Production and Analysis of Alloy Composites Exhibiting Improved Bonding Using a Novel Vacuum Casting Process

A thesis submitted in fulfilment of
the requirements of the degree of
Doctor of Philosophy

by

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In memory of my daughter

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ABSTRACT

A new composite manufacturing process has been developed that permits the production of white iron/steel composites. The key differences of the new vacuum casting process compared to other current processes for composite manufacture include:

i. Elimination of machining or grinding
ii. Removal of brazing alloy
iii. Enhanced design flexibility
iv. Enhanced control of microstructural features
v. Lower cost of production

The new vacuum casting process involves the following key steps:

- Heating a white cast iron and steel substrate together within a vacuum furnace until the temperature inside the vacuum furnace is typically 50^{o}C above the liquidus of the white cast iron.
- Before the white cast iron becomes molten, adding a partial pressure of inert gas (typically nitrogen) into the vacuum furnace to increase the pressure of the chamber above the vapour pressure of the liquid white cast iron.
- Holding the temperature above the liquidus of the white cast iron to allow the white iron to partially dissolve the steel substrate.

The experimental work outlined in this research has permitted the development of a low melting point white cast iron having the nominal composition of Fe-12Cr-1.6Mn-1.0Ni-0.5Si-4.1C, with a measured liquidus temperature of 1209^{o}C. The microstructure of the low melting point alloy consists of a small volume fraction of primary austenite, with a eutectic of M_7C_3 carbides and austenite. Some of the M_7C_3 carbides have undergone a quasi-peritectic reaction. The austenite has undergone a partial transformation to form ledeburite (ferrite plus M_3C carbide in the form of cementite).

The microstructures of the vacuum cast samples show the presence of four zones within the interface region.

i. Zone 1 – original steel substrate, consisting of hypoeutectoid steel

ii. Zone 2 – heat affected zone steel substrate

iii. Zone 3 – “carbide-free” area of low melting point white cast iron adjacent to interface

iv. Zone 4 – low melting point white cast iron

Manufacturing and field trials have been conducted on a range of composite products to establish the potential benefit of using composite white iron/steel components in mining wear applications. The vacuum casting process has been used successfully to produce a significant volume of trial wear parts, indicating the process is robust enough to be considered for repetitive production, and can also be adapted to manufacture a wide range of products.

DECLARATION OF ORIGINALITY

I certify that this thesis has not been submitted previously for any degree and is not being submitted as part of candidature for any degree. The research work presented was performed under the guidance of Associate Professor Besim Ben-Nissan and Dr Greg Heness of the Department of Chemistry, Materials and Forensic Science (UTS). I certify that I have written the thesis and that help that I have received in its preparation, and all sources used, have been duly acknowledged.

Production Note:
Signature removed prior to publication.

Paul Huggett

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NOMENCLATURE

$\varphi(y)$	=	Gaussian Error Function
Bulk C%	=	overall carbon weight percent
C_0	=	concentration of semi-infinite solid
Cs	=	surface concentration
C_x	=	concentration of diffusing species
C%	=	carbon weight percent
Cr%	=	chromium weight percent
Cr/C	=	chromium/carbon ratio
D	=	diffusivity or diffusion coefficient
D_0	=	temperature independent pre-exponential, m^2/s
$\frac{dC}{dx}$	=	concentration gradient
EC Cr%	=	eutectic Carbide Chromium Content
ECVF%	=	eutectic carbide volume fraction %
ETC%	=	eutectic trough carbon %
FM Cr%	=	ferrous Matrix Chromium Content %
J_x	=	flux of diffusing species
PC Cr%	=	primary Carbide Chromium Content
PCVF%	=	primary carbide volume fraction %
PFMVF%	=	primary ferrous matrix volume fraction %
Q_d	=	activation energy for diffusion, J/mol
R	=	Gas constant, 8.314 $J.mol^{-1}.K^{-1}$
t	=	time, seconds
T	=	Temperature, Kelvin
x	=	distance, mm

OUTLINE OF THESIS

Chapter One provides background information and significance of this research work.

Chapter Two describes the development of a low melting point white cast iron. The low melting point white iron development involved analysis of the Fe-Cr-C phase diagram and computer modelling using CALPHAD techniques to result in a white cast iron having a liquidus (melting point) of approximately 1200^{o}C. The low melting point white iron was essential to enable standard electrical element materials to be adopted for the vacuum heat treatment furnace development.

Chapter Three describes the development of the vacuum casting process, providing theory of vacuum heat treatment, background to other composite alloy manufacturing processes, and the experimental work and outcomes for the new vacuum based composite alloy manufacturing process.

Chapter Four provides a detailed analysis of the composite interface developed between a steel substrate and the low melting point white cast iron. The analysis of the interface is used to provide confirmation of the vacuum casting model developed in Chapter 3, and to demonstrate the quality and power of the vacuum process to develop 100% fully bonded metallurgical bonds.

Chapter Five provides detail on the development of trial parts for use in various mining applications. The trial parts involved the manufacture of full scale parts for use on heavy duty mining equipment. Laboratory wear test results are provided and compared to field trial performance.

Chapter Six outlines the conclusion of the thesis and summarises the project outcomes.

References have been listed in the sequence of their use within the main thesis text and then numerically numbered.

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