convective heat transfer coefficient	10.8 W/(sq- cm °K)

IV. RESULTS AND DISCUSSION-FEM ANALYSIS.

Finite Element Analysis was carried out for obtaining Solidification Behavior of Cylindrical Hollow Castings of Different Configurations (TABLE 1) .In the present study, Aluminium-4.5% Copper Alloy was used. CO2-Sand was used as a material for mould and core. ANSYS 5.4 package was used in the present study for analysis.

The following observations were made with the above analysis through FEM package.

Table 4. Fem values of solidification time

Sl.No	OD D-mm	ID d-mm	Thickness t- mm	Height of Casting h-mm	Solidification Time t-secs.
1	75	25	25	250	10.204
2	125	25	50	250	15.864
		50	37.5		14.935
3	175	25	75	250	32.227
		50	62.5		22.272
		75	50		18.461

Heat absorbed by the moulds during solidification depends purely on the time and decreases with thickness. It was also observed that heat extraction rates depend on cylinder dimensions (FIG.7, FIG.8 and FIG. 9). Initially heat extraction rate was found to be more rapid and tends to be gradual later on. Since thickness of the mould influences heat extraction it is obvious that higher the thickness, higher is the heat removal.

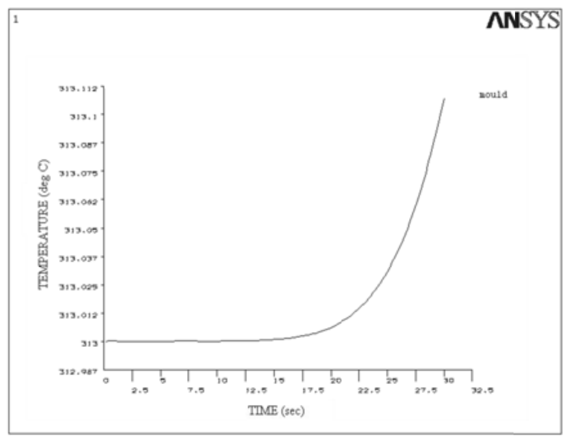

Fig. 7. Temperature Distribution in the Mould during Solidification for 25mm Thickness (75mm Od, 25mm Id)

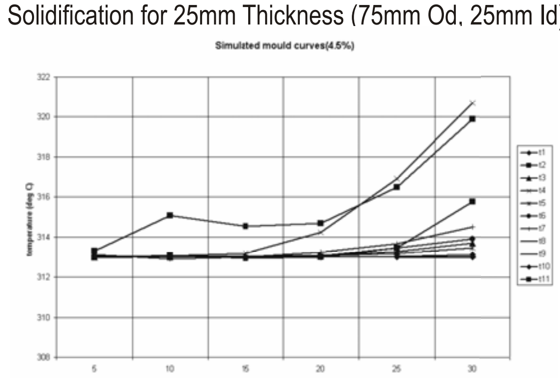

Fig. 8. Temperature Distribution in the Mould for different Thickness of Castings (Table1) During Solidification.

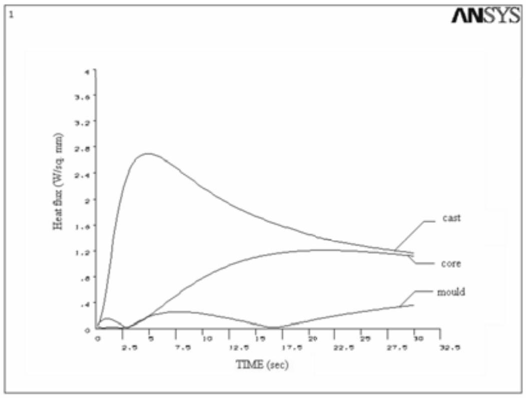

Fig. 9. Heat Transfer In Core, Cast And Metal During Solidification for 25mm Thickness (75mm Od, 25mm Id)

The core temperature increases at a rapid rate initially, later gradually and reaches to its saturation point, which is above the solidification temperature and decreases gradually (FIG.10 and FIG. 11). This may be due to; initially the core was at room temperature and heats up rapidly because of convergent heat transfer.

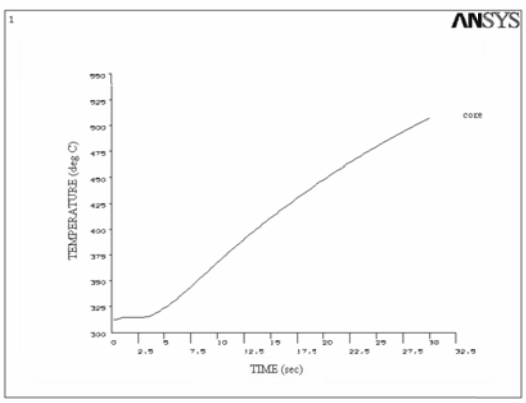

Fig. 10. Temperature Distribution in the Core During Solidification For 25mm Thickness (75mm Od, 25mm Id)

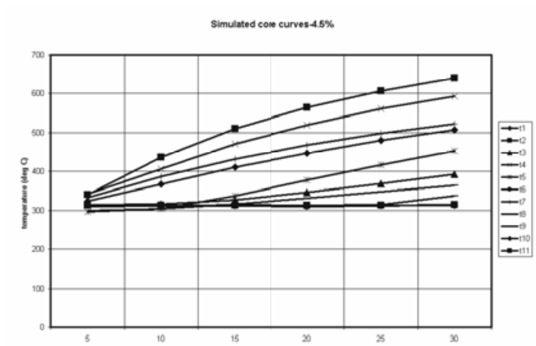

Fig. 11. Temperature Distribution In the Core For different Thickness Of Castings (Table1)during Solidification

During solidification of hollow casting it was observed that the temperature of metal drops rapidly during initial stages and drops gradually at later stages of Solidification (FIG. 12 and FIG. 13). As was discussed earlier, the mould temperature is at room temperature initially and increases gradually causing rapid temperature drop in the casting initially which decreases at later stages of heat extraction

Solidification time was obtained with the help of FEM analysis (Table 4).

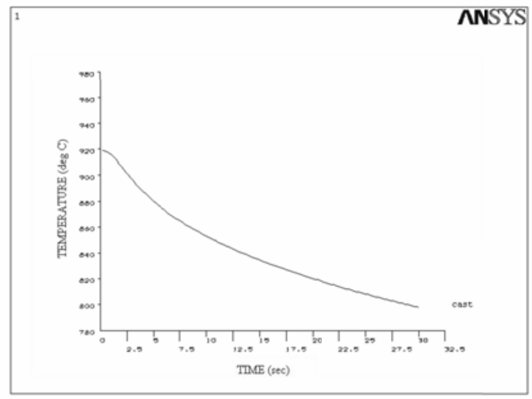

Fig. 12. Temperature Distributioni in the Cast during experimental for 25mm Thickness(75mm Od, 25mm Id).

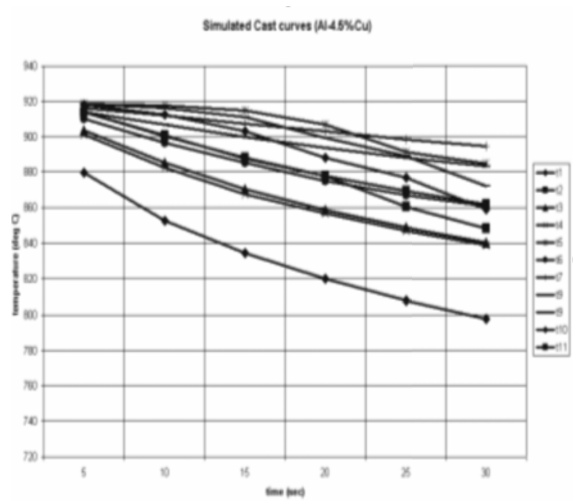

Fig. 13. Temperature Distribution in the Cast for different Thickness (Table 1) during Solidification for 25 mm Thickness (75mm Od, 25mm Id)

Table 5. Comparison Of Solidification Time For Al - 4.5%Cu

Sl.No.	OD D-mm	ID d-mm	Thickness T-mm	Heigt Of Casting h-mm	Solidification Time in Secs		% OF Deviation
					Experimental	FEM	
1	75	25	25	250	10.204	10.863	6.06
2	125	25	50	250	15.864	16.724	5.14
		50	37.5		14.935	15.614	4.35
3	175	25	75	250	32.227	33.482	3.74
		50	62.5		22.272	22.957	2.98
		75	50		18.461	18.921	2.43

V. CONCLUSIONS

In the present study, the solidification time of hollow casting has been obtained by experiment as well as with the help of ANSYS FEM Package. The results are in close agreement with each other. The analysis of solidification behaviour obtained through FEM analysis can be used for variety of casting configurations and different types of metals/alloys.

The following salient conclusions can be drawn from experiment as well as FEM Analysis of hollow castings for Aluminum – 4.5 % Copper.

1. Solidification time predicted through FEM agrees very well with the experimental results (Table 5) and (Fig.14).

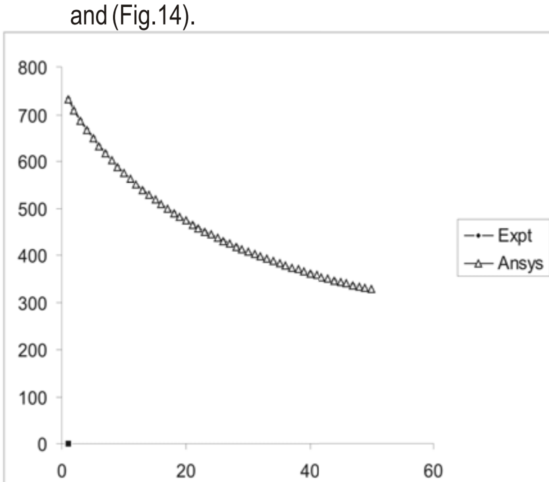

Fig. 14. Comparison of Temperature Distribution During Solidification (Fem-Expt.)

2. Solidification time of hollow cylinders is strongly governed by physical properties of the metal, thickness of the casting, mould and core dimensions.
3. Initially during solidification of hollow casting, the temperature of metal drops rapidly and gradually at later stages as seen from Experimental and FEM analysis.
4. Heat absorbed by the moulds during solidification depends on thickness of the mould. Heat extraction rates depend on cylinder dimensions.
5. It is observed that, core extracts heat rapidly in the initial stages and later on reaches saturation.

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