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DEVELOPMENT OF A CERAMIC FOAM FILTER FOR FILTERING MOLTEN ALUMINUM ALLOY IN CASTING PROCESSES

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DEVELOPMENT OF A CERAMIC FOAM FILTER FOR FILTERING MOLTEN ALUMINUM ALLOY IN CASTING PROCESSES

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT OF A CERAMIC FOAM FILTER FOR FILTERING MOLTEN ALUMINUM ALLOY IN CASTING PROCESSES

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EHSAANREZA BAGHERIAN

September 2009

Chairman: Dr. Mohd Khairol Anuar Mohd Ariffin,Phd

Faculty: Engineering

Metal casting component are found in 90 percent of manufactured goods and equipment, from critical components for aircraft and automotive industry to home applications. However, molten metal used to produce metal casting in practice generally contains impurities and inclusions which are deleterious to final cast metal product. Currently, filtration technique by using ceramic foam filter has been accepted as a successful method of reducing inclusions from molten metal during the casting of metal parts.

The present research has been done to fabricate and improve a ceramic foam filter for using in filtration of molten metal, especially aluminium based alloys. It is an objective of the present innovation to provide a ceramic foam filter characterized by cost of raw materials. Ceramic foam filters are produced by impregnating polyurethane foam with ceramic slurry, drying, baking and finally firing the foam in the oven.

Experimental tests were carried out to the filters to measure dimensions, weight, cold compression strength, and permeability properties before

pouring process. After pouring process, the filter was cut into several sections to measure the macro and microstructure of the filter and ensure that impurity particles captured by a filter.

Thermal shock properties, obtained from pouring liquid aluminium when filter was placed in the gating system to ensure that the filters could withstand temperatures of aluminium alloys.

Further experiments were carried out to investigate and determine the efficiency of produced ceramic foam filter on quality of cast products. The result obtained in this investigation, the mechanical properties for aluminum LM6 alloy sand casting increased when ceramic foam filter was inserted into the gating system.

A produced filter by using new materials is economical to be produced. Further more, the analysis data shows present innovation filter which can be made in any shape and size, has excellent thermal shock resistance, adequate compressive strength, acceptable density and permeability properties.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBANGUNAN PENAPIS BUSA SERAMIK UNTUK PENURASAN ALOI ALUMINUM CECAIR DIDALAM PROSES TUNGAN

Oleh

EHSAANREZA BAGHERIAN

September 2009

Pengerusi: Dr. Mohd Khairol Anuar Mohd Ariffin,Phd

Fakulti: Kejuruteraan

Komponen tuangan logam ditemui dalam 90 peratus daripada barang-barang pembuatan dan peralatan, terdiri daripada komponen kritis untuk industri aeroangkasa dan otomotif hinggalah rumah aplikasi. Namun, logam cair yang digunakan untuk menghasilkan tuangan logam secara umumnya mengandungi ketidakmurnian dan inklusi yang akan merugikan produk akhir tuangan logam. Pada masa ini, teknik penapisan dengan menggunakan penapis busa seramik telah diterima sebagai satu kaedah yang berjaya bagi mengurangkan inklusi daripada logam cair semasa tuangan pada bahagian logam.

Penyelidikan sekarang dirangka untuk meningkatan busa penapis seramik untuk digunakan didalam penapisan logam cair, khususnya pada asas aluminium aloi. Ini adalah bertujuan daripada inovasi yang hadir untuk menyediakan busa penapis seramik bercirikan oleh kos bahan asas. Penapis busa seramik adalah dihasilkan dengan mencelupkan busa

poliuretan dengan sluri seramik, pengeringan, dibakar dan akhirnya menembak busa kedalam ketuhar.

Ujian-ujian percubaan dilaksanakan untuk penapis bagi mengukur dimensi, berat, kekuatan mampatan sejuk, dan ciri-ciri ketelapan sebelum dituang proses tuangan. Selepas proses penuangan, turas akan dipotong ke beberapa bahagian bagi mengukur makro dan mikrostruktur turas dan untuk memastikan zarah-zarah bendasing itu ditangkap oleh penapis.

Ciri-ciri kejutan haba, diperolehi dari penuangan cecair aluminium apabila turas adalah diletakkan kedalam sistem pengegetan bagi memastikan bahawa penapis tersebut boleh bertahan dengan suhu-suhu pancalogam-pancalogam aluminium.

Eksperimen-eksperimen selanjutnya dijalankan bagi menyiasat dan menentukan kecekapan untuk menghasilkan busa seramik turas bagi kualiti produk tuangan. Berasaskan hasil yang diperolehi didalam siasatan ini, sifat-sifat mekanikal untuk aluminium aloi LM6 tuangan pasir bertambah apabila turas busa seramik diletakkan ke dalam sistem pengegetan.

Sebuah penapis yang dihasilkan dengan menggunakan bahan-bahan baru adalah lebih jimat untuk dihasilkan. Lebih lanjut, data analisis yang menunjukkan kehadiran inovasi turas yang boleh dibuat pada sebarang bentuk dan saiz, terdapat rintangan kejutan haba, kekuatan mampatan mencukupi, ketumpatan boleh diterima dan ciri-ciri ketelapan yang baik.

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I certify that an Examination Committee has met on 10th September 2009 to conduct the final examination of Ehsaanreza Bagherian on his Master of Science thesis entitled "DEVELOPMENT OF A CERAMIC FOAM FILTER FOR FILTERING MOLTEN ALUMINUM ALLOY IN CASTING PROCESSES" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the relevant degree.

Member of the Examination Committee were as follows:

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follow:

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Date: 10 December 2009

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that if has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia (UPM) or other institutions.

Ehsanreza Bagherian

Date:

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

LIST OF ABBREVIATION

CFF	Ceramic Foam Filter
cm	Centimetre
CO_2	Carbon dioxide
TiB_2	Titanium boride
Ca	Calcium
Na	Sodium
Li	Lithium
Mg	Magnesium
ml	Millilitre
G	Gram
Si	Silicon
Cu	Copper
Mn	Manganese
Ni	Nickel
C_2Cl_6	Hexachloroethane
µm	Micrometre
min	Minute
AL_4C_3	Aluminium carbide
AL	Aluminium
AL_2O_3	Aluminium oxide
H	Hydrogen
ΔG	Gibbs free energy
γ	Interfacial energy
γ_{MI}	Interfacial energy between the melt and the liquid inclusion
γ_{MF}	Interfacial energy between the melt and the liquid inclusion
γ_{FI}	Interfacial energy between the filter and the liquid inclusion

ppi	Pores per inch
Da	Down sprue area (cm^2)
G	Poured weight (kg)
ξ	Friction factor
φ	Density (kg/dm^3)
t	Required pouring time (s)
H	Effective pressure or pouring height (cm)
Cr_2O_3	Chromium oxide
Cao	Calcium oxide
SiO_2	Silicon dioxide
Mgo	Magnesium oxide
B_2O_3	Boric oxide
°C	Celsius degree
KN	Kilo Newton
mm/min	Millimetre per minute
MPa	Mega Pascal
Kgf	Kilogram force
D	Diameter of the ball, mm
F	Test force, N
d	Mean diameter of the indentation, mm

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Metal casting is basically a process including (a) pouring molten metal into a mold patterned after the part to be manufactured, (b) allowing it to solidify, and (c) removing the part from the mold [1].

Many industrial parts and components are produced by the method of casting process such as engine blocks, crankshafts, automotive components, railroad equipment, plumbing fixtures, and power tools to home application [2]. Metal casting is a unique competitive process with other metal manufacturing processes. The most important reasons are: capable of producing complex shape components in both ferrous and non-ferrous metal, ranging in weight from less than an ounce for a single part to several hundred tons [1].According to the recent trends with increased competition, sales of metal castings are expected to grow to US$37.7 billion in 2008 [3].

The quality of casting basically is considered as producing casting products free of defects. Casting defects are divided into three groups [4]:

- Surface defect are due to poor design and quality of sand mould.
- Visible defect are causes of insufficient mould strength, low pouring temperature and bad design of casting.

- Internal defects found in the castings are mainly due to dirty metal. These defects also occur when excessive moisture or excessive gas forming materials are used for mould making.

Usually surface and visible casting defects can be repaired by technical operation such as welding, machining or sand blast operation, but inclusions may came from metal reaction with environment, crucible, mould materials, chemical reaction, slag and foreign material entrapped in molten metal can be reduced the strength of casting. Therefore the inclusion particles smaller than 30µm, should be filtered out during to casting process [1, 4].

"Filtration is the process of separating solid particles from the melt, with the solid particles being captured on the filter and the liquid phase passing through the filter. In addition to solid particles, there are also semi-liquid phases of high viscosity in molten metals; this fraction is captured by the adhesion mechanism and stick to the filter walls" [5].

Filter according to mechanism of filtration divided into multi-dimensional and single-dimensional. In single-dimensional filters, only inclusion on surface can be removed and inclusion smaller than the minimum cell or hole size are passed through the filter hole size. But, the small particle in multi-dimensional filters can be trapped in the internal filter surface [6].

Filtration technology was introduced into the aluminium industry in the late 1950`s [7]. Then, various filtration systems have been developed. The development of the Ceramic Foam Filter (CFF) or reticulated ceramic was in 1974 [8]. Then the application of filtration techniques expanded in the aluminium foundry industries. In 1992, eight million metric tons of aluminium was filtered with ceramic foam filter, It equivalent to almost 50% of the total production of aluminium in the world [9]. Since now, a majority of both ferrous and non-ferrous alloy are filtered during casting. Estimated global filter consumption in 2003 is presented in Table 1. As indicated to table 1, the product type totals in 2003 is equal to more than 650 million ceramic foam filter pieces per year [10].

1.2 Problem Statement

Since 1976-2007 several efforts had been done to fabricate various ceramic foam filters in foundry industry include U.S. Pat. No. 3947363 (Ceramic foam filter 1976), U.S.Pat. No. 4343704 (Ceramic foam filter 1982), U.S. Pat. No. 4391918 (Ceramic foam filter and aqueous slurry for making same 1983) and U.S. Pat. No. WO/2007/120483(Low expansion corrosion resistant ceramic foam filters for molten aluminum filtration 2007). Although all of the filters which have been fabricated in these patents have achieved acceptable ideal properties (high thermal shock resistance, adequate strength and low density), but none of them have been able to reach an acceptable price. Expensive price of these filters are related to high costs of additive raw materials such as Montmorillonite, Magnesium oxide, Chromium oxide, Calcium oxide, Boron trioxide or Silicon dioxide [11, 12, 13, 14].

1.3 Objectives

The key objectives in this study are:

(1) To fabricate ceramic foam filter for filtration of aluminium alloy with new cheaper additives materials including: Carbon, Bentonite, Silicon Carbide and sand from beach instead of Silicon Dioxide.

(2) To investigate and determine how the designed CFF affect the quality of cast products.

1.4 Thesis layout

This thesis is structured into 5 chapters and started with introduction and literature review to clarify the advantage and limitation of casting defects and refining technique. Detailed elaboration of theory and mechanism of filtration, benefit of ceramic foam filters and filters application in gating system. the Chapter 3 presents the methodology comprises the manufacturing process of ceramic foam filters which is includes: raw material preparation, selecting the sponge, slurry preparation , sponge immersing, removing excess slurry, drying and burning the sponge and other experimental tests to control the quality of filters. Results of experiments and data analysis overall discussed and explained in Chapter 4. The final conclusions of this study and recommendations for future research are in Chapter5.

Table 1: Estimated global filter consumption in 2003 [10]

Area	Foam (million)	Extruded (million)	Pressed (million)	Total (million)
Europe	149	16	53	218
N. America	55	72	102	229
Japan	74	7	4	85
S. America	40	0	6	46
S. Korea	36	3	1.5	40.5
Other Regions	10	5	20	35
Product type total	364	103	186.5	653.5
Global consumption	55.7%	15.76%	53%	100%

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The history of metal casting goes back to 3200 BC, through finding a copper frog which was found in Mesopotamia [15]. Since now, after 5000 years of technological advances, metal casting process plays a greater part in industry.

Global shipment of metal casting is growing at high rapid rate in the world which reached 90 million tons in 2008. Table 2 shows, shipments of metal casting worldwide are increase at an average annual rate of 2.4% from 2004 to 2008 [16]. Therefore, in this study, the selected literature is deliberated to provide knowledge on important aspects of sand casting and filtration process for refining of aluminum alloy.

2.1.1 General aspects of casting process

Mold designing and manufacturing process are two steps of metal sand casting process.

(1) Mold designing is the first step of sand casting process. The sand mold is enclosed in flask which involves of two parts: cope, the upper half and drag, the lower half. The plane between cope and drag is called parting plane which consists of sprue, runner and gate as shown in Figure1 [17].

- Sprue or down sprue is the vertical passage in parting plane connected to pouring cup.
- Runner is the horizontal distribution channels in parting plane.
- Gate is the connection between the runner and cavity of parting plane to be cast.

(2) Manufacturing process of sand casting is includes (a) mold preparation, (b) melting and casting, and (c) finishing operation.

- Mold preparation: Casting technology can be divided into two board categories according to the type of mold used: (a) permanent and (b) expandable mold [18, 19]. Permanent mold is one that can be used over and over again to produce many castings. It is generally made of metal that can withstand the temperature of alloy to be cast. Expandable mold is the mold that must be destroyed after solidification. Expandable mold is made by sand with the appropriate usage of binder such as clay, organic oil, resin and silicates [20, 21].
- Melting and casting: The melting of metals can be carried out in suitable furnace such as cupola, arc, induction and etc [22]. Cupola furnace is normally used for cast iron [23]. Electric arc furnace is use