



Faculty of Manufacturing Engineering

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



Mohd Khairul Nizam Bin Suhaimin

Master of Science in Manufacturing Engineering

2020

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

MOHD KHAIRUL NIZAM BIN SUHAIMIN



Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

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 :

Name : Mohd Khairul Nizam Bin Suhaimin

Date :



اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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 : اونیورسیتی تکنیکل مالیزیا ملاک

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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 Fatimah 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 20°C 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.

ACKNOWLEDGEMENTS

In The Name of Allah, The Most Gracious, The Most Merciful

I would first like to thank my main supervisor, Associate Professor Dr. Zuhriah Bt Ebrahim for the continuous support of my master study and related research, for her patience, motivation, and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. I would also like to express my greatest gratitude to Professor Ts. Datuk Dr. Mohd Razali Bin Muhammad on his willingness to become co-supervisor in this research. He always open whenever I ran into a trouble spot or had a question about my research or writing.

I also would like to acknowledge the priceless contributions of the highest executive, managers, engineers and technicians from Sapura Technical Centre Sdn. Bhd. and Sapura Asian Automotive Steel Sdn. Bhd. for helping me in term of advice, knowledge transfer, experiment set-up assist and food coupon for almost 1 year which I've been there for this research purpose.

Special gratitude also for my colleagues in UTeM (Ahmad Nawawi, Halimaton Hakimi and Umar Mukhtar) for supporting me through their encouragement and honest comment on my research.

Last but not least, special thanks for Universiti Teknikal Malaysia Melaka under Zamalah Scholarship Scheme for financial support of my publication during the study.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF APPENDICES	xii
LIST OF ABBREVIATIONS	xiii
LIST OF PUBLICATIONS	xiv
CHAPTER	
1. INTRODUCTION	1
1.1 Introduction	1
1.2 Problem statement	3
1.3 Research questions	7
1.4 Research objectives	7
1.5 Scope of research	7
1.6 Significance of study	9
1.7 Organisation of thesis	9
1.8 Summary	11
2. LITERATURE REVIEW	12
2.1 Introduction	12
2.2 Resistance heating study	13
2.2.1 Resistance heating definition	13
2.2.2 Application and advantages of resistance heating	14
2.2.3 Related works on resistance heating study	15
2.2.4 Factors that affect the effectiveness of resistance heating	18
2.3 Cold bending process	22
2.3.1 Applications of cold bending technology in manufacturing industry	23
2.4 Spring steel	25
2.4.1 Characteristic of spring steel	26
2.4.2 Recent studies on spring steel	28
2.5 Stabilizer bar	31
2.5.1 The manufacturing processes of stabilizer bar	32
2.5.2 Bending process (cold bending)	33
2.5.3 Heat treatment on stabilizer bar production	33
2.5.3.1 Heating stage	34
2.5.3.2 Quenching stage	35
2.5.3.3 Tempering stage	35
2.5.4 Quality inspection	36
2.5.5 Relationship between resistances heating with length	36

expansion of spring steel bars	37
2.5.6 Painting	37
2.5.7 Defects in manufacturing of stabilizer bar	38
2.5.7.1 Rework process (manual bar bending)	39
2.5.8 Design of experiment (DoE)	41
2.6 Theoretical framework	42
2.7 Summary	43
3. RESEARCH METHODOLOGY	45
3.1 Introduction	45
3.2 Planning the activities	46
3.3 Data collection and sample size	47
3.3.1 Qualitative data	47
3.3.2 Quantitative data	47
3.4 Stage 1: Determine the significance factors for effective resistance heating	48
3.4.1 Data collection and literature study	48
3.4.2 Data analysis	50
3.4.3 Result and discussion	51
3.5 Stage 2: Analysis of the effect for heating temperature and heating time to the effectiveness of resistance heating	52
3.5.1 Planning the design of experiment	53
3.5.2 Experiment set up	55
3.5.3 Data analysis	59
3.5.3.1 Main effects plot	59
3.5.3.2 Interaction plot	60
3.6 Stage 3: Analysis of significant factors of resistance heating with different diameter of spring steel bar	61
3.6.1 Data collection	62
3.6.2 Data analysis	64
3.7 Summary	65
4. RESULT AND DISCUSSION	66
4.1 Introduction	66
4.2 RO1: Identifying the significant factors that affect the RH effectiveness	66
4.2.1 Data collection	66
4.2.1.1 Sources of literature material	67
4.2.1.2 Publishing year of literature papers studied	67
4.2.2 Data analysis	68
4.2.2.1 Analysis of the best combination of significant resistance heating factors	68
4.2.3 Result and discussion	69
4.2.3.1 Heating temperature	71
4.2.3.2 Heating time	71
4.2.3.3 Findings	72
4.3 RO2: Analysis of the effect for heating temperature and heating time to resistance heating effectiveness	73
4.3.1 Data collection	73

4.3.2	Analysis of result and discussion	74
4.3.2.1	Main effects plot for number of defects	75
4.3.2.2	Interaction plot for number of defects	76
4.3.3	Findings	77
4.4	RO3: Analysis the effect of different diameter of SUP9 spring steel bars to its length expansion through resistance heating	78
4.4.1	Data collection	78
4.4.2	Analysis of result and discussion	79
4.4.2.1	20 mm-diameter SUP9 spring steel bar	79
4.4.2.2	22 mm-diameter spring steel bar	84
4.4.2.3	24 mm-diameter spring steel bar	88
4.4.3	Findings	93
4.5	Summary	97
5.	CONCLUSION AND RECOMMENDATIONS	99
5.1	Introduction	99
5.2	Conclusion from research findings	99
5.3	Contribution of research (stabilizer bar)	102
5.3.1	Academic contributions	103
5.3.2	Industry contributions	103
	REFERENCES	104
	APPENDICES	125



LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Definition of resistance heating	14
2.2	Recent studies on the topic of resistance heating (RH) and its method	16
2.3	Recent studies on factors that affect the effectiveness of RH	19
2.4	Recent studies on cold bending technology and its method	24
2.5	Chemical composition of SUP9 spring steel (%)	27
2.6	Physical properties of SUP9 spring steel	27
2.7	Mechanical properties of SUP9 spring steel	28
2.8	Recent studies on spring steel	29
3.1	Synonym of the keywords	50
3.2	Parameters (variable factors) and setting level for DOE plan	54
3.3	Series of experiment	55
3.4	Check sheet will be used for data collection of Stage 3	63
4.1	Percentages of different types of literature papers studied	67
4.2	Percentages of literature studies based on year-range	68
4.3	Series of experiment for determining RH effectiveness through heating temperature and heating time for cold bending SUP9 spring steel bar (18mm diameter)	74

4.4	Series of experiment for determining RH effectiveness through heating temperature and heating time for cold bending SUP9 spring steel bar (20mm diameter)	79
4.5	Series of experiment for determining RH effectiveness through heating temperature and heating time for cold bending SUP9 spring steel bar (22mm diameter)	84
4.6	Series of experiment for determining RH effectiveness through heating temperature and heating time for cold bending SUP9 spring steel bar (24mm diameter)	88
4.7	Summary of the nine series of experiments for different diameters	95
4.8	Setting of heating time and heating temperature for different diameters of SUP9 spring steel bar	97



LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	The estimated worldwide automobile production from 2000 to 2018	3
1.2	Global light vehicle production forecast from 2015 to 2023	4
1.3	The monthly number of reworks of spring steel bars in 2017	5
1.4	K-Chart of the research	8
2.1	Example of spring steel used for cold bending	26
2.2	Example of Stabilizer bar (Sapura Industrial)	31
2.3	Process flowchart for the manufacturing of stabilizer bar	32
2.4	Jig used for quality inspection of spring steel for stabilizer bars	36
2.5	Machine used for rework process (STC,2017)	40
2.6	Rework process conducted by operator (STC, 2017)	40
2.7	Theoretical framework	42
3.1	Main process flow of the research methodology	46
3.2	The process flow of Stage 1	49
3.3	Process flow of Stage 2	52
3.4	3 ² Design Schematic	53
3.5	Experimental set up; resistive heater machine	56
3.6	Resistance heating process of spring steel	57

3.7	Actual Jig for quality checking length of SUP9 spring steel bars	58
3.8	CAD Jig design for quality checking length of SUP9 spring steel bars	58
3.9	Example of main effect plots	60
3.10	Example of interaction plot	61
3.11	Flow chart of Stage 3	62
4.1	Factors influencing the effectiveness of resistive heating	69
4.2	Main effects plot for number of defects	75
4.3	Interaction plot for number of defects	77
4.4	Number of defects for 20 mm-diameter spring steel bar	80
4.5	Main effects plot for number of defects on 20 mm-diameter spring steel bar	81
4.6	Interaction plot for number of defects on 20 mm-diameter spring steel bar	82
4.7	Number of defects for 22 mm-diameter spring steel bar	85
4.8	Main effects plot for number of defects in 22 mm-diameter spring steel bar	86
4.9	Interaction plot for number of defects in 22 mm-diameter spring steel bar	87
4.10	Number of defects for 24 mm-diameter spring steel bar	89
4.11	Main effects plot for number of defects on 24 mm-diameter spring steel bar	91
4.12	Interaction plot for number of defects on 24 mm-diameter	92

	spring steel bar	
4.13	Number of defects for different diameters of spring steel bar	94
5.1	Conclusion for research objective 2	100
5.2	Overall setting of heating time and heating temperature for different diameters of SUP9 spring steel	101



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt chart	125
B	Request letter of placement in Sapura Technical Centre (STC)	126
C	Digital library of paper study for objective 1	127
D	Type of paper studied for objective 1	129
E	Year of paper study for objective 1	130
F	RH parameters studies for objective 1	131
G	Example of check sheet data (quality inspection) for Design of Experiment of 18mm diameter (objective 2)	134
H	Data Collection (from data logger) for DOE of 18 mm diameter bar	137
I-1	Data collection of DOE for different diameter bars (18 mm & 20 mm)	138
I-2	Data collection of DOE for different diameter bars (22 mm & 24 mm)	139

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 (Saber, 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.

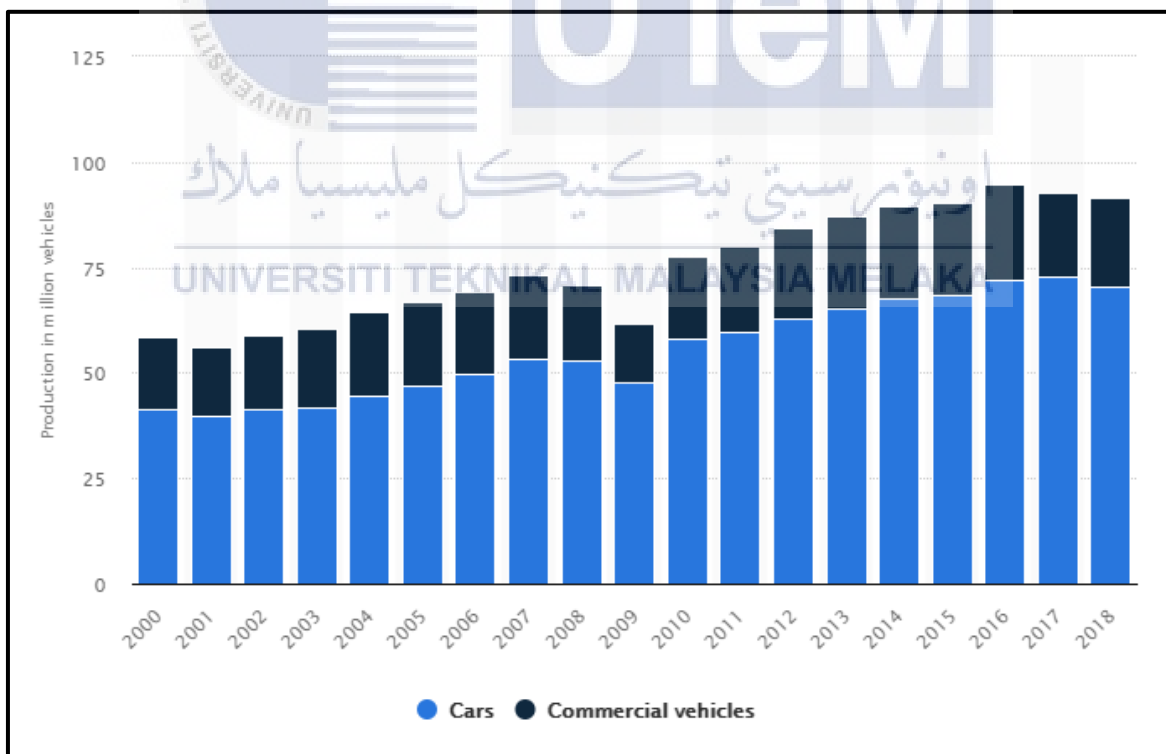


Figure 1.1: The estimated worldwide automobile production from 2000 to 2018

(<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.

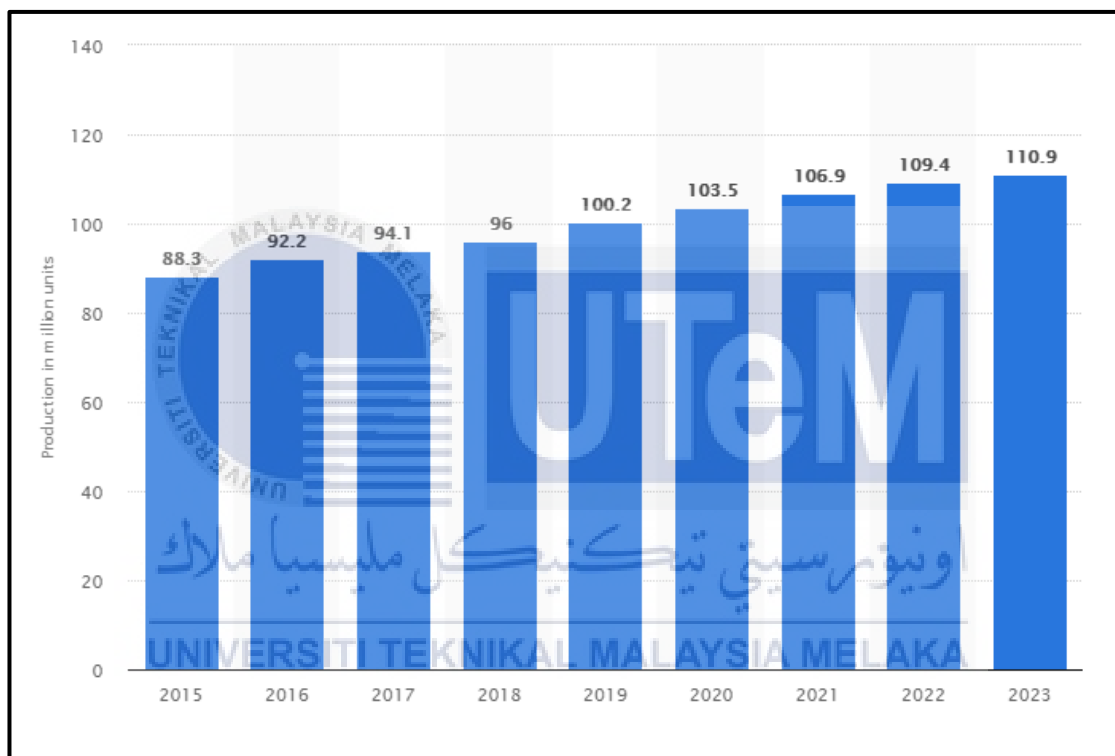


Figure 1.2: Global light vehicle production forecast from 2015 to 2023

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.

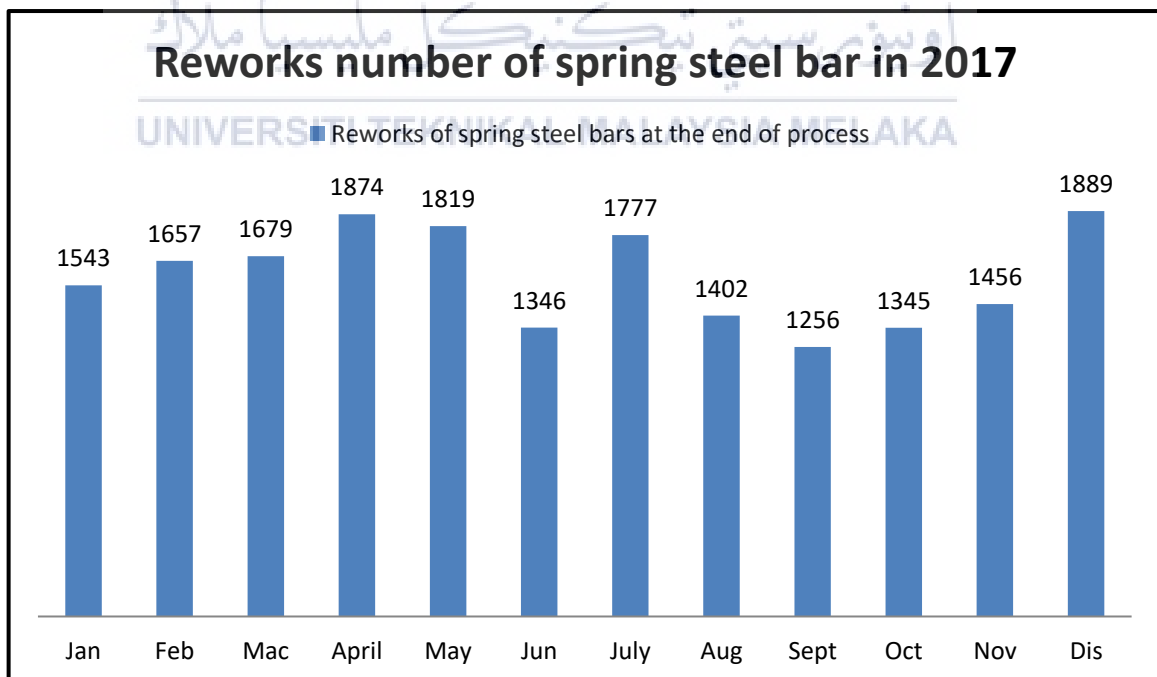


Figure 1.3: The monthly number of reworks of spring steel bars in 2017

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