International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 6 June 2021, pp: 756-767 www.ijaem.net ISSN: 2395-5252

Evaluation of Heat Transfer in Aluminium Alloy Sand Casting

Israel Olabode Aroge[1]; Oluwasegun Oluwole Gbore[2]; Oyewale Julius Ojo[1] and Saliu Ojo Seidu[3]

[1]*Department of Project Management Technology,*
The Federal University of Technology, Akure, Nigeria
[2]*Department of Production Engineering,*
University of Benin, Benin City, Nigeria,
[3]*Department of Metallurgical and Materials Engineering,*
The Federal University of Technology, Akure, Nigeria

Submitted: 25-05-2021 Revised: 01-06-2021 Accepted: 05-06-2021

ABSTRACT: The quality of a cast product is largely determined by the solidification process. However, poor management of the process can lead to defect in production and ultimately amount to waste. In recent times, simulation of the casting design is known to increase optimization of output and reduce defect since it can be used to obtain temperature distribution of various parts of the mold. It is therefore necessary to evaluate using finite element analysis of the heat transfer process in Aluminum alloy sand-casting as well as the experimental investigation of the rate of solidification in various depth and time interval. This study was carried out such that the casting of Aluminum alloy was produced while the parameters for pouring temperature, mould temperature and depth of mold and cast was also applied to the finite element analysis for congruency in the experimental and analytical methods of design. The heat exchange with time variation of casting was recorded from which the solidification time table and cooling curves were obtained for the determination of solidification time of the cast and mold. The analysis of the solidification process of the cubic casting was presented in two, four, six and sixteen elements simulation with temperature distribution recorded every six minutes. The simulation results were compared with the experimental reading which showed good agreement and the direction of heat transfer from the core of the molten metal to the mold. Also, the temperature of molten metal reduces drastically, close to the mold wall due to the chilling effect of the mold.

Keywords- Sand Casting, Finite Element Method, Heat Transfer, Discretization, Conduction

I. INTRODUCTION

The critical and continual need for basic and sophisticated material products has necessitated the need for castings but the unending waste as a result of poor design and implementation in the course of production calls for optimization of the casting process. According to [1], sand casting is an inexpensive method for the production of materials. Raw castings are transformed into finished products or components. The least costly of all casting methods is sand casting. Sand casting is used to manufacture a large range of metal parts of different sizes and weights in complicated geometries. These casting products are found in automobile parts and airspace [2], communication and power generation parts [3], petrochemicals [4], construction parts [5] and many more. [6] explained that, sand casting which is also known as sand molded casting, involves pouring of molten metal into the mold cavity through the pouring basin and then the gate. The molten metal is seen to mount quickly at the riser when the cavity is full.

[7] differentiated the sand mold and metal mold conditions. The sand mold contains a dissipation structure, air filled capillary-permeable body that forms the sand mold layer. All three methods of heat transfer are shared: radiation, convection and conduction. These basic heat transfer systems are theoretically disconnected to allow for evaluation, although the events occur and interrelate at varying intensity at the same time. Also, [8] relayed that certain processes optimum impact are within a certain heat range. This definition shows why sand mold deposition has a reduced thermal value than a metal mold. Thus, solidification happens faster in cast metal mold since it is a denser conductive system. [9] noted that, the variation of heat throughout the mold and

cast represents the thermal energy situations of the Fourier differential equation.

[10] opined that sand casting necessitates the use of replica that forms the cavity of the required product to be made so that molten substance poured into the mold can take the desired shape. However, [11] were of the opinion that, the aforementioned assertions of [10] causes some amount of heat flow to be released from the molten substance to the environment, which is the mold wall. The metal solidifies and it is separated from the mold after very much cooling. [12], emphasizes some factors that influence the quality of the required product such as melting temperature, heat transfer, stress concentration, shrinkage and other factors. However, [13], considered an equilibrium environment instead of seeking a generic composite structure out of equilibrium. [14], defined metal solidification as the change of metal from its molten state to solid state after it has been poured into the mold. This procedure starts rapidly after pouring the molten metal into a mold and followed by chain of events. [15] stressed that the main principle of solidification is the conversion phase of the liquid to solid along a transient interface, which is followed by the liberation and redistribution of latent heat energy at both stages. This shift in the phase of the substance varies according to the content of the material, that is, either a pure or alloyed. [16] exclaimed that pure metallic substance solidifies at a specific temperature. An alloy solidifies at over a temperature spectrum, based on the characteristics that make up the metal. The cooling feature that results in solidification has a major influence on the size of the grain. According to [17], a rapidly cooled casting region would have a small grain size, and a zone steadily cooled would have a rough grain size. Also, [18], added that the quality of the finished casting depends primarily on the solidification pace, as faster solidification produces better microstructure, finer grain size with better mechanical properties as well as certain metallurgical characteristics. [15], also described the mold as a hollow for which the liquid metal is filled to solidify and create the required appearance. Therefore, among several factors influencing the casting product is the mold. [19], stated that the solidification of molten metal in the mold is a result of the extraction of heat from the metal by the mold that surrounds it. This process of heat extraction is called heat transfer.[20], therefore concluded that the solidification challenge of casting is a transient heat transfer problem and hence the temperature distribution in the metal casting and the mold during the solidification process is to be tracked. [21] Describe finite element method as a very momentous tool capable of simulating the heat transfer in the solidification process and also the casting, mold and air gap formation. It is in fact important to understand the sand casting procedure to be able to model the temperature distribution process. According to [22], the molten metal fills the mold immediately it is poured but the air gap created between the mold wall and the molten metal increases due to metal shrinkage as solidification takes place. Meanwhile, [23] opined that, the capacity for heat to migrate through the casting, interface and mold strongly impacts the emergence of solidification which plays a prominent role in deciding the freezing state and then the soundness of the casting. The goals of finite element analysis in the manufacture of casting products are to have an oversight of the casting process at every stage of the solidification and transformation of the product, to predict defects in its design stage and proactively control the process in order to obtain the most desired products.

[24], rationalized the need for treating each casting production process as special and that they require precision planning and execution. They bemoaned that discrepancies during manufacturing, such as inappropriate pouring temperature, may have detrimental effect on the final output. Even though the pattern and mold are made with extreme accuracy, flaws during the process of molding can result in significant waste of resources. They however discussed few of the defects that occur frequently during casting processes, which are shifts, warpage, fin, swell, blowholes, drop, dirt, honeycombing or sponginess, metal penetration and rough surface, sand holes, pin holes, scabs, shrinkage cavity, hot tears (Pulls), cold shut and mission, poured sort, internal air pocket.[25] also stressed that casting rejection is the dilemma of the foundry industry as energy, materials and time can be saved should the casting defects be predicted and corrected in the casting design prior to molding. Since the temperature distribution in sand casting molten metal and mold can be predicted, monitored and analyzed appropriately as the process forms the properties of the resulting cast then, one must employ an analytical method for the optimization of the sand-casting process.

[26] emphasized the distinctiveness of the finite element method as the division of a given domain into a set of simple sub-domains, called finite elements. He proceeded to state that any geometric shape that allows computation of the

solution or its approximation or provides necessary relations among the values of the solution at selected points, called nodes, of the sub-domain, qualifies as a finite element. [27] referred to the finite element method (FEM) or finite element analysis (FEA), as an analytical technique used to obtain approximate solutions of boundary value problems in engineering. [28], itemized the various numerical solution methods to complex problems and they include; least-squares method, the Rayleigh-Ritz method, methods of weighted-residuals, finite element method, the Petrov-Galerkin method, the Galerkin method and the collocation method. [29], expressed fears of the threat of porosity, voids in metals and gas bubbles that remain inherent byproduct of the casting process and added that the various effects can be studied by generating the model of internal void with the help of finite element methods. [30] asserted the high cost of analyzing and solving solidification challenges in casting using experimental design analysis and the geometries and complex boundary conditions that sometimes defy analytical solutions. The report of [30] maintained that, the heat conduction coupled with thermal stress analysis packages were considered in order to forecast the mechanical behaviour such as cracking and eventual failure of the cast. The report also included the phase change interface and latent heat effects. [31], studied the solidification process of metal during casting using Finite element method. It was analyzed and named a non-linear transient phenomenon. They described the solidification period in which the hottest region inside the casting is solidifying as the most important instant of time.

In many simulation techniques where comparison is made between foundry experiment and simulation methods, attention is given to the analytical result while neglecting the several effects of the immediate sudden freezing of the molten metal during the pouring process. Therefore, in this research, the mold was preheated and the same was incorporated into the analysis. Also, the molten metal must be poured at optimum melting temperature since according to [32], mis-run can ensue from pouring molten metal at very low temperature which can lead to a discontinued fluid metal flow. Furthermore, [33] relayed the causes, features and consequent implication of sand burning. This occurs due to pouring of molten metal at very high temperature such that the thin sand crusts firmly glue to the casting surface. Taking temperature measurements around this region can impair the result and relevance of the research. The basic objective of this research is to clarify, collect, and establish the quantitative relationships between the heat transfer process associated with the Aluminium alloy sand casting experiment and the finite element analysis simulation.

II. METHODOLOGY

This research work made use of the Linear Lagrange interpolation function of the finite element methods to analyze the temperature distribution in a thin solidifying Aluminum alloy cast governed by the 1-D transient heat conduction equation. Therefore, the Linear Lagrange interpolation function of the finite element methods was employed. The variables that were obtained while performing the experiment such as the initial temperature of the mold and pouring temperature of the molten Aluminum alloy were inputted into the equation and the MATLAB programme so as to obtain comparable results with the Finite element methods.

The Governing Equation

The governing equation is represented by:

$$\rho_{Alu\,\mathrm{minium}} C_{PAlu\,\mathrm{minium}} \frac{dT}{dt} = K_{Alu\,\mathrm{minium}} \frac{d^2T}{dx^2} + \frac{dK_{Alu\,\mathrm{minium}}}{dT}\left(\frac{dT}{dx}\right)^2$$

$$\rho C_P \frac{dT}{dt} = K \frac{d^2T}{dx^2} + \frac{dK}{dT}\left(\frac{dT}{dx}\right)^2 \qquad 1$$

Expansion of equation 1 gives;

$$\rho C_P \frac{dT}{dt} = K \frac{d^2T}{dx^2} + \frac{dK}{dT}.\frac{dT}{dx}.\frac{dT}{dx} \qquad 2$$

Applying the chain rule of the form; $\frac{dy}{dx} = \frac{dy}{du}.\frac{du}{dx}$ 3

According to Barnes (1999), the function notation can be written as; $\frac{dy}{dx} = f'(g(x)).g'(x)$

Equation 2 can then be written as

$$\rho C_P \frac{dT}{dt} = K\frac{d^2T}{dx^2} + \frac{d}{dx}\left(K\frac{dT}{dx}\right) - K\frac{d^2T}{dx^2} \qquad 4$$

The model equation is finally reduced to;

$$\rho C_P \frac{dT}{dt} = \frac{d}{dx}\left(K\frac{dT}{dx}\right) \qquad 5$$

The Boundary Conditions

In other to prevent the melt from causing thermal damage during pouring due to instantaneous and sudden increase in the temperature of the mold [34], the mold was preheated to a considerable temperature and the initial temperature in the casting, mold and mold-metal interface were:

Tc = Tp
Tg = Tm = TM

The temperature (T_i) at the interface between the two materials that is the cast and the mold on pouring the molten metal are as follows:

$$T_i = \frac{(\rho mCmTm)+(\rho cCcTc)+(\rho c\Delta H)}{\rho mCm + \rho cCc} \qquad 6$$

$$T_B = \frac{T_P + T_A}{2}$$

$$Q_{1st} = h_1(T_P - T_B)$$

$$Q_{last} = h_2(T_M - T_A)$$

Weak Formulation

Rearrange equation 5 (the derived equation) equals zero, that is:

$$\frac{d}{dx}\left(K\frac{dT}{dx}\right) - \rho C_P\frac{dT}{dt} = 0 \qquad 7$$

Multiplying equation 5 through with a weight function w(x) to introduce it into the problem results into: $w(x)\frac{d}{dx}\left(K\frac{dT}{dx}\right) - \rho C_P w(x)\frac{dT}{dt} = 0$ 8

Therefore, derive the weak form of the equation using the method of Integration by parts, introducing the notations:

$$\int^e w(x)\frac{d}{dx}\left(K\frac{dT}{dx}\right) - \int^e \rho C_P w(x)\frac{dT}{dt} = 0 \qquad 9$$

In order to weaken the form, recall the part $w(x)\frac{d}{dx}\left(K\frac{dT}{dx}\right)$ from equation 7

$$\int_{xi}^{xi+1} U\frac{dV}{dx}dx = [UV]_{xi}^{xi+1} - \int_{xi}^{xi+1} V\frac{dU}{dx}dx \qquad 10$$

If $U = w(x)$ and $\frac{dV}{dX} = \frac{d}{dx}\left(K\frac{dT}{dx}\right)$ then $\frac{dU}{dx} = \frac{dw(x)}{dx}$ and $V = K\frac{dT}{dx}$ 11

$$\int_{xi}^{xi+1} w(x)\frac{d}{dx}\left(K\frac{dT}{dx}\right)dx = \left[w(x)K\frac{dT}{dx}\right]_{xi}^{xi+1} - \int_{xi}^{xi+1} k\frac{dT}{dx}\frac{dw(x)}{dx}dx \qquad 12$$

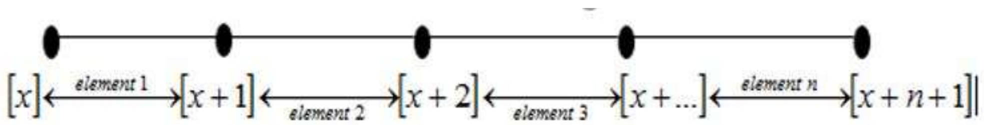

Fig 1. The structural representation of the difference between two successive nodes such as x_i and x_{i+1} and its relationship with other elements combined. [26], An Introduction to Finite Element Method. Second Edition, McGraw-Hill, Inc.

Assembling the whole equation 7 again with the part $w(x)\frac{d}{dx}\left(K\frac{dT}{dx}\right)$ being replaced by equation 10, it becomes:

$$\int_0^h w(x)\rho C_p\frac{dT}{dt}-\left[w(x)K\frac{dT}{dx}\right]_{xi}^{xi+1}+\int_{xi}^{xi+1}k\frac{dT}{dx}\frac{dw(x)}{dx}dx=0 \qquad 13$$

Derivation of the Finite Element Interpolation Functions

Equation 13 is the integral variable, $\left[-w(x)K\frac{dT}{dx}\right]$ is the natural variable while $-K\frac{dT}{dx}$ is the natural boundary condition and secondary variable and T is the essential boundary condition that is the primary variable assuming a finite element solution of the form:

$$T^e(x,t)\approx T^e(x,t)=\sum_{j=1}^{n}T_j^e(t)\psi_j^e(x) \qquad 14$$

The approximate solution is a decoupled formulation where $T_j^e(t)$ is the value of the solution at the nodes of the finite element, it is a function of time and w(x) is replaced by $\psi_j^e(x)$, it is the approximation function over the element in x direction. Therefore, w(x) is substituted from equation 13 to give:

$$\int_0^h \psi_j^e\rho C_p\frac{dT}{dt}-\left[\psi_j^e K\frac{dT}{dx}\right]_{xi}^{xi+1}+\int_{xi}^{xi+1}k\frac{dT}{dx}\frac{d\psi}{dx}dx=0 \qquad 15$$

From equation 15 $\frac{dT}{dx}$ and $\frac{dT}{dx}$ are evaluated

$$\frac{dT}{dt}=\sum_{j=1}^{n}\frac{dT}{dt}(t)\psi_j^e(x) \qquad 16$$

$$\frac{dT}{dx}=\sum_{j=1}^{n}T_j^e(t)\frac{d\psi}{dx}(x) \qquad 17$$

In element notation $T^e(x,t)\approx T^e(x,t)=\sum_{j=1}^{n}T_j^e(t)\psi_j^e(x)$ where (s = 1, 2, 3,… n) time counter.

Note $T_j^s(t)$ is the value of T(x, t) at time t = t_s for node j of the element n.
Thus, we have:

$$\int_0^h \rho c\left(\sum_{j=1}^{n}\frac{dT}{dt}(t)\psi_j^e(x)\right)\psi_j^e(x)+\int_0^h\left(\frac{d\psi(x)}{dx}\right)K\left(\sum_{j=1}^{n}T_j^e(t)\frac{d\psi}{dx}(x)\right)-\left[K\sum_{j=1}^{n}T_j^e(t)\frac{d\psi}{dx}(x)\psi_j^e(x)\right]_0^h=0$$

$$\int_0^h \rho c\left(\sum_{j=1}^{n}\frac{dT}{dt}(t)\psi_j^e(x)\right)\psi_j^e(x)+\int_0^h\left(\frac{d\psi(x)}{dx}\right)K\left(\sum_{j=1}^{n}T_j^e(t)\frac{d\psi}{dx}(x)\right)=\left[K\sum_{j=1}^{n}T_j^e(t)\frac{d\psi}{dx}(x)\psi_j^e(x)\right]_0^h \qquad 18$$

Application of the ∝- Family of Approximation

Considering the time aspect in the problem, to resolve this, we introduce an appropriate time approximate scheme which is the ∝- family of approximation. The model developed being a one-dimensional time dependent problem will describe time approximation scheme and convert the differential equation to algebraic equation with respect to time.

$$(1-\alpha)\dot{T}_s+\alpha\dot{T}_{s+1}=\frac{T_{s+1}-T_s}{\Delta t_{s+1}} \quad 0\le\alpha\le1 \qquad 19$$

$$\left([M^e]+\alpha\Delta t[K^e]\right)\{T^e\}_{s+1}=\left([M^e]+\Delta t(1-\alpha)[K^e]\right)\{T^e\}_s+\Delta T\left(\alpha\{Q^e\}_{s+1}\right)+(\alpha)\{Q^e\}_s \qquad 20$$

The equation 18 is however reduced to equation 20 using the Backward Difference Scheme

Evaluation of the Finite Elemental Matrices

The system model is of the form: $\left[M^e\right]\left\{\dot{T}_s\right\}+\left[K^e\right]\left\{T_s\right\}=\left\{Q_s^e\right\}$ 21

Where the conductivity matrix $M_{ij}=\rho C_p\int_0^h\left(\psi_i\psi_j\right)dx$

The Enthalpy matrix $K_{ij}=\int_0^h\left(K\frac{d\psi_i}{dx}\frac{d\psi_j}{dx}\right)$ and

The one-dimensional Lagrange quadratic interpolation function for the equation becomes: $\psi_1=1-\frac{x}{h}$,

$\psi_2=\frac{x}{h}$ 22

The interpolation properties ψ_1^e is equal to one at node one and zero at node two while ψ_2^e is equal to zero at node one and one at node two [26].

Using the Linear Lagrange interpolation function in equation 22 to obtain all the M_{ij} and K_{ij} in the matrix in equation 21

To obtain M-matrix for M_{ij}

$$M_{11}=\rho C_p\int_0^h\left(\psi_1\psi_1\right)dx$$

$$M_{11}=\rho C_p\int_0^h\left(1-\frac{x}{h}\right)\left(1-\frac{x}{h}\right)$$

$$M_{11}=\rho C_p\left[\frac{h}{3}\right] \quad 23$$

$$where\, M_{11}=M_{22}$$

$$M_{11}=\frac{\rho C_p h}{3}$$

$$M_{12}=\rho C_p\int_0^h\left(\psi_1\psi_2\right)dx$$

$$M_{12}=\rho C_p\int_0^h\left(1-\frac{x}{h}\right)\left(\frac{x}{h}\right)$$

$$M_{12}=\rho C_p\left[\frac{h}{6}\right] \quad 24$$

$$where\, M_{12}=M_{21}$$

$$M_{12}=\frac{\rho C_p h}{6}$$

To obtain K-matrix for K_{ij}

$$where\ \psi_1=1-\frac{x}{h}$$

$$\frac{d\psi_1}{dx}=-\frac{1}{h} \quad 25$$

$$where\ \psi_2 = \frac{x}{h}$$

$$\frac{d\psi_2}{dx} = \frac{1}{h} \qquad 26$$

$$K_{11} = K\int_0^h \left(\frac{d\psi_1}{dx}\right)\left(\frac{d\psi_1}{dx}\right)dx$$

$$K_{11} = K\int_0^h \left(-\frac{1}{h}\right)\left(-\frac{1}{h}\right)dx$$

$$K_{11} = K\left[\frac{1}{h}\right] \qquad 27$$

$$where\ K_{11} = K_{22}$$

$$K_{11} = \frac{K}{h}$$

$$K_{12} = K\int_0^h \left(\frac{d\psi_1}{dx}\right)\left(\frac{d\psi_2}{dx}\right)dx$$

$$K_{12} = K\int_0^h \left(-\frac{1}{h}\right)\left(\frac{1}{h}\right)dx$$

$$K_{12} = K\left[-\frac{1}{h}\right] \qquad 28$$

$$where\ K_{12} = K_{21}$$

$$K_{12} = -\frac{K}{h}$$

$$Q = \sum h\left[\psi T\,\frac{d\psi}{dx}\right]_0^h$$

$$Q_{11} = \left[\psi_1(x)T_1\,\frac{d\psi_1(x)}{dx}\right]_0^h$$

$$Q_{12} = \left[\psi_1(x)T_2\,\frac{d\psi_2(x)}{dx}\right]_0^h \qquad 29$$

$$Q_{21} = \left[\psi_2(x)T_1\,\frac{d\psi_1(x)}{dx}\right]_0^h$$

$$Q_{22} = \left[\psi_2(x)T_2\,\frac{d\psi_2(x)}{dx}\right]_0^h$$

The assembled Enthalpy matrix K_e is given as:

$$\begin{bmatrix} \frac{\rho C_p h}{3} & \frac{\rho C_p h}{6} \\ \frac{\rho C_p h}{6} & \frac{\rho C_p h}{3} \end{bmatrix}\begin{Bmatrix} \dot{T}_1 \\ \dot{T}_2 \end{Bmatrix} \qquad 30$$

The assembled Conductivity matrix M_e is given as:

$$\begin{bmatrix} \frac{K}{h} & -\frac{K}{h} \\ -\frac{K}{h} & \frac{K}{h} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \end{Bmatrix} \qquad 31$$

The Global System of Algebraic Equations

The Conductivity matrix and the Enthalpy matrix are derived and assembled by substituting the Linear Lagrange interpolation function represented in equation 23 to 31 to become:

$$\begin{bmatrix} M_{11}^{1} & M_{12}^{1} \\ M_{21}^{1} & M_{22}^{1} \end{bmatrix} \begin{Bmatrix} \dot{T}_1 \\ \dot{T}_2 \end{Bmatrix} + \begin{bmatrix} K_{11}^{1} & K_{12}^{1} \\ K_{21}^{1} & K_{22}^{1} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \end{Bmatrix} = \begin{Bmatrix} Q_1 \\ Q_2 \end{Bmatrix}$$

32

$$\begin{bmatrix} \frac{\rho ch}{3} & \frac{\rho ch}{6} \\ \frac{\rho ch}{6} & \frac{\rho ch}{3} \end{bmatrix} \begin{Bmatrix} \dot{T}_1 \\ \dot{T}_2 \end{Bmatrix} + \begin{bmatrix} \frac{K}{h} & -\frac{K}{h} \\ -\frac{K}{h} & \frac{K}{h} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \end{Bmatrix} = \begin{Bmatrix} Q_1 \\ Q_2 \end{Bmatrix}$$

$$For\ cast\ \rho = 2650\,, c = 921, K = 230\,, h = 0.3$$

$$For\ mold\ \rho = 1495\,, c = 1172\ .304\,, K = 0.519\,, h = 0.1$$

$$\begin{bmatrix} M_{11}^{1} & M_{12}^{1} & 0 & 0 \\ M_{21}^{1} & M_{22}^{1} + M_{11}^{2} & M_{11}^{2} & 0 \\ 0 & M_{21}^{2} & M_{22}^{2} + M_{11}^{3} & M_{12}^{3} \\ 0 & 0 & M_{21}^{3} & M_{22}^{3} \end{bmatrix} \begin{Bmatrix} \dot{T}_1 \\ \dot{T}_2 \\ \dot{T}_3 \\ \dot{T}_4 \end{Bmatrix} + \begin{bmatrix} K_{11}^{1} & K_{12}^{1} & 0 & 0 \\ K_{21}^{1} & K_{22}^{1} + K_{11}^{2} & K_{12}^{2} & 0 \\ 0 & K_{21}^{2} & K_{22}^{2} + K_{11}^{3} & K_{12}^{3} \\ 0 & 0 & K_{21}^{3} & K_{22}^{3} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{Bmatrix} = \begin{Bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{Bmatrix}$$

$$\begin{bmatrix} \frac{\rho ch}{3} & \frac{\rho ch}{6} & 0 & 0 \\ \frac{\rho ch}{6} & \frac{\rho ch}{3} + \frac{\rho ch}{3} & \frac{\rho ch}{6} & 0 \\ 0 & \frac{\rho ch}{6} & \frac{\rho ch}{3} + \frac{\rho ch}{3} & \frac{\rho ch}{6} \\ 0 & 0 & \frac{\rho ch}{6} & \frac{\rho ch}{3} \end{bmatrix} \begin{Bmatrix} \dot{T}_1 \\ \dot{T}_2 \\ \dot{T}_3 \\ \dot{T}_4 \end{Bmatrix} + \begin{bmatrix} \frac{K}{h} & -\frac{K}{h} & 0 & 0 \\ -\frac{K}{h} & \frac{K}{h} + \frac{K}{h} & -\frac{K}{h} & 0 \\ 0 & -\frac{K}{h} & \frac{K}{h} + \frac{K}{h} & -\frac{K}{h} \\ 0 & 0 & -\frac{K}{h} & \frac{K}{h} \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{Bmatrix} = \begin{Bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ Q_4 \end{Bmatrix}$$

33

Numerical Results and Discussion

This study required that, the thermo physical properties of the mold and cast used to be the same with the exact design and operating parameters applied to the numerical method and the results of the finite element under consideration are presented. The convergence characteristics of the results investigated using the finite element method and the same was compared with that obtained using the casting design experiment carried out in the laboratory.

Table 1.0: The experimental and simulation results for the Aluminium alloy casting with varying depth and time interval.

Time	Depth	Experiment	Two Elements	Four Elements	Six Elements	Sixteen Elements
10 seconds	0.15 0.30 0.40	1015.82 953.34 379.15	1010.62193548723 972.834367062859 366.885868037	1011.4086497234 961.582369410282 367.979633911067	1011.32808769438 986.582369410282 368.749801035115	1011.84574063924 989.008197030979 369.383791960745
360 seconds	0.15 0.30 0.40		1002.60128154947 877.16289321656 394.652136611883	1000.8413338759 882.190974091672 365.186127568229	1006.39117216883 886.190974091672 365.650220955691	998.485029826962 887.133056961885 357.767302458377
720 seconds	0.15 0.30 0.40		965.260582592331 7416.258005786902 339.162232268195	991.051395987855 767.404835359105 362.5688643843	989.051395987855 757.404835359105 354.611217801332	984.754919273365 764.397293851935 351.103400524978
1080 seconds	0.15 0.30 0.40		974.749201952007 972.941578725648 353.338482761951	969.955651996747 955.679615465766 342.916408006907	971.955651996747 954.745524285497 345.916408006907	977.358343087221 973.40960345229 345.944465321136
1440 seconds	0.15 0.30 0.40		945.358493023358 869.634722984895 366.961035509941	949.479308870257 947.350788646681 334.988951727876	968.479308870257 949.547981761712 334.988951727876	971.05702280206 968.067538874531 341.844849306516
1800 seconds	0.15 0.30 0.40	945.05 872.46 347.02	942.030324663603 866.385206874759 360.025415812382	944.426345032196 942.751381337014 331.499288197603	961.426345032196 942.751381337014 331.499288197603	965.406394192991 963.064756170268 339.554511701917
2160 seconds	0.15 0.30 0.40		940.761309272347 863.191932781068 352.551459512522	939.694732250537 938.373536917547 331.884868610573	956.694732250537 938.373536917547 331.884868610573	960.205015866332 958.339083327116 339.5328579542
2520 seconds	0.15 0.30 0.40		959.549267985032 860.052871254271 354.55877746047	935.215337676801 934.177157168021 335.312634518446	951.215337676801 934.177157168021 335.312634518446	955.338117742265 930.840124854382 341.765216114214
2880 seconds	0.15 0.30 0.40		956.392123733624 856.96604677231	930.938748679611 930.1317784967	950.938748679611 930.1317784	950.732433232328 949.5294542804

			9 336.066275998307	85 341.001489079903	96785 341.001489079903	61 345.972621125803
3240 seconds	0.15 0.30 0.40		936.287875616786 853.929555403903 337.092172579989	936.828606160706 926.21415550944 348.308054541091	946.828606160706 926.21415550944 348.308054541091	946.337699468701 945.377678917276 351.786812963571
3600 seconds	0.15 0.30 0.40	918.37 834.93 340.76	920.234595671709 850.941562603757 337.654020672623	922.857665597759 922.406449909048 356.730322049026	941.857665597759 922.406449909048 356.730322049026	942.117681711018 941.362024906496 358.843000336387

Source: Author's Field Work (2019)

III. CONCLUSIONS AND RECOMMENDATIONS

Table 1, showed the analytical results retrieved using the Linear Lagrange interpolation function of the Finite element analysis in comparison with the experimental outcome obtained from the laboratory indicated slight variations in different time interval. This is an indication that plugging in the exact laboratory conditions into the mathematical formulation of the physical process will yield comparable result and so evaluation of heat transfer in casting process can be achieved using finite element analysis. More so, due to the complexity of the solidification process, the compactness and intricacies present in the casting designs, it is usually difficult to take readings of the temperature distribution in the casting design. Therefore, the finite element simulation method affords the whole casting material into sub domains and analyzed the mid-section of the cast, the cast-mold interface and the mold wall.

The study therefore revealed the essence of preheating as seen in Table 1.0 that immediately after pouring the molten metal, there is a sudden drop in the temperature of the casting. Finally, this analytical result easily provided temperature history of the casting, mold wall and the mold every three (3) minutes after pouring the molten metal in the mold. This evidently shows that the finite element method is an efficient and accurate method in the simulation of heat transfer in sand casting.

The study thereby recommends the following based on the outcome of the analysis:

1. Casting Engineers and various Researchers in manufacturing sectors should prioritize the knowledge and the use of finite element analysis in casting.
2. Government should encourage the various engineering professions about the use of finite element analysis tool through optimization of casting designs.
3. The casting engineers should ensure that they improve their knowledge of finite element analysis for effectiveness.

REFERENCES

[1]. Kumar, C.L., Prasad, V.S., Varma, J.L., and Haritha, B.N., (2019). "Design and Experimentation of 3D Printed Pattern and Wooden Pattern for Sand Casting Process", International Research Journal of Engineering and Technology, IRJET; 6(4), 3685-3690

[2]. Ozioko, F.U. (2012) "Casting of Motorcycle Piston from Aluminium Scrap using Metallic Mold", Leonardo Journal of Practices and Technologies, 11(21), 82-92.

[3]. Ravi, S., Josh, D and Chougule, R. (2005). "Survey of Computer Applications in Indian Foundry Industry: Benefits and Concerns" 53rd Indian Foundry Congress, Institute of Indian Foundrymen, Kolkata.

[4]. Sheidi, H.M. (2012). "Investigation on Properties of Local Zircon Sand for Sound Casting: AzaraLafia Deposit Nigeria", Research Journal in Engineering and Applied Sciences; 1(6), 404-407.

[5]. Adegbuyi, P. A. O., Adedeji, K. A., Raji, N. A. and. Akinbuja, A. O. (2012). 'The Effect of Cooling Rate on the Microstructure and Mechanical Properties of Al-Si Alloy", Elixir Internal Journal of Mechanical Engineering; 52, 11638-11644

[6]. Heine, R.W., Loper, C.R and Rosenthal, P.C. (1967). "Principles of Metal Casting" The McGraw-Hill Companies.

[7]. Machuta, J and Nova, I. (2016). "Analysis of Heat Transfer Conditions in the Sand and Metal Moulds and Their Effect on the Solidification of the Casting".

[8]. Jelinek, J. (2004). "Binding Systems of Molding Sands", Chemistry Foundry Binders. 1.vyd, Ostrava.

[9]. Kleckova, Z and Hasek, P, (1990). "Determination of the Thermal Diffusivity of the Molding Mixture of the Chemical Composition Depending on the Temperature", Journal for Science, Research and Production; 16(2), 1213-2489.

[10]. Wang, W., Stoll, H.W. and Conley, J.G.(2010). "Rapid Tooling Guidelines for Sand Casting" Mechanical Engineering Series, Springer Science.

[11]. Nawi, A., Siswanto, W.A. and Ismail, A.E (2014). "A Study of Auto Pour in Sand Casting Process", Applied Mechanics and Materials, 660, 74-78

[12]. Jones, J.C (2000). "The Principles of Thermal Science and their Application to Engineering", Whittles.

[13]. Crawford, F.H. (1963). "Heat, Thermodynamics, and Statistical Physics", Rupert Hart-Davis, London, Harcourt, Brace & World, Inc.

[14]. Rihan,Y and El-Bary, A (2010). "Numerical Study on the Effect of Solidification Parameters during the Continuous Casting of Al-Sn Alloys", Online Journal of Mathematics and Statistics; 1(1), 8-12

[15]. Bala, K. C. and Khan, R. H. (2013). "Experimental Determination of the Effect of Mold Thickness on the Solidification Time of Aluminium Alloy (Al-Mn-Ni-Si) Casting in Rectangular Metallic Molds", International Journal of Engineering Research & Technology, 2(3), 482-487

[16]. Eman, J. A. (2011). "The influence of different casting method on solidification time and mechanical properties of Al –Sn castings", International Journal of Engineering Research & Technology; 11(6), 34-44

[17]. Madhusudhan, N.S., Mohankumar, G.C., and Mukunda, P.G (2010). "Effect of Mold Wall on Rate of Solidification of Centrifugal Casting", International Journal of Engineering Science and Technology; 2(11), 6092-6096

[18]. Madhusudhan, N.S.., Kumar, G.C.M., and. Mukunda, P.G (2010). "Experimental Study on Rate of Solidification of Centrifugal Casting":, International Journal of Mechanical and Materials Engineering; 5(1), 101-105.

[19]. Duval, J (1958). "Bureau of ships: Manual, Navy department." Navships, 250-0334.

[20]. Muthuraman,V., Arunkumar, S., and Baskarlal, V.P (2017). "Modelling and simulation analysis of metal castings". ARPN Journal of Engineering and Applied Sciences, 12(6), 1876–1879

[21]. Seetharamu, K.N., Paragasam, R., Quadir, G.A., Zainal, Z. A., Prasad, B. S. and Sundararajan, T (2001). "Finite Element Modelling of Solidification Phenomena", Sadhana Printed in India, 26(2), 103–120

[22]. Dhodare, A.S., Ravanan, P.M., and Dodiya, N (2017). "A Review on Interfacial Heat Transfer Coefficient during Solidification in Casting". International Journal of Engineering Research & Technology (IJERT) 6(2), 464 – 467

[23]. Kulkarni, S.N and Radhakrishna, D.K. (2011). "Effect of Casting/Mold Interfacial Heat Transfer during Solidification of Aluminium Alloys Cast in CO2-Sand Mold", Materials Science. 29(2), 135-142.

[24]. Belsare, S. U., Bhosale, A. B., Bogam, R. R., Deokate, M. V and Adewar, S. S. (2017). Study of Modeling and Finite Element Analysis for a Die Casting Component: A Review. International Journal of Innovative and Emerging Research in Engineering, 4(1)

[25]. Choudhari, C.M., Narkhede, B. E., and Mahajan, S. K. (2013). "Modeling and Simulation with Experimental Validation of Temperature Distribution during Solidification Process in Sand Casting, 78(16), 23–29

[26]. Reddy, J.N. (1993). "An Introduction to Finite Element Method. Second Edition, McGraw-Hill, Inc, 6-7.

[27]. Hutton, D.V. (2004). "Fundamentals of Finite Element Analysis" Massachusetts class note, 1.

[28]. Erhunmwun, I. D. and Ikponmwosa, U.B. (2017). "Review on Finite Element Method", J. Appl. Sci. Environ. Manage; 21(5), 999-1002

[29]. Awate, S.S. and Kore, S. (2014). "Finite Element Based Analysis of the Effect of Internal Voids on the Strength and Stress Distribution of Component", International Journal of Engineering Research and Technology. 3(12).

[30]. Lewis, R.W. and Roberts, P.M. (1987). "Modeling the Flow and Solidification of Metals: Finite element simulation of

solidification problems". Springer, Dordrecht; 61-92.

[31]. Kshetri, R., Gunwant, D., and Rawat, K.S. (2016). "Determination of Stress Concentration factor in Linearly Elastic Structures with Different Stress-Raisers Using FEM." Int. Journal of Engineering Research and Application; 6(2), 29-35

[32]. Juriani, K. (2015). "Casting Defects Analysis in Foundry and Their Remedial Measures with Industrial Case Studies", International Organization of Scientific Research (IOSR) Journal of Mechanical and Civil Engineering; 12(6), 43 -54

[33]. Rajkolhe,R., and Khan, S. (2014). "Defects, Causes and Their Remedies in Casting Process: A Review" International Journal of Research in Advent Technology; 2(3), 375-384.

[34]. Akpobi, J.A.., Erhunmwun, I. D. and Osunde, T. A. (2019). "Numerical analysis of the Temperature distribution in centrifugal casting", International Journal of Engineering Science and Application. 1(3).