DEFECT ANALYSIS ON INVESTMENT CASTING: A CASE STUDY

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to mak and abah,
Kakak, abang and adik[2],
And a friend who always be there,

Kalian amat berharga…

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ABSTRACT

Investment casting process is a manufacturing method for many critical and value added components in many industrial and commercial applications. The principal advantage over other processes such as fabrication, forging and extrusion is the production of a single and complex casting. the process is more prone to defects due to its complexity of part design and process.Therefore, this research has been conducted to identify defect that occurred in a part, which cast by investment casting process. Body Valve 1 is a product of MMI Precision Sdn. Bhd., and after a few batch of manufacturing, it was identified that leakage is one of major problem of the part. MAGMAsoft, a casting simulation software has been chosen as a tool to simulate the casting process, and the defect was predicted. To demonstrate the ability and accuracy of defect predictions made with MAGMAsoft, casting inspection has been done to verify the computational predicted result. Radiographic examination by using x-ray has become an option in comparing both experimental and computational result. It shows that there is excellent agreement between computer predicted and the result from Radiography as the defects occur at the same predicted locations and appears as shrinkage porosity. It is characteristic of a shrink to appear at heavier sections, at change of sections or at hot spots.

ABSTRAK

Proses tuangan pelaburan atau tuangan lilin adalah salah satu proses pembuatan untuk menghasilkan pelbagai komponen di bidang industri dan komersial. Berbanding proses pembuatan yang lain seperti tempaan dan penyempritan, tuangan pelaburan menjadi pilihan kerana kebolehannya menghasilkan produk tanpa melalui proses kedua. Namun begitu, proses tuangan pelaburan mudah terdedah kepada kecacatan semasa menghasilkan komponen yang mempunyai rekabentuk yang kritikal dan rumit. Maka, kajian in telah dilakukan untuk mengkaji kecacatan pada produk tuangan lilin. Perumah Injap 1 adalah salah satu produk keluaran MMI Precision Sdn. Bhd., dan telah dikenalpasti bahawa kebocoran pada produk menjadi punca masalah kepada pengeluar. Di dalam kajian ini, MAGMAsoft, satu perisian simulasi tuangan telah digunakan untuk menganalisis kecacatan pada Perumah Injap. Hasilnya, beberapa kecacatan telah diramalkan dan dikenalpasti. Untuk mengukur keberkesanan analisis berkomputer, pemeriksaan Radiografi menggunakan sinaran X-ray telah dilakukan ke atas spesimen. Hasil kajian simulasi dan eksperimen menunjukkan bahawa berlaku kecacatan porositi pada Perumah Injap. Kecacatan berlaku oleh pengecutan pada kawasan yang mempunyai luas permukaan yang lebih besar, pada perubahan bahagian permukaan atau pada kawasan hotspot.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Competition in many industries, especially the automotive and aerospace industries, is becoming increasingly intense. As manufactures of components strive to maintain profit margins whilst reducing cost, it is evident that the manufacturing process involved should be more productive with higher quality. Investment casting process is a manufacturing method for many critical and value added components in many industrial and commercial applications. Emphasis on the production of near-net shape components has further stimulated the growth of the investment casting industry in recent years. The principal advantage over other processes such as fabrication, forging and extrusion is the production of a single and complex casting. From jewelry and medical implants to larger industrial components, this process has evolved due to both market demand as well as technology advancements.

1.1.1 Investment Casting Process

Investment casting is among the most ancient of metal-crafting arts, conversely, it is among the most modern. The process of investment casting can be traced back to the early dynasties of China where artisans cast intricately detailed boxes from bronze to contain their masters' treasures.

The "lost wax" investment casting method was used by an Italian monk some 900 years ago to craft large statues. The monk's process was very similar to those used in investment casting today. For many centuries, jewelers used rubber molds to cast large quantity of rings and bracelets, and during the late 19th Century, dentists were using investment casting processes to manufacture dental fillings and inlays.

Industry realized the need for investment castings at the beginning of World War II with the sudden increase in demand for large quantities of intricately machined armament and aircraft parts. Manufacturers found that the "lost wax" process of casting these parts virtually eliminated all but the closest machining operations; thereby increasing their ability to produce critical items such as turbine blades and gun part at a fraction of their original costs. Knowledge gained from the dental trade was combined with the permanent die techniques perfected by jewelers to produce critical items in unbelievable quantities. The investment casting process begins by producing a wax pattern employing a precision mould, with similar technology as used in plastic injection moulding. The pattern is assembled with gates and risers, coated in ceramic layers, and is melted from the mould, leaving a cavity into which liquid alloy is cast. The technology embraces components from a few centimeters to more than 1.5 metres in overall size.

Investment castings are utilized today in virtually every industry where production quantities of metal parts are required. Furthermore, investment castings are now obtainable for prototype quantities of complex devices such as electronic housings, microwave components and subassemblies; without the necessity of producing the permanent dies to cast these devices.

1.1.2 Defects on Investment Casting

In many manufacturing process, there are defects in materials, processes or products. Investment casters face the same problem to achieve 100 percent free-from casting defect. Furthermore, the process is more prone to defects due to its complexity of part design and process. The common types of defects encountered in investment casting such as cold shut, hot spot, porosity caused by turbulence, hot tearing and hot cracks, unexpected deformation and distortion, micro-porosity caused by improper cooling, shrinkage porosity, misrun, shrinkage, stress cracks, inclusions and trapped gas. The occurrence of the defects will become a significant problem to the investment caster.

1.1.3 Defect Analysis

Quality control implies both prevention and cure of casting defects. Preferably, wasted production which results in a rejected casting should be prevented before it occurs. In quality control program, however, it is also necessary to correct diagnose defects which have occurred so as to promote proper methods to prevent reoccurrence in the future. Defect analysis is one way to identify the particular defect and prerequisite to correcting and control the quality of casting. A defect investigation and subsequent analysis should determine the primary cause of the flaw, and based on the determination, corrective action should be initiated that will prevent similar failure.

Often there are large numbers of inter-related factors affecting the occurrence of any defect and it becomes difficult to determine the exact causes. Even in controlled process, defects in the output can occur which defy rational explanation. Resulted from combination of varied discipline of physics, thermodynamics and chemistry, the root cause of a casting defects can truly become a mystery. It is therefore essential to understand the causes behind these defects so that they may be suitably eliminated.

1.2 Problem Statement

In this current work, a case study has been conducted in Metal Investment (MMI) Precision Sdn. Bhd., Ipoh. The company has been producing complex investment casting parts for many industries, namely electrical, mechanical and defense since two decade ago. Until now, much of the successes of MMI's engineering are a result of accumulated practical foundry knowledge over the past 20 years of doing business. The design process which involves high geometric complexity and material properties, has resulted "reactive engineering" since both factors requires the designers to endeavor to solve all sorts of problems encountered. Typically, mould designs go through iterations before a final configuration is achieved. In this case, trial and error approach is implemented during the development process. This is due the complexity of the process itself, which on the other hand helped the engineers to improve their skills and knowledge. Positively, they are gaining more insight to control the key variables each day during focusing on experimentation.

One of the problems associated with this method is when the design does not fulfill the design specifications; it produces defects on the casting part. A defect may arise from a single clearly defined cause or result from combination of factors, making it difficult to clarify its original cause. Recent practices are to correct design errors through modifications to the design itself or to the process, based on experience without attempting to diagnose the exact cause of the defects. Since it is relatively complex and expensive compared to other casting processes, these approach will become tedious, time consuming and significantly affect the total manufacturing costs.

Body Valve 1 is a product of MMI and manufactured for Paint maker, a company associated to paint production. This product is the imported to Italy. The part is made from high resistant corrosion stainless steel by an investment casting process. Since the product functions to control high pressure liquid flow, any defect can result leakage or break which may contribute to fatal accidents. After a few batch of manufacturing, it was identified that leakage is one of major problem of the Body Valve 1. Since the defects cannot be detected by visual inspections, an analysis should be conducted to determine the possible causes of the defects.

1.3 Casting Simulation Analysis

In recent years computer simulation of the process has begun to complement the experience-based approach in meeting the demands of high quality investment cast parts in a cost-effective manner. Modelling of solidification is becoming increasingly feasible with the advent of parallel computers. Software is available not only for thermal and flow modeling, but for calculation of grain structure, porosity, hot tearing, hotspot, and solid-state transformation. By visualizing the entire casting process in a virtual environment, problems associated with fluid flow, solidification and part distortion become apparent to the designer and foundry engineer.

In this research, an advantage should be taken by using this newly developed software to analyze possible causes that results defects during filling and solidification process. One of the most powerful casting simulation software in industry has been chosen as a tool to simulate the filling of a molten metal and the subsequent solidification of the metal, so that the defects can be predicted. The software used is MAGMAsoft, which is capable in predicting where folds or other defects may appear.

To demonstrate the ability and accuracy of defect predictions made with MAGMAsoft, another type of analysis has been done to verify the computational predicted result. Nondestructive (NDT) method is chosen, which detects and locates the casting defects present in the external part of the cast product. Radiographic examination by using x-ray has become an option in comparing both experimental and computational result.

1.4 Research Objective

The objective of this research is to identify the defect occurred in Body Valve 1, which cast by investment casting process.

1.5 Scope of Work

The analysis should be able classify the type of defect, probable location of defect and as well as explaining the cause of particular defect. Works documented in this research include

- A literature study on investment casting process and common defects on casting.
- Analyze the defects using computer simulation
- Verify the result using casting inspection,
- Suggest possible causes and remedies.

1.6 Definition

Investment Casting is a casting metal into a mold produced by surrounding, or investing, an expandable pattern with a refractory slurry that sets at room temperature, after which the wax or plastic pattern is remove through the use of heat prior to filling the mold with liquid metal. Also called precision casting or lost wax process.

Casting defect, by definition, is any imperfection in a casting that does not satisfy one or more of the required design or quality specifications. His term is often used in a limited sense for those flaws formed by improper casting solidification.

Defect Analysis is an action taken when defective casting is produced, containing general procedures, techniques and precautions employed in the investigation and analysis.

CHAPTER II

LITERATURE REVIEW

2.1 Overview

This chapter presented an introduction of investment casting, a brief outline of the process and some of its advantages. It is followed by discussion on casting defects and casting inspection. A new technology of casting simulation software was discussed in the last of this chapter and a few cases from a past and current research were reported.

2.2 Investment Casting Process

Investment casting uses a mold that has been produced by surrounding an expandable pattern with refractory slurry that has sets at room temperature. The pattern, usually of wax is then melted or burned out, leaving the mold cavity. Investment casting is also known as the lost wax or precision casting. The process of investment casting has many steps and unique compare with other casting. In sand casting, wood or metal patterns are used to make the impression in the molding material. The pattern can be re-used, but the mold is expandable. In investment casting, a metal pattern die is used to produce the wax patterns, which, in turn, are used to produce ceramic molds. Both the patterns and ceramic molds are expandable.

2.2.1 Investment Casting Process Outline

A typical investment-casting process involves the following operations, as shown in Figure 1. The process starts with inject the wax into molds to produce pattern. The pattern is made with an allowance for shrinkage. The wax patterns are assembled with the gating and feeding system and cleaned prior to their investment with the ceramic coating. This ceramic coating is built up through successive stages of dipping and stuccoing. The coated tree is thoroughly dried.

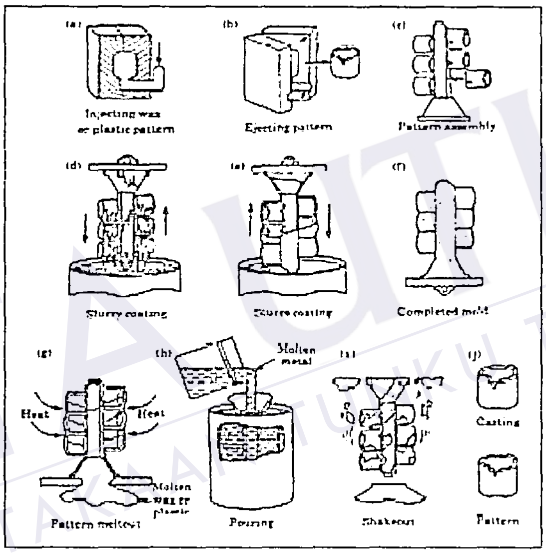

Figure 1: Illustration of Investment Casting Process

The pattern, gate, and sprue material is melted out of the mold by inverting (sprue opening down) and heating it in fire furnace. This produces a ceramic mold, the cavity of which takes on the shape of the original wax assembly. The mold then is burned out to remove all traces of wax to cure the investment. The mold is preheated, and the liquid metal is cast into it. After the mold cools and the cast metal solidifies, the mold material is remove from the tree, typically with an air-powered hammer or vibratory machine. The parts removed from the tree by bandsaw or abrasive wheel.

2.2.2 Advantages of Investment Casting Process

The benefits of the investment casting process are many, particularly for high performance parts and may be summarized as follows:

- Elimination of fabrication welds.
- Weight reduction.
- Machining reduction due to near-net shape maximized configuration complexity.
- Dimensional repeatability and consistency.
- Integration of complex design features.
- More efficient stress distribution.
- No draft necessary.
- Dense structure provides full mechanical properties.
- Smooth consistent surface finish.
- Single source convenience instead of numerous subcomponents from multiple sources.

2.3 Common Defects on Investment Casting

Defects that occur in investment castings generally are the same as those found in castings produced by other processes. The most common defects are gas holes and porosity, shrinkage, hot tears and inclusions.

2.3.1 Gas Holes and Porosity

Gas holes in casting are cavities, either spherical, flattened or elongated. Fundamentally, they are caused by localized gas pressure that exceeds the metal pressure in any locality during solidification of the metal. Gas follows the path of least resistance and hence moves usually towards the cope portions of the casting. Blows or gas holes may appear as depressed areas in the surface of the casting or as a subsurface cavity. Figure 2 shows Aluminium alloy casting containing blowholes.

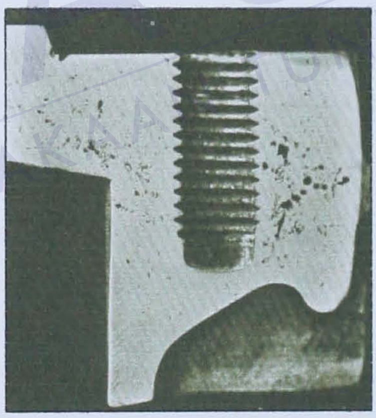

Figure 2: Gas Holes in an Alluminium Alloy Casting Cross-Section

Pinholes, blisters and body scars as well as certain types porosity are variations of gas holes. Gas holes and porosity are caused by the evolution and entrapment of gas in the solidifying metal. This gas may result from several sources: the entrapment of air during pouring, from evolution on contact between liquid metal and moulding material, or may be participated during solidification as a result either chemical reaction or of a change in solubility with temperature (Beeley, 1972). Colangelo and Heiser (1974) identified that the gas holes and porosity may occur individually or in massive clusters, depending on the gas concentration. They referred the individual cavities as gas holes and reserved the term gas porosity for those clusters or groupings. When the gas holes appear in an indeterminable number, they are generally referred to as gas porosity.

Due to Campbell (1991), surface turbulence is one of common mechanism which can produce gases during such action as pouring, splashing and stirring the molten metal. Reynolds number is usually cited to deal with turbulence, especially in running and gating system, defined as

$$\mathrm{Re} = Vd\rho / \mathrm{n} \tag{2.1}$$

where V is the velocity of the liquid, ρ is the density of the liquid, d is a characteristic linear dimension of the geometry of the flow path and n is the viscosity. At values of Re below about 2000, viscous forces prevail, causing the flow to be smooth and laminar, i.e. approximately parallel to the walls. At values of Re higher than 2000, flow tends to become turbulent; the walls are too far away to provide effective constraint and momentum therefore overcomes viscous restraint, causing the flow to degenerate into a chaos of unpredictable swirling patterns. Turbulence as predicted and measured by Reynolds's number is strictly bulk turbulence. Another dimensionless number known as the Weber number could be used to predict and measure surface turbulence:

$$We = V^2 \rho r / \gamma \tag{2.2}$$

where V is the velocity of the liquid, ρ is the density of the liquid, r is the radius of curvature of the surface and γ is surface tension. Generally to say, *We* numbers in the range 0.2-0.8 define the maximum limit for flow conditions that are free from surface turbulence. The above formulas indicate that adjusting the pouring velocity (if the dimensions and materials are fixed) can control the turbulence so as to avoid porosity as well as cracks related to gaseous interactions with the melt..

2.3.2 Shrinkage Defects

A shrinkage cavity is a jagged hole or spongy area lined with fernlike crystals called dendrites. Shrinkage is always occur during solidification. Solidificationof a metal casting begins at the casting surface and proceeds inward. As cooling and solidification proceed, contraction occurs. Colangelo and Heiser (1974) experienced that the contraction as a result of cooling of the liquid, change from the liquid to the solid and cooling of the solid. Usually, these various volume changes are occurring simultaneously in various parts of the casting. Thus, the last metal to solidify, usually near the center of the main casting or in heavier sections, bears the full impact of the contraction, and if the casting is not fed from a molten pool, a cavity will form. Figure 3 shows internal shrinkage on Al-Si alloy..

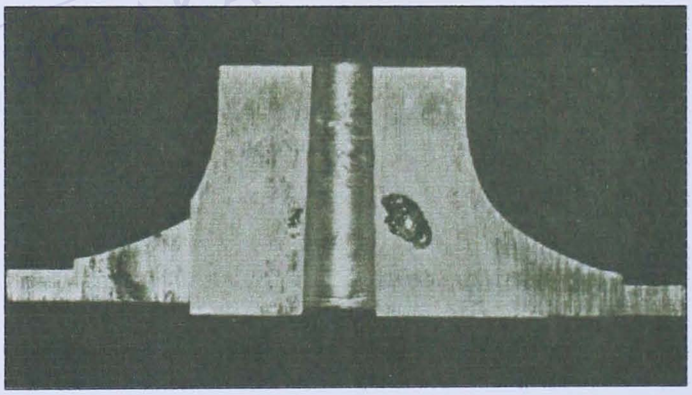

Figure 3: Internal Shrinkage Due to Excessive Metal Thickness

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