



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**STUDY THE EFFECT OF HEAT TREATMENT TEMPERATURE
AND TIME ON CARBIDE FORMATION AND HARDNESS
VARIATION OF DEPOSITED NICKEL BASED ALLOY**

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Degree Bachelor of Manufacturing Engineering (Engineering Material) with Honours

By:

MOHD LUTFI BIN NORDIN

FACULTY OF MANUFACTURING ENGINEERS

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(TANDATANGAN PENYELIA)

(TANDATANGAN PENULIS)

Alamat Tetap:

32-0-4 BAMBU D, JLN 27/56

KERAMAT WANGSA,

54200 KUALA LUMPUR

Cop Rasmi:

DR NUR IZAN SYAHRIAH BINTI HUSSEIN
Pensyarah

Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka


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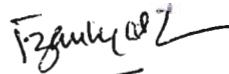
Signature : 

Author's Name : Mohd Lutfi Bin Nordin

Date : 14 APRIL 2010

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Material). The members of the supervisory committee are as follow:



Dr. NUR IZAN SYAHRIA BT HUSSEIN
(Main Supervisor)

DR NUR IZAN SYAHRIA BINTI HUSSEIN
Pensyarah
Fakulti Kejuruteraan Pembuatan
Universiti Teknikal Malaysia Melaka

ABSTRACT

The microstructure of two different types of the nickel-based superalloy Waspaloy were characterized. One alloy was in the as-received condition whilst the other processed by Shaped Metal Deposition using Tungsten Heat source welding manipulator under argon. In this study, the effects of heat treatment temperature and time on carbide formation and hardness variations on the two Waspaloy samples were investigated; using optical microscopy technique and hardness test. The samples were then subjected to X-Ray diffraction analysis. It was found that Waspaloy consists of γ matrix, γ' precipitates and carbide particle. The XRD analysis displayed a presence of carbide and austenitic phase in the as-received Waspaloy and deposited Waspaloy, indicating that the particles are possibly MC carbides and $M_{23}C_6$ carbide. Following solution treatment process, the as-received and deposited waspaloy had lower hardness and strength when compared to solution treatment and ageing process. The ageing process for 16 and 30 hours dramatically increase the strength of the as-deposited samples. For instance, from the initial hardness of 295 kgfmm^{-2} to 433 kgfmm^{-2} . The results show that the optimum temperature and time for heat treatment is similar to the standard heat treatment of the wrought Waspaloy which is solution treatment at $1080 \text{ }^\circ\text{C}$ for 4 hours/air cooling, followed by stabilization at $845 \text{ }^\circ\text{C}$ for 4hour/ac and to aging at $760 \text{ }^\circ\text{C}$ for 16 hour/ac.

ABSTRAK

Microstruktur dari dua jenis bahan berbeza pada Waspaloy telah di perincirkan. Bahan yang pertama diperbuat dari logam tempawan dan bahan yang kedua adalah daripada logam yang telah deposisikan kan menggunakan kimpalan pengolah automatik dibawah tekanan gas argon. Berdasarkan kajian ini, kesan pengaruh perlakuan suhu panas rawatan haba dan masa ke atas pembentukan karbida dan kekerasan struktur pada dua jenis bahan Waspaloy telah dikaji menggunakan mikroskop optik dan ujian kekerasan. Kemudian kajian diteruskan menggunakan pembelaun sinaran X. Berdasarkan kajian ini, telah didapati bahawa Waspaloy terdiri daripada matriks gama, mendakan gama utama dan karbida. Ujian pembelaun sinaran X telah menunjukkan kehadiran karbida dan fasa austenite pada kedua-dua jenis bahan Waspaloy dan ianya berkemungkinan adalah MC karbida dan $M_{23}C_6$ Karbida. Sampel yang telah diuji dengan proses rawatan haba larutan (solution treatment) hanya memiliki kekerasan yang lebih rendah berbanding dengan kekuatan sampel yang telah melalui proses rawatan haba larutan (solution treatment) dan proses jenis rawatan haba penuaan (ageing treatment). Proses rawatan haba penuaan (ageing treatment) yang telah dilakukan selama 16 dan 30 jam telah mengakibatkan peningkatan kekuatan kekerasan bahan, Sebagai contoh pada bahan yang telah deposisikan menggunakan kimpalan, didapati kekerasan bahan pada awalnya adalah sebanyak 295 kgfmm^{-2} , tetapi telah meningkat melalui proses rawatan haba (ageing treatment) iaitu kepada 433 kgfmm^{-2} . Keputusan daripada kajian ini menunjukkan bahawa suhu dan masa rawatan haba yang sesuai adalah pada suhu $1080 \text{ }^\circ\text{C}$ selama 4 jam, di ikuti proses rawatan haba (stabilization) selama 4 jam dan proses rawatan haba jenis penuaan (ageing) pada suhu $760 \text{ }^\circ\text{C}$ selama 16 jam.

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LIST OF SYMBOLS

T	-	Temperature ($^{\circ}\text{C}$)
N	-	Number of Previous Pulse
Q	-	Heat Source (W)
e_{fibre}	-	Fibre Efficiency
a	-	Absorptivity
C	-	Specific Heat Capacity ($\text{J kg}^{-1}\text{k}^{-1}$)
t	-	Time (h)
T_{cycle}	-	Period Length (s)
T_{pulse}	-	Pulse Length (s)
T_f	-	Duty Cycle
V	-	Traverse Speed (ms^{-1})
x, z	-	Linear Dimensions (m)
x_{pulse}	-	x Position of Instantaneous Point Source
d	-	Diameter (m)

LIST OF ABBREVIATIONS

•

CAD	-	Computer Aided Design
DOE	-	Design of Experiment
OM	-	Optical Microscope
ST	-	Solution Treatment
ST&A	-	Solution Treatment and Ageing
SEM	-	Scanning Electron Microscopy
TIG	-	Tungsten Inert Gas
TIT	-	Turbine Inlet Temperature

CHAPTER 1

INTRODUCTION

This chapter introduces the basic Ni-based superalloy concept of directly deposited Waspaloy, in terms of its microstructure and heat treatment process. Background and problem statement are also stated in this chapter. Finally, the objectives, scope, overview of report and importance of study are outlined.

1.1 Introduction

Nickel based superalloys are widely used in the manufacturing of aircraft component whereby their work conditions are at high temperature. It is also used for gas turbine engine components that call for considerable strength and corrosion resistance at high operating temperatures. Current and potential applications include compressor and rotor discs, shafts, spacers, seals, rings and casings, fasteners and other miscellaneous engine hardware, airframe assemblies and missile systems.

Ni-based can be either solid solution or precipitation strengthened. In the most demanding applications, such as hot sections of gas turbine engines, a precipitation strengthened alloy is required. Most Ni-based contain 10 to 20 % Cr, up to 8 % Al and Ti, 5 to 10% Co, and small amounts of B, Zr, and C. Other common additions are Mo, W, Ta, Hf, and Nb. In broad terms, the elemental additions in Ni-based can be categorized as being γ formers (elements that tend to partition to the γ matrix), γ' formers (elements that partition to the γ' precipitate, carbide formers, and elements that segregate to the grain boundaries. Elements which are considered γ formers are Group V, VI, and VII elements such as Co, Cr, Mo, W, Fe. The atomic diameters of these

alloys are only 3 to 13% different than Ni (the primary matrix element). γ' formers come from group III, IV, and V elements and include Al, Ti, Nb, Ta, Hf. Moat R.J. *et al.*(2009).The atomic diameters of these elements differ from Ni by 6 to 18%. The main carbide formers are Cr, Mo, W, Nb, Ta, Ti. The primary grain boundary elements are B, C, and Zr. Their atomic diameters are 21 to 27 % different than Ni. Moat R.J. *et al.* (2008)

The suitable heat treatment will be performed to provide oxidation resistance as well as precipitation strengthening. The addition of elements such as Cr, Al, Ti and Co will create the excellent properties for these alloys. Predominantly component or products are made by casting or by machining from wrought material. However the cost for maintenance and repairing for this material is higher and need a much time. One such process is termed Shaped Metal Deposition (SMD) which involves direct metal deposition by robotic TIG welding using CAD model to control the robot tool path, thus an effective process for depositing complex three-dimensional structure for rapid manufacture and component repair. Elemental microsegregation and varying micro hardness have been observed in the as-deposited material. Heat treatment can be applied to obtain a more homogenous microstructure and uniform mechanical properties.

The general aim of this project is to study the effects of heat treatment on the microstructure of weld-deposited. This study will concentrate on Waspaloy, and consider what happen to the properties of the material as the temperature and time of the standard heat treatment are varied. Optical microscopy and scanning electron microscopy will be used to observe phases that develop in the alloy. All samples will be subjected to microhardness testing and where applicable, micro hardness testing to analyses the material's resistance to plastic deformation. In this study, the microstructure and micro hardness of the deposits especially in terms of carbide formation will be investigated to establish the effect of condition heat treatment

1.2 Background of the Problem

Based on the recent research, Carbides, principally $M_{23}C_6$ are particle that act as point strengtheners at grain boundaries. They also provide some degree of strengthening and are necessary to control grain size in the wrought Waspaloy. Although Waspaloy is a well-established wrought material, it has characteristics that make it difficult to successfully fusionweld . For example, it can be susceptible toweld and heat affected zone cracking and porosity formation. (Hussein, N.I.S .*et. al.*, 2008)

At the elevated temperature at which these Waspaloy operates, many microstructure evolution processes can occur, such as MC carbide dissolution. In order to obtain maximum strength in the alloy, the γ' precipitate must form and grow to the optimal size.

The purpose of this research is to study the effects of heat treatment and suitable heat treatment duration on the microstructure of deposited Waspaloy compared to wrought Waspaloy. The variable temperature and time of the standard heat treatment will be used to determine the properties of the material.

1.3 Problem Statement

Based on the review of previous work, several question need to be answered in this study such as how the temperature and time affect the microstructure especially the carbide formation in direct deposited Waspaloy after being subjected to Solution Treatment, Stabilization and Ageing. That also, which heat treatment condition give the influence to the microhardness variations and finally, what is the optimum heat treatment condition to achieve optimum microhardness properly almost 420 kg mm^{-2} , such as hardness of wrought Waspaloy after $1080^\circ\text{C}/4\text{H}/\text{AC} + 845^\circ\text{C}/24\text{H}/\text{AC} + 760^\circ\text{C}/16\text{H}/\text{AC}$. (Hussein, N.I.S .*et. al.*, 2008)

1.4 Objective

- (a) Study the effect of heat treatment temperature and time carbide formation and hardness of deposited Nickel based superalloy
- (b) Optimizing the mechanical properties of Nickel based superalloy

1.5 Scope and overview of report

- (a) Study the effect of heat treatment temperature to of deposited Nickel based superalloy.
- (b) Study the time carbide formation of deposited Nickel based superalloy.
- (c) Study the mechanical properties in the deposited Nickel based superalloy structure
- (d) Study the potential of deposited Nickel based alloy as a superalloy

In order to examine the microstructural features sample were cut from the deposits and heat treated in a tube furnace under argon. Three heat conditions were employed namely solution treated (ST), solution treated and age (ST&A) and ageing. ST sample were given the following variable temperature. This is for to investigate how the different time heat treatment process affected the microstructure and microhardness of the deposits Waspaloy. The samples were prepared and etched using standard procedures and were examined using optical microscopy. The microhardness of the deposits along the build direction were determined from the cross-sectional samples. Tests were performed using Vickers microhardness test instrument with load as shown in figure 1.1

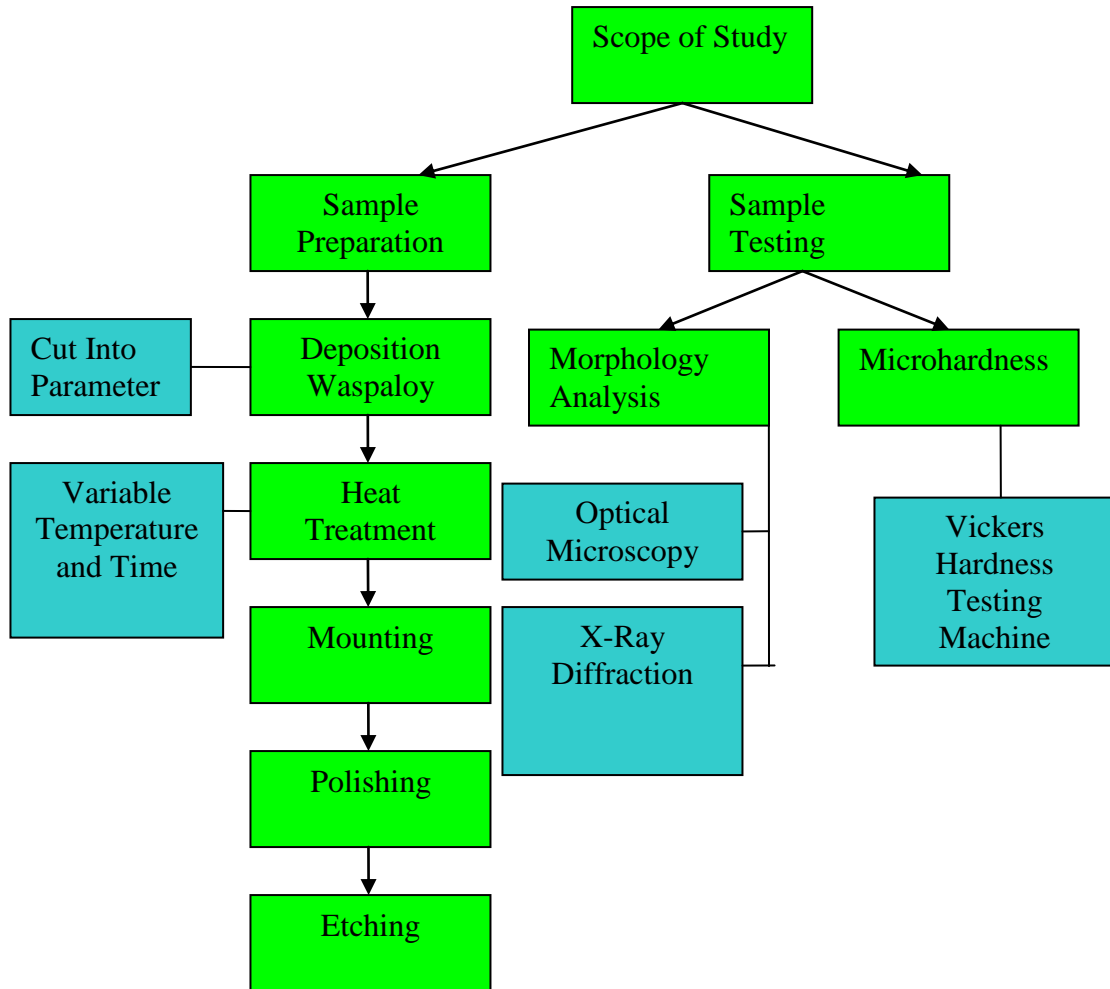


Figure 1.1: Flowchart of scope of study.

1.6 Importance of this Study

- (a) To apply the advantages of deposited Nickel based superalloy in term of engineering technology.
- (b) Analysis the potential of Nickel based alloy as a superalloy
- (c) Develop deposited as Nickel based alloy as one of the raw materials for technology application.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews metallurgy of Waspaloy and its heat treatment process. Summary of this topic is related or refer to the previous research by observing the effect of heat treatment temperature and time on carbide formation and hardness.

2.1 Superalloy

A superalloy, generally refers to high performance alloy. It is also known as a metallic alloy, which its elements of 75 % of the 112 elements in the periodic table of the elements and are found towards the left-hand side and the bottom of the table the properties of superalloy basically are creep resistance at high temperature, exhibits excellent mechanical strength, oxidation resistance and corrosion.

Usually, superalloys have a matrix with an austenitic face-centered cubic crystal structure. The element base alloying is usually nickel, cobalt and chromium. Typical applications are in the aerospace, industrial gas turbine and marine turbine industry, for example for turbine blades for hot sections of jet engines. (Dempster, I.et. al.,2005)