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Aluminium Experimental and Numerical Study of Cooling Rate and Solidification in Green Sand Mould

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Abstract

Unsteady numerical simulation of unsteady state conduction heat transfer has been done for solidification of pure Aluminium in green sand mould. Experimental work on aluminium for studying its cooling rate and ANSYS software for the same has been conducted in the present paper. As during the solidification heat transfer by conduction will dominate over convection and radiation. Heat conduction equation in two-dimensional Cartesian co-ordinate governs the problem. Convective boundary condition has been considered at the interface of the casting part and mould cavity. Heat conduction equation in unsteady state has been solved using ANSYS to study the thermal flow and cooling rate. The pure aluminium and green sand mould will be used as a molten material and mould cavity material respectively.

Keywords: *Solidification, ANSYS, Aluminium, Experimental*

1. Introduction

Casting which also known as founding is one of the earliest metal shaping methods known to human being. It generally means the pouring of molten metal into the refractory mould with a cavity of the shape to be made then allowing it to solidify. When solidified, the desired metal object is taken out from the refractory mould either by breaking the mould or ejecting the mould part. The solidified part is called casting. Casting has been extensively used in manufacturing because of its many applications and advantages. Tools required for casting moulds are very simple and cheap and any intricate shape, either external or internal can be casted that would be otherwise challenging or uneconomical to make by other methods. A large variety of materials are used in foundries for manufacturing moulds and cores. The most commonly used materials are metals or other cold setting materials that can be made after mixing of two or more components together like: epoxy, concrete, plaster and clay.

2. Mathematical Formulation

2.1. Physical Domain

Schematic of the mould cavity has been represented in Figure 1. Origin of the mould cavity has been considered at the bottom-left corner. Cavity dimensions are length (L) and height (H) in x and y direction respectively.

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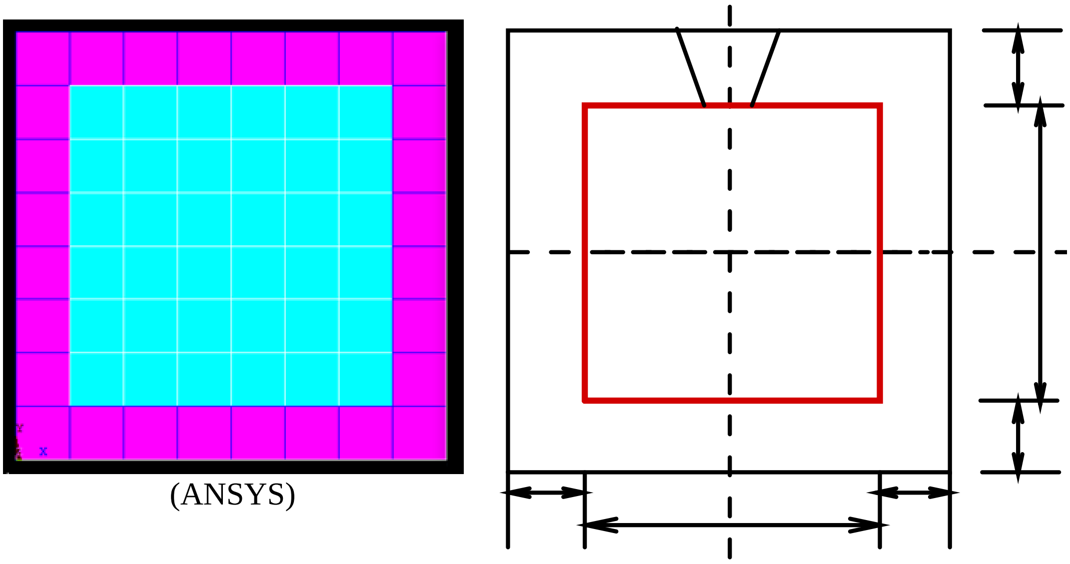


(ANSYS)

Figure 1. Schematic of Mould Cavity and Casting Part

3. Governing Equation

Unsteady state $$\alpha_{Al}\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right]=\frac{\partial T}{\partial t} \text{Poisson's equation} \qquad (1)$$

Above equation is a heat conduction equation in two-dimensional co-ordinate system for unsteady state. T is the temperature in kelvin (K) and is the only dependent variable in the present problem while x and y are the dependent variable. Properties appearing in the above equations are, $\alpha=k/\rho C_v$ is thermal diffusivity, k is thermal conductivity, ρ density, C_p is specific heat and t is time in seconds.

4. Boundary Conditions

$$k\left.\frac{\partial T}{\partial x}\right)_{x=0}=h(T_{x=0}-T_{ref})$$

$$-k\left.\frac{\partial T}{\partial x}\right)_{x=L}=h(T_{x=L}-T_{ref})$$

$$k\left.\frac{\partial T}{\partial y}\right)_{y=0}=h(T_{y=0}-T_{ref})$$

$$-k\left.\frac{\partial T}{\partial y}\right)_{y=H}=h(T_{y=H}-T_{ref})$$

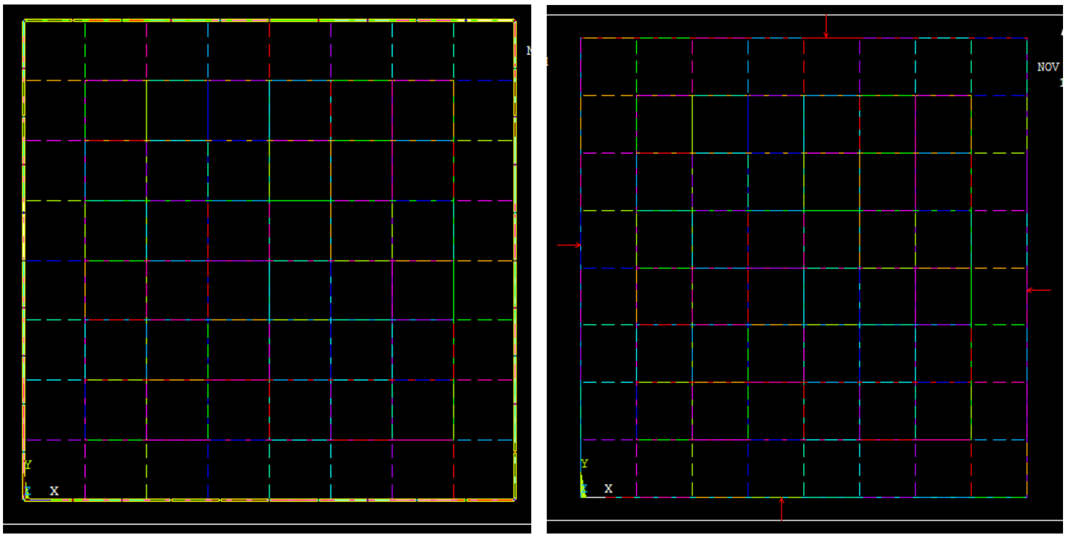


Figure 2. Application of Boundary Conditions

4. Assumptions

1. Convection and Radiation have been neglected
2. Molten metal and green sand mould properties are considered to be isotropic
3. Temperature independent properties
4. Mass and momentum change has been neglected.

Table 1. Physical Property of Pure Aluminium and Green Sand Mould

Material	**Specific heat (KJ/Kg-K)**	**Density (Kg/m^3)**	**Thermal conductivity (W/m-K)**
Aluminium	0.8963	2700.0	237.0
Green sand	1172.3	1494.71	0.52

Latent heat of fusion of aluminium h_f = 10.71 KJ/mol

5. Numerical Technique

1. A modelling of the mould-casting using ANSYS in Mechanical APDL has been modelled.
2. PLANE55 can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node.
3. Modelled has been discretized into number of parts for fine result shown in figure 3.
4. Properties of the materials have been considered in pure form, Table 1 represents the properties of the Aluminium and green sand mould.
5. Atmosphere temperature is T_{ref}= 310 K andmolten metal temperature is T= 973 K.
6. Simulation has been run for 3600 seconds and the results have been obtained.

Partial terms can be represented in algebraic form using schemes[9]

$$\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1,j} - 2T_{i,j} + T_{i-1,j}}{(\Delta x)^2}$$

$$\frac{\partial^2 T}{\partial y^2} = \frac{T_{i,j+1} - 2T_{i,j} + T_{i,j-1}}{(\Delta x)^2}$$

Using schemes fortime/temporal term[8], two-dimensional heat conduction equations can be written as,

$$\alpha\left[\frac{T_{i+1,j,t} - 2T_{i,j,t} + T_{i-1,j,t}}{(\Delta x)^2} + \frac{T_{i,j+1,t} - 2T_{i,j,t} + T_{i,j-1,t}}{(\Delta y)^2}\right] = \left[\frac{T_{i,j,t+1} - T_{i,j,t}}{\Delta t}\right]$$

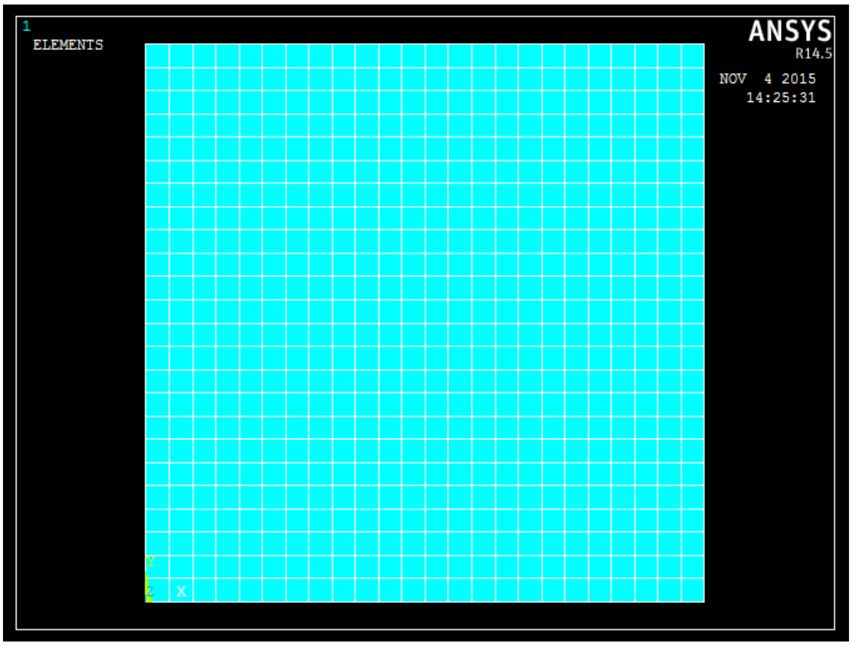
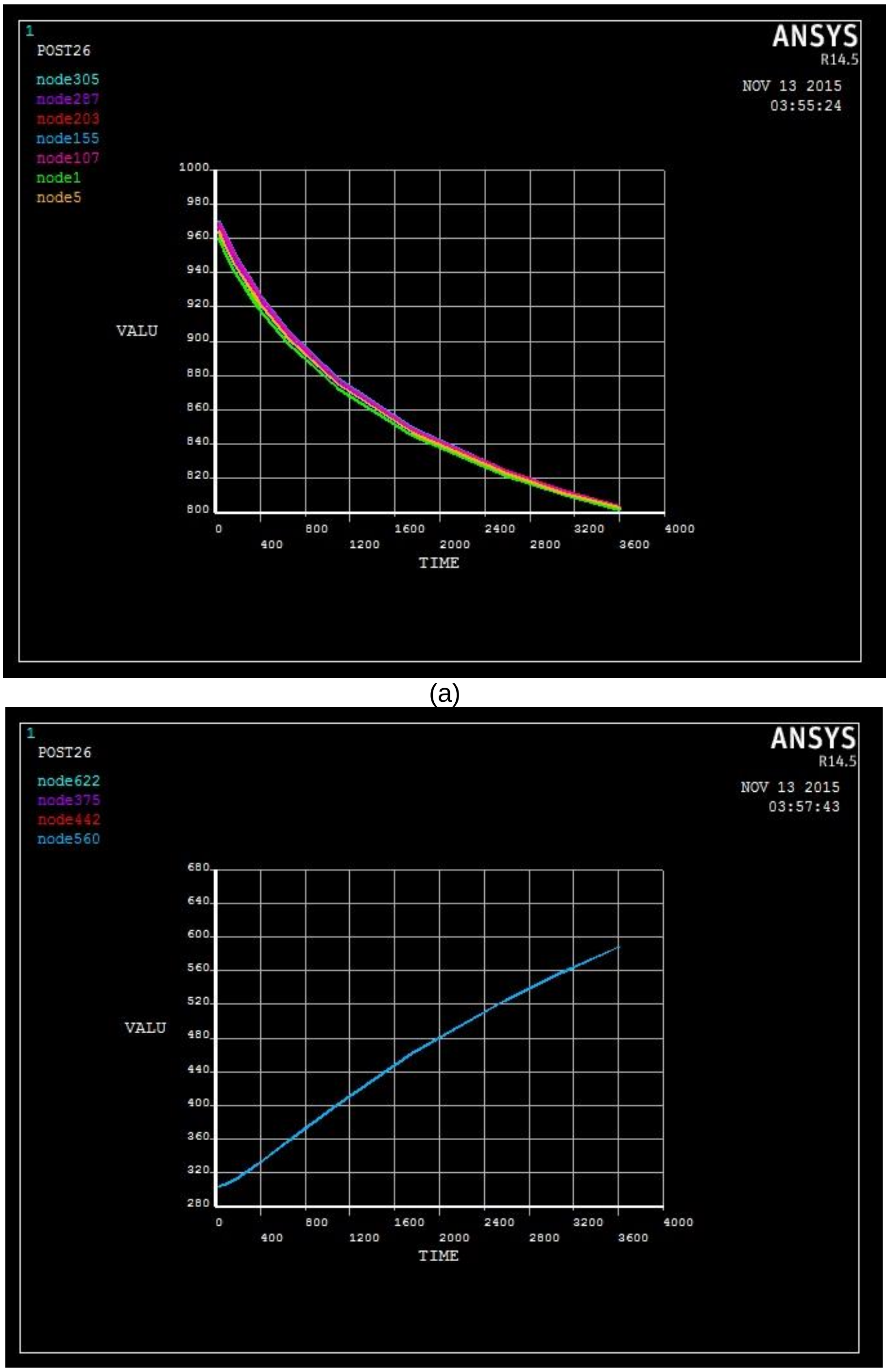


Figure 3. Meshed Mould-casting Part

6. Numerical Results

Figure 4 (a & b) represents the cooling rate inside the casting part and mould cavity. It can be noticed that in the casting part temperature is going down with the time while in the mould cavity temperature is increasing with the time because the heat get transferred from casting part to the mould cavity then from the mould cavity to the atmosphere.

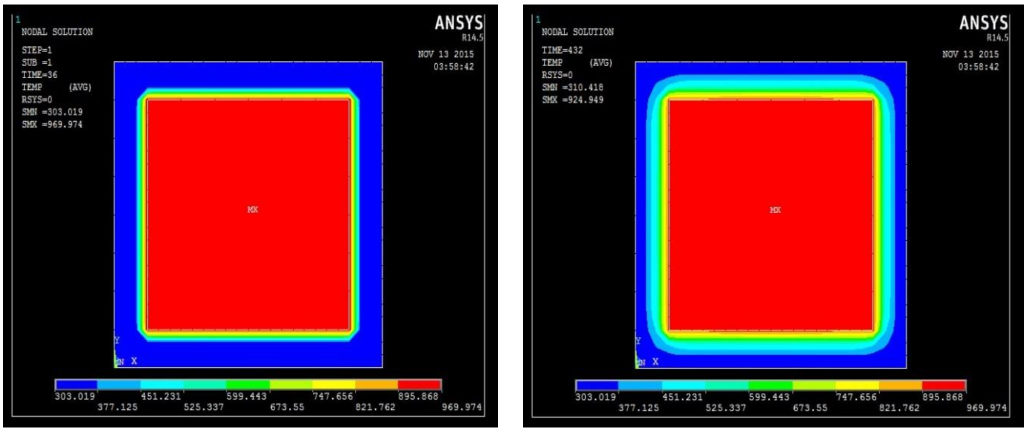


(a)

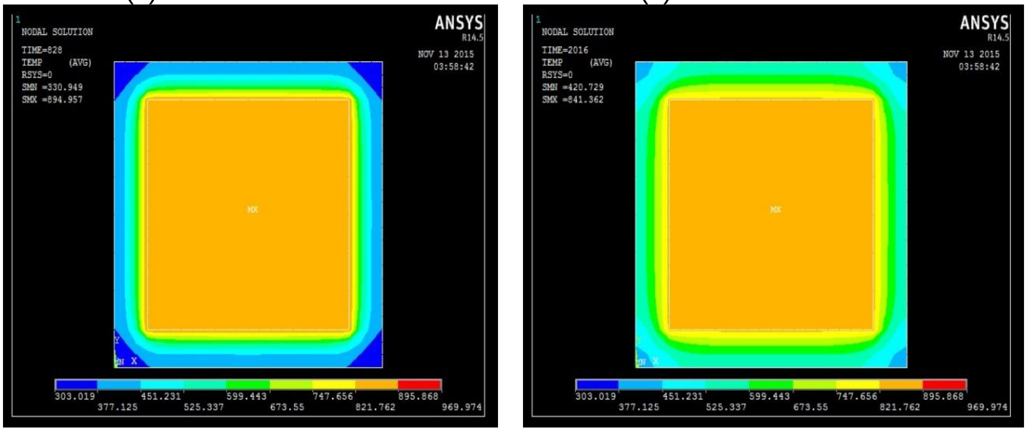
(b)

Figure 4. Temperature Variations with Time (a) Casting Part (b) Mould Cavity

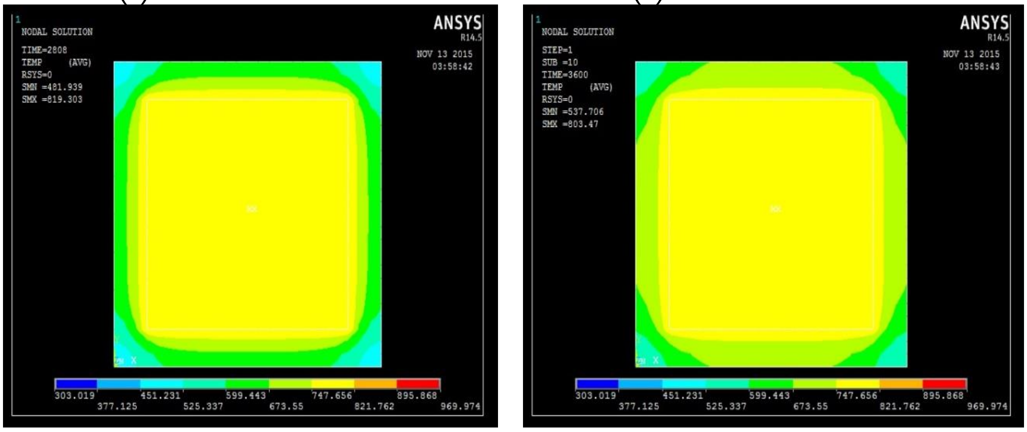
Figure 5 (a-f) represents the temperature distribution inside the cast-mould assembly. The simulation has been run for 3600 seconds. The plots have been taken for six different number of time duration. One can notice the temperature distribution in the cast-mould assembly.



(a) Time 36 Seconds (b) Time 432 Seconds



(c) Time 828 Seconds (d) Time 2016 Seconds



(e) Time 2808 Seconds (f) Time 3600 Seconds

Figure 5. (a-f) Temperature Distributions in Cast-Mould Assembly

7. Experimental Results

Table 2. Experimental Temperature Data with Time for Aluminium Casting

Temp (°C)	Time (sec)	Temp (°C)	Time (sec)	Temp (°C)	Time (sec)
794	0	172	1170	73	2370
626	30	167	1230	70	2430
596	60	162	1260	69	2460
551	90	157	1290	67	2490

535	120	155	1320	65	2520
523	150	152	1350	64	2550
509	180	148	1380	63	2580
496	210	145	1410	62	2610
485	240	141	1440	61	2640
471	270	138	1470	60	2670
450	300	135	1500	58	2700
434	330	132	1530	57	2730
412	360	128	1560	56	2760
391	390	125	1590	55	2790
374	420	122	1620	54	2820
355	450	120	1650	53	2850
339	480	118	1680	52	2880
324	510	115	1710	51	2910
317	540	113	1740	50	2940
305	570	110	1770	49	2970
295	600	108	1800	48	3000
286	630	105	1830	47	3030
276	660	103	1860	46	3060
269	690	101	1890	45	3090
261	720	98	1920	45	3120
254	750	96	1950	44	3150
247	780	94	1980	43	3180
239	810	93	2010	43	3210
232	840	91	2040	42	3240
227	870	89	2070	41	3270
222	900	87	2100	41	3330
215	930	84	2160	39	3360
210	960	82	2190	38	3390
205	990	81	2220	38	3420
200	1020	79	2250	38	3450
195	1050	77	2280	37	3480
190	1080	76	2310	36	3510
184	1110	74	2340	35	3540
179	1140	72	2400	32	3600

Figure 6. Images from the Experiments

Figure 6 and 7 represents the experimental results. In Figures 6 images has been shown during conducting the casting of aluminium metal. A K-type thermocouple and millimetre has been used to measure the time-temperature data. Data obtained by thermocouple with time has been represented in Figure 7, which represents the cooling rate of aluminium. Table 2 represents the data obtained by experiments using K-type thermocouple and millimetre.

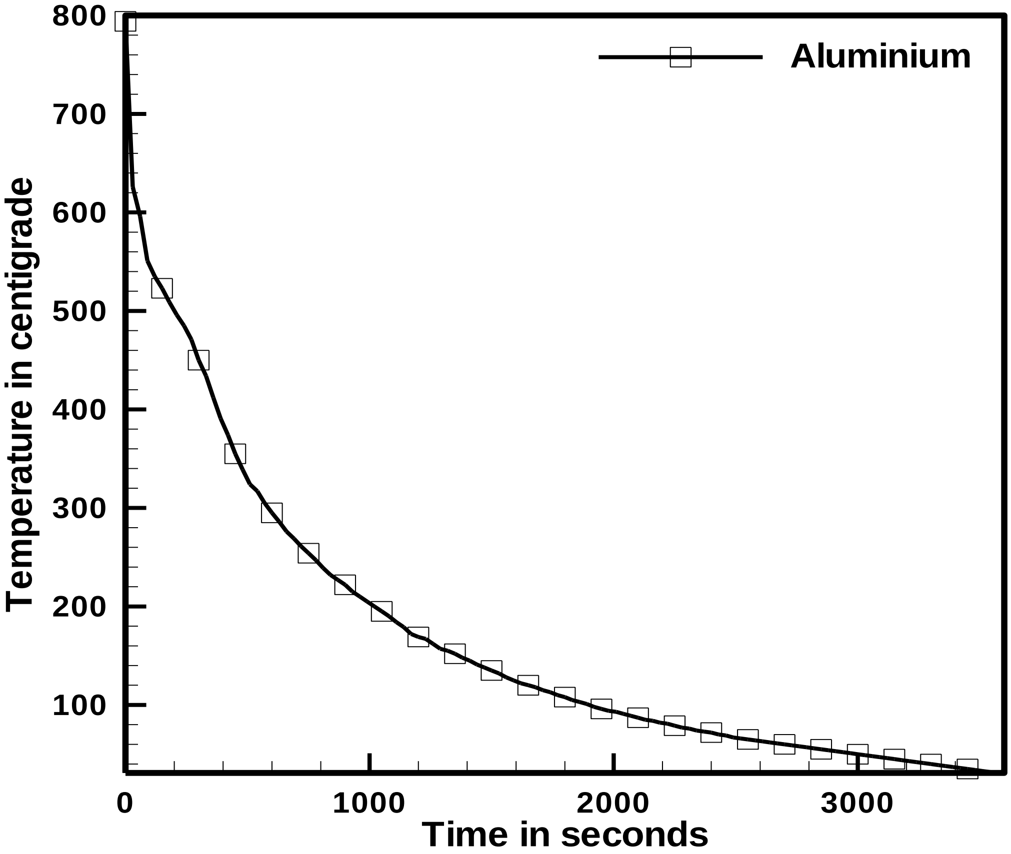


Figure 7. Cooling Rate of Aluminium Casting Experimental

8. Conclusion

1. Cooling rate of Aluminium has been plotted experimentally and numerically (ANSYS).
2. K-type thermocouple and millimetre have been used to measure the temperature data with respect to time.
3. Aluminium in the pure form has been adopted in the present case.
4. Temperature distribution inside the casting-mould assembly has been plotted.
5. Cooling rate inside the mould cavity has also been plotted.

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