



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**INVESTIGATION ON THE EFFECT OF HEAT TREATMENT
ON FRACTURE TOUGHNESS OF PRESURE VESSEL STEEL**

This report submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (Utem) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) with Honours.

by

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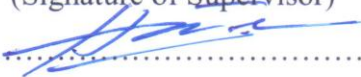
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APPROVAL

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 (Manufacturing Process) with Honors. The member of the supervisory committee is as follow:

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ABSTRACT

Structural failure by fracture toughness in pressure vessel steel A516 Grade 70 of low carbon steel can have severe consequences in term of heat treatment. Fracture toughness K_{IC} test is used to examine the toughness of each specimen after heat treatment process done. In this research, the most common type of this term is discussed and analyzed. The types of heat treatments that have been done like tempering on 400°C, quenching in water, normalizing and full annealing. The structural after heat treatment exposed to change the mechanical properties to this material. Resulting from these changes affected the fracture toughness K_{IC} value. The methodologies were used such as Scanning Electron Machine and Axioscope Zeiss Optical Microscope to examine the microstructure by 50x magnification. Vickers Hardness and Tensile Test also were used to observe the mechanical properties of each specimen. Fracture toughness K_{IC} value is obtained by using Instron Machine. As result, K_{IC} graph show that tempering heat treatment make specimen tougher, hard and high strength compare to full annealing, normalizing and base metal. But, this specimen has low ductile and brittle.

ABSTRAK

Kegagalan tanki keluli pada bahan A516 kelas 70 metal yang mempunyai karbon yang rendah dapat dikesan daripada proses rawatan haba. Semua sampel yang telah mengalami proses rawatan haba akan diuji untuk menentukan kekuatan bahan tersebut daripada retak menggunakan ujian K_{IC} . Dalam kajian yang telah dijalankan, terdapat beberapa jenis rawatan haba yang telah dibuat ke atas bahan A516 kelas 70 seperti, pembajaan pada suhu 400 darjah celsius, sepuh lindap kejut menggunakan air, penormalan dan juga penyepuhlindungan didalam relau. Hasil daripada rawatan haba ini telah merubah struktur sampel dan juga sifat mekanikal. Seterusnya ini akan memberi kesan terhadap perbezaan nilai kekuatan retakan K_{IC} . Mesin Imbasan Elektron dan Optik Mikroskop telah digunakan untuk melihat struktur dalaman pada sampel. Nilai pembesaran yang digunakan untuk semua sampel adalah 50x0.70. Mesin Instron pula digunakan untuk mendapatkan nilai kekuatan sampel yang hendak diuji daripada retak. Ujian kekerasan dan juga ujian ketegangan turut dijalankan untuk mengenalpasti sifat mekanikal yang terdapat pada sampel ini. Graf K_{IC} telah menunjukkan bahawa rawatan haba pembajaan telah menjadikan sampel lebih kuat dan k eras berbanding yang lain. Namun begitu, rawatan jenis ini membuatkan sampel lemah dari segi kelikatan dan rapuh apabila mencapai pada satu tahap

DEDICATION

I dedicate this report especially to UTeM, to my supervisor, to my parents and my family. Never forget to my friends and to all people that help and support me during my completion of this report.

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For the first words in this research, I want to gratitude to god, most gracious and merciful to show me guidance in accomplishing this research. Without His help and consent, I could not finish this final year project based one. Actually this topic is recommendation by one person where he is very interested and committed to know something why the problem of this topic still happened until now. What I am learned from this person, he didn't never give up to give their supported, time spending, knowledge about this project, guidance and what ever to ensure this research done and achieve based on the objective in chapter 1. Million of thanks for everything and a special acknowledgment for what I mean is Mr. Mohamad Haidir Bin Maslan as a UTeM lecturer and also as a project supervisor. I wish to express my appreciation also to Dr. Mohd Warikh Bin Abd Rashid as an examiner for guiding and sharing some ideas for improve my project report.

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TABLE OF CONTENTS

| | |
|------------------------------------|------|
| Abstract | i |
| Abstrak | ii |
| Dedication | iii |
| Acknowledgement | iv |
| Table of Content | v |
| List of Tables | viii |
| List of Figures | ix |
| List of Abbreviations | xii |

1. INTRODUCTION

| | |
|----------------------------|----|
| 1.1 Problem Statement..... | 02 |
| 1.2 Objective..... | 03 |
| 1.3 Scope of Project..... | 03 |

2. LITERATURE REVIEW

| | |
|--|----|
| 2.1 Introduction of Pressure Vessel Steel..... | 04 |
| 2.2 Structural and Material Considerations..... | 05 |
| 2.3 Pressure Vessel Steel..... | 06 |
| 2.3.1 ASTM A516 Grade 70 or ASME SA 516..... | 07 |
| 2.4 Steels..... | 08 |
| 2.5 Heat Treatment..... | 11 |
| 2.5.1 Objective of Heat Treatment..... | 11 |
| 2.5.2 Principles of Heat Treatment of Steel..... | 13 |
| 2.5.2.1 The Fe-C Phase Diagram..... | 13 |
| 2.5.2.2 Transformation Diagrams..... | 20 |
| 2.5.2.3 Kinetics of Phase Transformations..... | 21 |
| 2.6 Types of Heat Treatment Steel..... | 22 |
| 2.7 Introduction for Fracture Toughness..... | 29 |
| 2.7.1 General Fracture Toughness Behavior..... | 32 |
| 2.7.2 Types of Specimen Configuration..... | 33 |

| | | |
|---------|--|----|
| 2.8 | Fracture Toughness Testing..... | 34 |
| 2.8.1 | Linear-Elastic Fracture Toughness..... | 35 |
| 2.9 | Fracture Mechanics..... | 37 |
| 2.9.1 | Linear-Elastic Fracture Mechanic..... | 39 |
| 2.9.1.1 | Crack Tip Stress..... | 39 |
| 2.9.2 | Pre-Cracking..... | 41 |

3. METHODOLOGY

| | | |
|---------|--|----|
| 3.1 | Introduction..... | 43 |
| 3.2 | Research and Design for This Project..... | 44 |
| 3.3 | Sample Preparation..... | 45 |
| 3.4 | Machining Equipment..... | 45 |
| 3.4.1 | Contour Bent Saw Machine..... | 46 |
| 3.4.2 | Milling Machine..... | 46 |
| 3.4.3 | Wire EDM Cutting Machine..... | 48 |
| 3.5 | Heat Treatment Process..... | 49 |
| 3.5.1 | Austenite Treatment Phase | 49 |
| 3.5.2 | Tempering..... | 50 |
| 3.5.3 | Quenching..... | 51 |
| 3.5.4 | Annealing..... | 52 |
| 3.5.5 | Normalizing..... | 52 |
| 3.6 | Testing of Sample Material A516 Grade 70..... | 53 |
| 3.6.1 | Fracture Toughness ASTM 399-90..... | 53 |
| 3.6.1.1 | Parameter of Jig, clip gauge (COD) and specimen..... | 54 |
| 3.6.2 | Hardness Vickers Test..... | 56 |
| 3.6.3 | Microstructure Analysis..... | 57 |
| 3.6.4 | Fractography Analysis..... | 58 |
| 3.6.5 | Tensile Test..... | 60 |

4. RESULTS AND DISCUSSIONS

| | | |
|---------|--|----|
| 4.1 | Tensile Result..... | 61 |
| 4.2 | Heat Treatment..... | 62 |
| 4.1.1 | Microstructure Analysis on Heat Treatment Process..... | 63 |
| 4.1.1.1 | Base Metal A516 Grade 70 (low carbon steel)..... | 63 |

| | |
|---|----|
| 4.1.1.2 Tempering Result..... | 64 |
| 4.1.1.3 Quenching Result..... | 64 |
| 4.1.1.4 Full Annealing Result..... | 65 |
| 4.1.1.5 Normalizing Result..... | 65 |
| 4.3 Cracking Surface..... | 66 |
| 4.4 Hardness Result..... | 66 |
| 4.5 K_{IC} Result..... | 68 |
| 4.6 Fractograph Result..... | 71 |
| 4.6.1 Scanning Electron Machine Analysis..... | 71 |
| 4.6.2 Comparison Structure..... | 72 |
| | |
| 5. CONCLUSIONS | |
| 5.1 Conclusion..... | 74 |
| 5.2 Recommendation..... | 75 |
| | |
| REFERENCES | 76 |
| | |
| APPENDIX | 79 |
| A Gantt chart PSM I | |
| B Planning Gantt chart PSM II | |

LIST OF TABLES

| <u>TABLE</u> | <u>TITLES</u> | <u>PAGE</u> |
|---------------------|---|--------------------|
| 2.1 | Composition range and limits for ASTM A 516 Grade 70 | 07 |
| 2.2 | Mechanical properties and their application of structural steel | 07 |
| 2.3 | Material composition A516 Grade 70 as received | 08 |
| 2.4 | Oxide color for tempering steel | 28 |
| 3.1 | ASTM standard scale frequently | 57 |
| 4.1 | Stree vs Strain Graph | 61 |
| 4.2 | Stress vs Strain Parameter Obtained | 62 |
| 4.3 | Hardness Parameter | 67 |
| 4.4 | K _q Comparisons | 71 |

LIST OF FIGURES

| <u>FIGURE</u> | <u>TITLES</u> | <u>PAGE</u> |
|----------------------|--|--------------------|
| 2.1 | Low carbon steel microstructure | 09 |
| 2.2 | High carbon steel microstructure | 10 |
| 2.3 | The Fe-C equilibrium diagram up to 6.67 wt% | 14 |
| 2.4 | Influence of alloying elements additions on eutectoid temperature and eutectoid carbon content | 16 |
| 2.5 | Example of eutectic and eutectoid reactions in Fe-Fe ₃ C | 16 |
| 2.6 | Microstructure of eutectoid of steel (I) | 17 |
| 2.7 | Microstructure of eutectoid steel (II) | 17 |
| 2.8 | Microstructure of hypoeutectoid steel (I) | 19 |
| 2.9 | Microstructure of hypoeutectoid steel (II) | 19 |
| 2.10 | Microstructure of hypereutectoid steel (I) | 19 |
| 2.11 | Microstructure of hypereutectoid steel (II) | 19 |
| 2.12 | Kinetics of phase transformation | 21 |
| 2.13 | Full annealing graph | 23 |
| 2.14 | Time temperature regime of normalizing, <i>a</i> heating, <i>b</i> holding at austenitizing temperature <i>c</i> air cooling <i>d</i> air or furnace cooling | 24 |
| 2.15 | Range of austenitizing temp for normalizing unalloyed steels depend on their carbon content | 24 |
| 2.16 | Effect of grain refining by normalizing a carbon steel of 0.5C. Left side, as-rolled or forged grain size ASTM 3 and right side normalized ASTM 6 magnification 500x | 25 |
| 2.17 | Transformation of a pearlitic structure to austenite when heating an unalloyed eutectoid steel of 0.8 % C | 26 |
| 2.18 | Cup and cone ductile fracture of a tensile specimen | 30 |
| 2.19 | Longitudinal section of a tensile-strained specimen just prior to fracture | 30 |
| 2.20 | Stress vs strain graph | 31 |

| | | |
|-------|---|----|
| 2.21a | Flat R curve | 32 |
| 2.21b | Rising R curve | 32 |
| 2.22 | Compact test specimen for pin 0.24W (+0.000W / -0.005W) diameter | 33 |
| 2.23a | linear-elastic | 34 |
| 2.23b | Elastics-plastic (failure before limit load) | 34 |
| 2.23c | Fully plastic (exhibits a limit load) | 34 |
| 2.24 | ASTM E 399 compact specimen for fracture toughness testing | 36 |
| 2.25 | Typical load-versus-displacement record for the K_{IC} test, two types. | 37 |
| 2.26 | Modes I (opening mode) | 39 |
| 2.27 | Modes I Crack | 40 |
| 2.28a | Test records | 41 |
| 2.28b | Heat-tinted fracture surface | 41 |
| 2.28c | J calculation | 41 |
| 2.28d | Resistance curve | 41 |
| 2.29 | Fatigue Pre-crack | 42 |
| | | |
| 3.1 | Process flow chart | 44 |
| 3.2 | Material A516 Grade 70 | 45 |
| 3.3 | Cutting area by using contour bent saw machine | 46 |
| 3.4 | Contour bent saw machine | 46 |
| 3.5a | Milling Machine | 47 |
| 3.5b | Surface Milling | 47 |
| 3.5c | Drilling | 47 |
| 3.6a | Wire EDM cutting area | 48 |
| 3.6b | Wire EDM cutting machine | 49 |
| 3.7 | Austenite graph | 49 |
| 3.8 | Tempering flow chart | 50 |
| 3.9 | Quenching flow chart | 51 |
| 3.10 | Full Annealing flow chart | 52 |
| 3.11 | Normalizing flow chart | 53 |
| 3.12 | Instron machine model 8800 | 54 |
| 3.13 | Instron machine model 8802 | 54 |
| 3.14a | Complete set jig with pin | 55 |
| 3.14b | Optical Telescope and specimen | 55 |

| | | |
|-------|---|----|
| 3.14c | Clip gauge | 55 |
| 3.14d | COD displacement measurement | 56 |
| 3.14e | Compact test specimen | 56 |
| 3.15 | Hardness Vickers test machine | 57 |
| 3.16 | 3% Nital solution | 58 |
| 3.17 | Axioscope Zeiss Optical Microscope | 58 |
| 3.18a | Scanning Electron Microscope | 59 |
| 3.18b | An example of fractographs, left side is brittle fracture | 59 |
| 3.19 | Tensile specimen | 60 |
| 3.20 | Universal Tensile Machine | 60 |
| | | |
| 4.1 | Stress vs Strain Graph | 61 |
| 4.2 | Base Metal Microstructure | 63 |
| 4.3 | Tempering Microstructure | 64 |
| 4.4 | Quenching Microstructure | 64 |
| 4.5 | Full Annealing Microstructure | 65 |
| 4.6 | Normalizing Microstructure | 65 |
| 4.7 | Cracking Surface | 66 |
| 4.8 | Heat Treated Low Carbon Steel vs Hardness Vickers | 67 |
| 4.9 | K_{IC} Base Metal Graph | 68 |
| 4.10 | K_{IC} Full Annealing Graph | 69 |
| 4.11 | K_{IC} Normalizing Graph | 70 |
| 4.12 | K_{IC} Tempering Graph | 70 |
| 4.13 | Base Metal Structure | 71 |
| 4.14 | Full Annealing Structure | 71 |
| 4.15 | Normalizing Structure | 72 |
| 4.16 | Tempering Structure | 72 |
| 4.17 | Pre-Cracking Microstructure | 72 |
| 4.18 | Fracture Microstructure | 73 |

LIST OF ABBREVIATIONS AND SYMBOLS

| | | |
|----------|---|--|
| ASTM | - | American Society for Testing and Materials |
| Al | - | Aluminium |
| AISI | - | American iron and steel institute |
| AC | - | Alternating current |
| BCC | - | Body centred cubic |
| BCT | - | Body centred tetragonal |
| BM | - | Base metal |
| CTOD | - | Crack-tip opening displacement |
| CGHAZ | - | Coarse-grained heat affected zone |
| C | - | Composition |
| CGB | - | Coarse-grained bainitic |
| CCT | - | Centre-cracked tension |
| Cr | - | Chromium |
| EDM | - | Electric discharge machining |
| EPFM | - | Elastic-plastic fracture mechanics |
| FCG | - | Fatigue crack growth |
| FCC | - | Face centred cubic |
| FGB | - | Fine-grained bainitic |
| FGHAZ | - | Fine-grained heat affected zone |
| GDS | - | Glow Discharge Spectrometry |
| HAZ | - | Heat affected zone |
| ICR | - | Inter-critical region |
| K | - | Critical stress |
| K_I | - | Stress intensity factor |
| K_C | - | Maximum fracture toughness |
| K_{IC} | - | Fracture toughness |
| LEFM | - | Linear elastic fracture mechanics |
| LPG | - | Liquefied petroleum gas |
| Mo | - | Molybdenum |
| Mn | - | Magnesium |

| | | |
|----------------|---|--|
| MPa | - | Mega pascal |
| Psig | - | Pound-force per square inch gauge |
| PWHT | - | Post weld heat treatment |
| SENT | - | Single edge notch tension |
| SENB | - | Single edge notch bend |
| SS | - | Stainless steel |
| Si | - | Silicon |
| Ti | - | Titanium |
| UNS | - | United Standard |
| WM | - | Weld metal |
| Zr | - | Zirconium |
| da/dN | - | Crack growth rate per cycle of loading |
| σ_x | - | Longitudinal stress |
| σ_y | - | Transverse stress |
| σ_m | - | Maximum stress |
| r | - | Radius |
| E | - | Young`s Modulus |
| a^* | - | Effective crack length |
| r_p | - | Circular plastic zone of radius |
| θ | - | Angular coordinate |
| τ_{xy} | - | Torque stress |
| f | - | Residual stress |
| G | - | Energy release rate |
| γ_s | - | Specific surface energy |
| t | - | Thickness |
| a | - | Width and Length |
| γ_p | - | Work of plastic deformation |
| σ | - | Applied stress |
| a | - | Crack length |
| $\sigma_{y,s}$ | - | Elastic-plastic boundary |

CHAPTER 1

INTRODUCTION

In this century, the world is more advanced together with turn of their rolling. These phenomena show that the industry is increasing and alert for new-technologies. Industries have now growing up caused of high demands on the quality of engineering technology. An either obvious of one example am requesting on the use of pressure vessels steel as autoclaves, boiler and others. This existed in all sector industry to generate one product having quality and durable. Pressure vessels are one device that it's very synonyms for high temperatures. This is very sensitive area so all factor fabrication of pressure vessels is not in consideration because it`s impact involve deaths and priceless property damage. Therefore, these books publish to investigate the fracture toughness of pressure vessel steel and relation on microstructure

1.1 Problem Statement

The main topic of this research is about to investigate on the effect of heat treatment on fracture toughness of pressure vessels steel. This research carried out base on still equivalent has been problem rose in pressure vessels steel.

Cracking of internal surface in pressure vessels is very synonym happened but until now to avoid this failure it's still undergoing. Cracks will occur at welds and in the HAZ of the weld and the crack will affect both parallel and transverse to the weld. Cracking has occurred just after welding and as well as during the intended service life. In particular, tensile residual stresses near the weld area may cause brittle fracture, stress raisers, fatigue failure and stress corrosion cracking when exposed to corrosive environments at certain temperature ranges [Challenger, N.V. 1995].

Semi-skilled or weaknesses during welding process is one of the critical failures in pressure vessels. This problem such as brittle cracking in the heat-affected zone (HAZ), often result from the use of steels containing excessive amounts of residual elements that increase hardens ability and susceptibility to cracking. Steel sometimes produced inadvertently when low-carbon steel is made in a furnace normally used to make high-alloy steel. The refractory lining of the furnace may impart sufficient residual chromium and other alloying elements to a heat of low-carbon steel that problems occur when components made from that heat are joined using standard welding procedures. Therefore, complete control of composition is of the almost importance when welding is involved [Powel, G.W. 2002].

1.2 Objective

The overall objective of these researches is as follow;

- i) To investigate the effect of heat treatment on fracture toughness of pressure vessel steel
- ii) To identify the fracture toughness on different microstructure.

1.3 Scope of the Project

The aimed of this research is to investigate the effect of heat treatment on fracture toughness of pressure vessels steel for two different materials. The material that used is from ASTM A516 Grade 70. Referring on ASTM standard, the properties of this material is low-carbon. As mention in chapter 2 on literature review, the carbon content of low-carbon steel is less 0.25% carbon. To ensure this research done with their objective and scope, a few methods of heat treatment and also testing hardness are used. On the heat treatment process this research used austenizing, annealing normalizing, quenching and tempering. This research also covers the determination of fracture toughness steel under predominantly linear-elastic fracture mechanic, elastic-plastic fracture mechanic plane-strain conditions using fatigue pre-cracked, Crack Tip Opening Displacement (CTOD) and K_{IC} . The details of test apparatus, specimen configuration, and experimental procedure are given based on ASTM standard E 399-90.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Pressure Vessel

Vessels tanks, and pipelines that carry, store, or receive fluids are called pressure vessels. A pressure vessel is defined as a container with a pressure differential between inside and outside. The inside pressure is usually higher than the outside, except for some isolated situations. The fluid inside the vessel may undergo a change in state as in the case of steam boilers, or may combine with other have a combination of high pressures together with high temperatures, and in some cases flammable fluids or highly radio active material. Because of such hazards it is imperative that the design be such that no leakage can occur. In addition these vessels have to be designed carefully to cope with the operating temperature and pressure. It should be borne in mind that the rupture of pressure vessels has a potential to cause extensive physical injury and property damage. Plant safety and integrity are of fundamental concern in pressure vessel design and these of course depend on the adequacy of design codes.

In other words of pressure vessel steel is a closed container designed to hold gases or liquids at a pressure different from the ambient pressure. The end caps fitted to the cylindrical body are called heads. The rules for pressure vessel are contained in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code [Harvey, J.F. 1985]. Pressure vessels are used in a variety of applications. These include the industry and the private sector. For examples of pressure vessels are; autoclaves, storage tanks or oil refineries.

Large pressure vessels were invented during the industrial revolution, particularly in England for making steam engines [Harvey, J.F. 1985]. Design and testing standards came about after some large explosions lead to loss off life and a system of certification and testing mutations.

Pressure vessels as components of a complete plant are designed to meet various requirements as determined by the designers and analysis responsible for the overall design. The first step in the designed procedure is to select the necessary relevant information, establishing in this way a body of design requirements. Once the design requirements have been established, suitable materials are selected and the specified design code will give an allowable design or nominal stress that is used to dimension the main pressure vessel thickness.

Generally, almost any material with good tensile properties that is chemically stable in the chosen application can be employed. Many pressure vessels are made of steel. To manufacture a spherical pressure vessel, forged parts would have to be welded together. Some mechanical properties of steel are increased by forging, but welding can sometimes reduce these desirable properties. In case of welding, in order to make the pressure vessel meet international safety standards, carefully selected steel with a high impact resistance and corrosion resistant material should also be used.

2.2 Structural and Material Considerations

The continued and prolonged use of pressure vessels for power generation, nuclear or chemical reactions, industrial processing, and storage requires them to withstand severe conditions of pressure, temperature, and other environments. Such environmental conditions include corrosion, neutron irradiation, hydrogen embrittlement, and so on. Pressure vessels are required to operate at a high temperature range from as high as 600°C to as low as -20°C, with design pressures as high as 140 MPa. Some vessels are designed to carry noncorrosive fluids; while others are designed to withstand harsh corrosive and highly radioactive environments. The type of service, whether steady or cyclic, may also vary considerably. For each set of operating parameters, the pressure vessels material may

be required to have certain properties. For example, operation at very low temperatures would require the use of materials with high notch toughness, while operation at high temperatures would require the use of materials with high creep strength.

Apart from the mechanical properties, considerations on manufacturability, commercial availability, as well as cost, has to be accounted for in the selection process. From researcher the materials that are used in pressure vessel construction are:

a) Steels

- i) Nonferrous materials such as aluminum and copper
- ii) Specialty metals such as titanium and zirconium
- iii) Nonmetallic materials, such as, plastic, composites and concrete
- iv) Metallic and nonmetallic protective coatings

b) The mechanical properties that generally are of interest are:

- i) Yield strength
- ii) Ultimate strength
- iii) Reduction of area (a measure of ductility)
- iv) Fracture toughness
- v) Resistance to corrosion

2.3 Pressure Vessel Steel

For this research, the types of material that used as follow the ASTM standard requirement. The material that will be used in this research is A516 Grade 70 or ASME SA 516 (low-carbon steel)

2.3.1 ASTM A516 Grade 70 or ASME SA516

The grade of this material is one of the most popular steel grades in market. It is primarily intended for use in welded pressure vessels where notch toughness is important. It comes in four grades 55, 60, 65 & 70. These grades cover a range of tensile strengths from 55 - 90 MPa and this versatility explains much of the specification popularity. For material tested were an ASTM A516 grade 70 hot-rolled steel of ferritic-perlitic structure is one of our most popular steels. The ASME standard composition is as follows (dependent on grade).

Referring the ASTM standard, table below shows the lists of chemical composition and mechanical property requirements for these grades. Most of the steel are given no heat treatment after hot rolling and thus develop their mechanical properties as a result of control of composition and grain size (through deoxidation practice). In some case, for example A515 and A516, plates greater than 50mm thickness are normalized. Although only moderate in yield and tensile strength, these kinds of steels have the proper combination of strength, ductility, toughness and weldability to perform satisfactorily in structural applications. The carbon content is rarely over 0.25% (to increase it above this level may reduce toughness and weldability) and will rarely be blow 0.15% for reasons of strength [Henkle, D. *et al* 2002]

Table 2.1: Composition range and limits for ASTM A 516 Grade 70

| ASTM GRADE | Type / Grade | UNS Designation | Heat Composition Ranges and Limits, % (a) | | | | |
|---------------|-----------------|--------------------|---|-----------|-------|------|-----------|
| | | | C | Mn | P | S | Si |
| A 516 | Grade 70 | K 02700 | 0.31 | 0.85-1.20 | 0.035 | 0.04 | 0.15-0.30 |

Table 2.2: Mechanical properties and their application of structural steel

| ASTM GRADE | USE | YIELD STRENGTH, MPa | TENSILE STRENGTH, MPa | ELONGATION IN 50mm, % |
|---------------|--------------------------------------|---------------------------|-----------------------------|--------------------------|
| A 516 / 70 | Pressure vessels, low temperature | 310 | 520 | 26 |