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TENSILE FRACTURE BEHAVIOR ON TEMPERED AISI 1040 MEDIUM CARBON STEEL

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"I declare this report is on my own work except for summary and quotes that I have mentioned its sources"

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To my beloved family

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ABSTRAK

Kajian ini meliputi kesan rawatan haba pembajaan AISI 1040 keluli karbon sederhana terhadap kelakuan patah berdasarkan perubahan mikrostruktur yang terhasil. Selain daripada itu, perubahan suhu pembajaan dikaitkan dengan jenis kelakuan patah spesimen yang terawat haba. Saiz dan bentuk spesimen yang digunakan adalah berdasarkan spesifikasi ASTM E8-04. Semasa pengaustenit, spesimen dipanaskan pada suhu 870° C dan dibiarkan selama 30 minit. Spesimen kemudiannya disejukkan dengan cepat dengan melindap kejut di dalam medium minyak dan dipanaskan semula ke pelbagai suhu pembajaan dengan julat suhu 300° C - 700° C. Masa pembajaan adalah tetap iaitu 60 minit manakala suhu pembajaan pula berbeza diikuti dengan penyejukan secara normal ke suhu bilik. Ujian tegangan dilakukan pada spesimen terbaja menggunakan mesin ujian universal untuk menentukan bentuk patah yang berlaku. Keputusan ujian tegangan menunjukkan kekuatan patah spesimen terbaja adalah 1213Mpa pada suhu pembajaan yang terendah, 300° C sementara kekuatan patah spesimen terbaja adalah 459Mpa pada suhu pembajaan yang tertinggi, 700° C. Ciri-ciri permukaan patah pada suhu pembajaan yang rendah adalah secara rapuh iaitu permukaan adalah rata. Sebaliknya, ciri-ciri permukaan patah pada suhu pembajaan yang tinggi adalah secara mulur iaitu permukaan adalah kasar dan berbentuk *"cup"* dan *"cone"*. Hal ini menunjukkan spesimen terbaja menjadi semakin patah secara mulur seiring dengan peningkatan suhu pembajaan. Analisis mikrostruktur juga dilakukan untuk melihat perubahan mikrostruktur akibat suhu pembajaan yang berbeza. Pemerhatian mikrostruktur dilakukan dengan menggunakan Axioskop 2 MAT. Analisis mikrostruktur dilakukan selepas proses pembajaan menunjukkan, mikrostruktur spesimen terbaja terdiri daripada alpha, α - ferit dan sementit, Fe_3C. Lanjutan pembajaan dengan peningkatan suhu pembajaan mengembalikan AISI 1040 keluli karbon sederhana hampir sepenuhnya ke struktur ferit dengan kemuluran yang tinggi.

ABSTRACT

This study includes the effects of tempering heat treated AISI 1040 medium carbon steel against fracture behavior based on the resulting changes of microstructure. Besides of that, tempering temperature changes were relates with the fracture behavior heat treated specimens. Size and shape of specimens used are based on ASTM E8 – 04 specifications. During austenitizing, specimen was heated at 870° C and holding it at this temperature for 30 minutes. Specimen will be cooling rapidly by quenching in oil and tempering the steel by reheating it to various tempering temperature with temperature range 300° C - 700 ° C. Tempering time is fixed for 60 minutes while tempering temperature is varied followed by normal cooling to room temperature. Tensile tests were performed on tempered specimens by using Universal Testing Machine to determine the fracture behavior. Tensile test result shows fracture strength of tempered specimen was 1213Mpa at lower tempering temperature, 300° C while fracture strength of tempered specimen was 459Mpa at higher tempering temperature, 700° C. Fracture surface characteristic at lower tempering temperature was brittle where surfaces were flat. On the other hand, fracture surface characteristic at higher tempering temperature was ductile where surfaces were rough and have the shape cup and cone. This shows the tempered specimens became more ductile fracture in tandem with increasing tempering temperature. Microstructure analysis is also done to see the microstructure changes at different tempering temperatures. An observation of microstructure is made by using Axioskop 2 MAT. Microstructure analysis carried out after tempering process shows microstructure of tempered specimens consists of alpha, α - ferrite and cementite, Fe_3C. Continued tempering with increasing tempering temperature will return the AISI 1040 medium carbon steel to almost fully ferritic structure and highly ductility.

CONTENT

CHAPTER	CONTENT		PAGE
	DECLARATION		ii
	DEDICATION		iii
	ACKNOWLEDGEMENT		iv
	ABSTRAK		v
	ABSTRACT		vi
	CONTENT		vii
	LIST OF TABLES		x
	LIST OF FIGURES		xi
	LIST OF SYMBOLS		xvi
	LIST OF APPENDICES		xvii
CHAPTER I	**INTRODUCTION**		1
	1.1	Background Research	1
	1.2	Problem Statement	3
	1.3	Objective of the Study	3
	1.4	Scope of the Study	3
CHAPTER II	**LITERATURE REVIEW**		5
	2.1	Introduction of AISI 1040 Medium Carbon Steel	5
	2.2	Tempering Heat Treatment	6
	2.3	Tempered Carbon Steel Fracture Behavior	11
	2.4	Tempered Steel Microstructure Observation	15

CHAPTER	CONTENT		PAGE
CHAPTER III	METHODOLOGY		18
	3.1	Methodology Introduction	18
	3.2	Material and Equipment	20
	3.3	Tempering Heat Treatment	23
	3.4	Tensile Test	24
	3.5	Microstructure Analysis	26
CHAPTER IV	RESULTS		28
	4.1	Fracture Behaviour of Tempered AISI 1040 Medium Carbon Steel	28
	4.2	Effect of Tempering Process on Mechanical Properties	31
	4.3	Ductility of Tempered AISI 1040 Medium Carbon Steel	32
	4.4	Microstructure Observation Result	33
CHAPTER V	DISCUSSION		
	5.1	Appearance of Fracture Behaviour or Surface on Tempered AISI 1040 Medium Carbon Steel	39
	5.2	Effect of Tempering Process on Mechanical Properties	42
	5.3	Measures of Ductility on Tempered AISI 1040 Medium Carbon Steel	45
	5.4	Microstructure Analysis at Near to Fracture Area After Tempering	47
	5.5	Microstructure Analysis between Different Areas From Fracture Area After Tensile Test	54

CHAPTER	CONTENT		PAGE
CHAPTER VI	**CONCLUSION & RECOMMENDATION**		67
	6.1	Conclusion	67
	6.2	Recommendation for Further Study	68
	REFERENCES		69
	APPENDICES		72

LIST OF TABLES

NO.	TITLE	PAGE
2.1	Composition of AISI 1040 Alloy Elements for Medium-Carbon Steel (Source: Mills *et al.*, 1985)	6
2.2	Differences Quenching Medium between Water and Oil	9
2.3	Summary of Changes Tempered Steel Microstructure at Different Temperature Range	9
2.4	Proposed Tempering Temperatures According to Application (Source: Nayar, 2002)	10
3.1	Overall of Tempering Process and Tests Performed	20
4.1	Mechanical Properties of Tempered AISI 1040 Medium Carbon Steel at Different Tempering Temperature (Tested According to ASTM E8-04)	31
4.2	Measures of Ductility at Different Tempering Temperature	32
5.1	Comparison Appearance Tensile Fracture at Variable Tempering Temperature	40

LIST OF FIGURES

NO.	TITLE	PAGE
2.1	Microalloyed Steel Microstructure Consists Only Martensite After Sample Austenitized at 920° C and Quenched in Iced Brine (-8 ° C) Solution (Source: Bello *et al.*, (2007))	8
2.2	Martensite Microstructure in Steel (a) 0.5% Carbon and (b) 0.8% Carbon (Source: Samuel and Hussein (1982))	8
2.3	Surface Ductile Fracture (Source: Charlie & Choudhury (2002))	12
2.4	Graph Show the Comparison Curve of Brittle Fracture and Ductile Fracture: (a) Brittle Fracture (b) Ductile Fracture (Source: Shahnum, *et. al.* (2001))	13
2.5	Stages of Ductile Tensile Fracture. (a) Voids (b) Penny-Shaped Internal Crack (c) "Cup and Cone" Appearance of a Fracture (d) "Double Cup" Appearance of a Fracture (Sumber: Courtney (2000))	14
2.6	Surface Brittle Fracture (Source: Charlie & Choudhury (2002))	14
2.7	Microstructure of Steel 1040 After Quench and Tempered, Nital Etched, x1200 (Source: Magdy and Said (2006))	15
2.8	Steel Microstructure After Tempering at (a) 250°C (b) 350°C (c) 450°C (Source: Bello *et al.*, (2007))	16
2.9	Microstructure Changes After Quenching and Tempering Steel 300-M: (a) Cementite Plate Inside Martensite Plate and (b) Alloy Carbide (Source: Totten (2007))	17
3.1	Study Flow Chart	19

NO.	TITLE	PAGE
3.2	Specimens AISI 1040 Medium Carbon Steel Shaped Dog Bone (Source: ASTM E8 – 04)	21
3.3	Furnace (Nabertherm, High Temperature Stand Alone Type Furnace)	21
3.4	Universal Testing Machine (Instron, Model 8802)	22
3.5	Axioskop 2 MAT	23
3.6	Graph Cycle for Tempering Process	24
3.7	Cutting of Specimens After Tensile Test for Microstructure Analysis	26
4.1	Appearance of Fracture Behaviour After Tempering at 300° C: (a) When Putting the Specimen Back Together After Fracture and (b) Surface Fracture	28
4.2	Appearance of Fracture Behaviour After Tempering at 500° C: (a) When Putting the Specimen Back Together After Fracture and (b) Surface Fracture	29
4.3	Appearance of Fracture Behaviour After Tempering at 600° C: (a) When Putting the Specimen Back Together After Fracture and (b) Surface Fracture	29
4.4	Appearance of Fracture Behaviour After Tempering at 650° C: (a) When Putting the Specimen Back Together After Fracture and (b) Surface Fracture	30
4.5	Appearance of Fracture Behaviour After Tempering at 700° C: (a) When Putting the Specimen Back Together After Fracture and (b) Surface Fracture	30
4.6	Microstructure at Tempering Temperature 300° C: (a) Near To Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	34
4.7	Microstructure at Tempering Temperature 300° C: (a) Near To Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	34
4.8	Microstructure at Tempering Temperature 500° C: (a) Near To	35

NO.	TITLE	PAGE
	Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	
4.9	Microstructure at Tempering Temperature 500° C: (a) Near To Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	35
4.10	Microstructure at Tempering Temperature 600° C: (a) Near To Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	36
4.11	Microstructure at Tempering Temperature 600° C: (a) Near To Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	36
4.12	Microstructure at Tempering Temperature 650° C: (a) Near To Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	37
4.13	Microstructure at Tempering Temperature 650° C: (a) Near To Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	37
4.14	Microstructure at Tempering Temperature 700° C: (a) Near To Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	38
4.15	Microstructure at Tempering Temperature 700° C: (a) Near To Fracture, R1 and (b) Far from fracture, R2 (Magnification 50x)	38
5.1	Plot of Ultimate Tensile Strength, UTS Versus Tempering Temperature, T	42
5.2	Plot of Yield strength, σ_y Versus Tempering Temperature T	43
5.3	Plot of Comparison Fracture Strength, σ_f at Different Tempering Temperature, T	44
5.4	Ductility (% RA and % EL) Versus Tempering Temperature, T for Tempered AISI 1040 Medium Carbon Steel	45
5.5	Microstructures Characterization at Near to Fracture, L1 and R1 After Tempering Temperature 300° C and 500 ° C (Magnification 50x)	48
5.6	Microstructures Characterization at Near to Fracture, L1 and R1 After Tempering temperature 600° C and 650 ° C (Magnification 50x)	50

NO.	TITLE	PAGE
5.7	Microstructures Characterization at Near to Fracture, L1 and R1 After Tempering temperature 700° C (Magnification 50x)	52
5.8	Microstructure Comparison at Tempering Temperature 300° C: (a) Near to Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	54
5.9	Microstructures Comparison at Tempering Temperature 300° C: (a) Near to Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	55
5.10	Microstructures Comparison at Tempering Temperature 500° C: (a) Near to Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	56
5.11	Microstructures Comparison at Tempering Temperature 500° C: (a) Near to Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	58
5.12	Microstructures Comparison at Tempering Temperature 600° C: (a) Near to Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	59
5.13	Microstructures Comparison at Tempering Temperature 600° C: (a) Near to Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	60
5.14	Microstructures Comparison at Tempering Temperature 650° C: (a) Near to Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	61
5.15	Microstructures Comparison at Tempering Temperature 650° C: (a) Near to Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	63
5.16	Microstructures Comparison at Tempering Temperature 700°: (a) Near to Fracture, L1 and (b) Far From Fracture, L2 (Magnification 50x)	64

NO.	TITLE	PAGE
5.17	Microstructures Comparison at Tempering Temperature 700° C: (a) Near to Fracture, R1 and (b) Far From Fracture, R2 (Magnification 50x)	65
A1	Process Flow Chart	72
B1	Under Graduate Study I Operating Flow Chart Project	73
B2	Under Graduate Study II Operating Flow Chart Project	74
G1	Scantool Bandsaw Machine (011058, Denmark)	79
G2	CNC Lathe Machine (OKUMA LB 200 R, Japan)	79
G3	Oil	80
G4	Mounting Machine (DMS3000 Mounting Press)	80
G5	Ultrasonic Water Bath Machine (DTH-8510)	81
G6	Manual Grinding Machine	81
G7	Polishing Machine (MECAPOL P 255 U)	82
G8	Electromagnetic Stir Machine	82
G9	Resine Phenolique	83

LIST OF SYMBOLS

A_{C1}	=	The Temperature at Which Transformation of Ferrite to Austenite Begins During Heating
A_{C3}	=	The Temperature at Which Transformation of Ferrite to Austenite is Complete During Heating
A_f	=	Final Respectively Cross Sectional Area
A_o	=	Original Cross Sectional Area
C	=	Carbon
d_o	=	Original Diameter
d_f	=	Final Respectively Diameter
e_f	=	Percentage Elongation
Fe_3C	=	Cementite
L_o	=	Original Length
L_f	=	Final Respectively Length
q	=	Percentage Reduction Area
T	=	Tempering Temperature
α	=	Alpha
σ	=	Stress
°C	=	Degree Celsius

LIST OF APPENDICES

NO.	TITLE	PAGE
A	Process Flow Chart	72
B1	Under Graduate Study I Operating Flow Chart Project	73
B2	Under Graduate Study II Operating Flow Chart Project	74
C	PSM I Gantt Chart	75
D	PSM II Gantt Chart	76
E	Specimen's Specifications and Dimensions	77
F	Heat Treatment Temperature	78
G	Material and Equipment	79
H	Tensile Test Result for AISI 1040 Medium Carbon Steel at Tempering Temperature 300 °C	84
I	Tensile Test Result for AISI 1040 Medium Carbon Steel at Tempering Temperature 500 °C	86
J	Tensile Test Result for AISI 1040 Medium Carbon Steel at Tempering Temperature 600 °C	88
K	Tensile Test Result for AISI 1040 Medium Carbon Steel at Tempering Temperature 650 °C	90
L	Tensile Test Result for AISI 1040 Medium Carbon Steel at Tempering Temperature 700 °C	92

CHAPTER I

INTRODUCTION

1.1 Background study

This study is to determine the type of fracture behavior that occurred in tempered AISI 1040 medium carbon steel and microscopic observations were made on the test materials after heat treatment to observe the microstructure changes due to different tempering temperatures and relate it with different types of fracture behavior shown by the test materials.

The purpose of the tempering process is to decrease the hardness, minimizing strength, stress, improving ductility and increasing toughness. Tempering process on steel is one of the heat treatment processes which are done normally after the quenching process. Steel will typically be heated to a temperature below the lowest critical temperature A_{C1} at 870° C where ferrite changes to austenite starts during heating and quench by using oil as the quenching medium. Tempering process includes reheating the study material to the specific tempering temperature and tempering time followed by a normal cooling process at room temperature.

Changes that can be associated with the tempering process where affect the microstructure and describe the fracture behavior changes on carbon steel when tensile load applied includes tempering temperature, tempering time, the rate of cooling from tempering temperature and carbon steel composition including carbon content and other elements. The first process is austenitizing process where medium carbon steel is heated in the furnace until reaching austenitizing temperature 870° C and hold for 30 minutes at austenitizing temperature to produce a solid solution. After that, this process followed by quenching process by using oil medium to form hardness in which resulting martensite microstructure. Then, re-heat the study material at different tempering temperatures with tempering time for 60 minutes. Both of tempering temperature and tempering time are interdependent with one another which may cause changes on the microstructure of the medium carbon steel.

Tensile test and microstructure analysis are done by using Universal Testing Machine, UTM to determine the fracture behavior of specimens after tempering process and by using Axioskop 2 MAT to see the changes on tempered medium carbon steel microstructure at different tempering temperatures. Type of fracture behavior on heat treated specimens will be related to the resulting microstructure. Type of fracture behavior that occurred over medium carbon steel is caused by changes in the carbon steel microstructure when imposed with the different tempering temperature and the fixed tempering time. Fracture behavior that often observed after tempering process is either in a ductile or brittle fracture. In the meantime, the comparison are made between the fracture strength values that can be applied on medium carbon steel due to tempering at different tempering temperature.

According to Nayar (2002), AISI 1040 medium carbon steel that has been carried out tempering process may be applied for industrial application. For example, the tempered medium carbon steel can be used for moderately stressed parts, such as axles, bolts, screws, hand tools, concrete reinforcing rods, connecting rods, crankshafts, screw driver blades, shafts, shims, sprockets, gears, steering arms, wheel flanges and wheel lugs.

1.2 Problem statement

After quenching, the medium carbon steel has martensite structure that is extremely hard but extremely brittle. This martensite structure does not have widespread application. However, tempering process can convert the martensite structure and medium carbon steel will become more ductile. In this research, the study of fracture behavior is done to prove that tensile load is decreased along with the increasing tempering temperature after the tempering process. On the other hand, it also performs microstructure analysis which describes its behavior.

1.3 Objective of the study

The purposes of this study are described as below:-

1) To study the fracture behavior of tempered medium carbon steel based on microstructure produced after tensile load is applied.
2) To relate the changes in tempering temperature on the fracture behavior of the heat treated specimens.

1.4 Scope of the study

The scope of this research is to analyze the resulting fracture behavior of tempered medium carbon steel based on microstructure. Microstructure changed when different tempering temperatures were applied on carbon steel is identified. In the meantime, the fracture behavior of the tempered medium carbon steel after applying tensile load is determined based on the different of tempering temperature. This research involved the tempering process which heating the specimens until reaching austenitizing temperature 870° C and hold it at that temperature for 30 minutes and this is followed by rapid quenching by using oil as a quenching medium. After that, the specimen is tempered by reheating at a different tempering temperature with constant tempering time followed by normal cooling to room temperature. Then, tensile tests were performed on the tempered medium carbon steel to determine the type of fracture behavior after the tensile load is applied by using Universal Testing Machine (UTM). In the meantime, this study is also conducted to find the applied load of the heat treated specimens that can be applied on tempered medium carbon steel before experiencing fracture. After that, microstructure analysis is done by using Axioskop 2 MAT to see the changes on the tempered medium carbon steel microstructure at different tempering temperatures. The shape of specimen used in this study is called 'dog bone shape'.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction of AISI 1040 medium carbon steel

According to Serdar (1999), The Society of Automotive Engineers (SAE) has established standards for specific analysis of steels. In the 10XX series, the first digit indicates a plain carbon steel. The second digit indicates a modification in the alloys. 10XX means that it is a plain carbon steel where the second digit (zero) indicates that there is no modification in the alloys. The last two digits denote the carbon content in points. For example AISI 1040 is a carbon steel where 40 points represent 0.40 % carbon content.

Carbon steel, also called plain carbon steel is a metal alloy, a combination of two elements, iron and carbon, where other elements are present in quantities too small to affect the properties. An element in carbon steel is such as carbon, manganese, phosphorus and sulfur. Percentage of these elements will affect the mechanical properties of carbon steel. For example when the carbon content which also the principal alloying element in steel increases, the tensile strength, yield strength, and hardness increase, whereas ductility, weldability, and toughness decrease. Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises the metal becomes harder and stronger but less ductile and more difficult to weld.

Higher carbon content lowers steel melting point and its temperature resistance in general.

The addition of manganese contributes to the strength and hardness of steel, but to a lesser degree than carbon. Increasing the manganese content decreases weldability, but to a much lesser extent than carbon. While phosphorus element increases the strength and hardness of carbon steels but reduces ductility and impact toughness, particularly in high-carbon steels that are quenched and tempered. Sulfur lowers the transverse ductility and notch-impact toughness of carbon steel but has only a slight effect on longitudinal tensile properties. The weldability of steel also decreases with increasing amount of sulfur. **Table 2.1** describes the composition of AISI 1040 alloy elements for medium-carbon steel.

Table 2.1: Composition of AISI 1040 alloy elements for medium-carbon steel

(Source: Mills *et al.*, 1985)

Elements	Composition (Weight, %)
Carbon, C	0.37 – 0.44
Manganese, Mn	0.6 – 0.9
Phosphorus, P maximum	0.04
Sulfur, S maximum	0.05

2.2 Tempering heat treatment

Tempering treatment involves several stages. Among the processes involved in tempering are austenitizing, quenching and tempering. Tempering is the process of reheating the steel after hardening process to reduce hardness, strength, stress, improving ductility and increasing toughness. The purpose of these heat treatments is to produce parts in which a desired hardness is obtained, either throughout the part or in the