SOLIDIFICATION SEQUENCE AND CARBIDE PRECIPITATION IN HIGH SILICON MOLYBDENUM DUCTILE IRON (SIMO)

By

Mervat Youssef Abd El-Hamid Ahmed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Metallurgical Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

Prof. Dr. Abdel-Hamid Ahmed Hussein

Professor of Metallurgy
Mining, Petroleum, and Metallurgical Department
Faculty of Engineering, Cairo University

Prof. Dr. Adel Abdel Moneim Saleh Nofal

Professor of Metal Casting
Foundry Technology Laboratory
Central Metallurgical for R&D Institute (CMRDI)

Prof. Dr. Elsayed Mahmoud Elbanna

Professor of Metallurgy
Mining, Petroleum, and Metallurgical Department
Faculty of Engineering, Cairo University

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Approved by the

Examining Committee:

Prof. Dr: Abdel-Hamid Ahmed Hussien,	Thesis Main Advisor
Prof. Dr.:Adel Abdel-Moniem Saleh Nofal, Central Metallurgical R&D Institute (CMRDI)	Advisor
Prof. Dr: Elsayed Mahmoud Elbanna,	Advisor
Prof. Dr: Mohammed Mamdouh Ibrahim,	Internal Examiner
Prof. Dr.: Mohamed Abdel Wahab Waly, Central Metallurgical R&D Institute (CMRDI)	External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2018

Engineer's Name: Mervat Youssef Abd El-Hamid Ahmed
Date of Birth: 29 / 7 / 1992
Nationality: Egyptian
E-mail: usf.mervat@gmail.com
Phone: 01000632852
Address: 10 Mohamed kamel, Awlad Ouf,
El Haram, Giza

Registration Date: 1 / 10 / 2014
Awarding Date: / / 2018
Degree: Master of Science
Department: Mining, Petroleum and Metallurgy Engineering

Supervisors:

Prof. Dr. Abdel-Hamid Ahmed Hussien,(Thesis Main Advisor)
Prof. Dr. Adel Abdel Moniem Saleh Nofal, (Advisor)
Central Metallurgical R&D Institute (CMRDI)
Prof. Dr. Elsayed Mahmoud Elbanna, (Advisor)

Examiners:

Prof. Dr.: Mohamed Abdel Wahab Waly, (External Examiner)
Central Metallurgical R&D Institute (CMRDI)
Prof. Dr: Mohammed Mamdouh Ibrahim, (Internal Examiner)
Prof. Dr. Abdel-Hamid Ahmed Hussien,(Thesis Main Advisor)
Prof. Dr. Adel Abdel Moniem Saleh Nofal, (Advisor)
Central Metallurgical R&D Institute (CMRDI)
Prof. Dr. Elsayed Mahmoud Elbanna, (Advisor)

Title of Thesis:

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Key Words:
SiMo; Thin-wall; carbides; solidification sequence; Thermal stability.

Summary:

When SiMo was introduced to be used for automotive applications, there were limitations regarding increasing service temperature.

The first point of this research aims at producing SiMo alloys and studies the effect of alloying element, inoculation type as well as influence of cooling rate on microstructure. The second point designed to study the phase transformation during solidification at different conditions. Finally, point three designed to measure the stability of the phases and determine the thermal expansion coefficient and A_1 temperature.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the reference section.

Name: Mervat Youssef Abd El-hamid Ahmed Date: 8/10/2018.

Signature:

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Nomenclature

SEM	Scanning Electron Microscopy
OM	Optical Metallography
EDS	Energy Dispersive X-Ray Spectroscopy
DSC	Differential Scanning Calorimetry
CTE	Coefficient of Thermal Expansion
SG	Spheroidal Graphite
TW	Thin-Wall
TWDI	Thin-Wall Ductile Iron
A_1	Austenite to ferrite transformation temperature.
FCC	Face Center Cubic
BCC	Body Center Cubic
BHN	Brinell Hardness Number
GS	Green Sand
INV	Investment Mold
Inc	Inoculation

Abstract

The automotive industry is concerned with fuel economy and gas emissions; whereas the cost consideration is customer mandated. Silicon Molybdenum ductile Iron (SiMo) is characterized with its combination of low cost and unique properties in high temperature applications, such as automotive parts like exhaust manifolds and turbocharger housings, furnace applications and turbine castings. A typical chemical composition of SiMo ductile iron contains 4% Si and 0.5-2.0% Mo and can be used up to 840-850°C.

The main objective of this research aims at developing technology to produce high quality thin wall castings and to introduce new grades of SiMo castings with specific properties that add to the performance of ductile iron castings in special high temperature applications. This research also aimed at reaching a better understanding of the influence of the cooling rate, inoculants chemistry and alloying elements such as Cr, Ni and V on the formation of precipitates in SiMo ductile irons.

In order to achieve these objectives, different molds of 3, 6, 9 mm thickness were prepared from greensand and ceramic material to give different cooling rates.

Optical metallography (OM) as well as Scanning Electron Microscopy (SEM) were used to clearly show the different phases, i.e., eutectic carbides and fine precipitates. Moreover, Energy Dispersive X-Ray Spectroscopy (EDS) analysis was followed to reach a semi - quantitative estimate of the relevant compositions. The solidification sequence as well as solid-state transformations were followed using phase diagram calculation via Thermo-Calc software, Differential Scanning Calorimetry (DSC) and dilatometry analysis.

Intensive SEM and EDS investigations have detected three types of carbides in the microstructure of SiMo-irons. Eutectic carbides of M_6C type were found embedded in a fine precipitate of Fe_2MoC/M_6C – type carbides in the vicinity of the intercellular regions. It is showed that the eutectic carbides are mainly (Fe, Mo, Si) Carbides containing up to 48% Mo, whereas the fine precipitate carbides contain lower Mo-contents. Both carbide types did not appear to have a strict stoichometric composition. The third type of carbides is fine dispersed precipitate of M_7C_3 in ferrite.

In alloyed SiMo angular carbides and dot-like carbide were clearly observed in the microstructure of the alloyed SiMo samples. The eutectic carbides are mainly (Fe, Mo, Cr, V, Ni) carbides with Mo-content reaching 45%, whereas the fine precipitate is of more complex nature with lower Mo-contents.

The morphology and composition of the eutectic carbides vary with the cooling rate. At high cooling rates the eutectic carbides have the Chinese script morphology with wide spectrum of Mo-contents. With slower cooling rates, fish-bone structures are frequently encountered with higher Mo-contents, related to higher degrees of segregations associated with slow cooling.

DSC data revealed that the fine precipitate forms on cooling below the lower critical temperature after the completion of proeutectoid and eutectoid reactions.

The dilatometer charts showed similar expansion behavior for both investment and green sand molds of the three different thicknesses at elevated temperature. The maximum operation temperature of the unalloyed SiMo alloys is 900 °C which is high enough when compared to the other tradition SiMo alloys in the market (max operation temperature 700-750 °C). In alloyed SiMo samples with the same thickness (Green sand and investment) showed a decrease in the A_1 temperature by about 30 to 50 °C. This apparently because of the 0.6% Ni which plays as austenite stabilizer.

Chapter 1 :Introduction

Silicon Molybdenum Ductile Iron (SiMo) is a special purpose heat resistant alloy which is considered to be the cheapest material compared to other austenitic alloys [1-3]. Moreover, SiMo can keep the dimensions without any changes for high numbers of cycles that can range from below freezing temperatures to very high temperatures up to 850°C. These properties nominates SiMo alloys to be suitable for automotive applications as exhaust manifolds and turbocharger housings, furnace applications and turbine castings [2]. However, When the operation temperature is increased, SiMo alloys show limitations unlike the very expensive austenitic alloys with its higher strength at high operation temperatures due to their FCC structure which has fewer slip systems making it difficult for deformations to happen and permits larger amounts of interstitial carbon in the structure compared to ferrite, which has a BCC structure, resulting in a higher solid solution strengthening effect in austenite [1][3][4].

So, the current objectives are currently being tackled through three trends: First, technological development to produce thin wall castings, down to 3 mm wall thickness. Second, development of new grades of SiMo castings, with specific properties, that adds to the performance of ductile iron castings in special high temperature applications. Third, study the solidification sequence and carbides nature and morphology.

The studied parameters include: chemical composition of the SiMo alloys with three inoculants chemistry, different cooling rate by using two molding techniques (investment casting and greensand), thermal and dimensional stability and heat treatment. The impact of these parameters on solidification behavior studied using advanced thermal analysis techniques, thermodynamic and kinetic analysis, DSC and dilatometry analysis.

The physical properties including thermal expansion, was also evaluated as related to the different metallurgical and technological conditions involved in the production process.