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SIMULATION OF SOLIDIFICATION BEHAVIOR OF CYLINDRICAL HOLLOW CASTING BY USING FEM TECHNIQUE

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Abstract Evaluation of solidification time is one of the very important parameters used for assessing the properties of the material. In the present study experimental investigation was carried out to measure the solidification time in a cylindrical hollow casting and the same has been compared with the analysis made through ANSYS FEM Package. Standard physical properties were taken from ASTM metal Hand book. With the help of physical properties of the material, analysis was done by using FEM technique. The solidification of cylindrical hollow was assumed to be one dimensional study heat flow. Al-4.5%Cu alloy has been used for the present study. An attempt has been made in this paper to introduce the FEM technique for analyzing the solidification behavior of cylindrical hollow castings and the same has been compared with experimental values. The result shows that the solidification time obtained by experimental study compares well with the one predicted by the analysis made with FEM technique.

Key words: Solidification, interface temperature, FEM

INTRODUCTION

A knowledge of solidification behavior of hollow castings & the thermal behavior of associated Moulds and Cores would be of immense value to a foundry man 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 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 analysis is made with the help of ANSYS FEM package for hollow castings. 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 (CO_2 –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 a FEM techniques. A FEM approach is best, in obtaining the knowledge of solidification and its subsequent application to practical problems. A transient heat conduction problem with moving boundary as resulting from this 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. In the second part 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.

EXPERIMENTATION

The details of the experimental study is given below:

Mould used

CO_2 moulds was used in the present work. Na_2Sio_3 (4%) was mixed with silica sand & hardened with CO_2 gas was used.

Alloy used

Al-4.5 % Cu (Commercial).

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The experiment work is done for the following different models

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

OD – Outside Diameter of Casting
ID - Core Diameter or Inner Diameter of Casting
t-- Thickness of Casting.

Methodology used

By inserting thermocouples at various points in the casting, in the core and also in the mould heating/cooling curves of the core, mould and casting were recorded.

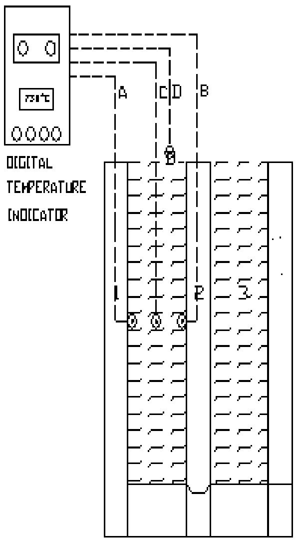

Fig. 1 Experimental set-up used

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 mound

2 - CO_2 sand core

3 - Molten metal.

In the present investigation, A calibrated digital temperature indicator was used. Cromel-Alumel thermocouples of 23 gauge at various locations was used for the thermal study to record temperature.

Melting and pouring

Molten metal was prepared using coke fired furnace. A 10kg capacity crucible was used for preparing the molten metal. Al-4.5% cu in form of ingots was used as the raw materialsThe molten metal was maintained at 100 c above the liquids temperature. The molten metal was treated with hexachlora ethane(cl2cl6) tablet(0.5% by weight of the molten metal). Then the slag was removed & molten metal was poured into the mould cavity. Immediately the thermocouple recorded using temperature recorder. A selector switch was used to record the temperature at various locations at an interval of 20 seconds. Using this information, variation of temperature with time was plotted at different locations. The same was used for further analysis.

RESULTS AND DISCUSSIONS

a)Experimental results

For various dimensions of cylindrical hollow castings, temperature was recorded for regular time intervals of 20 seconds for a total duration of 30 minutes. A graph of Time Vs Temperature for molten metal, mould, core, and metal surface was plotted. From these graphs solidification time and heat extraction rates were calculated.

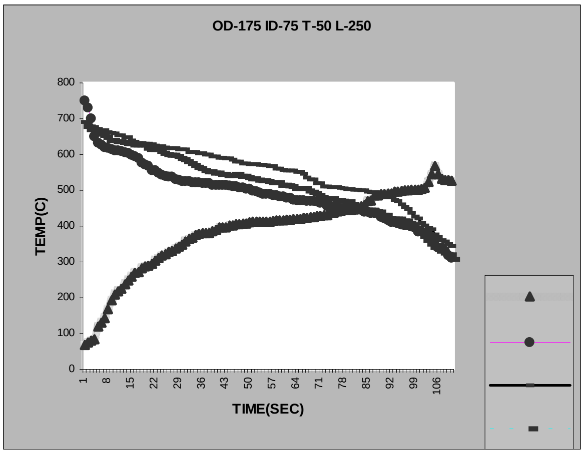

Fig. 2 Temperature distribution of cylindrical hollow casting for 50mm thickness

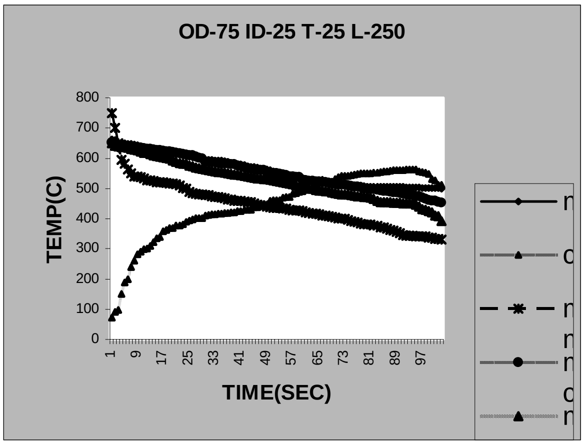

Fig. 3 Temperature distribution of cylindrical hollow casting for 25mm thickness

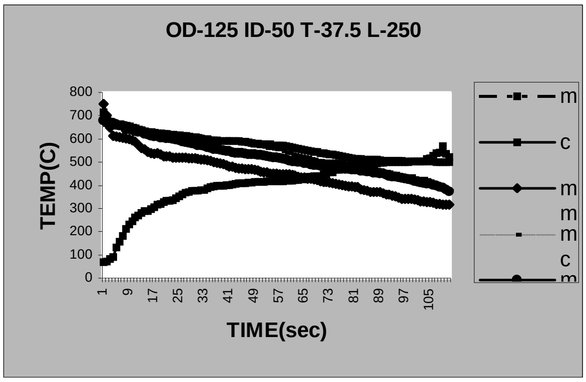

Fig. 4 Temperature distribution of cylindrical hollow casting for 37.5mm thickness

With the help of these graphs, the heat extraction, rate of solidification and other parameters are observed.

- Temperature of the mould decreases with time & rate of solidification depends on thickness of casting.
- The temperature of core increases at a faster rate, later gradually, reaches to its saturation, which is above the solidification temperature & decreases gradually.
- In some cases it was also observed that at a particular point core temperature line & metal temperature meets approximately at solidification temperature of the metal,
- With the help of above graphs solidification time can be obtained.

Table –1 Experimental values for Solidification time

Sl. No.	D/d	Solidification time in secs.
1	0	0
2	2.33	14.5
3	2.5	17.5
4	3.0	18.95
5	3.5	23.05
6	5.0	25.75

FEM ANALYSIS

NOMENCLATURE:

G= Eulars constant
E= Bessels functions
K= Thermal conductivity of the metal, W/m-k
ρ= Density of the metal, Kg/m^3
C= Specific heat of the metal , J/Kg.k
L= Latent heat of the metal, J/Kg
Um=Solidification temperature ^{o}C
Uo= Ambient temperature ^{o}C
Up= pouring temperature ^{o}C
C_1= Specific heat of the sand (mould and core)
ρ_1= Density of the sand
α_1= Mean thermal diffusivity of the sand, Cm^2/sec
ω_1= Mean heat diffusivity of sand, Cm^2/sec
U_1= Temperature in the mould ,^{o}C
K_1= Thermal conductivity of sand

i) Thermal Analysis

In this thermal analysis, thermal isotropic loading was applied. Room temperature & interface temperatures were applied on 10 nodes. Any number of nodes can be considered. In the present study 10 nodes were considered. Modeling was developed for the given cylindrical hollow casting of the Aluminium – 4.5 % Copper alloy were used to obtain thermal analysis by using FEM technique. With the help of the following information for the given alloy i.e. Density, Thermal Conductivity, Specific heat, Emissivity, Electrical resistance and heat generation rates, Thermal analysis of the alloy was obtained. The values of above mentioned properties were taken from ASTM Metal hand Book.

Table –2 Temperature Distribution through FEM

Nodes	Temperature ^{0}C
1.	557 -> Input
2.	505.12
3.	452.12
4.	399.53
5.	346.7
6.	293.95
7.	241.16
8.	188.37
9.	135.582
10.	82.7
11.	30 ->Input

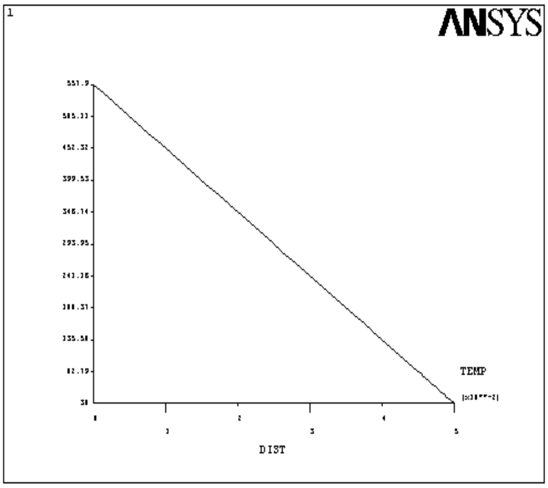

Fig. 5 Temperature Distribution over the Nodes By FEM

With the help of above analysis it was observed that the cooling takes place approximately by following linear law. Thermal flux & temperature gradient was also obtained.

Node	Flux
1.	-0.122E-8
2.	0.350E-9
3.	-0.201E-9
4.	0.187E-9
5.	-0.109E-9
6.	-0.637E-9
7.	0.253E-9

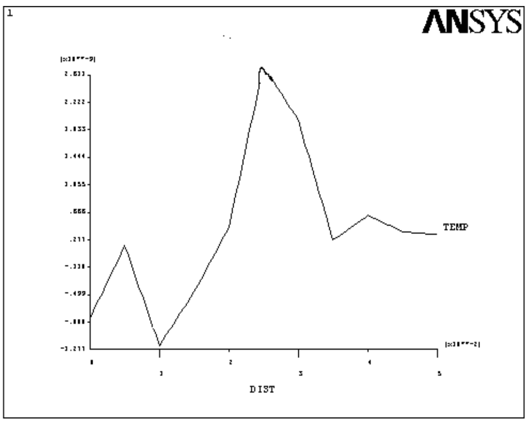

Fig. 6 – Heat flux distribution

ii) Solidification time of hollow casting for Al-4.5%Cu alloy

Solidification behavior of hollow casting for the given alloy was obtained by loading the enthalpy value at different temperatures which was required for solving the problem were obtained from ASTM Metal Hand Book.

Sl. No.	Temperature ^{0}C	Enthalpy J/kg.
1.	0	0
2	400	34.0385
3	600	34.6358
4	750	35.675

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

$$K=[\ \{1.2(10^{-4})+4.9(10^{-9})\}1/\rho]T$$

Where,
K=Thermal conductivity in W/m-k
ρ=Electrical resistance in ohm/m
T=Absolute temperature in k

Thermal conductivity value for different temperatures is given below

Sl. No.	Temp. ^{0}C	Thermal conductivity K (W/m-k)
1	0	4.036
2	400	9.9227
3	600	12.893
4	750	15.114

With the help of the above information the problem was solved and the results were obtained.

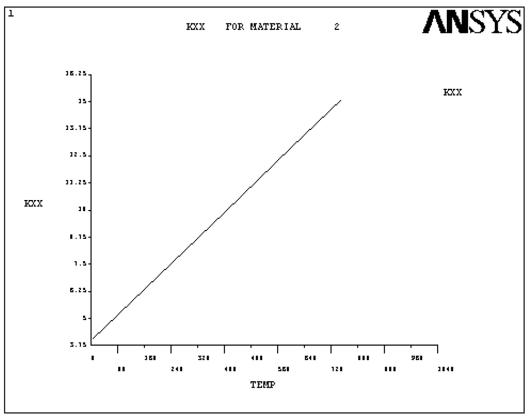

Fig. 7 Temperature-Thermal conductivity relation

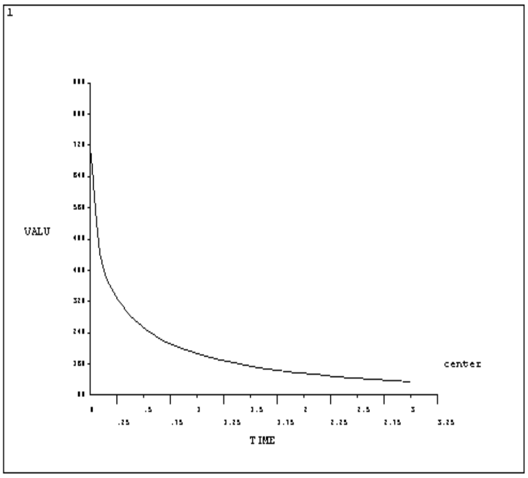

Fig. 8 Solidification behavior of casting

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

1) Heat absorbed by the moulds during solidification purely depends on time and decreases with time. It was also observed that heat extraction rates depends on cylinder dimensions. Initially heat extraction rate was found to be more rapid and gradual subsequently.

2) In thermal analysis it was observed that temperature distribution along the thickness of the hallow casting is linear.

3) With the above analysis it was noticed that thermal conductivity increases with temperature.

4) Flux distribution was found to be unsymmetric along the distance of hollow castings.

5) During solidification of hollow casting it was observed that the temperature of metal drops rapidly during initial stages and drops gradually at later stages.

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 behavior obtained through FEM analysis can be used for variety of casting configurations and different types of metals/alloys. Thermal analysis of the castings can be easily obtained by FEM analysis. The following salient conclusions can be drawn from experiment as well as FEM Analysis of hollow castings for Aluminium – 4.5 % Copper.

1) Solidification time of hollow cylinders are strongly governed by physical properties, Thickness of the casting and core dimensions.

2) Cooling takes place approximately by following linear law.

3) Heat absorbed by the moulds during solidification depends on time. Heat extraction rates depends on cylinder dimensions.

4) Thermal conductivity of the metal increases with time. Flux distribution is unsymmetric along the distance of hollow castings.

5) Initially during solidification of hollow casting, the temperature of metal drops rapidly and gradually at later stages.

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