EFFECT OF MAGNESIUM ADDITION ON THE MICROSTRUCTURE AND PROPERTIES OF DUCTILE Ni-RESIST ALLOY USING IN-MOULD MAGNESIUM TREATMENT METHOD

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ABSTRACT

For engineering reasons, ductile Ni-resist alloys are widely used in oil and gas, automotive industries and elevated temperature purposes. Ductile Ni-resist offers an advantage because this alloy has an austenitic structure at all temperatures. However, ductile Ni-resist alloy faces economical limitation due to the high price of nickel for alloying of ductile Ni-resist. Therefore, the present study aims to explore the possibility to reduce nickel consumption by substituting nickel with manganese to generate austenitic structure of ductile Ni-resist. Austenitic structure was formed by adding a nickel with much higher manganese percentage consumption as compared to standard usage. The control of carbide formation due to increasing Mn/wt. % was conducted using inoculation method. The effect on solidification was evaluated using cooling curve thermal analysis, complemented by microscopic observation and mechanical properties. It was observed that both Mn/wt. % and inoculation affect the austenitic structure and solidification cooling curve. Solidification cooling curve was lowered with increasing Mn/wt. %.It was also observed that graphite microstructure can be modified by both Mn/wt. % and inoculation. The morphology and graphite distribution was affected by increasing Mn/wt. % and inoculation. An isolated region due to segregation known as 'Last To Freeze' was the last area to solidify. Tensile strength and elongation at room temperature dropped by 21.5% (12Mn-10Ni wt %) and 20.0% respectively as compared to D2 standard alloys. Tensile strength at elevated temperature showed that this alloy can withstand up to 150 MPa, dropped by 6.15% (12Mn-10Ni wt. %) compared to D2 standard alloy. Corrosion test proved that corrosion rate is comparable to unmodified ductile Ni-resist. Three dense oxide layers were formed on the alloy surface at elevated temperature. A good agreement was observed between the result of the solidification cooling curve, microstructure and mechanical properties.

ABSTRAK

Aloi Nikel-rintang mulur digunakan secara meluas bagi keperluan kejuruteraan seperti industri minyak dan gas, automotif dan persekitaran bersuhu tinggi.Kelebihan ini disebabkan oleh kewujudan austenit pada semua suhu. Walaubagaimanapun, aloi ini mempunyai kekangan dari sudut ekonomi kerana harga nikel yang mahal untuk tujuan pengaloian. Oleh itu, kajian ini dilakukan untuk mengkaji kesan penggunaan mangan bagi mengurangkan komposisi nikel untuk menghasilkan struktur austenite dalam aloi Nikel-rintang mulur. Pembentukan karbida disebabkan oleh peningkatan peratusan mangan dikawal dengan kaedah penyuntikan. Kesan terhadap pemejalan dinilai melalui analisa terma lengkung penyejukan, dan disokong oleh pemerhatian mikrostruktur dan kekuatan mekanikal. Kajian menunjukkan peratusan penambahan mangan dan kaedah penyuntikan memberi kesan kepada struktur austenit dan lengkung penyejukan pemejalan. Lengkung penyejukan pemejalan menurun dengan penambahan peratusan mangan. Pemerhatian juga menunjukkan mikrostruktur grafit, morfologi dan taburannya boleh diolah dan dipengaruhi oleh peratus penambahan mangan dan penyuntikan. Wujud suatu kawasan terpinggir akibat dari proses pengasingan yang dikenali sebagai 'kawasan terakhir memejal' yang merupakan kawasan yang terakhir memejal. Kekuatan tegasan dan pemanjangan pada suhu bilik masing-masing merosot 21.5% (12Mn-10Ni wt. %) dan 20.0%. Kekuatan bahan pada suhu tinggi adalah 150 MPa, merosot sebanyak 6.15% (12Mn-10Ni wt. %) berbanding aloi kelas D2. Ujian kakisan membuktikan aloi setanding dengan aloi Nikel-rintang mulur yang tidak diubahsuai. Tiga lapisan berlainan oksida tumpat terbentuk pada permukaan aloi. Terdapat pertalian berpadanan di antara keputusan lengkung penyejukan pemejalan, mikrostruktur dan sifat mekanikal.

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LIST OF ABBREVIATIONS

T – T – T	-	Time – Temperature – Transformation
ADI	-	Austempered Ductile Iron
ASTM	-	American Standard for Testing Material
FeMn	-	Ferro Manganese
FeCr	-	Ferro Chrome
FeSi	-	Ferro Silicon
NiFeMg	-	Nickel Ferro Magnesium
NiFe	-	Nickel Ferro
DNR	-	Ductile Ni-Resist
FCC	-	Face Centred Cubic
BCC	-	Body Centred Cubic
TAL	-	Temperature of the Liquidus Arrest
TES	-	Temperature of Eutectic Nucleation
TEU	-	Temperature of Eutectic Undercooling
TER	-	Temperature of Eutectic Recalescence
TEE	-	Temperature of the End of Eutectic Solidification
DTA	-	Differential Thermal Analysis
LTF	-	Last To Freeze
DAS	-	Dendrite Arm Spacing
SDAS	-	Secondary Dendrite Arm Spacing
TC	-	Total Carbon
CEV	-	Carbon Equivalent
CAE	-	Calculation of Liquidus Value
SEM	-	Scanning Electron Microscopy
MgFeSi	-	Magnesium Ferro Silicon

NiFeMg	-	Nickel Ferro Magnesium
NiFe	-	Nickel Ferro
EDX	-	Energy Dispersive X – Ray Spectroscopy
XRD	-	X – Ray Diffraction
OM	-	Optical Microscope
GDS	-	Glow Discharge Spectroscopy
kW	-	kilo Watt
HCl	-	Hydrochloric
KOH	-	Kalium Hydroxide
NaOH	-	Natrium Hydroxide
HMV	-	Hardness Micro Vickers
HV	-	Hardness Vickers
SCE	-	Saturated Calomel

LIST OF SYMBOLS

γ	-	Austenite iron
α	-	Ferrite iron
∂	-	Ferrite iron
T_{liq}	-	Liquidus temperature
T_{und}	-	Undercooling temperature
T_{eut}	-	Eutectic temperature
T_{end}	-	End of solidification temperature
dT / dt	-	1st derivation
T_L	-	Austenite liquidus temperature
T_E	-	Equilibrium point of graphite eutectic temperature
T_C	-	Equilibrium point of carbide eutectic temperature
V	-	Volume
P	-	Density
C_p	-	Heat capacity
Q_L	-	Heat of solidification
T	-	Time
H	-	convection heat transfer coefficient
A	-	Area
T	-	Temperature
D	-	Diffusion rate of carbon in austenite
R	-	Nodule size of graphite
S	-	Distance
X	-	Molar fraction
K_s	-	Segregation coefficient

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CHAPTER 1

INTRODUCTION

1.1 Background

In the new global economy, austenitic ductile iron material has become a central issue as it offers better casting flowability, high strength-cost ratio, good machinability, austenite structure at all temperatures and relatively good mechanical properties. These exceptional properties enable austenitic ductile iron or known as Ductile Ni-Resist (DNR) to be employed in oil and gas, automotive, and power plant applications (Forrest, 1983, Fallon, 1993 and Morrison, 1998). Nowadays, DNR has experienced a significant consideration in related industries due to its strength in corrosive and oxidize environment which is almost similar to austenitic steel (Fatahalla *et al.*, 2009).

However, despite its processing advantages, DNR suffers from several major drawbacks. Nickel (Ni) is comparably expensive material and faced economical limitation due to the high price for alloying DNR. Its price fluctuated around RM140 -160 per kg. Generally the as-cast austenite microstructure of DNR occurs due to the influence of nickel contained in the composition that acts as austenite matrix promoter. At minimum of 18 wt %, Ni suppresses austenite transformation (γ) to ferrite (α) in conventional ductile iron. In order to minimise the processing cost, research is required to reduce the use of Ni wt %.

However, far too little attention has been paid on alternative elements other than nickel. Other researchers (Forrest (1983), Fallon (1993) and Morrison (1998)) reported the potential of manganese (Mn) and copper (Cu) as alternatives for the DNR alloying elements. Previous studies on Mn and Copper as alternative alloying elements that formed austenite structure with Fe has shown different effect. Cu although formed austenite structure but at the same time has deleterious effect on nodule graphite of DNR. As a result, the contribution of Cu to promote austenite structure of DNR dismissed (Morrison, 1998).

At present, Mn was used solely for alloying purposes to improve DNR impact toughness property instead of austenitic matrix stabilizer and does not contribute to the reduction use of Ni. Mn usage was limited at 2.40 wt.% at maximum (ASTM 439-83, 2009).

The effect of inoculation on the austenitic matrix of DNR was also found not being studied by researchers. The area of research that have been investigated by other researchers is shown in Figure 1.1.

The aim of this research was to evaluate the effect of the higher Mn percentage addition and inoculation by late treatment technique on the solidification cooling curves, microstructure, and mechanical properties of modified DNR. This parameter was examined due to research gap existed as shown in Figure 1.1. Examination was also held to evaluate the effect of high Mn wt % alloyed parameters on corrosion behaviour by seawater and isothermal oxidation behaviour of modified DNR by furnace atmosphere-air. This research simulates environment conditions suitable for corrosive environment such as marine application and elevated temperature application at up to 765°C, such as furnace parts, exhaust lines, and valve guides. This set-up examined because there is no report published to explain the corrosion and oxidation behaviour of modified DNR in literature. Particular attention wholly directed to the mechanical properties of the iron alloys in relation to the solidification and microstructural inhomogeneities in the casting, necessitated by the fact that the alloying elements' percentage of modified DNR is large.

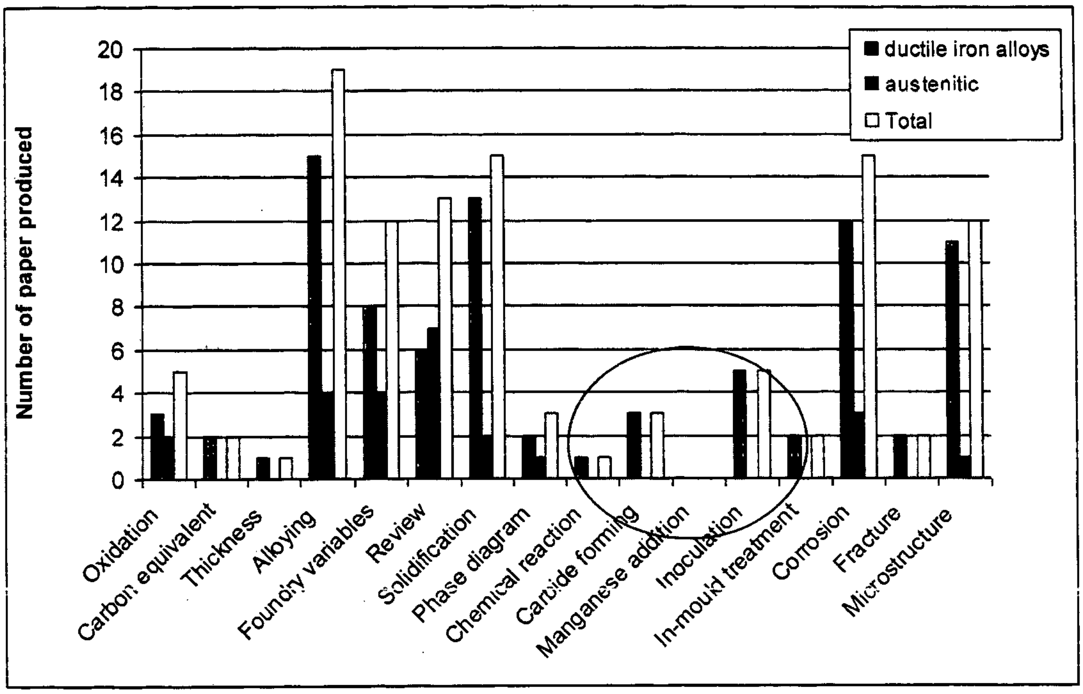

Figure 1.1 Areas that has been research on ductile Ni-resist and its alloys

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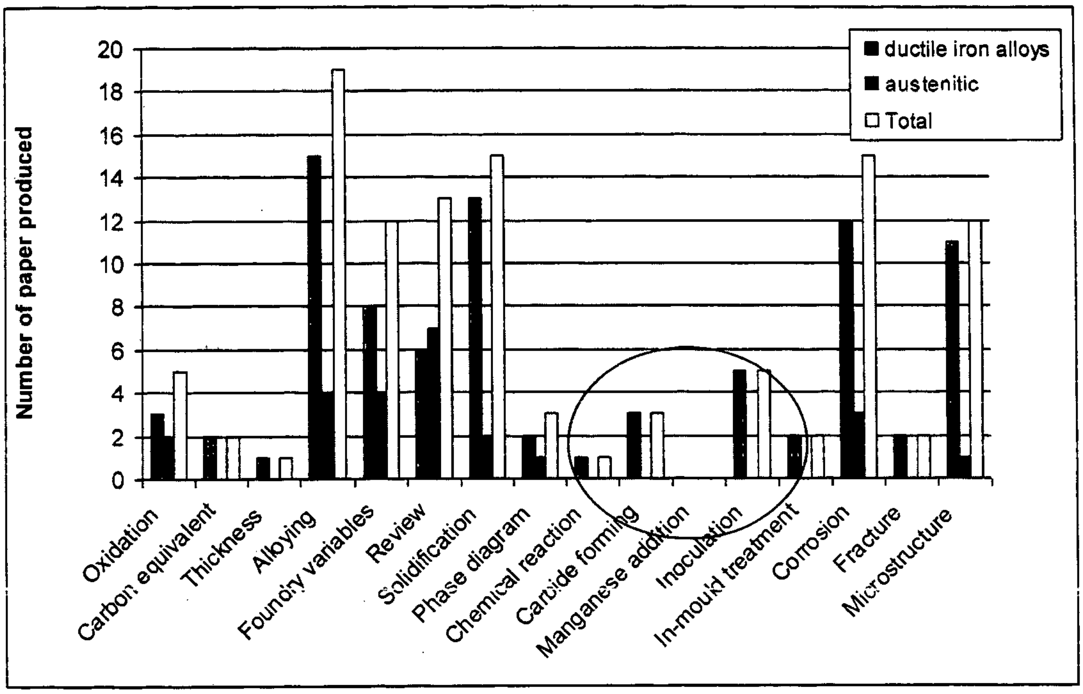


Figure 1.1 Areas that has been research on ductile Ni-resist and its alloys

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Introduction

This chapter details the experiments conducted to achieve the stipulated objectives.

The experimental work is divided into three phases as shown in Figure 3.1. In the 1st phase, the preliminary experiment involved the development of cast iron as the base for the DNR experiments. Nodularisation and inoculation processes were then carried out by adding 0.1-1.0% MgFeSi and 0.5-1.0% FeSi respectively. The 2nd phase of the research was to establish the effect of Mn addition, MgFeSi and FeSi on the mechanical properties and microstructure of the DNR. Thermal analysis was also conducted to observe the behavior of the molten metal during solidification. The alloy development based on pig iron is shown in Figure 3.2. In the 3rd phase of the research, analysis were conducted to determine the mechanical properties, microstructure of DNR using optical microscopy, Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray Spectroscopy (EDX), X-Ray Diffraction (XRD) and image analyzer. A series of mechanical properties testing involving tensile (room and elevated temperature), hardness (macro and micro), corrosion and high temperature oxidation were studied in depth to support the analysis.

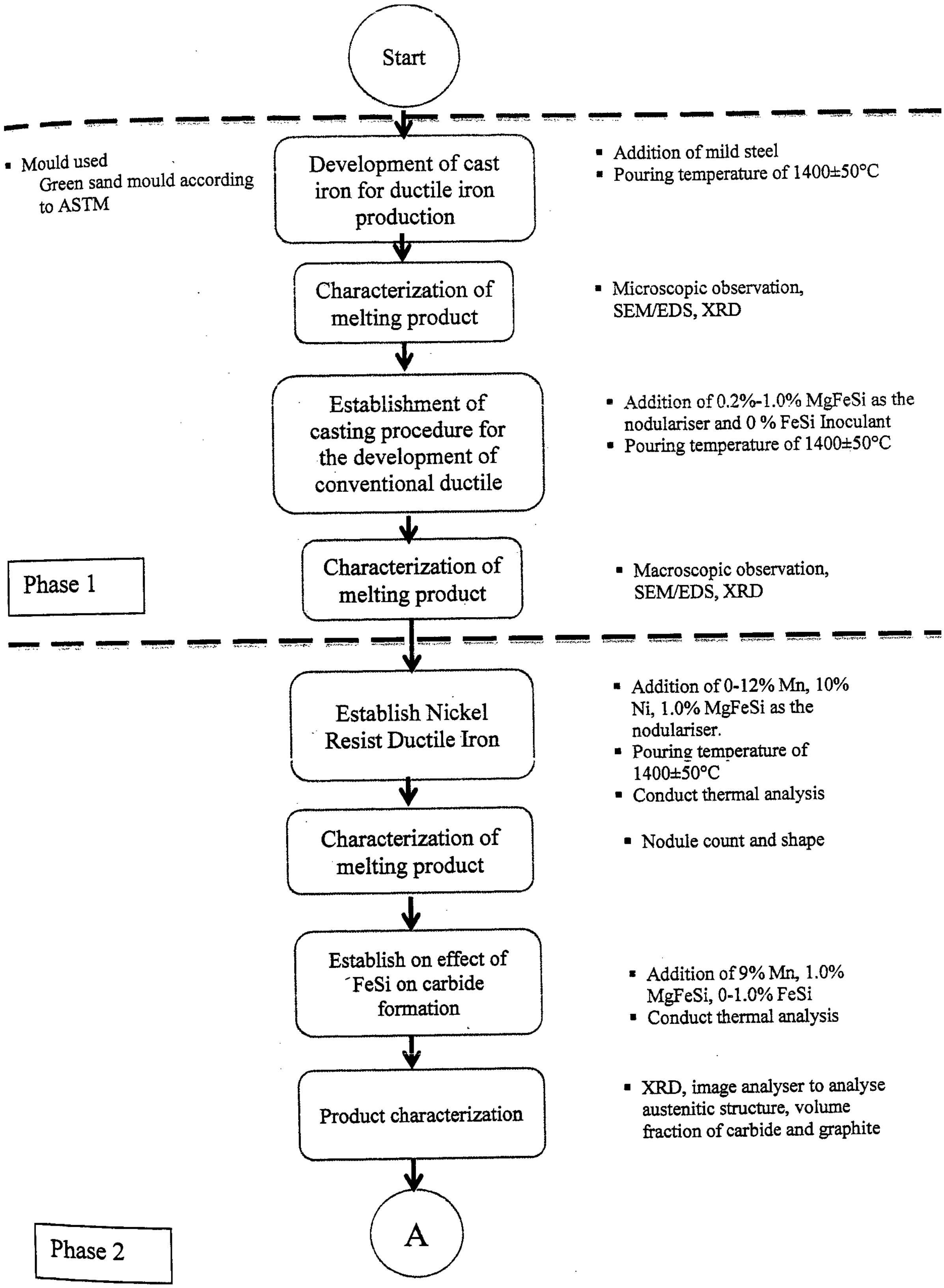
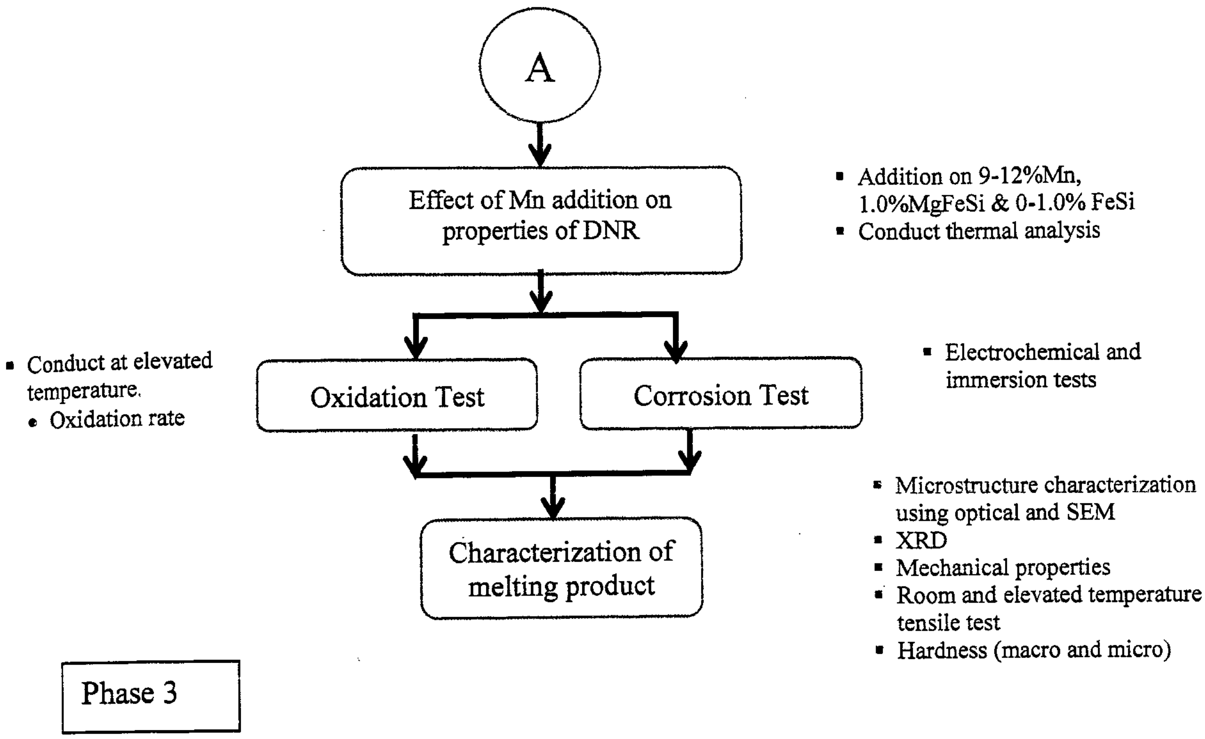


Figure 3.1 Overall experimental activities flowchart (continue)



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