UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMIZING CERAMIC SHELL THICKNESS TO ENHANCE ITS PERMEABILITY

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Design) (Hons.).

by

LEE PEI JING

B051210060

920422-14-5288

FACULTY OF MANUFACTURING ENGINEERING

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DECLARATION

I hereby, declared this report entitled “Optimizing Ceramic Shell Thickness to Enhance Its Permeability” is the results of my own research except as cited in the references.

Signature	:	……………………………………………
Author’s Name	:	……………………………………………
Date	:	……………………………………………

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons.). The member of the supervisory is as follow:

…………………………………….

(Official Stamp of Supervisor)

ABSTRAK

Laporan ini berkisahkan kajian berkenaan kadar optimum bagi ketebalan shell seramik untuk menambahbaik kebolehtelapannya seterusnya dapat mengurangkan kecacatan yang terhasil sewaktu proses casting. Sedikit pengenalan berkenaan teknik casting, kecacatan casting, dan cara penambahbaikkan untuk casting diterangkan. Suatu model CAD 3D telah direka sebagai ujian spesimen dengan ketebalan 4 mm hingga 8 mm untuk laporan ini. Kajian perbandingan dilakukan antara pengiraan manual dengan hasil daripada simulasi yang dijalankan. Pengiraan manual tersebut dilakukan menggunakan applikasi pengatucaraan Java manakala simulasi casting dijalankan menggunakan perisian AnyCasting. Perbincangan dalam laporan ini mengfokuskan tafsiran hasil kajian yang diperolehi daripada kedua-dua cara dan hubung kait mereka. Telah disimpulkan bahawa, cara pengoptimuman ketebalan shell seramik untuk menambahbaik kebolehtelapan adalah dengan mengurangkan ketebalan shell seramik tersebut, 4 mm adalah ketebalan terbaik dalam projek ini.

ABSTRACT

This report investigates the optimum thickness of ceramic shell thickness to enhance its permeability which can reduce the defection during casting process. A brief introduction of the technique of casting, casting defects and optimization method for casting are initially outlined. The 3D CAD model being designed as a test specimen with its thickness of range 4 mm to 8 mm for this report. The comparative study between manual calculation and simulation result is conducted. The manual calculation was applied using the Java programming while the casting simulations was carried out using AnyCasting software. The discussion then focuses on the interpretation of the results obtained from both methods. It is concluded to optimize the ceramic shell thickness to enhance it's permeability was achieved by minimizing the thickness of the ceramic shell to 4 mm.

DEDICATION

To my beloved parents

To my lovely brothers

To my honoured project supervisor

To my humble lecturers

To my circle of friends

Thank you Very Much

from Lee Pei Jing

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Thanks with lovely appreciation.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

&	-	and
3D	-	Three-Dimensional
ANOVA	-	Analysis of variance
CAD	-	Computer-Aided Design
CAE	-	Computer-aided engineering
cm	-	centimeter
DoE	-	Design of Experiments
Dr.	-	doctor
etc.	-	et cetera
FKP	-	Faculty of Manufacturing Engineering
FTK	-	Faculty of Engineering Technology
FYP	-	Final Year Project
GUI	-	Graphical User Interface
HPDC	-	High pressure die casting
LPDC	-	Low pressure die casting
m	-	meter
min	-	minutes
mm	-	millimetre
MOR	-	Modulus of Rupture
Mr.	-	mister
PSM	-	Project Sarjana Muda
STL	-	STereoLithography
TNS	-	The Natural Step
UTeM	-	University Technical Malacca Malaysia
XRD	-	X-ray powder diffraction
µm	-	micrometer

CHAPTER 1

INTRODUCTION

This chapter explains the background of the project. The title of this project is the "Optimizing Ceramic Shell Thickness to Enhance Its Permeability". Besides, the problem statements, the objectives of the project and the scope of the project are included in this chapter.

1.1 Project Background

This project investigates the optimum thickness of ceramic shell to enhance its permeability which can reduce the defection during casting process. Ceramic is an inorganic and non-metallic solid materials formed by shaping and heating in a specific high temperature. One of the methods normally used in industry is casting. Casting is a manufacturing method which a liquid material poured into a mould that contains a hollow cavity of the specified form, and so allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mould to complete the process. Metal casting needs the mould that normally uses ceramic as raw materials. Besides, there are some casting methods to make the ceramic product, and also several parameters which can affect the casting quality. Thus, the casting parameters are required to be analysed, design and control in order to produce better quality of casting. Different parameters can cause different casting defect. The parameters of casting are casting speed, casting temperature, mould surface, casting geometry and design of casting section. The parameters depend on the choice of mould materials and the casting methods.

The permeability is a measure of a ceramic material’s porosity, which is also referred as the passage of air through a given thickness of material at certain temperature and pressure. The manipulation of ceramic’s permeability is important in order to avoid air trapped in the shell cavity during casting. In this project will focus on the design of casting section by using different thickness (4 mm – 8 mm) with constant parameters such as temperature and pressure to find out the best thickness of material to magnify the permeability ability. The case study is carried out using SolidWork, AnyCasting software and the Java NetBeans programming. The SolidWork software is a tool to enable the creation of 3D CAD drawing, and the drawing can then be transfer to STL file for casting simulation purposes. On the other hand, the AnyCasting software is a tool to solve the casting analysis, which makes predictions possible on molten metal filing and solidification during the casting process. Then the gas permeability formula in Java software is used to obtain the value of gas permeability of investment casting with different shell thickness respectively. Lastly, both results from casting simulation and the calculation have been compared and conclude.

There are a total of five chapters in this project. The first chapter consists of introduction, problem statement, objective and scope of this project. Next, chapter two covers the literature reviews from previous researches that were related to the project such as the casting process, parameters of casting, casting defects, permeability properties and optimization methods for casting process. Meanwhile, chapter three was about the methodology of the project, describes the methods to conduct and execute the project. The result of the project and discussion of the result was written in chapter four. Finally, the whole project was summarized and concluded in the chapter five.

1.2 Problem Statement

Casting is one of the processes for the formation of ceramic product. The process paramaters are required to be manipulated accordingly to yield a good casting quality. As casting is a process that possess risk of failure, the process parameters need to control by having the knowledge about the effect of process parameter on the defect (Rajkolhe & Khan, 2014). There are some types of defects: surface defects (blow, scar, scab, drop, penetration and buckle), internal defects (blow holes, pin holes) and visible defects (wash, rat tail, hot tear, shrinkage, swell, shift and misrun). All these defects have its causes and remedies.

One of the common defects is blowhole, a type of cavities defect that the gases are trapped by the solidifying metal on the casting surface or body. The defects are always located in the cope part of the mould that undercut and poorly vented pockets. The blowhole defect has some possible causes. One of the causes is related to the low gas permeability of sand. The excessive gas is not able to flow through the mould. Then, the gas accumulates and forms into bubble in a mould cavity and the liquid metal are not able to filling the space. Besides, the other defects that caused by low gas permeability are the pinholes and gas porosity. The pinhole is very tiny hole that same as the blowhole which the gases are trapped in the casting body while undergo the solidifying process. Furthermore, the gas porosity is caused by the air that trapped when molten metal is filling the cavity of the mould and then compressed as more and more metal streams into the mould cavity and the pressure increases. When the cavity is full, the air becomes dispersed as small spheres of high pressure air and thus the swirling flow cause them to become elongated.

Furthermore, casting quality becomes a common issue in manufacturing industries. The casting quality is among the main factors that affect the production cost. The design of casting mould depends on the engineer’s experience and knowledge to carry out good quality of casting (Taufik et al., 2014). This trial and error method needs more development time and manufacturing cost. Hence, CAD design and simulation software are developed to optimize the casting quality. Meanwhile, the Ayoola et al. (2012) stated that the poor quality of casting can directly affect the mechanical properties of the casting product. The mechanical properties of casting product that undergoes poor casting quality such as tensile strength, ductility, hardness and surface roughness will decrease compared to the product that produced by good quality casting.

1.3 Objectives

The aim of this project is to find the best ceramic shell thickness to enhance its permeability.

The objectives of this project are as follows:

1. To develop a 3D CAD model of the test specimen for the case study.
2. To use the AnyCasting software to check the casting defects through simulation.
3. To conduct the comparison study between simulation results and manual calculations for finding out the optimal ceramic shell thickness to enhance its permeability.

1.4 Scope of Project

The investment casting was chosen as a casting method of forming a ceramic shell in this project. This is because this method is commonly used in the casting industry whereby it form a layer of ceramic shell on the surface of the wax with the shape of the product and then removes the wax to become a ceramic mould. This project mainly focuses on the case study to design the casting section by using different thickness (4 mm – 8 mm) with constant parameters such as temperature and pressure to find out the best thickness of the casting shell to magnify the permeability ability.

The design of the wax pattern is a solid cylinder shape, which is one of the simple shape for testing the different thickness which affect the permeability of the casting. The dimension of the wax part is following the design in journal written by Arunkumar, Deshpande, & Gunjati (2015). The tool used to design the wax part is SolidWork. Then, the tool that chose to use for this project is AnyCasting software due to it have advanced application to solve the AnyCasting software is a tool to develop the casting analysis, which makes predictions possible on molten metal filing and solidification during the casting process. In this software, the parameters such as processing temperature, pressure can be set constantly. The AnyCasting software can predict the possible defection in the cavity. Then, the gas permeability is calculated by using the Java programming with the respective formula. Lastly, both results from casting simulation and the calculation was compared and concluded.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the literature review on the optimizing ceramic shell thickness to enhance its permeability. The secondary sources such as journals, books, conference paper, research and websites were used to get the related information regarding the project. This chapter would provide a preliminary insight regarding the introduction of ceramics, introduction of casting, casting methods, casting rules and the casting defects.

5.1 Introduction of Ceramics

Ceramics are one of the three major industrial materials. The ceramic is an inorganic, non-metallic solid which created from either metal or non-metal materials that are formed then heated in high temperature for hardening purpose. The word “ceramic” comes from word in the Greek called “keramos”, which implies “pottery” or “burned clay”. Ceramics can divide into two classes: traditional and advanced (Rahman et al., 2014). The traditional ceramics are pottery, tableware, sanitary ware, tiles, refractories, blocks, structural clay products and electrical porcelain while the advanced or fine ceramics are highly refined materials with precisely adjusted compositions undergo well controlled process such as Barium Titanate ($BaTiO_3$), Silicon Carbide (SiC), Alumina (Al_2O_3) and etc.(Somiya, 2013).Generally the ceramics are considered as materials that brittle, hard; can withstand compression, high temperature and chemical erosion while weak in shearing and tension. Ceramic is high strength, high hardness, corrosive resistance and light weight which was stated in Tawadrous, Attia, & Laissy (2015). According to Bouville et al. (2014), ceramics are tough, strong and stiff which can retain their properties at high temperature about 600 °C. Besides, Ćurković et al. (2011) also indicates that ceramic is brittle, high wear and corrosive resistance, and have low density. The general properties of ceramic are shown in Table 2.1.

Table 2.1: The general properties of ceramic (The American Ceramic Society, 2014).

Mechanical Properties	**Level (Low/High/Very High/ Depend)**
Hardness	Very High
Elastic modulus	Very High
Thermal expansion	High
Ductility	Low
Corrosion resistance	High
Wear resistance	High
Electrical conductivity	Depends on materials
Density	Low
Thermal conductivity	Depends on materials
Magnetic	Depends on materials

5.2 Casting Methods

The casting is the most common technology which is economic to produce the components using raw materials such as metal and ceramic (T. Wang, Yao, & Shen, 2015). The casting technique need use ceramic to act as the mould for manufacture the metal components. Shruthi, Ramachandra, & Veerashekhar (2014) have states that the casting can produce components that are metal and ceramic, however for metal casting also need ceramic mould to produce the desired shape of the parts. The ceramic casting consists of several methods such as slip casting, tape casting and gelcasting while metal castings are sand casting, investment casting and plaster mould casting (S. Blackburn, 2005). All these methods have different procedures to produce the ceramics that meet certain function requirements.

2.2.1 Slip Casting

Most widely used in industry field of ceramic products is slip casting. This casting is a common traditional wet consolidation technique which will provide a uniform green compact through smooth particle movement and arrangement throughout the casting method (Kim et al., 2015). According to Zhang et al. (2015), an experiment was done to identify the optimum slurry composition to prepare the qualified green $BaCo_{0.7}Fe_{0.2}Nb_{0.1}O_{3-\delta}$ (BCFNO) tubular membrane using slip casting methods. The closed one ended membrane tubes were produced by steps in Figure 2.1. The aqueous slurry was prepared and poured into plaster moulds. Then, the green tubes were dried and sintered at high temperature for dwelling time.

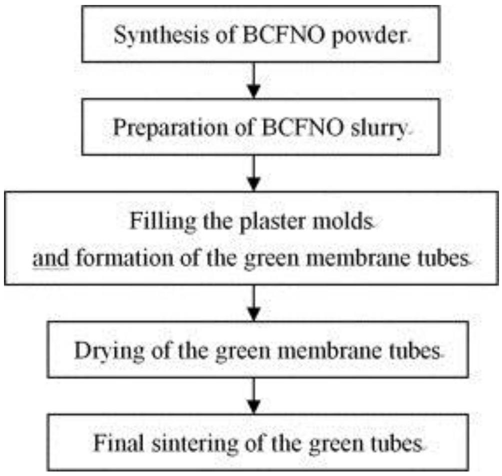

Figure 2.1: Schematic diagram for slip casting of BCFNO tube (Zhang et al., 2015).

2.2.2 Tape Casting

Another well-known ceramic casting technology is tape casting. Tape casting is suitable and cost effective technique to fabricate flat, thin ceramic sheets (Yu et al., 2015). The ceramic slurry is located in an initial chamber which hasa small ‘gap’. The thickness of the ceramic tape is controlled by a ‘doctor blade’. The thickness range of the ceramic tape is 1 - 1000µm. The slurry then passes through the oven to remove the liquid and forming a solid ceramic tube which will roll into a spool. The products produced from tape casting multilayer structure capacitors, solid electrolytes, ceramic substrates and solid oxide fuel cells (SOFCs). The alumina ceramics can be strengthened for improving its' reliability by using tape casting as proved by Yu et al. (2015). Furthermore, Nie et al. (2015) explains the fabrication of SOFC single cells is scalable and cost effective while applying tape casting and co-firing methods.

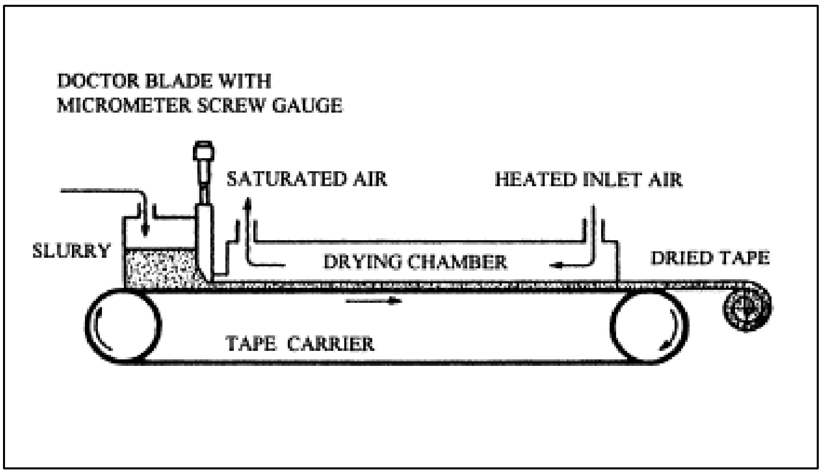

Figure 2.2: A continuous tape caster (Tok et al., 1999).

2.2.3 Gelcasting

Gelcasting is advanced ceramic forming technologies that have high performance in making ceramic parts with complex shape (Guo & Technology, 2011). Concentrated ceramic slurry is produced when ceramic powder mixed with monomer solution. Then, the ceramic suspensions are poured into a mould with specific design and undergo a heating process for the monomers to polymerize in-situ and create a green body. The remaining ceramic suspension in solvent form was removed by drying in air and burnout for binder removal. Lastly the ceramic product is sintered for obtaining optimal density(Yang et al., 2011). The flow chart of gelcasting process is shown in Figure 2.3.

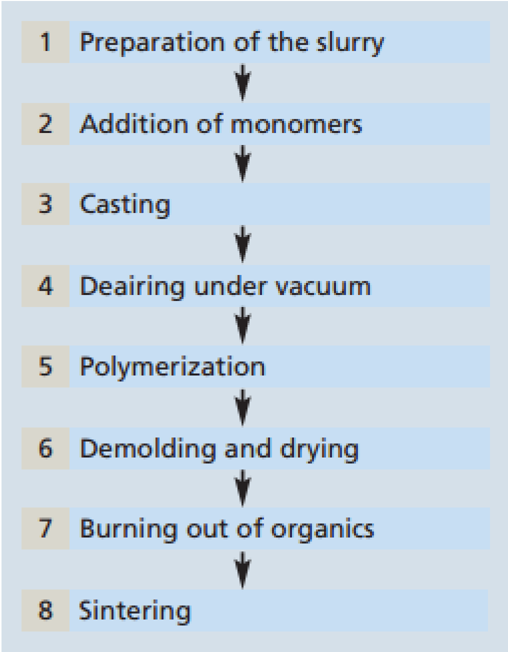

Figure 2.3: The flowchart of the gelcasting method(Dresden, 2013)

Guo & Technology (2011) indicates that the ceramic defects such as cracking and shrinkage in ceramic body were reduced while using gelcasting technique. The high solid content of the ceramic suspension with low viscosity and the higher solid loading was desired in gelcasting to have good performance to produce good quality of ceramic products. However, in gelcasting process will face difficulty to cast the ceramic slurry into the mould as the slurry having high viscosity. Therefore the monomer solution is added to attaining flowable of slurry.

2.2.4 Investment Casting

Investment casting is also called as lost wax casting which commonly used in producing a complex geometry of ferrous or non-ferrous materials. The ceramic shell casting methods become widely used techniques in major engineering applications (Pattnaik et al., 2012). The investment casting normally used to manufacture small and thin walled casting with complex geometry. The slurry is made of ceramic binder and powders contained of silica, zircon, alumina or other ceramic material (Jafari et al., 2013). The pattern which made of wax is dipped into the slurry to have a coating on the pattern's surface. After the thickness of refractory coat over the