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ANALYSIS OF DIFFERENT MOLD AND CAST MATERIALS IN RELATION TO THERMAL PERFORMANCE

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Abstract - *During the casting process, many complicated phenomena supporting metal solidification occur, such as cast metal flow, thermal gradient, and heat transmission between the cast metal and the mould. Both of these events, as well as the geometrical parameters and thermo-physical properties of the metal and the mould, determine the grain size and mechanical properties of cast metal. Convectional heat loss from the mould to the environment can impact the mechanical characteristics of cast metal. Using the finite element approach and the ANSYS software programme, two-dimensional numerical simulations of pure iron solidification in industrial AI 50/60 AFS greensand and mullite moulds were performed in this study. For this aim, the thermo-physical characteristics of iron were assumed to be temperature dependent, whilst the properties of sand and mullite were assumed to be constant, and the convection phenomenon was also studied on the mold's external surface. Metallurgical parameters such as the assault zone in the feed head and the hot top were not included in this study since they have no bearing on the metal's heat transmission to the mould. This type of problem is nonlinear because of the temperature-dependent thermo-physical characteristics of iron. The heat transfer data, as well as the thermal flux, thermal gradient, and convergence curves that determine the feasibility of the Newton-Raphson algorithm calculation process, are displayed in two dimensions. The heating and cooling curves in the mould, as well as the cooling curves at various sites of the solidified specimen, were also exhibited. These findings were deemed important.*

Key words: *Numerical simulation; finite elements; solidification of iron; sand and mullite mold*

1. INTRODUCTION

Casting is the process of producing metal into a determined shape by melting solid metal into liquid form, pouring it into a mold and letting it solidify into the desired shape. The mold is a negative copy of the shape of the casting. There are many other methods of shaping metals, such as machining, forging, welding, stamping and hot working. Casting has many advantages over the other methods of metal shaping for producing some particular shapes of metal and types of metal.

Casting can simplify production by casting a single complex shape piece instead of manufacturing a product that requires assembling several pieces together. Mass production of products can be done by casting; a large number of products in a single mold or in other cases by reusing the mold. Very large heavy objects can be cast which would be extremely difficult or economically impossible to produce by other methods. Some engineering properties in casting are better than objects produced by other methods. For example, uniform properties throughout the casting can be achieved if properly cast. Casting can give an economic advantage resulting from one or more of the advantages shown which may help in the competition against other types of manufacturing. (Heine et. al., 1995)

There are situations where other shaping methods are more suitable. For example, machining can achieve better surface finish and dimensional accuracy not achievable by casting; welding can join metal objects which may be produced by wrought or casting into more complex structures, stamping produces light weight sheet metal parts; and forging helps improve the strength and toughness of steel, etc. An engineer with knowledge of the possibilities of each shaping method may select a method or a combination of methods which best suits his or her work achieving high quality, low priced products (Heine et. al.,1995).

There are many processes for producing a casting depending on size, type of metal, complexity, dimensional allowance, quality and whatsoever. One of the oldest methods known is sand casting. Sand is mixed with binders and water so the sand grains hold shape, compacted in a flask which can be separated into two or more pieces with a pattern in the middle. This pattern will have approximately the same shape and size (or may be slightly different depending on the dimensional tolerance, shrinkage/expansion of the metal or machining allowances) of the desired casting. The mold is then parted, the pattern is removed and the compacted sand will have a negative shape of the pattern. The mold may be assembled with cores to give the casting hollow shapes, and the gating system, including runners, in gates, risers, sprues, etc., will be made in the mold. The liquid metal would then be poured into the mold. After the casting has cooled down, the mold is broken to remove the casting. The casting's gating system and risers would be broken off, the casting cleaned and then machined into the desired product.

Sand casting may be separated into green-sand mold casting, no-bake sand mold casting and shell-mold casting. Green-sand mold casting is silica sand and clay mixed with water, no-bake sand mold is silica sand mixed with resin that hardens within minutes after shaping and shell-mold casting is silica sand mixed with resin, shaped and baked to form the wanted mold shape (Society of Manufacturing Engineers).

Sand casting may be classified as Expendable Mold/Reusable Pattern process. Other Expendable Mold/Reusable Pattern process casting methods are the plaster-mold casting process, and ceramic-mold casting process (Society of Manufacturing Engineers). The lost wax casting method or investment casting process was used by Asian Indians to make sculptures of gods and goddesses for hundreds of years.

Full mold casting or evaporative-foam casting is done by packing loose silica sand around an expanded polystyrene (EPS) pattern. Molten metal is then poured into the mold through the gating system, burning out the foam pattern as it fills the mold. It is called full mold casting because the pattern is not removed, hence the name full mold. This method is suitable for even intricate castings and requires less labor and skill compared to sand casting. A mold must be used to make the EPS patterns and the mold should properly vent out the gases generated from burning the foam.

Another variation is vacuum casting, which also uses loose sand but held between two thin plastic sheets by vacuum applied to a pattern with a number of vent holes (Ravi, 2005).

Investment casting and evaporative-foam casting can be classified as Expendable Mold/Expendable Patterns Process. Another classification of casting process is Permanent Mold/No Patterns Process. The casting processes in this classification are permanent mold casting, die casting and centrifugal casting (Society of Manufacturing Engineers).

Gravity die casting (also called the permanent mold process) is a method which molten metal is poured into a cast iron mold coated with a ceramic mold wash. Cores can be made from sand or metal. After the casting has cooled down, the mold is parted and the casting is removed. This method is suitable for non-ferrous metals with medium sizes and moderate complexity and thickness (Ravi,2005).

Pressure die casting is a process which molten metal is injected into a hardened steel die under pressure. Usually this type of die is water-cooled and metal cores must be used instead of sand cores. The casting is removed by parting one half of the die and the casting is removed by ejector pins. This process is suitable for non-ferrous castings with small to medium size, varying complexity and thin walls (Ravi, 2005).

Centrifugal casting is a process which molten metal is poured into a horizontal rotating mold where the centrifugal force would push the molten metal to the mold wall.

	Tool Costs	**Labor Costs**	**Typical Tolerances**	**Surface Finish**	**Typical Volume**
Permanent Mold	High	Low	+/- .01 - .03 in	Good	Medium – High
Greensand	Low	Low	+/- 0.03-0.06 in	Average	Low-High
Die	Very High	Low	+/- 0.01 - 0.15in	Very good	Very High

Table 1 Various Casting Process costs and finishing

This method can produce pipes of tubes without using cores (Ravi, 2005) and the thickness of the casting wall depends on the amount of molten metal poured into the mold (Society of Manufacturing Engineers). An alternative to this process is the semi- centrifugal casting process which axis-symmetrical castings, like pulleys, gears and rotors can be produced while rotating about a vertical axis rotating mold. Another variation called the centrifuge casting is a process which mold cavities are arranged around a central axis. This method uses the rotation of the mold to get better filling characteristics (Ravi, 2005).

Squeeze casting or semi-solid casting is a process which semi-solid metal is forced under pressure into a metal mold. This method would give a casting fine microstructure free from dendrites. The mechanical properties of these castings are close to those of forgings. This method is useful for non-ferrous metals and composites and is also applied for aerospace and automotive parts (Ravi,2005).

The casting process starts from receiving an order from a customer which may include the design, dimension, physical properties, etc., then the foundry must plan how to make the castings, what methods must be used, then produce a prototype of the casting, modify the casting methods to get rid of the defects, produce the product, and last of all, the send the final product to the customer. Figure 1.1 shows the main procedures of a casting process, but the procedures in each casting facility may differ in detail.

Casting Process	**Cost**			**Production rate (Pieces/Hour)**
	Die	**Equipment**	**Labor**	
Sand	L	L	L-M	20
Investment	M-H	L-M	H	1000
Die	H	H	L-M	200

Table 2 Characteristics of various Casting Process

2. LITERATURE REVIEW

Guharaja et al. (2018) used Taguchi's approach to determine the ideal green sand casting parameters for attaining the best quality attributes of spheroidal or ductile cast iron. Green strength, moisture content, permeability, and mould hardness were all examined as process characteristics. The effect of the selected process parameters and their levels on casting defects, as well as the subsequent optimal parameter settings, were achieved using Taguchi's parameter design approach and confirmed with actual trials.

There must be studies and researches into the features of each component in each process in order for a casting simulation software programme to anticipate the results of a casting. Because casting pressure conditions in die casting have a significant impact on casting defects such as gas porosity, shrinkage porosity, and gas holes, Liu et al. (2015) investigated the effects of casting pressure, loading time, and piston position of pressure intensification on pressure variation and casting quality. Casting pressure, loading time, and piston location of pressure intensification were discovered to have significant effects on mould pressure variances, casting quality, and casting performance.

Metals usually shrink when they lose heat, which is similar to how a casting shrinks when it solidifies in a mould, but depending on the material, the casting may start to expand when it cools down to a specific temperature. The heat transfer rate is determined by the heat transfer coefficient (h) between two types of surfaces, which in the case of casting are the casting and the mould. However, because a casting may shrink during the solidification process, the h value may change due to the gap of air created by the casting shrinkage. The interfacial heat transfer coefficient (h) between high temperature casting alloys and moulds was measured by Wang et al. (2013) during the casting process due to gap creation. It was discovered that at the start of the casting, a high value of interfacial heat transfer coefficient is attained, then the value lowers abruptly, increases to a specific value, and then progressively falls. The heat transfer coefficient (h) value is also controlled by the mould material rather than the casting alloys; castings with ceramic moulds have a h value between 22W/m^2-K and 350W/m^2-K, whereas sand moulds have a h value between 40W/m^2-K and 90W/m^2-K.

De Looze (2015) investigated how the operational parameters of a low pressure die cast (LPDC) machine and the quality level of the aluminium melt influenced the casting cooling rate and/or microstructure. Microporosity generation and dispersion in the castings were employed as indicators of casting quality and solidification conditions, and experimental evidence for burst feeding in low pressure die casting was discovered. Die cooling resulted in considerable directional solidification improvements as well as micro structural refinement. Wong (2018) studied how to manufacture high-quality aluminium castings using Campbell's 10 casting criteria (Campbell, 2004). Campbell's criteria were used to create the runner and gating system, with proper runner and gating system designs including bottom filling, low filling rate, and good pouring basin, riser, and venting designs. The designs were then confirmed using CAE software. Three castings were manufactured and examined in this study, all of which passed X-ray and fluorescence penetration inspections. A CVD heater was cast using the sand casting method, a gate valve body was formed using the permanent mould die casting method, and an aerospace housing was cast using the Quick cast method.

Filipic (2014) investigated the use of an optimization tool that included an optimization algorithm and a casting process simulator. It was used to optimise spray coolant flows in an industrial casting machine. The manual control of coolant flow was greatly enhanced.

3. OBJECTIVES

1. To evaluate the cast material and mould material deformation and its durability with the help of Ansys.

2. To study the thermal stress of the cast material and mould material.

3. To interpret the temperature and Liquid fraction at each second of the cast material and mould material.

4. To analyze the heat flux from the container to the atmosphere.

4. RESULT & DISCUSSION

4.1 Results of the FE Modeling

Figure 1depicts the data collected from the simulations created to approximate the temperatures measured by vertically and horizontally mounted thermocouples.

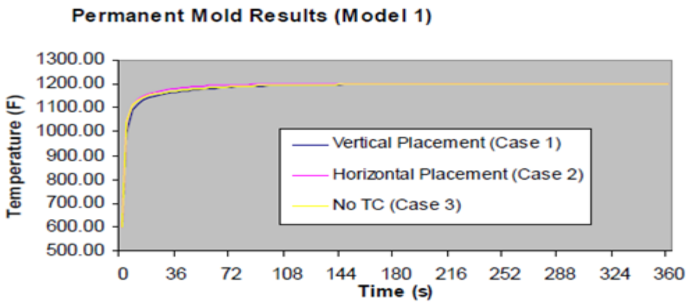

Figure 1. "Measured" Temperature vs. No TC

Figure 2 shows how the temperatures measured by vertically and horizontally mounted thermocouples differ from the temperature result.

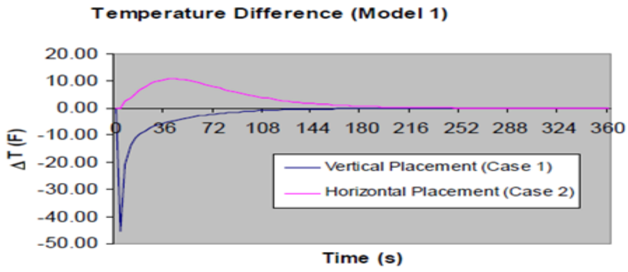

Figure 2. Temperature Difference Obtained by Comparing Each Thermocouple Configuration

The temperature field distortion can be seen by cutting a plane through the thermocouple bead (Figures 3 and 4). To show how the distortion progresses, a contour plot is given for different points in time.

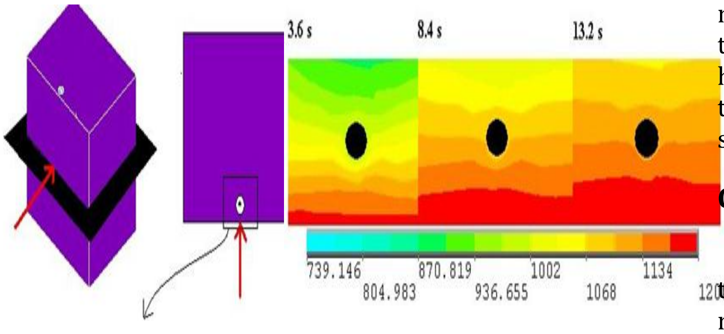

Figure 3. Temperature Field Distortion Caused by a Thermocouple Mounted Vertically in a Permanent Mold

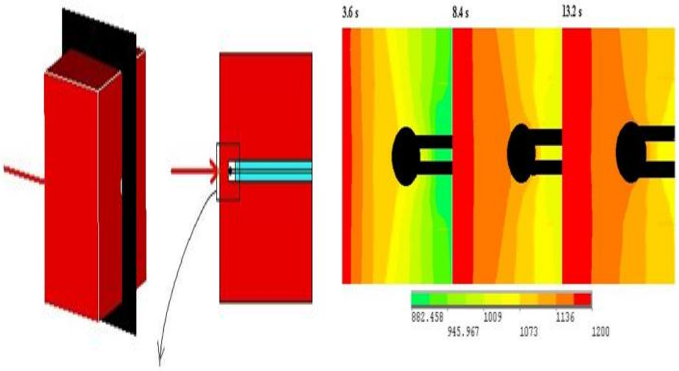

Figure 4. Temperature Field Distortion Caused by a Thermocouple Mounted Horizontally in a Permanent Mold

Figures 3 and 4 show a close-up view of the temperature field around the thermocouple bead at a certain point in time, with the arrow representing the step temperature applied to the front face of the mould material. The temperature scale is in Fahrenheit units.

Discussion

The necessity of thermocouple placement when recording transient temperatures is highlighted by the FE analysis discussed above. In permanent moulds, a hole must be bored to appropriately locate the thermocouple, and the hole, regardless of its contents, becomes a source of distortion. As a result, the temperature at the bottom of the hole will be different than it would be in an undamaged mould. As a result, even a perfect thermocouple would generate inaccurate temperature readings. A hole must be drilled to accommodate the thermocouple and insulator when the thermocouple is positioned vertically. The temperature field is plainly altered as a result of the hole's entrance. As a result, readings from a thermocouple bead placed at the bottom of the hole will be off from the real temperature. Continuing our consideration of permanent moulds, the hole itself has a substantial effect on the temperature when the thermocouple is positioned horizontally (perpendicular to the isotherms). As a result, the horizontally positioned thermocouple readings differ somewhat from the real temperature.

CONCLUSIONS

When using thermocouples to obtain transient temperature data, the placement of the thermocouple relative to the isotherms is crucial. By appropriately positioning the thermocouple, the error caused by temperature field distortion can be greatly decreased. In permanent moulds, the length of the thermocouple should be perpendicular to the isotherms. This arrangement improves overall temperature measurement accuracy by allowing you to adjust the distance between the interface and the thermocouple bead. In sand moulds, the thermocouple should be parallel to the isotherms, resulting in less conduction through the lead wires and more accurate temperature measurements.

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