UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

THE EFFECT OF RESISTANCE HEATING TO THE LENGTH EXPANSION OF COLD BENDING SPRING STEEL BAR

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "The Effect of Resistance Heating to the Length Expansion of Cold Bending Spring Steel Bar" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ……………………………….

Supervisor Name : Associate Professor Dr. Zuhriah Bt Ebrahim

Date : ……………………..…………

DEDICATION

I would like to dedicate my highest acknowledgement to my beloved; father, Haji Suhaimin bin Yasin and mother Hajjah Hayati binti Mohd Nor, my wife, Nur Fatihah binti Ismail and also my precious siblings for always being with me through all the hardship of my study by giving consistently support and encouragement.

ABSTRACT

Resistance heating (RH) is a technique of heating process for metal by which the passage of an electric current passes through a conductor that produces heat. It also known as Joule Heating or Ohmic Heating. In automotive industry, RH technique has been applied in producing stabilizer bar after cold bending process as it can reduce manufacturing cost. However, the effectiveness of RH technique in this case has been questionable as number of rework case is almost 100% per production. The rework case is due to length defects of the stabilizer bar. Up to this date, there is limited study on the factors that have significant effects to RH effectiveness especially the length expansion of spring steel bar in different diameters. Hence, the aim of this study is to provide an optimum setting for significant factors of RH that can reduce the rework case in manufacturing of stabilizer bar. There are three objectives of this study. First, is to identify the significant factors that affect RH effectiveness. Second, is to analyse the effect of the significant factors of RH to the length expansion of the spring steel, and the third one is to analyse the effect of different diameter of SUP9 spring steel bars to its length expansion through resistance heating. The study opted for an exploratory study using literature study to identify the significant factor that affect RH effectiveness. A simple statistical analysis is used in identifying the significant factors. Heating temperatures and heating time have been clarified as the significant factors of RH. Design of experiment was carried out to analyse the effect of the significant factors of RH to the length expansion of spring steel bar based on the number of defects determined. The type of spring steel bar used known as spring steel of SUP9 (type code) which is a high quality cold bending spring steel that belong to the high quality carbon alloy spring steel. The result of analysis shows that small changes in heating temperature up to 20ºC and heating time up to four seconds at RH process do affect the length of SUP9 spring steel bars. that had gone through cold bending process beforehand. Overall, heating temperature and heating time are the significant factors of RH that affect the expansion length of SUP9 spring steel bar which different setting is required for a range of diameter sizes for example 18mm, 20mm, 22mm, and 24mm. The result clarified that as the diameter increase, it is necessary to increase heating time by 2s for each 2mm increment of diameter. The heating temperature shall remain if the increment of diameter range within 4mm. However, the heating temperature has to be increase 10°C once the diameter change more than 4mm. The findings are valuable to automotive industry in reducing the defects due to inappropriate setting of heating temperature and heating time have been used at RH technique.

KESAN PEMANASAN RINTANGAN KEPADA PENGEMBANGAN PANJANG BAR KELULI PEGAS LENTURAN SEJUK

ABSTRAK

Pemanasan rintangan (RH) adalah proses pemanasan yang mana arus elektrik melalui konduktor lalu menghasilkan haba. Ia juga dikenali sebagai Pemanasan Joule atau Pemanasan Ohmik. Dalam industri automotif, aplikasi teknik RH ini sangat penting bagi pembuatan bar penstabil untuk diteliti berikutan kajian ini menunjukkan isu hampir 100% pembuatan semula diperlukan bagi setiap pengeluaran. Kes pembuatan semula ini disebabkan oleh ketidaksempurnaan pada panjang bar penstabil. Sehingga kini, kajian terhadap faktor-faktor yang mempunyai kesan signifikan kepada keberkesanan RH masih lagi terhad terutamanya apabila melibatkan pengembangan panjang pada bar keluli pegas dalam diameter yang berbeza. Oleh itu, tujuan kajian ini adalah untuk menyediakan tetapan yang optimum kepada faktor-faktor signifikan RH yang boleh mengurangkan kes pembuatan semula dalam pengeluaran bar penstabil. Terdapat tiga objektif dalam kajian ini. Pertama adalah untuk mengenalpasti faktor-faktor signifikan yang mempengaruhi keberkesanan RH. Kedua, adalah untuk menganalisis kesan faktor-faktor signifikan RH terhadap pengembangan panjang bagi bar keluli pegas dan ketiga adalah untuk menganalisis faktor-faktor signifikan RH terhadap bar keluli pegas yang berbeza diameter. Kajian ini memilih kajian penerokaan melalui kajian kesasteraan untuk mengenalpasti faktor-faktor yang signifikan dalam mempengaruhi keberkesanan RH. Analisis statistik digunakan dalam mengenalpasti faktor-faktor yang signifikan. Suhu pemanasan dan masa pemanasan telah dikenalpasti sebagai faktor-faktor yang signifikan kepada RH. Satu rekabentuk eksperimen telah dijalankan bagi menganalisis kesan faktor-faktor signifikan RH iaitu suhu pemanasan dan masa pemanasan terhadap pengembangan panjang bar keluli pegas melalui bilangan kerosakan bar penstabil yang dikenalpasti. Jenis keluli pegas yang digunakan adalah keluli pegas SUP9 (jenis kod) yang merupakan keluli pegas lenturan sejuk. Ianya sejenis keluli berkualiti tinggi yang mana ianya tergolong dalam keluli pegas yang mengandungi aloi karbon yang berkualiti tinggi. Keputusan analisis menunjukkan bahawa perubahan kecil pada suhu pemanasan lingkungan 20°C dan suhu pemanasan lingkungan 4 saat semasa process RH mempunyai kesan terhadap keluli pegas SUP9 yang melalui proses lenturan sejuk sebelumnya. Keseluruhannya, suhu pemanasan dan masa pemanasan merupakan faktor-faktor yang signifikan RH yang mempengaruhi pengembangan panjang bar keluli pegas SUP9 yang mana tetapan berbeza diperlukan bagi setiap diameter berbeza, contohnya 18mm, 20mm, 22mm, dan 24mm. Keputusan turut diperjelaskan bahawa apabila diameter bertambah, amatlah perlu untuk meningkatkan masa pemanasan sebanyak 2 saat bagi setiap 2mm peningkatan diameter. Suhu pemanasan perlu kekal jika peningkatan diameter masih berada dalam lingkungan 4mm. Walau bagaimanapun, suhu pemanasan perlu bertambah 10°C apabila diameter mengalami perubahan melebihi 4mm. Penemuan ini sangatlah bernilai kepada industri automotif dalam mengurangkan kerosakan bar keluli pegas berikutan tetapan yang tidak sesuai kepada suhu pemanasan dan masa pemanasan yang sebelum ini pernah digunakan dalam teknik RH.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
CFS	-	Cold Formed Steels
CFRPs	-	Carbon-Fiber-Reinforced Plastics
DoE	-	Design of Experiment
DC	-	Direct Current
HSS	-	High Strength Steel
OOA	-	Out-of-Autoclave
QC	-	Quality Control
RH	-	Resistance Heating
STC	-	Sapura Technical Centre
SUP9	-	Spring steel's code
UTeM	-	Universiti Teknikal Malaysia Melaka

LIST OF PUBLICATIONS

1. Khairul, N. S., Ebrahim, Z., and Razali, M. M., Kamalrudin, M., and Hakimi, M., 2019. Effects of Resistance Heating Parameters on Spring Steel by using Design of Experiment. *International Journal of Recent Technology and Engineering (IJRTE)*, 8 (1C2), pp. 851-856.
2. Khairul, N. S., Ebrahim, Z., and Razali, M. M., 2018. Kinematic Analysis Performance Between Short Long Arm and Parallel Suspension for Racing Car. *The Turkish Online Journal of Design, Art and Communication* (TOJDAC), September, pp. 2697-2709.
3. Khairul, N. S., Ebrahim, Z., and Razali, M. M., 2018. Kinematic Analysis Performance Between Short Long Arm and Parallel Suspension for Racing Car. *Journal of Advance Research in Dynamical and Control Systems* (JARDCS), 10(05)-Special Issue, pp. 321-327.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Resistance heating (RH) is defined as the heat produced by passing an electric current through a material that preferably has high resistance (Barber, 1982). According to Mikno and Bartnik (2016), RH also can be stated as a heating method when current flows through a heated work piece between two contacting fixed electrodes which increases in temperature. To summarise, those definitions actually share the same key points which define RH as a heating method or process, with a flow of current through the material that has a resistance between two contacted electrodes to produce heat.

Length expansion of resistance heating can be defined as the increment in length and dimension linearly due to increasing temperature as the current flow through the heated work piece between two contacting fixed electrodes (Martin et. al., 2017). The study of length expansion is important, especially in the heating stage of the heat treatment process that applies the cold bending method. There are various applications of the cold bending method, which include home appliances or metal furniture, production of building steel sheds and manufacturing of stabiliser bar of the vehicles. In the stabiliser bar production, the application of spring steel is essential. One of types of the spring steel used in stabilizer bar production is SUP9 spring steel. SUP9 spring steel is a high quality spring steel that belong to the high quality carbon alloy spring steel which is suitable for cold bending process (Harada et. al., 2014). The utilisation of spring steel in making stabiliser bar is essential as the bar itself needs to be light and strong (Podgornik et. al., 2015).

In manufacturing the stabiliser bar, two bending methods can be applied while the material undergoes heat treatment process either cold bending or hot bending. However, the focus of this study is the length expansion as a result of resistance heating when the material goes through the cold bending method; this procedure is ideal for producing parts that are long or in large quantities. Cold bending is generally a lower-cost process compared with other metal forming processes (Hadjioannou et. al., 2013), and it is essential in producing high-quality spring steel automotive parts. Hence, the salient parameters during the heating stage need to be identified in order to determine the length expansion of the material, so that stabiliser bars produced are of high strength.

Currently, there is no study about the length expansion related to resistance heating for spring steel production; such investigation entails the identification of the various factors that can improve the resistance heating process and the study of the relationship between these factors. Therefore, this research aims to study the length expansion of the SUP9 spring steel bars when the material undergoes resistance heating. The main research objective is to identify the parameters that contribute to the efficient process of resistance heating for the SUP9 spring steel bar, which affects the final length of the SUP9 spring steel bars at the end of the production line. The efficient resistance determined by the number of the length defects of the steel bar. Then, the significance parameters that already identified will be studied in conducting experiment which to determine RH's effectiveness.

Hence, it is crucial to understand the best parameter setting for the specific types of steel in order to reduce the dimensional defects caused by the Resistance Heating technique. In this regard, a number of experiments are necessary so as to determine the best parameter setting of resistance heating. Therefore, the Design of Experiment (DoE) is applied as the methodology is an effective tool for upgrading the level of measurement and assessment (Krishna and Xavior, 2016).

1.2 Problem statement

Globalisation has transformed the automotive industry in various countries of the world, with fierce competition amongst the automotive vendors. The automobile industry is a powerful catalyst for developing and improving a country's socioeconomics; the sector mobilises a humongous amount of capital and employs a large number of knowledge-based workers and hence the economic spin-off is enormous (Krasova, 2018). Currently, the auto-industry is booming, and it draws in more and more countries to participate in the production of cars, while the interacting forces of the automotive market are constantly changing (Saberi, 2018). This rapid growth of the automotive industry can be seen from the statistics of the global automobile production for the years of 2000 to 2018 (in million vehicles), as provided by The Statista (2018), and displayed in Figure 1.1.

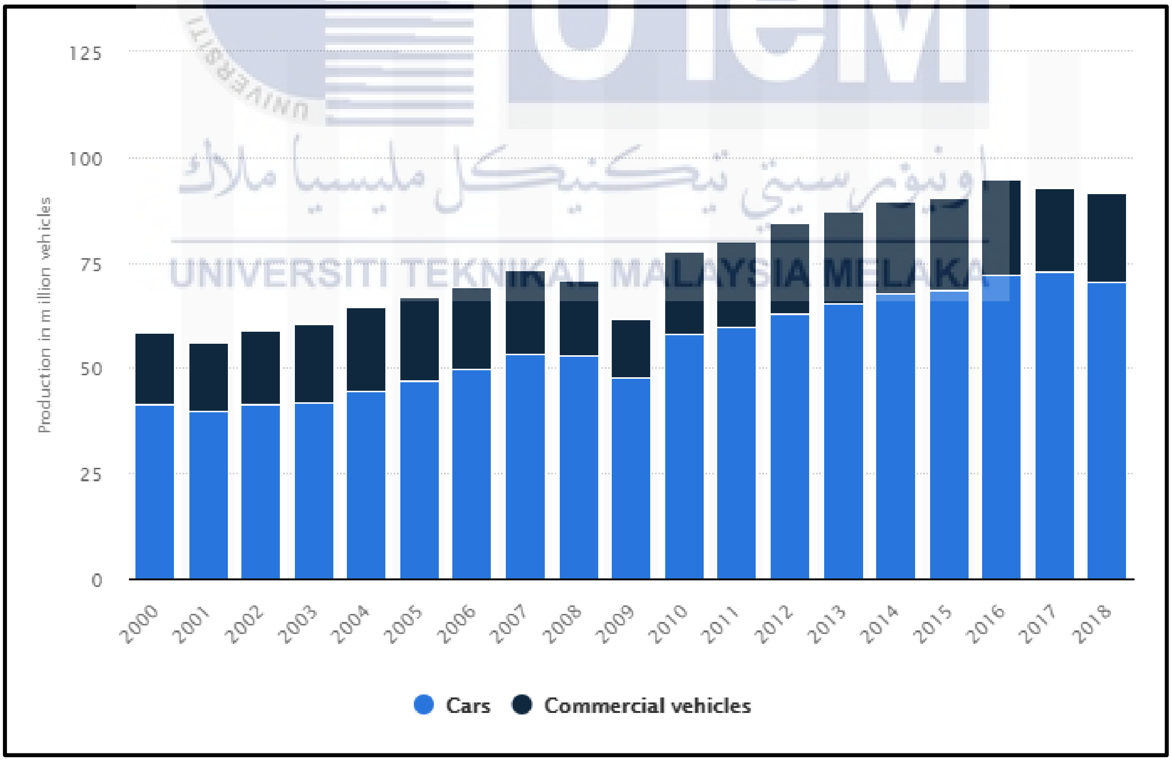

Figure 1.1: The estimated worldwide automobile production from 2000 to 2018

(https://www.statista.com/statistics/262747/worldwide-automobile-production-since-2000)

According to Spitsin and Mikhalchuk (2018), it is believed that the automotive industry growth will be maintained as the Internet Of Things (IoT) and AI Unleashed Transformation continue to revolutionise the automotive sector, driving unprecedented transformations across the vehicle and device connectivity, autonomous driving, electric powertrains, and shared mobility. This statement is supported by the statistics of light vehicle production forecast, prepared by The Statista (2018), and displayed in Figure 1.2.

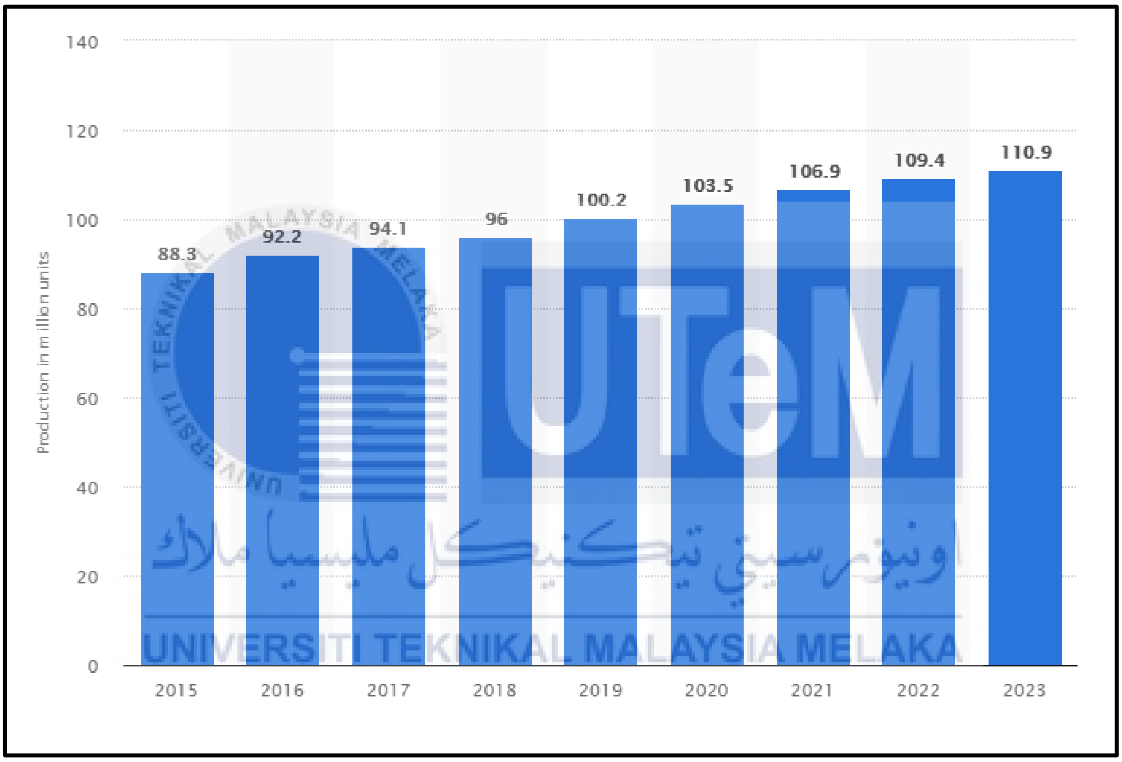

Figure 1.2: Global light vehicle production forecast from 2015 to 2023

Basically, from the graph, it can be seen that from the year 2015, the pattern of light vehicle production is expected to increase steadily until the year 2023. These impressive figures reinforce the importance of studying the matrices of the automotive industry. The growing automobile industry is a major factor that drives the demand of stabiliser bars. The stabiliser bar is one of the key components for manufacturing any automobile as it keeps the vehicle safe by reducing the automotive body roll during fast cornering or moving over road irregularities. The commercial high quality spring steel that known as SUP9 spring steel is one of the essential implementation in stabilizer bar production as it belong to the high quality carbon alloy spring steel which is suitable for cold bending process. This study focuses on one of the RH applications in the automotive industry that is the heating of SUP9 spring steel in the production of stabiliser bars. According to Fragoudakis et. al. (2014), the most crucial step in the manufacturing process of the spring-steel stabiliser bar is heat treatment. Of course, one of the essential stages is heating; and this research focuses on resistance heating.

However, its happen at the cold bending method facilitated by resistance heating causes almost 100% reworks at the end of the process due the length defects of the cold bending SUP9 spring steel bars produced. Figure 1.3 shows the monthly numbers of reworks of spring steel bars in the year 2017 in Sapura Technical Centre.

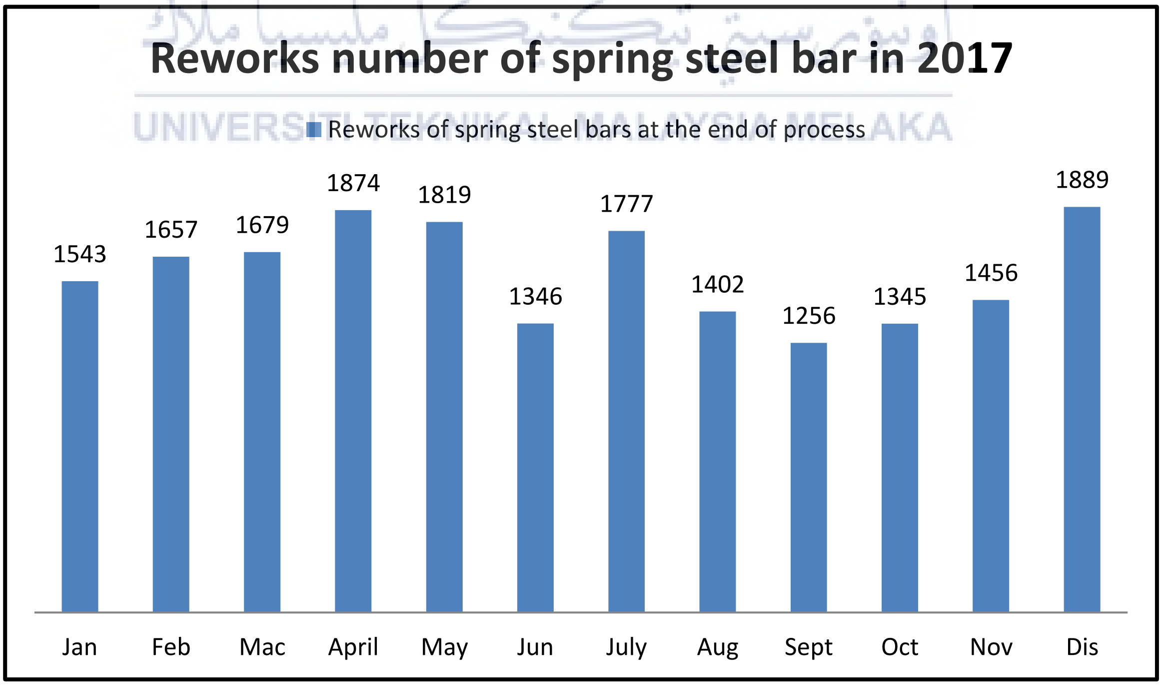

Figure 1.3: The monthly number of reworks of spring steel bars in 2017

(Source: Sapura Technical Centre's data reworks in 2017)