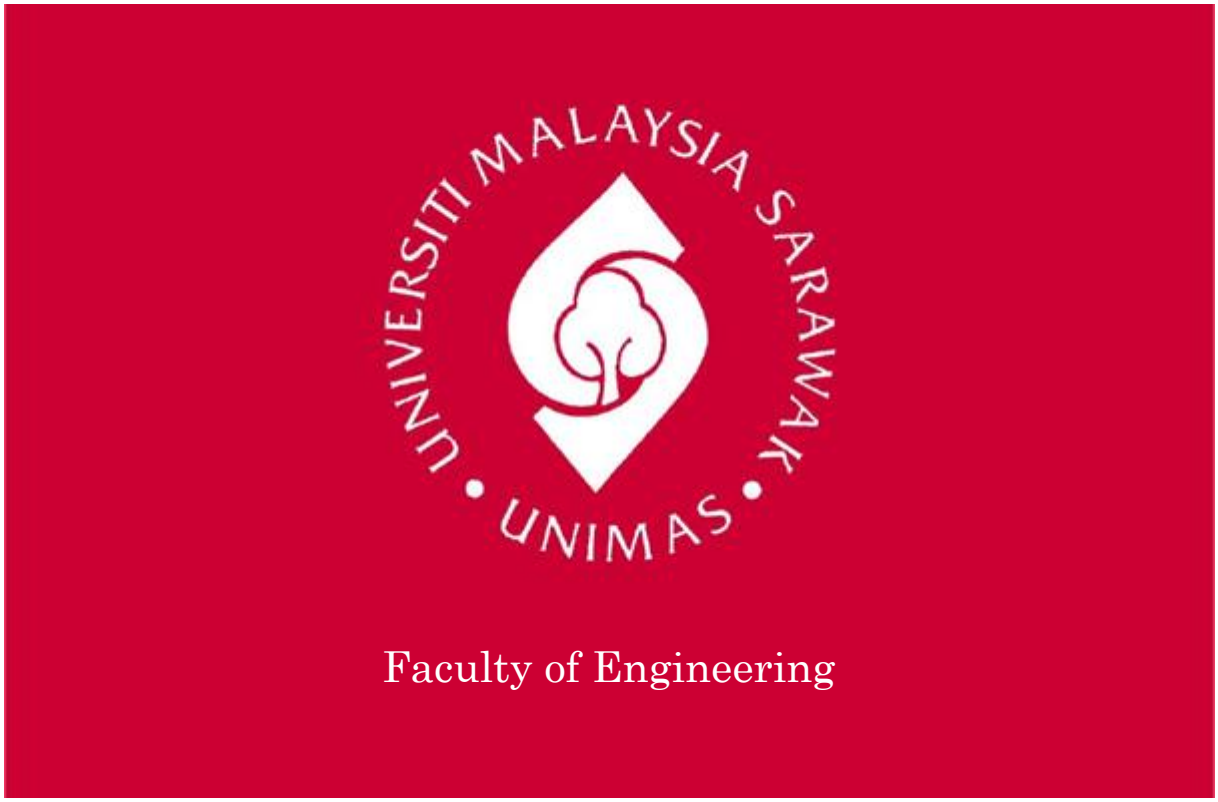


# MORPHOLOGICAL ANALYSIS OF NI-CR ALLOYS TREATED VIA CO2 LASER

Giovanni Lusom anak Andrew

Bachelor of Engineering (Hons)

Chemical Engineering and Energy Sustainability

2022

# MORPHOLOGICAL ANALYSIS OF NI-CR ALLOYS TREATED VIA CO2 LASER

GIOVANNI LUSOM ANAK ANDREW

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Chemical Engineering and Energy Sustainability

Faculty of Engineering

Universiti Malaysia Sarawak

2022

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1st July 2022

Dr. Dayang Salyani binti Abang Mahmod

(Final Year Project Supervisor)

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# ABSTRACT

Nickel-Chromium (Ni-Cr) is a highly used in the engineering field as heating elements in machineries due to its property of being able to resist oxidation, high temperature corrosion and wear. Nevertheless, Ni-Cr tends to lose its initial ductility and hardness if extreme pressure, temperature and external force are being applied to it for a long period of time due to the alterations in the molecular arrangment of the alloy. Hence, this experiment aims to tackle the problem related to decrement in the performance of Ni-Cr by treating the surface of Ni-Cr composite via employing low-power Carbon Dioxide, $CO_2$ laser. The objectives of this research are to prepare Ni-Cr pellets via cold compaction pelletizing device, to vary the parameters onto Ni-Cr alloy pellets and to analyze the surface morphology and tensile strength of the laser-treated Ni-Cr alloys via Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray (EDX), X-Ray Diffraction (XRD), Porosity Test and Vickers Hardness Test. The initial step in the experiment methodology is material preparation. This is followed by pelletizing, sintering and laser surface treatment. Once the pellets are done the analyses are done on the composites. This research proves that low power $CO_2$ laser can be considered as a way to treat Ni-Cr alloys due to the changes in the structures of the pellets and the physical properties.



**Keywords**: Nickel-Chromium, Laser treatment, Carbon Dioxide Laser

# ABSTRAK

Nikel-Kromium (Ni-Cr) sering kali digunakan dalam bidang kejuruteraan sebagai elemen pemanas dalam jentera kerana sifatnya yang mampu menahan pengoksidaan, hakisan pada suhu tinggi dan kehausan. Namun begitu, Ni-Cr cenderung kehilangan kekerasan awalnya jika tekanan, suhu dan daya luar yang melampau dikenakan padanya untuk jangka masa yang panjang disebabkan oleh perubahan dalam susunan molekul aloi. Oleh itu, eksperimen ini bertujuan untuk menangani masalah yang berkaitan dengan penurunan prestasi Ni-Cr dengan merawat permukaan komposit Ni-Cr melalui laser $CO_2$ berkuasa rendah. Objektif penyelidikan ini adalah untuk menyediakan pelet Ni-Cr melalui peranti pelet pemadatan sejuk, untuk mengubah parameter pada pelet aloi Ni-Cr dan untuk menganalisis morfologi permukaan dan kekuatan tegangan aloi Ni-Cr yang dirawat laser melalui Mikroskopi Elektron Pengimbasan. (SEM), X-Ray Dispersive Tenaga (EDX), X-Ray (XRD), Ujian Porositi dan Ujian Kekerasan Vickers. Langkah pertama dalam metodologi eksperimen ialah penyediaan bahan. Ini diikuti dengan proses pemghasilan pellet, pensinteran dan rawatan permukaan laser. Setelah pelet selesai dihasilkan, analisis dilakukan pada komposit tersebut. Penyelidikan ini membuktikan bahawa laser $CO_2$ kuasa rendah boleh dianggap sebagai satu cara untuk merawat aloi Ni-Cr disebabkan oleh perubahan dalam struktur pelet dan sifat fizikal.

**Kata kunci**: Nikel-Kromium, Rawatan Laser, Laser Karbon Dioksida

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| | |
|---|---|
| Ni-Cr | Nickel Chromium |
| Ni | Nickel |
| Cr | Chromium |
| $C_3H_6O$ | Acetone |
| SEM | Scanning Electron Microscopy |
| EDX | Energy-Dispersive X-Ray |
| XRD | X-Ray Diffraction |
| $CO_2$ | Carbon dioxide |
| $N_2$ | Nitrogen |
| $Cr_2O_3$ | Chromium (III) oxide |
| O | Oxygen |
| C | Carbon |
| Fe | Iron |
| Aluminium | Al |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Research

Industries of the present like manufacturing and automotive industries are among of the most dominant fields that uses the knowledge of material science and engineering as the fundamental basis for the well doing of the operation of these industries. Due to the emerging of these massive fields, the role of metal has been highlighted as it is one of the most required materials for building construction and fabrication of machines as the elemental body parts. Pure metals are rarely being used in any industries as they are incapable of offering a crucial range of properties. A part from being expensive, pure metals are also known to be brittle and are not sustainable for engineering uses. This is when an alloy makes its significance to the world of manufacturing. According to Naeem et al. (2013), the best combination of metal properties can be achieved via the application of alloys that are made up of two or more metals that are joined together by the process of alloying. Nickel-Chromium is one of the most commonly used alloys in any industries. The Ni-Cr system demonstrates that chromium is a soluble metal in nickel. This reaches a peak of 47% at eutectic temperature and then declines to around 30% at ambient temperature. This stable solution is the foundation for a variety of commercial Ni-Cr alloys.

Oketola et al. (2022) mentioned that in chemical engineering, Ni-Cr is employed as the main alloy used for the body or components of the machineries in the processing factories. This is due to the high-temperature corrosion resistance of Ni-Cr (Galerie, 2010). Due to the facts that it has greater oxidation and hot corrosion resistance than cheaper iron-nickel-chromium alloys, the 80/20 Ni-Cr alloy is frequently used for wrought and cast parts for high temperature applications. According to Obadele (2017) Ni-Cr alloys are able to retain the ductility and stability at high temperature of over 700°C. Oketola et al. (2022) also mentioned that Ni-Cr alloy is well-suited to oxidation-resistant applications. Higher chromium content alloys are more suited in applications where fuel

ashes or deposits such as alkali metal salts such as sulphates are encountered. This is due to the reaction between the fuel ashes with the oxide scale. Vanadium-containing ashes are particularly aggressive in this regard, having a fluxing effect on the scale and increasing the alloy's vulnerability to oxidative attack. The ability of Ni-Cr in resisting corrosion and oxidation is a very crucial property since this can prevent contamination of products and help to retain its purity throughout the processing procedures.

According to Aghdam et al (2015), Ni-Cr is used in aerospace and aircraft engineering especially as the material for the construction of turbines, compressors and other components. This application is as a result of Ni-Cr being resistant to wear action. Wear mechanisms are complex, but high hardness and good corrosion resistance contribute to good wear resistance. Ni-Cr alloys are a cost-effective alternative to weld-deposited cobalt-chrome alloys with carbon and tungsten additives, which are commonly employed in wear-resistant applications. Network (2022) mentioned that Ni based alloys with composition of other metals as additives such as 8-12 % Cr, 0.3-1.0 % C, 3-% Si, 1.5-% B, 1-4 % Fe is an example of a Ni-Cr alloy for this type of application. The coating of Ni-Cr alloy material deposited by inert gas shielded arc methods would be in the range 40-50 Rockwell °C.

Network (2022) further mentioned that Ni-Cr commonly employed as a heating element in most machines. With increased chromium additions, electrical resistance rises dramatically. For electrical resistance cables suited for heating elements, a chromium addition level of 20% is regarded optimal. This material has good electrical qualities as well as strength and ductility, making it ideal for wire drawing. Ni-Cr alloy is also famously used in dentistry due to it being cost-effective. The hardness and elastic modulus of the Ni-Cr alloy allows for the use of a thinner cross-section of material; the thinner cross-section provides more space for porcelain veneering while still offering good resistance. Another advantage is their linear thermal expansion coefficient, which is similar to that of veneering porcelain. The similarity in thermal expansion reduces the risk of cracks and fractures during processing.

In the present study, Ni-Cr alloy is being treated with laser, specifically with low power $CO_2$ laser with aim of changing the microstructures of the composites and enhancing its mechanical properties. Ni-Cr alloys are being prepared by the process of compacting the powder mixture into the form of pellets via cold compaction. This process is also known as pelletizing. Pre-liminary experiments are being done in order to

determine the suitable parameters for the next subsequent steps in the research methodology which are sintering and followed by laser surface treatment. When the pellets have been prepared and treated, analyses are done in order to observe the effects of laser surface treatment on the surface morphology and mechanical as well as physical properties of the Ni-Cr pellets.

## 1.2 Problem Statement

It is well mentioned that the alloy Ni-Cr is ductile, having the ability to large external force. But the problem here is, the strength of the nickel-chromium will wear off over time. Thurn et al. (2012) mentioned that nichrome tends to lose its ductility and gain brittleness when heating is done to the alloy. The huge amount of heat energy during heating will slowly disrupt the molecular arrangement of the Ni-Cr composite. Eventually, the Ni-Cr alloy will lose its initial ductility. This will affect the performance of the Ni-Cr alloy in the long run. There are a few drawbacks related to this study specifically on laser treatment. These problems need to be taken into consideration before conducting the treatment. The areas that need to be determined are the power density on materials temperature, laser interaction time on depth of melting and melt depth and laser density on average cooling rates. These parameters need to be determined in order to successfully densify the Ni-Cr alloy. Most of the researchers are employing high power of laser for the purpose of treating the alloy. For example, Zhang et al. (2015) applied high power of $CO_2$ laser of 2500 W for the treatment of 800H alloy. Lack of research specifically with treatment of alloy with low power $CO_2$ laser has made the parameter determination for this research an issue.

## 1.3 Research Gap

One of the limitations to this study is that treating alloy with laser is not widely done in the research industry. A few past researches did proof that laser will cause changes to the microstructure of the composite but is the resulting mechanical properties of the treated and non-treated composite is not widely discussed in the research industry. The parameters on the laser treatment of Ni-Cr alloy also had not been done, specifically on the low power $CO_2$ laser.

## 1.4 Research Questions

A few questions arise from the problem statement.

1. How to prepare Ni-Cr powder mixture into pellet form?
2. What are the suitable parameters for the laser treatment for Ni-Cr alloy pellets?
3. How does laser treatment parameter effect on the Ni-Cr alloy?

## 1.5 Research Objectives

The aim of this study is to investigate the morphological structure of the laser treated Ni-Cr. There are a few objectives formulated for this study in order to solve the problem arises in the problem statement which are:

1. To prepare Ni-Cr alloy pellets via pelletizing device.
2. To vary the parameters of laser treatment onto Ni-Cr alloy pellets.
3. To analyse the surface morphology and tensile strength of laser treated Ni-Cr alloy

## 1.6 Scope of Research

The scope of this study is including the research on the properties of the laser-treated Ni-Cr alloy. The research scope is including its application as well. Research on laser, which is specifically $CO_2$ laser. The study emphasises on the procedure of the laser treatment, determination of parameters and the effects of the laser treatment to Ni-Cr composite. The pellets of Ni-Cr with the determined composition will be prepared and then the sample will be brought to laser treatment. The Ni-Cr will be treated by using carbon dioxide laser. The parameters of the $CO_2$ will be studied and recorded for further usage in the upcoming discussion. Then, the morphological structure and properties of the Ni-Cr that has been treated will be studied. The experimental work will be carried out at Basic Chemistry Lab (pelletizing), Bio Process Lab (porosity analysis) and Workshop (tubular furnace for low temperature sintering for preliminary experiment purposes) of the Department of Chemical Engineering and Energy Sustainability. In the Mechanical Engineering and Manufacturing Department, the working area covered are Mechanical Engineering Metallurgy Lab (high temperature sintering) and Mechanical Non-Destructive Lab (laser treatment)

## 1.7 Significance of Research

Significance of this research are being outlined into a few parts. The first significance is in depth knowledge of Ni-Cr for engineering application. This study covers the properties of Ni-Cr which makes it suitable for different applications in different fields. For example, Ni-Cr is employed in chemical engineering as the material for construction of most machineries parts in the processing industries (Oketola et al., 2022). This because it is capable to resist corrosion in high temperature and maintain its stability as well. Ni-Cr is also widely used in aerospace and aircraft due to its excellency in its mechanical strength and wear resistant property (Aghdam et al., 2015). This in-depth knowledge of application of Ni-Cr in most of the industries is crucial in order to put Ni-Cr into highlights of why this alloy is so important to most fields especially in engineering. This is also to put more awareness and attention into Ni-Cr for the evolution and growth development of the engineering field in the near future.

Another major significance of this research is the determination of parameters. High sintering temperature of over 1000°C is crucial in order for a full consolidation of the Ni-Cr alloys. This research also studies on the effect of low sintering temperature and the property of the sintered pellets. A low temperature below 1000°C results in more porosity of the alloys which is indication of insufficient heat energy and stress applied to the alloy for a full complete sintering process to occur for Ni-Cr alloy. This is supported by literature review on Mohamad et al. (2017), on which the study compared the properties of Ni-Cr alloys sintered at two different temperatures of 1000°C and 1200°C. The pellets sintered at lower temperature show higher in porosity percentage and lower hardness value.

Determination of parameters for low power $CO_2$ laser is also another major significance of this research. Most studies focus on employing high power laser for the treatment of alloy. For example, the treatment of 800H alloy with 2400W $CO_2$ laser (Zhang et al., 2015). Low power $CO_2$ laser is being used for other application but not for the treatment of alloy. Moghadasi and Tamrin (2020) applied low power $CO_2$ laser for cutting Carbon/Kevlar Fibre-reinforced Hybrid composite. This research aims to provide new findings and literature sources for treating alloy with low power $CO_2$ laser. A

significance that should be highlighted as well in this research is that laser surface treatment via low power $CO_2$ laser is able to bring changes on the microstructures of Ni-Cr alloy along with the new physical properties as well.

The significance of this research also plays around the concept of sustainability. Vast majority of nations nowadays are focussing their attention the sustainable development by making it as a goal to be achieved especially in engineering field of processing and energy. Sustainability is being defined in many terms but in general, sustainability is being inclusive of three aspects that must be taken into considerations which are environment, economy and social (Rosen, 2012). This research is aiming to promote sustainability in the chemical engineering. Mohamad et al. (2017) mentioned that the processing industry encounters massive losses in the faulty of the machinery parts. The laser surface treatment of Ni-Cr alloy is able to sustain and lengthen the work-life of the alloy to be used in machineries, making the alloy more heat and wear resistance than before. This also covers the economic aspect of sustainability by which less costs are being needed for the maintenance of the manufactories. Indirectly, this is also touching the environmental sustainability by which less faulty machineries parts that will lead to wastage.

## 1.8 Summary

In this chapter, the general overview of this study was mentioned. The main aim of this study is to investigate the morphological structure of the laser-treated Ni-Cr. Based on the problem statement, a few objectives are formulated which are to prepare Ni-Cr alloy pellets via pelletizing device (1), to vary the parameters of laser treatment onto Ni-Cr alloy pellets (2), to analyse the surface morphology and tensile strength of laser treated Ni-Cr alloy (3). The research scope is being inclusive on the research of Ni-Cr material and its application as well as $CO_2$ laser.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Nickel-Chromium (Ni-Cr) Alloy

An alloy is metal composed of two or more elements, one of which must be a metal. Alloys are usually created by mixing these materials together in their molten form. The result is a uniform metal that has a combination of the physical, chemical and electrical properties of all the materials used to make the alloy (Corrosionpedia, 2020). An alloy is produced through the process of alloying. Alloying is defined as the process of adding one or more elements or compounds to interact with base metal. This is in order to obtain beneficial changes in its mechanical, physical or chemical properties or processing characteristics (Davis, 2001). Alloying is greatest gift of metallurgy to humanity. Nickel-Chromium alloy is an alloy that is made up of Nickel and Chromium. Nickel chrome alloy, or Nichrome as it is more frequently known, is a nickel, chromium, and iron alloy. The alloy is frequently represented in the chemical formula of Ni-Cr. Nichrome alloys are typically made of 80% nickel and 20% chromium (Nichrome 80/20), while other compositions in various ratios can be found. The colour of nichrome is silver-grey, and it possesses a strong resistance to electrical flow and heat.

### 2.1.1 Properties of Ni-Cr alloy

Ni-Cr alloy is the combination of both Nickel (Ni) and Chromium (Cr) metal. Each metal element has different properties. The alloying of these two metals to form Ni – Cr will for sure create new properties of the alloy. The properties of Ni, Cr and Ni-Cr are being presented in the **Table 2.1** below.

**Table 2.1:** Properties of Nickel, Chromium and Nickel-Chromium

| Type | Property | References |
|---|---|---|