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DEFECT DETECTION IN HIGH PRESSURE DIE CASTING PRODUCT
USING IMAGE PROCESSING TECHNOLOGY

by

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Abstract

In this thesis an Automated Visual Inspection (AVI) system for defect detection of High Pressure Die Casting (HPDC) product has been developed. The system is enabling to detect external structural defects of the product particularly for crack and hole. This thesis also describes detailed procedures based on image processing technology which include enhancement/preprocessing, segmentation, coding/feature extraction and image analysis/classification/interpretation. The commercial Matlab image processing has been used to implement these procedures. An intelligent approach based on morphology and fuzzy logic is proposed to detect such structural defects on the surface.

The proposed method has been implemented and tested on a number of HPDC product. The results suggest that the method provide an accurate identification to the defects and be extended for further application. The results also suggest that the system work well enough to help die casting manufacturer to improve the value of die casting product that they can obtain from automated inspection system.

A few suggestions have been discussed for future research to address the limitations of this research.

Acknowledgments

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Special thanks to my wife Anizam Mohamed Yusof and my children Mursyidah & Danial for their love and encouragement. I dedicate this thesis to my parents for their unflagging faith in me. Without their devotion, support, patience, and encouragement throughout the period of study, this work would not have been possible.

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Nomenclature

Symbol	Explaination
A^*	The conjugate of matrix A
A'	The transpose of matrix A
$A \times B$	The matrix product of A and B
$\notin$	'is not an element of'
$\in$	'is an element of'
$\subset$	'is a subset of'
Σ a	$\Sigma a = a(x_1) + a(x_2) + \ldots + a(x_n)$

Chapter 1: Introduction

This chapter will begin by giving a rather detailed explanation of the background of the problem and explaining why it is necessary to introduce an automated visual inspection for High Pressure Die Casting (HPDC). Then, the suggestion to the problem, objective and limitation will be discussed.

1.1 Background of the problem

During the last two decades, the manufacturing environment has seen the introduction of many new technologies that have automated most of the major functions in a typical manufacturing environment. However, one major manufacturing function that still remains to be successfully automated is that of quality control and part inspection [1].

Traditionally, the inspection and quality control tasks have been performed on a labor intensive or manual inspection basis [2, 3]. These traditional inspection methods were based on a statistical quality control system in which the quality of an entire batch of products is defined by a process of statistical inference drawn from the inspection of a sample population of parts taken from the batch. The sample of products drawn from the batch would be inspected by a team of human inspectors that are inherently prone to making inspection errors although they are required to inspect a considerably reduced number of parts. Several independent surveys reported by Newman and Jain [1] have concluded that, even when given a rigid set of explicitly defined inspection tasks, human inspectors can at best only achieve inspection efficiencies in the region of 80%.

Traditional human inspector based inspection is an inefficient, time consuming and costly process that increases the overall production costs without being able to give 100% assurance of the quality of the part.

The delivery of a batch of poor quality parts can result in a drop of between 10% and 15% of the total sales of most products and up to 20% for manufactured components [4]. Considering the competitive nature of the global consumer market and its expectation for higher levels of quality at continually reduced values, manufacturers can no longer afford to implement traditional inspection techniques. As a result a method for automated inspection is required.

1.2 Problem addressed to die casting

High Pressure Die Casting (HPDC) process is considered as a modern manufacturing process, and mass production facility for high speed production. Compared to other manufacturing processes, HPDC is among the fastest production and can produce approximately 100 parts/minutes [5] for small components. Because of this, the inspection task become more complex and is normally the bottle-neck in an operation. As most products are manually inspected, many products may have to be scrapped when come to the final inspection stage after the process has been completed due to the lack of appropriate inspection systems at early stages. This problem can be reduced if all defects are identified as early as possible and the information is feedback to the controller to diagnose and control defects.

HPDC process is suitable for high volume production. If all products manufactured with HPDC need to be inspected, manual inspection will no longer economic as it contributes about 20% to the total production cost.

1.2 Suggested solution

With the increasing pressure on manufacturers and processors to deliver products at lower cost with increased quality, sometimes known as a '*zero defect culture*', has highlighted the need of applying automated inspection throughout the process [6]. Automatic inspection system can overcome many of these disadvantages and offer manufacturers to significantly improve quality and reduce cost.

The automated inspection system will greatly reduce the costs typically associated with the inspection process whilst simultaneously improving the quality assurance of the manufactured products. Furthermore the utilization of Automated Visual Inspection (AVI) technologies should significantly reduce the labor costs incurred in the inspection process by replacing the large team of semi-skilled workers with a small group of skilled operators, which is of particular benefit to developed countries where labor cost is very high and process innovations are urgently required by employing advanced technology.

Quality is more than just a manufacturing issues, it is also a marketing and business issue. By improving quality, production costs will decrease by labor saving through reducing or eliminating rework and scrap, and saving warranty and repair cost.

1.2 Aim/objective of the project

The aim of this project is to develop a visual inspection system using image processing technology. The system will be used for automatically detecting structural defects on high pressure die casting (HPDC) products. At this stage, only two types of defects i.e. crack and hole, will be analyzed in this study. However, the algorithm developed in this work for cracks and holes can be easily extended for the examination of any other kinds of defects.

The inspection system must be able to identify and classify those defects only using images taken from product and should be very quick and robust. These requirements are needed if the systems are going to be used for real industrial application and online inspection. They will replace the current human inspection system in the HPDC processes which is subjective and has many drawbacks mainly caused by human tiredness and slowness.

This project also demonstrates the application of an image processing tool Matlab, to the establishment of the inspection system. It will implement some algorithms that have been established in the Matlab to perform image processing tasks.

1.3 Scope and limitation

The following tasks have been setup in order to accomplish the aim of the project.

In this project, an overview of die casting process and vision system will be presented as a background knowledge and understanding to the problem. Only relevant information in image processing technology to be used in the current study discussed in details (as a methodology to solve the problem).

This project also requires developing a system to automatically detect any defects of HPDC products such as crack and holes. The system must be able to identify and classify the defects from a given image through the use of algorithms in image processing. The development of such a system will be based on technique and options available in the processing tool.

Images of defective components are taken from a previous project. No image acquisition process will be involved in this project. However procedures and processes of acquiring image for the normal situation will be presented.

1.4 Thesis roadmap

This thesis consists of five chapters. Chapter 2 describes an overview about high pressure die casting (HPDC) process, advantages and its application in manufacturing industries. It also discuss on different kind of defects in die casting and current procedure on inspection and technique to control defects. Overview on human vision and machine vision will also be discussed as well as their application in current industries. Chapter 3 describes an overview of an image acquisition process and storage. Chapter 4 describes image processing technology and procedure to detect defective area in the images. Chapter 5 describes an image analysis, classification and interpretation. Finally, Chapter 6 will summaries the finding of the study and describes the future research that needs to address the limitations of this work.

Chapter 2:

Literature Review

This chapter will discuss an overview of die casting process as background knowledge to the process on how the product has been made. Then, it followed by explanation of common defects and current procedure to detect defective component. The purpose of this discussion is to define what capability of the current procedure is to make sure all products are free from manufacturing defects. An overview of human and machine vision and some application on machine vision in robot and manufacturing process will also be discussed. Finally, an Artificial Intelligence (AI) used in industrial vision application will be discussed. The purpose of this description is to highlight that the use of an Artificial Intelligence is necessary particularly in decision making to enhance the system capability to adaptively control and monitor any possible defects on product.

2.1 Die Casting Process

The North American Die Casting Association (NADCA) [7] has defined the die casting as:

A manufacturing process for producing accurately dimensioned, sharply defined, smooth or textured-surface metal parts. It is accomplished by forcing molten metal under high pressure into reusable metal dies.

Die castings are among the highest volume, mass-produced items manufactured by the metalworking industry. Die castings are important components in thousands of consumer, commercial and industrial products such as automobiles, household appliances, recreation, farm and garden equipment, electrical equipment, general hardware, power tools, computers, toys, and a great many others too numerous to mention. In fact, die castings have greater utility and are used in more applications than components produced by almost any other metal forming process.

Die-casting can be done using a cold chamber or hot chamber process [8].

2.1.1 Hot Chamber Machines

Hot chamber machines (Figure 2.1) are used primarily for zinc, and low melting point alloys which do not readily attack and erode metal pots, cylinders and plungers. Advanced technology and development of new, higher temperature materials has extended the use of this equipment for magnesium alloys [8].

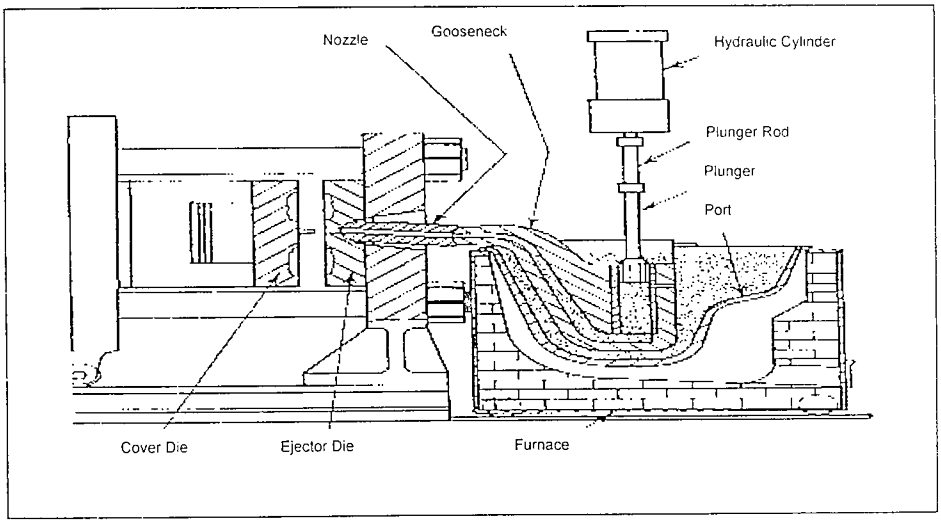

Figure 2.1 Hot chamber machine [8].

In the hot chamber machine, the injection mechanism is immersed in molten metal in a furnace attached to the machine. As the plunger is raised, a port opens allowing molten metal to fill the cylinder. As the plunger moves downward sealing the port, it forces molten metal through the gooseneck and nozzle into the die. After the metal has solidified, the plunger is withdrawn, the die opens, and the resulting casting is ejected [8].

Hot chamber machines are rapid in operation. Cycle times vary from less than one second for small components weighing less than one ounce to thirty seconds for a casting of several pounds. Dies are filled quickly (normally between five and forty milliseconds) and metal is injected at high pressures (1,500 to over 4,500 psi). Nevertheless, modern technology gives close control over these values, thus producing castings with fine detail, close tolerances and high strength [8].

2.1.2 Cold Chamber Machines

Cold chamber machines (Figure 2.2) differ from hot chamber machines primarily in one respect, the injection plunger and cylinder are not submerged in molten metal. The molten metal is poured into a "cold chamber" through a port or pouring slot by a hand or automatic ladle. A hydraulically operated plunger, advancing forward, seals the port forcing metal into the locked die at high pressures. Injection pressures range from 3,000 to over 10,000 psi for both aluminum and magnesium alloys, and from 6,000 to over 15,000 psi for copper base alloys [8].

In a cold chamber machine, more molten metal is poured into the chamber than is needed to fill the die cavity. This helps sustain sufficient pressure to pack the cavity solidly with casting alloy. Excess metal is ejected along with the casting and is part of the complete shot.

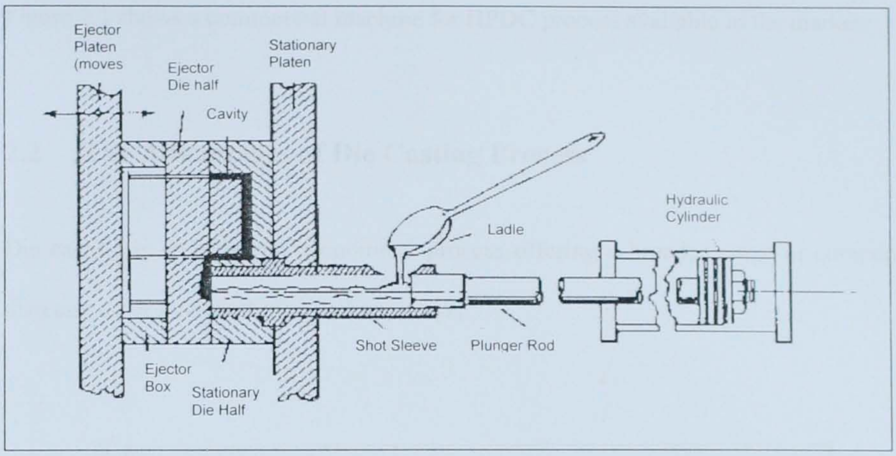

Figure 2.2 Cool chamber machine [8]

Operation of a "cold chamber" machine is a little slower than a "hot chamber" machine because of the ladling operation. A cold chamber machine is used for high melting point casting alloys because plunger and cylinder assemblies are less subject to attack since they are not submerged in molten metal [8].

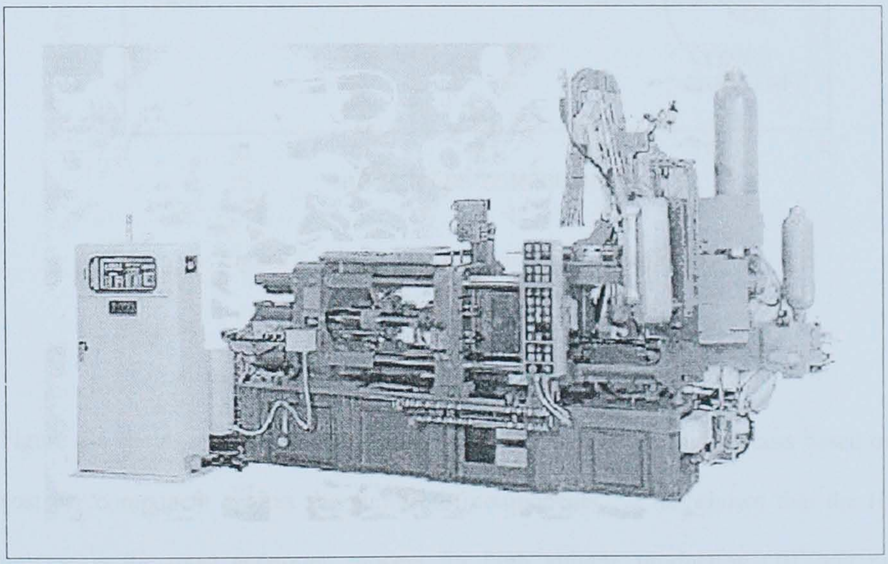

Figure 2.3 Commercial High Pressure Die Casting machine [9]

Figure 2.3 shows a commercial machine for HPDC process available in the market.

2.2 The Advantages of Die Casting Process

Die casting is an efficient, economical process offering a broader range of components than any other manufacturing techniques [9].

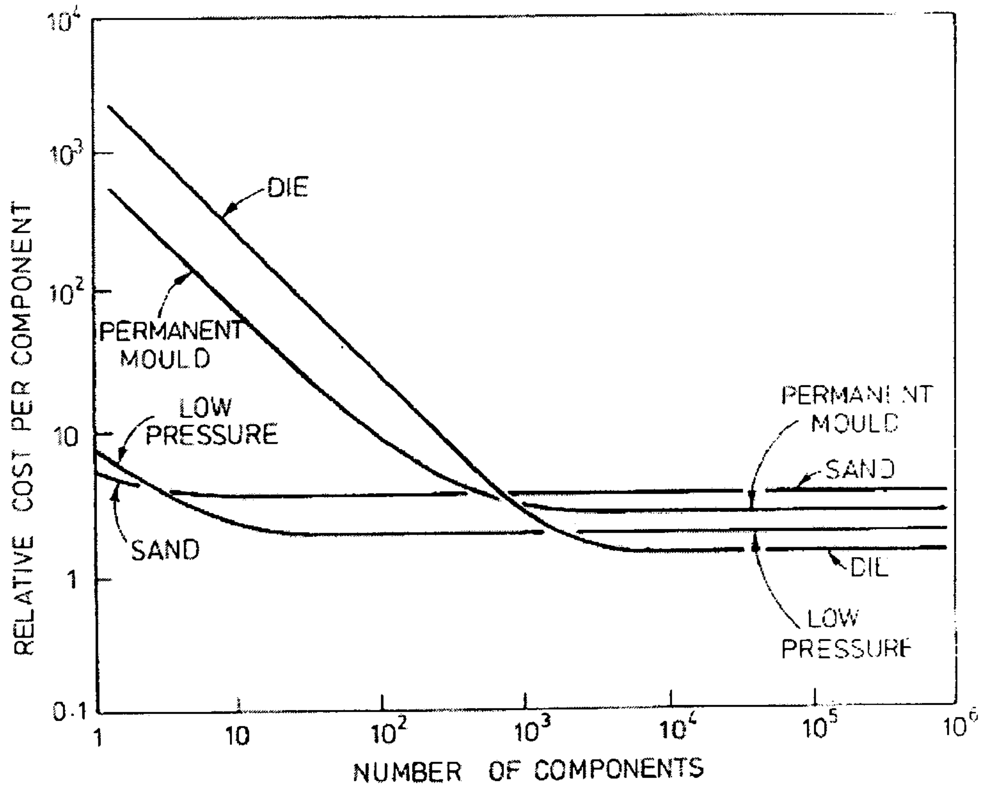

Figure 2.4 Process economic for die casting [5]

Figure 2.4 shows a chart for economic selection of several casting process based on the cost per component against the number of components. It has shown that the HPDC process is the most economic process for high volume production (10^3 and more).

followed by low pressure, permanent mold and finally sand casting. Other advantages are [5]:

High-speed production

Die casting provides complex shapes within closer tolerances than many other mass production processes. Little or no machining is required and thousands of identical castings can be produced before additional tooling is required.

Dimensional accuracy and stability

Die casting produces parts, while maintaining close tolerances.

Strength and weight

Die cast parts are stronger than plastic injection moldings of the same dimensions. Thin wall casting is stronger than those possible with other casting methods. In addition, because die casting is not consisted of separate parts welded or fastened together, the strength is that of the alloy rather than the joining material.

Multiple finishing techniques

Die cast parts can be produced with small textured surfaces, and they are easily plated or finished with a minimum surface preparation.

Simplified assembly

Die castings provide integral fastening elements, as bosses and studs. Holes can be cored and made to tap drill sizes, or external treads can be cast.

2.3 Application of Die Casting

Each of the metal alloys available for die casting offers particular advantages to the components. Therefore, the selection of materials for components varies depending on their function and properties of the components. Figure 2.5 shows the application of several alloys in different industry.

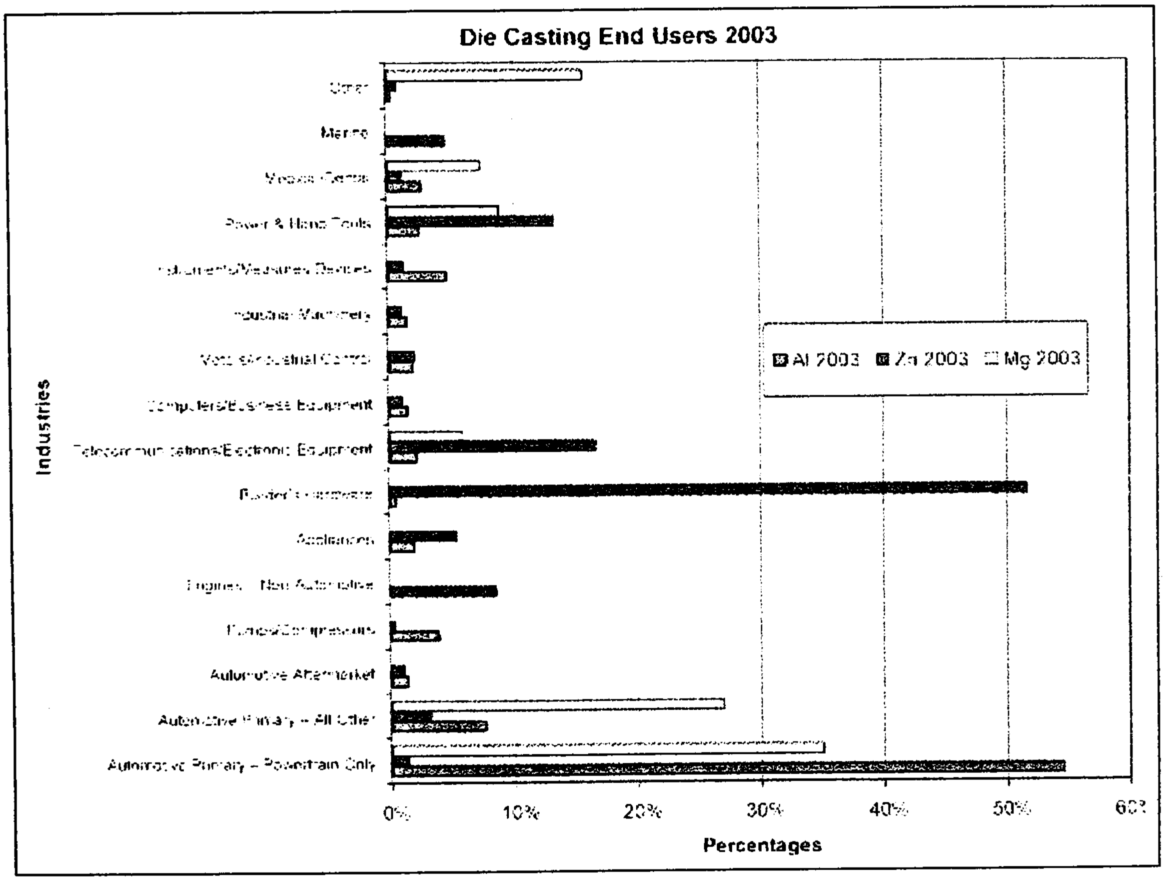

Figure 2.5 Die casting end user 2003 [5]

Some of the applications for these alloys are [5]:

Aluminum Die casting

Aluminum is lightweight and while processed high dimensional stability of complex shapes and thin walls can be achieved. Aluminum has good corrosion resistance and mechanical properties, high thermal and electrical conductivity, as well as strength at high temperature. Examples are the transmission housing in motor industries and the base for a Teleprinter.

Zinc Die casting

Zinc is the easiest alloy to cast, it offers high ductability, high impact strength and is easier platable. Zinc is economical for small parts and has a low melting temperature which prolongs the die life; Examples are the toys, small size components and the components that have a good surface finish such as chrome-plated.

Brass Die casting

This alloy possesses high hardness, high corrosion resistance and the highest mechanical properties of alloy cast. It offers excellent wear resistance and dimensional stability, with strength approaching that of a steel part; Example is the plumber hardware such as water taps and shower mixer.

Magnesium Die casting

The easiest alloy to machine, magnesium has an excellent strength-to-weight ratio and is the lightest alloy commonly die cast; Example is a mobile phone case.

2.4 Die Casting Defects

Die casting defects can be classified into external and internal defects. External defects are normally related to surface defects which can be visually identified whereas the internal defects are those defects that built internally and can be seen when certain operation has been carried out such as X-Ray, Ultra sound or any destructive process.

Both internal and external defects also have many different categories depending on geographical areas and when or how the defect has been accrued.

Some of the typical defects are as follows [10];

Surface defect:	Those defects are commonly called cold flow
Laminations:	Defect from layers of metal forming during the process
Gas Porosity:	Internal porosity from trapped gas of various kinds.
Blisters:	Surface manifestation of trap gas
Flow porosity:	Surface or internal porosity from poor pressure condition
Shrink porosity:	Porosity from the volume change as the metal changes state.
Sinks:	Surface depression from shrinkage porosity problems
Leakers:	Porous sections of the casting
Cracks :	Visible and not-so-very visible cracks in the casting
Inclusions:	Foreign material that may cause machining problems.
Holes:	Similar to crack, but it is a hole.

Sample images of the above defects are listed in Appendix A.

2.4.1 Defect for detection

As mentioned in chapter one, only two types of defect will be analyzed in this project, that is, cracks and holes. Cracks along with sinks and leakers are among the defects that have shrinkage problems as their common underlying cause. However, while shrinkage is the root problem for a great many cracks, there are a number of other factors that can also cause a crack.