UNIVERSITI PUTRA MALAYSIA

SIMULATION OF LM6 ALLOY WITH TI-B REFINEMENT IN SQUEEZE CASTING PROCESS

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By

MONA KIAEE

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, In Fulfillment of the Requirements for the Degree of Master of Science

April 2015

DEDICATION

To:

My dear husband

Mohammad

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

SIMULATION OF LM6 ALLOY WITH TI-B REFINEMENT IN SQUEEZE CASTING PROCESS

By

MONA KIAEE

April 2015

Chairman : Shamsuddin Sulaiman, PhD
Faculty : Engineering

Squeeze casting is a technique of casting which comes with the advantage of making casting products almost without porosity. It combines the advantages of casting and forging process and results in higher quality of products compare to the conventional casting techniques. Squeeze casting is widely used to produce quality casting of light materials such as magnesium or aluminum alloys. In this study, simulation of Finite Difference Method (FDM) was used to investigate the effect of die pre heat temperature and melt temperature on mechanical properties of squeeze cast aluminium alloy. The common defects of squeeze casting process and solidification on Al-Si alloys were also investigated. This study included three sections; the first set of simulation was to compare and verified the results with an experimental work on gravity die casting of aluminium-11.8% silicon alloy and Ti-B as a refinement. In the second section of this research, effect of squeeze casting process parameters on tensile strength, hardness and elongation was studied. In the final section, obtained results from first two sections were used to simulate a complex shape product of squeeze cast aluminium-11.8% silicon with Ti-B refinement. This section was to study the effects of squeeze casting parameters on microstructural and mechanical properties of Al-Si alloys. The common defects of air entrapment and air pressure were also investigated.

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

SIMULASI ALOI LM6 DENGAN PENGHALUSAN TI-B DALAM PROCES PENUANGAN HIMPITAN

Oleh

MONA KIAEE

April 2015

Pengerusi : Shamsuddin Sulaiman, PhD
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Penuangan himpitan adalah satu teknik penuangan dimana memberikan kelebihan produk penuangan dengan hamper ketiadaan keliangan. Dengan gabungan kelebihan penuangan dan proses tempaan memberikan keputusan kualiti produk yang tinggi berbanding teknik penuangan konvensional. Penuangan himpitan digunakan meluas untuk menghasilkan produk berkualiti dengan bahan yang ringan seperti aloi magnesium dan aluminium. Dalam kajian ini, simulasi Kaedah Perbezaan Terhingga (FDM) telah digunakan untuk mengkaji kesan suhu pra pemanasan dan suhu cair terhadap sifat mekanikal aloi aluminium menggunakan perisian Anycasting. Kecacatan biasa proses penuangan himpitan dan pemejalan aloi Al-Si juga telah dikaji. Kajian ini merangkumi tiga bahagian; set pertama simulasi adalah untuk membandingkan dan mengesahkan keputusan eksperimen penuangan acuan gravity aluminium-11.8% silicon dengan penghalusan Ti-B. Dalam bahagian kedua penyelidikan ini, kesan parameter penuangan himpitan ke atas kekuatan tegangan, kekerasan, dan pemanjangan telah dikaji. Di bahagian terakhir, keputusan yang diperolehi dari dua bahagian ini telah digunakan untuk simulasi bentuk produk komplek penuangan himpitan aluminium-11.8% silicon dengan penghalusan Ti-B. Dalam bahagian ini kesan parameter penuangan himpitan ke atas struktur mikro dan sifat bahan aloi Al-Si dan juga kecacatan biasa udara terperangkap serta tekanan udara telah diselidiki.

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I wish to express my special thanks and appreciation to my lovely husband who is my best friend and also a great thanks to my sweet heart Taravat.

I wish to express my special thanks to my dear family and my father and memory of my mother.

I certify that a thesis Examination Committee has met on 8 April 2015 to conduct the final examination of Mona Kiaee on her thesis entitled "Simulation of LM6 alloy With TiB Refinement in Squeeze Casting Process" in accordance with Universities and University Colleges Act 1971 and Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the candidate be awarded the Master of Science.

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LIST OF ABBREVIATIONS

Al-Si	Aluminium Silicon
ASM	American Society for Metals
BEM	Boundary Element Method
BS	British Standard
DAS	Dendrite Arm Spacing
DOE	Design of experiment
FDM	Finite Difference Method
FEM	Finite Element Method
HRC	Rockwell Hardness, C scale
HV	Vickers Hardness
M.T	Melt Temperature
MCF	Metal Compression Forming
MMC	Metal Matrix Composite
P.D	Pressure Duration
P.T	Pre Heat Temperature
PCPC	Pressure Counter Pressure Casting

SC	Squeeze Casting
SEM	Scanning Electron Microscope
SVD	Vacuum Die Casting Machinery
UTS	Ultimate Tensile Strength
YS	Yield Strength

CHAPTER 1

INTRODUCTION

1.1 Introduction

Since squeeze casting process is considered as a new technology for light alloys like aluminum and magnesium, more basic research is required for a scientific understanding of the practice. In distinct, as a cost-effective and resource-efficient tool, advanced numerical modeling in conjunction with dynamic boundary condition sand capabilities of predicting the formation of casting defects have to be fully developed for the optimization of squeeze casting processes. Nowadays various industries such as automotive industry have been moving towards making lighter parts. This light weight is usually achieved by redesigning, downsizing of part or using lighter materials such as aluminium (Al), magnesium (Mg) alloys [1].

The actual increase of usage in aluminium mostly results from conventional processes such as die casting and sand casting. As a result of process limitations, however, there are issues related to the nature of casting processes such as die cast products which have poor mechanical properties because of porosity and entrapped gas. Hence this technique is not an ideal procedure to fabricate large and thick components such as for automotive industries in which maximum engineering efficiency is needed.

Squeeze casting is a technique of casting which comes with the advantage of making casting products almost without porosity. It combines the advantages of casting and forging process and results in higher quality of products compare to the conventional casting techniques [2]. With this unique advantage, squeeze casting technology has been extensively developed and widely used for different aluminium alloys. The aluminium-11.8% silicon alloy, which is chosen for this research is an alloy with following advantages and disadvantages:

- High corrosion resistance
- Good hot tear resistance
- Good machinability
- Excellent pressure tightness
- poor weld ability [2].

The most common application of squeeze casting is to manufacture automotive parts from engine blocks to road wheels [3]. Although the metal casting family has a long history [4], squeeze casting process is comparatively new amongst varieties of castings. In spite of considerable research and study on squeeze casting process, there are still some unanswered fundamental questions. At the meantime, optimization must be done in order to expand SC applications [5].

Mathematical modeling of casting processes has been used since 1965. Today computer simulation facilitates the analysis and optimization of the process in advance and undertakes defects prevention jobs. The advantages of using simulation are as below:

- Product defects elimination
- Design and development times shortening
- Production cost reduction
- Product quality enhancement
- Process efficient enhancement [6].

1.2 Problem Statement

In squeeze casting the casting die interfacial (boundary) conditions are different from other conventional casting such as sand casting or die casting. In fact because of applied pressure to the molten metal before, during and after of solidification, the boundary conditions are changing when molten metal is changing its phase from liquid to solid [5]. In casting simulation model as same as other computer simulations, minor changes in the boundary conditions can totally change the modeling prediction results. Hence, to have valid and reliable simulation results, proper boundary conditions must be imposed.

Despite the fact that there have been several studies on the simulation of squeeze casting, they have investigated only one parameter or some of the casting parameters independently. While there is lack of research work on the effect of combination of parameters on phase changing, heat transfer, fluid flow and casting-die interaction in squeeze casting. The effect of parameters on squeeze casting defects is also essential to be further studied.

1.3 Research Objectives

The aim of this project is to build a numerical model for simulating squeeze casting processes for aluminium alloy. The objectives of this study are:

1. To simulate the squeeze casting process of aluminium silicon 11.8% alloy with Ti-B refinement and to investigate effect of different casting parameters on simulation results.
2. To verify simulation results with experimental works and to find the optimum parameters to be used for simulation of squeeze casting on a complex shape model.
3. To analyze the effect of casting parameters on common defects of squeeze cast product for simulated models.

1.4 Scope of the Study

The current work attempts to use computational simulation method using Anycasting software in order to model a squeeze casting process of aluminium-

11.8% silicon alloy to determine pressure, melt temperature and die pre-heat temperature parameters performance on mechanical properties.

This study includes three sections; the first set of simulation is to compare and verify the results with an experimental work on gravity die casting of aluminium-11.8% silicon alloy and Ti-B as a refinement. In the second section of this research, effect of squeeze casting process parameters on tensile strength, hardness and elongation have been studied. In the final section, obtained results from first two sections have been used to simulate a complex shape product of squeeze cast aluminium-11.8% silicon with Ti-B refinement. In this section effect of squeeze casting parameters on microstructural and mechanical properties of Al-Si alloys and defects of air entrapment and air pressure have been investigated.

1.5 The Layout of the Thesis

The research will report the whole process and results of performed research in five chapters as listed below:
Chapter 1, Introduction, presents an introduction and background of the research, the problems and the main objectives of this study. Chapter 2, Literature review, presents the previous research on squeeze casting to give both a basic concept of this casting process and a background review of modeling and simulation development in the casting industry. Chapter 3, Methodology, explains the methods and strategies, which are used in the research to achieve the specified objectives. The procedures of the model pre-processing and post-processing modules of ANYCASTING are also discussed. Chapter 4, Results and Discussions, expresses the obtained modeling results in details and presents a complete discussion and validation with empirical data from standards and previous works. The results are illustrated as Tables, plotted curves, Figures. Finally Chapter 5, Conclusions and Recommendations, lists the final achievements and verifies them with the drawn objective in the first chapter to ensure that the objective has been fulfilled. Some of the shortage within this research and developments are presented at the end, in order to recommend some ways to improve the present research in future.

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APPENDICES

Appendix A: Structure of Anycasting simulation program

Anycasting software package includes 4 modules:

1. anyPRE (Geometry & Mesh Generation)
2. anyDBASE (Material & Defect Database)
3. anySOLVER (Flow & Solidification Solver)
4. anyPOST (Post Processor & Auto-Report)

System Capabilities

- **FEM Thermal Stress System**
  - FDM / FEM Interface by Multi-Phase Interpolation
  - Fast Generation of Surface & Solid FEM Element
  - Element & Geometry Error Correction Functions

- Mushy Zone & Air Gap/Contact Considerations
- Critical Deformation during Heat Treatments

- **Quick Simulation Control**
  - Automatic Gate Detecting: Multiple Gates, Inlet Types
  - Solution Running with All Display Views
  - Easy Implementation of Measuring Sensor
  - Solution Control Functions

- **Excellent Solving Speed**
  - Speed: 3 hours for 5 million meshes by 1GB PIII
  - Memory: 25 Megabyte for 1.5 million meshes
  - Stable and Exact Calculation

- **Heat Transfer Coefficient**
  - Automatic Material Contact Detecting
  - Selection of HTC from Database
  - Temperature, Time Dependent, User Defined

- **Coating Layer Effects**
  - Set Coating Conditions (Type, Thickness, etc.)
  - Coating Properties from Database, User Defined

- **Fully 3D Graphic System**
  - Open GL Based, MDI(Multiple Document Interface)

- Any Section View & Free Moving in All Directions
- Acceleration Tech.: Graphic and File Accessing

- **Mechanical Properties Prediction**
  - Based on Empirical Formulas by Experiments
  - Hardness, UTS, YS, Elongation, etc.

Appendix B

International Cross References – Aluminium and Aluminium Cast Alloys

INTERNATIONAL CROSS REFERENCES – ALUMINUM & ALUMINUM CAST ALLOYS						
USA AA	UK BS	GERMANY DIN	FRANCE NF	INTERNATIONAL ISO	JAPAN JIS	RUSSIA GOST
A242	4L35	---	A-U4NT	Al Cu4Ni2Mg2	---	AL1
---	---	AlCu4Ti	---	Al Cu4Ti	---	AL19
204	---	AlCu4TiMg	A-U5GT	Al Cu4MgTi	AC1B	---
295	L154	---	---	---	AC1A	AL7
203	---	---	A-U5NKZr	---	---	---
---	---	---	A-U8S	---	---	---
222	LM12	---	---	---	---	---
355	LM16	3.2134	---	AlSi5Cu1Mg	AC4D	AL5
363	---	---	A-S5U3G	AlSi5Cu3	AC2A	AK5M2
---	LM4	---	A-S5U3	---	---	AL6
319	LM21	AlSi6Cu4	A-S5UZ	AlSi6Cu4	AC2B	AK5M
---	LM27	---	---	---	---	AK7M2
320	---	---	A-S7U3G	---	---	---
380	LM24	AlSi9Cu3	A-S9U3	AlSi8Cu3Fe	AC4B	AK8M3
---	---	---	A-S9U3Z	---	---	---
383	LM2	---	---	---	---	---
---	---	VDS-Nr260	A-S12UNG	---	AC8A	---
---	---	---	---	---	---	---
---	---	---	---	---	---	AK12M2N
390	LM30	---	---	---	---	---
---	LM28	---	---	---	---	---
393	LM29	---	---	---	---	AK21M2N2
A443	---	---	---	Al Si5	---	---
B443	---	---	---	Al Si5Fe	---	---
A444	---	---	---	---	---	AK7
---	---	---	A-S9	---	---	---

INTERNATIONAL CROSS REFERENCES – ALUMINUM & ALUMINUM WROUGHT ALLOYS						
USA AA	UK BS	GERMANY DIN	FRANCE NF	INTERNATIONAL ISO	JAPAN JIS	RUSSIA GOST
1050	---	---	---	---	A 1050	---
1050A	1B	A199.5	A5	Al 99.5	---	---
1060	---	---	---	Al 99.6	A 1060	A6
1065	---	---	---	---	---	---
1070	---	---	---	---	A 1070	A7
1070A	---	A199.7	A7	Al 99.7	---	---
1080	---	---	---	---	A 1080	---
1080A	A8	A199.8	A8	Al 99.8(A)	---	---
1085	---	---	---	---	A 1085	---
1090	---	---	---	---	A 1N90	---
1098	---	A199.98R	---	---	---	---
1100	A45	---	A45	Al 99.0 Cu	A 1100; A 1N00	---
1185	---	---	---	---	A 1185	A85
1199	---	---	---	---	---	A99
1200	A4	A199	A4	Al 99.0	A 1200	A0
1230	---	---	---	Al 99.3	A 1N30	---
1250	---	---	---	---	---	---
1350	---	---	---	E-Al 99.5	---	A5E
1350A	---	E-A1	---	---	---	---
1370	---	---	---	E-Al 99.7	---	---
2001	---	---	A-U6MT	---	---	---
2007	---	AlCuMgPb	---	---	---	---
2011	FC1	AlCuBiPb	A-U5PbBi	Al Cu6BiPb	A 2011	---
2011A	H15	---	---	---	---	---
2014	---	AlCuSiMn	A-U4SG	Al Cu4SiMg	A 2014	1110
2014A	---	---	---	Al Cu4SiMg(A)	---	---
2017	---	---	---	Al Cu4MgSi	A 2017	---

Appendix C: Result of squeeze casting simulation

Simulation and result of squeeze casting step 1

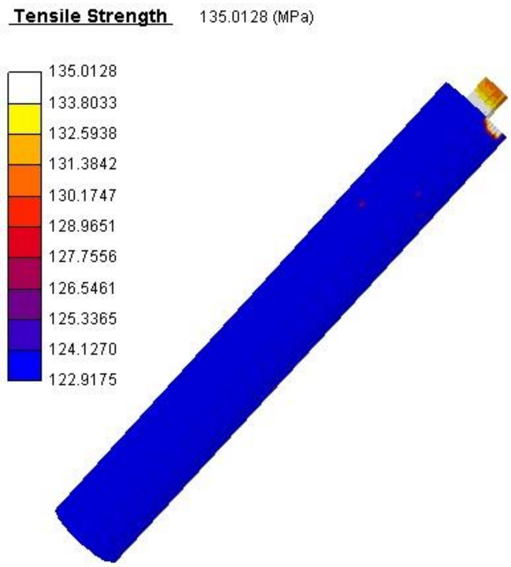

Figure C. 1Simulation of tensile strength, step 1 (S.P: 50MPa, D.P: 350°C, M.T: 700°C)

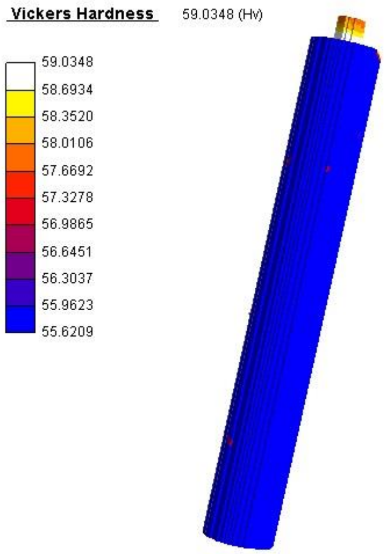

Figure C. 2 Simulation of Vickers hardness, step 1 (S.P: 50MPa, D.P: 350°C, M.T: 700°C)

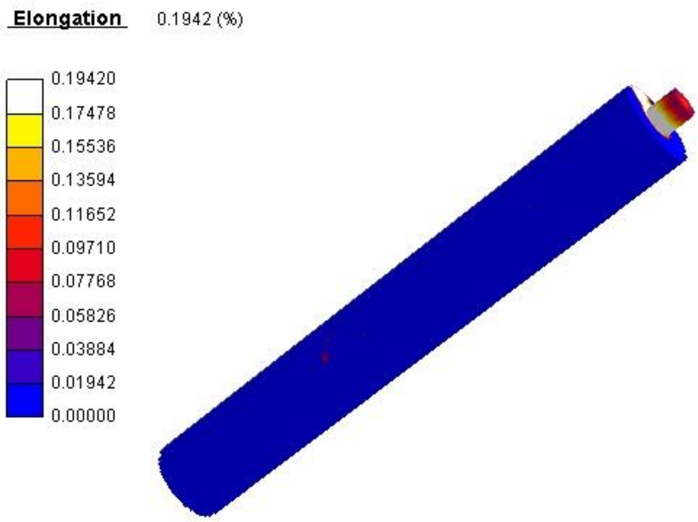

Figure C. 3 Simulation of elongation, step 1 (S.P: 50MPa, D.P: 350°C, M.T: 700°C)

Simulation and result of squeeze casting step 2

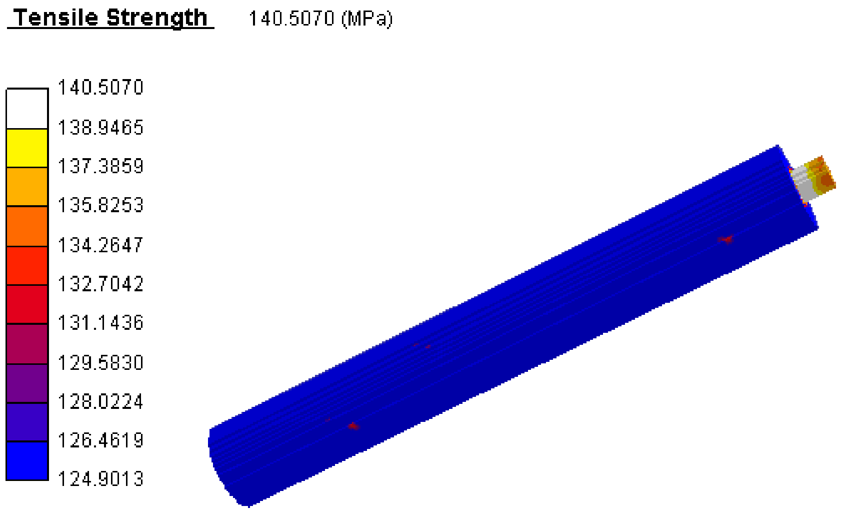

Figure C. 4 Simulation of tensile strength, step 2 (S.P: 150MPa, D.P: 350°C, M.T: 600°C)

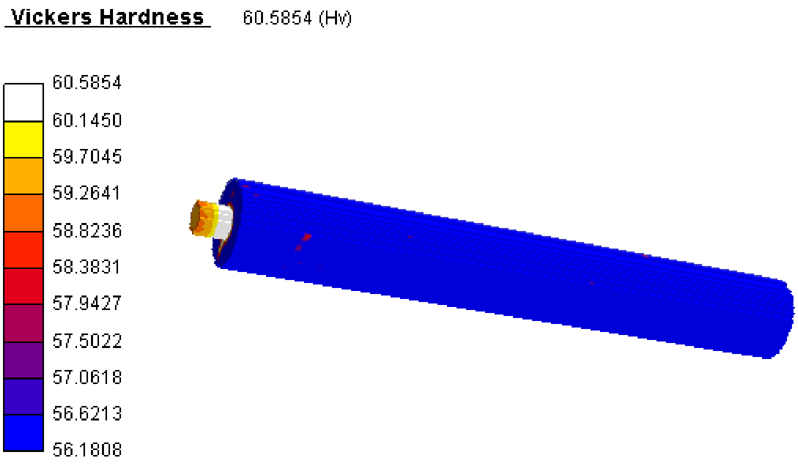

Figure C. 5 Simulation of hardness, step 2 (S.P: 150MPa, D.P: 350°C, M.T: 600°C)

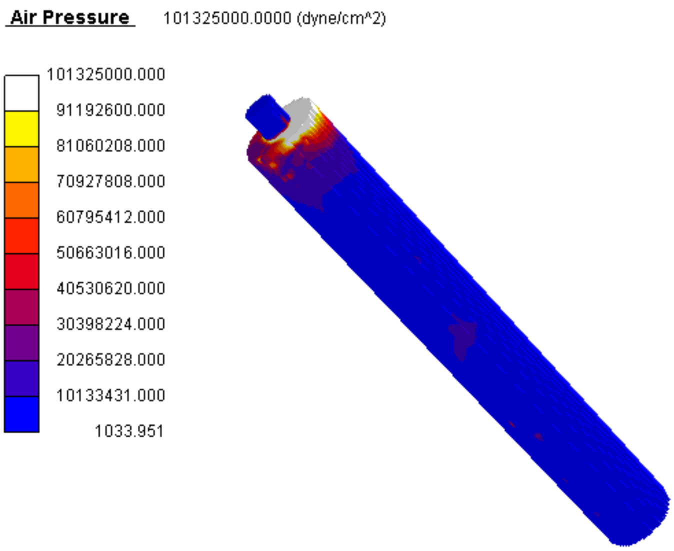

Figure C. 6 Simulation of air pressure, step 2 (S.P: 150MPa, D.P: 350°C, M.T: 600°C)

Simulation and result of squeeze casting step 3

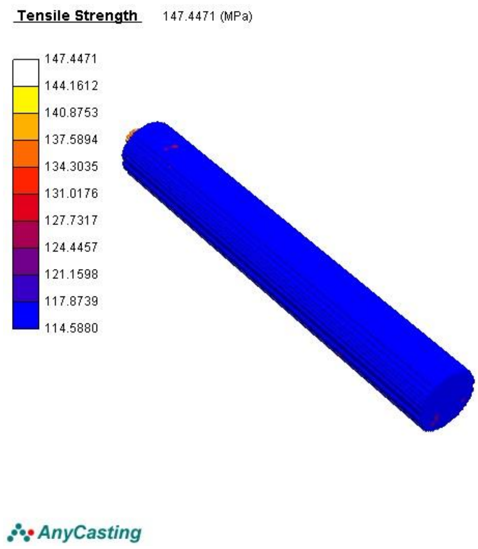

Figure C. 7 Simulation tensile strength of step 3 (S.P: 110MPa, D.P: 200°C, M.T: 700°C with %0.02 TiB)

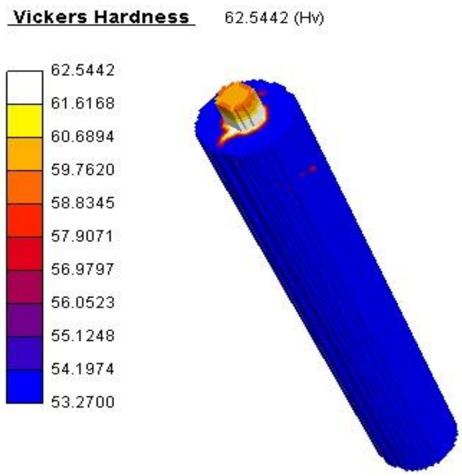

Figure C. 8 Simulation of hardness step 3 (S.P: 110MPa, D.P: 200°C, M.T: 700°C with %0.02 TiB)

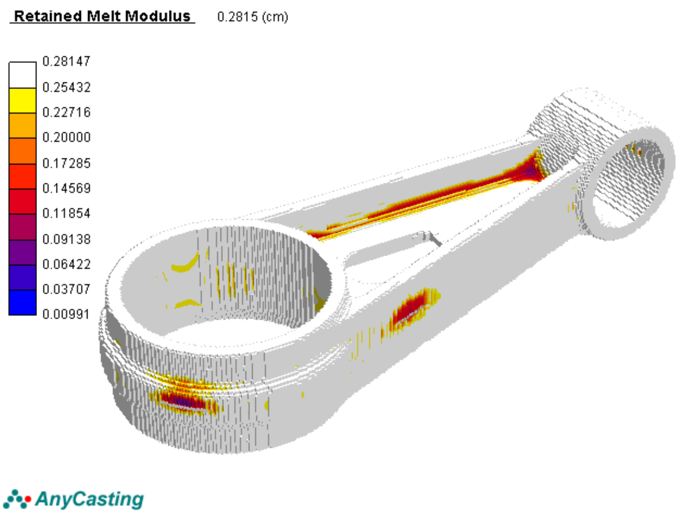

Figure C. 9 Simulation of retained melt modulus step 3 (S.P: 110MPa, D.P: 200°C, M.T: 700°C with %0.02 TiB)

BIODATA OF STUDENT

Mona Kiaee was born in Tehran, Iran on October 10th 1981. She graduated in bachelor degree from Islamic Azad University, South Tehran Branch, Iran in Mechanical Engineering (Designing Solids) in 2004. Her research interest is Casting and CAD softwares.

LIST OF PUBLICATIONS

Accepted International Conference Paper:

Mona Kiaee, Shamsuddin Sulaiman, T.S. Hong and M. Mohammadi, *Investigation on Microstructure and Mechanical Properties of Squeeze Cast Al-Si Alloys by Numerical Simulation*, International Conference of Engineering and Innovative Materials (ICEIM 2014), Kuala Lumpur, Malaysia , September 4-5, 2014. *Published on: Advanced Materials Research*, 2014, pp. 31-35.

Accepted Journal Paper:

Mona Kiaee, Shamsuddin Sulaiman, T.S. Hong and M. Mohammadi, *Numerical Simulation on Microstructure and Mechanical Properties of Squeeze Casting Al-Si Alloys*, American journal of mechanical engineering,(ISSN : 2328-4102), Impact Factor: 0.9404.

Mona Kiaee, Shamsuddin Sulaiman, T.S. Hong and M. Mohammadi, *Numerical Simulation on Microstructure and Mechanical Properties of Squeeze Casting Al-Si Alloys*, International research journal, Advances in Theoretical and Applied Mechanics, (ISSN :1313-6550), Impact Factor: 0.679.

Journal Paper (Under Review):

Mona Kiaee, Shamsuddin Sulaiman, T.S. Hong and M. Mohammadi, *Effect off squeeze casting parameters on microstructural properties of Al-Si products*, Elsevier , Journal of Materials Processing Technology (ISSN: 1873-4774), Impact Factor: 1.95.

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