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Effect of Tempering Temperature and Tempering Time on ASTM A36 Carburized Steel

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

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Mechanical Engineering (Mechanical Design)

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Advisor: Dr. Daniel Tilahun

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School of Mechanical and Industrial Engineering

Effect of Tempering Temperature and Tempering Time on ASTM A36 Carburized Steel

by

Abiyu Alemayehu

Submitted in accordance with the requirements for the degree

MASTER OF SCIENCE(M.Sc.)

Approved By Board of Directors

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I hereby declare that the research entitled: Mechanical Property Characterization of Carborized A36 Steel using Tempering Tempratur and Tempering Time this thesis is my own independent work, and has no previously been submitted to any other University in order to obtain a degree. I further cede copyright of the dissertation in favor of Addis Ababa Institute of Technology.

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Abstract

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Addis Ababa University, 2016

This research is concerned to evaluate the influence of tempering temperature and time of ASTM A36 structural steel; it is one of the accessories for the buildings, bridges and off-highway vehicles and equipment. This steel was heat treated using pack carburization method at the temperature of 900^0c for 6 hour and cooled in the Furness then hardened at the temperature of 830 ^{0}c for 30min then quenched in water , after this, it was tempered at temperature (200,400&600) ^{0}c for 30, 60&90 minutes for each tempering temperature to modify desired properties. The mechanical behavior, particularly, ultimate tensile strength, yield strength and elongation were investigated using universal testing machine; while the hardness measurement was done on Rockwell hardness testing machine, its toughness was done using Izod impact testing machine and the composition of the material were tested by spectrometer and finally the microstructur of the sample has been tested in metallographic microscope. Result that expected is the ultimate tensile strength and the yield strength decrease while the elongation increases with an increase in tempering temperature and tempering time of different tempered specimen. The hardness of quenched/hardened specimen decreases with an increase in tempering temperature and tempering time. Furthermore, increasing temperature and lowering time produces approximately same result as decreasing temperature and increasing time.

Key Words: Carburizing, Hardening, Tempering, Quenching, Martensite, Muffle Furnace composition test, Hardness, impact test, tensile test

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Nomenclature

Symbol:	Property:
m	meter
mm	millimeter
Mpa	mega Pascal
GPa	Giga Pascal
J	Joule
µm	micro meter
X	times
L	Length
W	width
T	temperature
t	thickness
F_0	Preliminary minor load
F_1	Additional major load
F	Total load
e	Permanent increase in depth of penetration due to major load F_1

List of Abbreviations and Acronyms

HRc	Rock well Hardness number in C-scale
Min	minute
ASTM	America Society for Testing and Material
U T M	Universal Testing Machine
L O M	Light Optical Microscopy

CHAPTER 1. :- INTRODUCTION

1.1 INTRODUCTION

The service conditions of many structural steel components such as buildings, bridges and off-highway vehicles and equipment make it necessary for them to possess both hard, wear resistant surface and at the same time, tough, shock resistant cores. This situation can be best dealt with by introducing ASTM A36 steel (ASTM A36 Steel) with suitable core properties. In this case the carbon penetrates the surface to a regulated depth (case depth) causing the material to be harder. These steel exhibits poor response to heat treatment (Quenching) as a means of improving its hardness. This is as a result of the fact that martensite can hardly be formed on quenching low carbon steel (Sybil, 1992, De Garmo et al, 1997). Therefore surface hardening is one of the several methods used for improving the mechanical property of low carbon steel (0.032%C). Surface hardening by carburizing can be classified into five kinds: solid carburizing, liquid carburizing, gas carburizing vacuum and plasma carburization in each of these processes, certain chemicals and methods are used. For the solid carburizing charcoal is used, and in liquid carburizing cyanide (CN) is used but in gas carburizing carbon monoxide gas (CO) is used (Shihab Al-Abed, 2011). Solid carburizing is used in this work because it is capable to improve the surface resistance of steel.[8]

The carburization provides a gradual change in carbon content and carbide volume from the surface to the bulk, resulting in a gradual alteration of mechanical and wear properties. The heat treatment and carburization increases the mechanical and wear resistance. Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures generally between 850 and 950°C, at which austenite, with its high solubility for carbon, is the stable crystal structure. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core. Carburizing steels for case hardening usually have base-carbon contents of about 0.02%, with the carbon content of the carburized layer generally being controlled at between 0.7 and 1% C. However, surface carbon is often limited to0.9% because too high a carbon content can result in retained austenite and brittle martensite.

Carburizing is one of the most widely used surface hardening processes. The process involves diffusing carbon into a low carbon steel to form a high carbon steel surface. Carburizing steel is widely used as a material of automobiles, form implements, machines, gears, springs and high strength wires etc. which are required to have the excellent strength, toughness, hardness and wear resistance etc. because these parts are generally subjected to high load and impact. Such mechanical properties and wear resistance can be obtained from the carburization and quenching processes. This manufacturing process can be characterized by the key points such as: it is applied to low carbon work pieces, work pieces are in contact with high carbon gas, liquid or solid, it produces hard work piece surface, work piece cores retain soft.[11]

Quench and Temper:

The quench and temper process involves heating the steel to form austenite at 900 °C, followed by quenching in a suitable media such as water. The rapid cooling causes the carburized steel become harder and stronger by the formation of martensite. Hardened steel then are tempered at a temperature, generally below 690 °C, to achieve the desired mechanical properties. Tempering reduce both the hardness and strength of quenched steels and increase materials properties such as ductility, toughness, and impact resistance. The tempering temperature must be carefully selected based on the specified hardness range, the quenched hardness of the part, and the material. Normally, the optimum tempering temperature is the highest temperature possible while maintaining the specified hardness range. It is to be remembered that hardness after tempering varies inversely with the tempering temperature used. After tempering, parts usually are air cooled at room temperature.[2]

1.2 BACKGROUND OF THE RESEARCH

Literature has been collected from various journals, books, papers etc. & has been reviewed as follows- Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material. Steels are heat treated for one of the following reasons:

- Softening
- Hardening
- Material Modification

Softening: Softening is done to reduce strength or hardness, remove residual stresses, improve toughness, restore ductility, refine grain size or change the electromagnetic properties of the steel. Restoring ductility or removing residual stresses is a necessary operation when a large amount of cold working is to be performed, such as in a cold-rolling operation or wiredrawing. Annealing-full Process, Spheroidizing, Normalizing and tempering Austempering, Martempering are the principal ways by which steel is softened.

Hardening: Hardening of steels is done to increase the strength and wear properties. One of the pre-requisites for hardening is sufficient carbon and alloy content. If there is sufficient Carbon content then the steel can be directly hardened. Otherwise the surface of the part has to be Carbon enriched using some diffusion treatment hardening techniques.

Material Modification: Heat treatment is used to modify properties of materials in addition to hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., stress relieving, or strength properties, e.g., cryogenic treatment, or some other desirable properties, e.g., spring aging. Heat treatment is a combination of timed heating and cooling applied to a particular metal or alloy in the solid state in such ways as to produce certain microstructure and desired mechanical properties (hardness, toughness, yield strength, ultimate tensile strength, Young's modulus, percentage elongation and percentage reduction). Annealing, normalizing, hardening and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. Hardening is the most common heat treatment applied to tool steels. It consists of three operations:

- Heating
- Quenching
- Tempering.

Heating is carried out by preheating the work piece until its temperature is equalized throughout, and then holding or soaking it at the processing temperature to dissolve its carbides (compounds of carbon and alloying elements) into the matrix (the surrounding material in which they are embedded). This makes the matrix richer in carbon and alloying elements, with the hardness finally achieved depending primarily on the amount of carbon dissolved. The alloying elements mostly determine the speed at which the steel must be quenched and the depth of hardness attained in it.

Quenching consists of cooling the heated work piece rapidly by immersing it in a liquid which is water, surrounding it with gas or air, or submerging it in a fluidized bed to keep the carbon in solid solution in the steel.

Tempering consists of reheating the quenched steel one or more times to the temperature, 200 to 600 °C, and cooling it again to develop the desired levels of ductility and toughness

1.3 STATEMENT OF THE PROBLEM

The purpose of this research is to improve the mechanical property of the low carbon A36 steel, in order to get high strength, wear resistance and improve its toughness by increasing its maximum strength to density ratio and reducing its size. Since Material property has great effect on weight reduction and load carrying capacity of the structure.

So this research has great response for the following two main points:-

- To improve the mechanical properties of a given steel.
- To decrease the weight and increase the strength of steel.

1.4 OBJECTIVE

General Objective

The general objectives of this research are to improve the mechanical properties of structural Steel material like hardness, strength, micro structure and wear resistance by using heat treatment.

Specific Objective

The specific objectives of this research are:-

To study structural Steel material like hardness, strength, micro structure and impact load resistance.

To select and identify at which tempering temperature and tempering time has a steel good properties.

To test the mechanical properties of steel before and after heat treatment with different temperature and time interval.

To evaluate the mechanical property based on the results that found from the experiment.

1.5 RESEARCH METHODOLOGY

The research regarding the heat-treatment influence on the mechanical properties was carried out by going deeply into the following fields of research:

1. Theoretical study of the recommendations offered by the specialty literature regarding the parameter values of the heat treatment applied to that steel.

2. Experimental study of the mechanical properties of samples with the same chemical Composition; those samples were applied various tempering temperature and time but at the same carburizing temperature.
3. Study of mechanical properties such as ultimate tensile strength, yield strength, toughness and hardness resulted for each type of tempering temperature and time.
4. Study of composition of the steel and micro structure.

1.6 SCOPE OF THE RESEARCH

The scopes of this study are:

I. Pack carburizing using commercial grade carbon granule which is steel A36.
II. Using 3 different tempering temperatures which are 200°C, 400°c and 600°C for carburized at 900^0c steel which is holding for 6 hours.
III. Using 3 different tempering times which are 30 min, 60 min and 90 min holding in the Furnace then quenching in atmospheric air.
IV. Using one medium which is water in quenching.
V. Using Rockwell hardness test to determine the hardness of certain part on the carbon steel and using universal testing machine to determine the ultimate tensile strength, yield strength and elongation.
VI. Using optical spectrometer to measure the composition of the steel.
VII. Using microscope to measure micro structure.

1.7 ORGANTHATION OF THE THESIS

This Thesis is organized in five chapters. The first chapter is devoted to brief description of how to improve structural steel A36 material using pack carburizing and tempering; the thesis back ground; problem of the statement; general and specific objectives research methodology and scope of the research. The second chapter presents literature review on carburizing low carbon steel and tempering temperature and time. The third chapter deals with the experimental program which focused on materials, test sample preparations, experimental methods, conditions and test set up for mechanical and microstructural tests of tempered steel. The fourth chapter addresses laboratory test results and discussion. The last chapter devoted to draw conclusions, recommendations and future works.

CHAPTER 2. LITERATURE REVIEW

According to **Mr. Jaykant Gupta** investigation or His research on the mechanical and wear behaviors of mild steels carburized at different temperature range of 850, 900 and 950^{0}C have been studied and it is found that the simple heat treatment greatly improves the hardness, tensile strength and wears resistance of the mild steels. His aim has been to examine the effects of these different carburization temperatures and conditions on the mechanical and wear properties of the carburized mild steels. First He did the mild steels are carburized under the different temperature range as stated above for 2 hour and then it is tempered at 200^{0}C for half an hour after this the carburized and tempered mild steels are subjected for different kind of test such as abrasive wear test, hardness test, tensile test and the toughness test. The results of these experiment shows that the process of carburization greatly improves the mechanical and wear properties like hardness, tensile strength and wear resistance and these properties increases with increase in the carburization temperature but apart from this the toughness property decreases and it is further decreases with increase in carburization temperature. His experimental results also shows that the mild steels carburized under different temperature range as stated above, within which the mild steels carburized at the temperature of 950^{0}C gives the best results for the different kinds of mechanical and wear properties. this experiment uses for carburizing.

Table 2-1 Proximate Analysis

coal	**Proximate analysis (Wt %)**			
	moisture	Volatile matter	Ash	Fixed carbon
	5	29	35	31

The result they got

Table 2-2 Experiment Result

Carburization condition		**Tempering condition**		**Hardness (Rc)**	**Toughness Joule(Nm)**	**Tensile Strength(mpa)**
Temp. ^{o}C	Soak time (hr)	Temp. ^{o}C	Soak time (hr)			
before	-	-	-	-	54	441
850 ^{0}c	2 hr	200 ^{0}c	0.5	51	37	1872
900 ^{0}c	2 hr	200 ^{0}c	0.5	55	35	1925
950 ^{0}c	2 hr	200 ^{0}c	0.5	57	32	1960

[11]

The research of **Ashish Verma et al**, investigation is concerned to evaluate the influence of heat treatment on mechanical behavior of AISI1040 steel; it is one of the grades of medium carbon steel of American standard containing 0.40% carbon in its composition. Specimens were heated in muffle furnace at a temperature of 900 0c, and were held for 120minutes and then the specimens were quenched into water. Then it was tempered at temperature (650,450&250)0c for 60, 90&120 minutes to modify desired properties.

Result shows that the ultimate tensile strength and the yield strength decrease while the elongation increases with an increase in tempering temperature and tempering time of different tempered specimen. The hardness of quenched/hardened specimen decreases with an increase in tempering temperature and tempering time. Furthermore, increasing temperature and lowering time produces approximately same result as decreasing temperature and increasing time.[6]

Mrs P. O. Offor1 et al, there studies Effects of various quenching media on the mechanical properties of inter critically annealed0.15wt%C – 0.43wt%Mn were studied. Pre quenching of a hot rolled low carbon steel was previously done from 900^{o}C (within the full austenitic range) using SAE 40 engine oil as quench ant. Sets of steel samples made from the previously quenched steel samples were inter critically heat treated from 750^{o}C to 810^{o}C at intervals of 10^{o}C for 1 hr in a laboratory muffle furnace and quenched in SAE 40 engine oil, water and brine quenchants respectively.

According to **Mrs P. O. Offor1 et al,** The effects of quenching media used and the inter critical annealing temperatures on tensile, hardness, ductility and notch impact toughness properties are discussed. The quenching media increased the strength and hardness properties but decreased the ductility and notch impact properties of the original hot -rolled steel. Steel quenched in brine had the highest strength (708.02N/mm2 at 810^{0}C) and hardness values (233 BHN at 810^{0}C) followed by those quenched in water (666.73 N/mm2 at 810^{0}C and 226 BHN at 810^{0}C respectively) while those quenched in oil had the least values (618.56 N/mm2 at 810^{0}C and 215 BHN at 810^{0}C respectively). Steel quenched in oil had highest ductility and notch impact toughness values (24.07% at 750^{0}C and22.8 J/cm2 at 750^{0}C respectively), followed by those quenched in water (20.33% at 750^{0}C and18.14 J/cm2 at 750^{0}C respectively) while those quenched in brine had the least values (16.49%at 750^{0}C and 13.96 J/cm2 at 750^{0}Crespectively). Higher inter critical annealing temperatures gave higher strength and hardness values (from 445.94 N/mm2 at 750^{0}C to 708 N/mm2 at810^{0}C and from 165 BHN at 750^{0}C to 233BHN at 810^0 C respectively), but lower ductility and notch impact toughness values (from 10.71% at 810^{0}C to 16.49% at 750^{0}C and from 7.38J/cm2at 810^{0}C to 13.96J/cm2 at 750^{0}C). [1]

The experiment **Mr Jamiu Kolawole Odusote et al,** takes on a Sample of medium carbon steel were examined after heating between 900ºC-980ºC and soaked for 45 minutes in a muffle furnace before quenching in palm oil and water separately. The experiment that they did is by taking different quenching media. The mechanical behavior of the samples was investigated using universal tensile testing machine for tensile test and Vickers pyramid method for hardness testing. The microstructure of the quenched samples was studied using optical microscope. The tensile strength and hardness values of the quenched samples were relatively higher than those of the as-cast samples, suggesting improved mechanical properties. However, the result they get from the experiment is samples quenched in palm oil displayed better properties compared with that of water-quenched samples. And they said The behavior was traced to the fact that the carbon particles in palm oil quenched samples were more uniform and evenly distributed, indicating the formation of more pearlite structure, than those quenched in water.[2]

According to **Saigeeta Priyadarshini et al,** the experiment they used on Low carbon steel containing 0. 15% to 0.3% of carbon does not respond to hardening heat treatment processes like quenching and tempering and hardly any martensitic transformation takes place on quenching. Thus, to improve the surface hardness carburizing treatment is done in which the surface composition of the low carbon steel changes by diffusion of carbon and results in to hard outer case with good wear resistance. The carburized a temperature that they taken900^{0}C for 5 hours. After carburizing, annealing, normalizing, hardening and tempering treatments were done. For this experiment Saigeeta Priyadarshini et al, did sample preparation and treatment procedure as follows.

The test specimens for hardness measurement were prepared from the steel collected by different machining processes as per ASTM standard whose dimensions are given as Length= 25 mm, Width = 10 mm and Thickness = 10 mm. Then the test specimens were carburized at 900^{0}C for 5 hours. After carburizing, the steel often becomes harder than the required value. It becomes too brittle for most practical uses. To improve this they were kept within the packing of charcoal for 24 hours. Thus, the carburized samples were again given different treatments. The carburized steel samples were heated for 30 minutes at 800^{0}C. Some samples were kept inside the furnace to be annealed and some were quenched in water. Due to the rapid cooling, severe internal stresses were developed. To relieve the internal stresses induced and to reduce brittleness, tempering process was done on hardened carburized steel samples at 150^{0}C for 30 minutes, and then cooled in air. And the results in to hard outer case with good wear resistance. [7]

The other literature is the experiment which is done by **Mrs Shabnam Hosseini et al,** On Manganese Steels have extensively application in industries due to good resistance to wear, high work hardening capability with high toughness and ductility. Carbon increasing in manganese Steels leads to produce grain boundaries carbides, that cannot be eliminate by long heat treatment. Thus the mechanical properties decrease. This paper purpose the optimum heat treatment cycle to minimize the grain boundaries carbides by changing in quenching solution.3 different quenching bath was utilized for quenching operation.1- Pure water, 2-solution with 1.5% NaCl and 3- solution with 3% NaCl.

Heat treatment probably results in developing toughness in alloy, therefore solution temperature would be too high so that carbide solve into austenite. In practice, the final structure will not be formed as austenite and some of carbides will be remained within grain boundaries, especially in thicker section. Forming these carbides between austenite grain boundaries will minimize impact strength of steel. [3]

For this Investigations **Mrs V.K. Murugan et al** were carried out to study the effects of heat treatment on the mechanical properties of medium carbon steel. Samples of medium carbon steel were examined after heating at 900^0C and soaked for 60 minutes in a muffle furnace and quenched in oil. and they were used tempered at different tempering temperature 250^0C to 550^0C. The mechanical behavior of the samples was investigated using universal tensile testing machine for tensile test and Rockwell hardness method for hardness testing. The hardness values and tensile strength of the quenched samples were relatively higher than those of the as-received samples, suggesting improved mechanical properties. Tensile test specimens were produced from medium carbon steel and were subjected to various forms of heat treatment processes like annealing, normalizing, hardening and tempering.

And the result they get from the four tempering temperature, The maximum hardness of 58HRC has been obtained at 900^0C hardening. The untreated samples value of mechanical behavior was noted as follows: tensile strength 325.42N/mm2, yield strength 209.47N/mm2, hardness 42 HRC, toughness 61.10J, and percentage of elongation 23.24. The hardened samples values of mechanical behavior were noted as follows: tensile strength 469.01N/mm2, yield strength 412.10N/mm2, hardness 58 HRC, toughness 41.00J, and percentage of elongation 23.00.The mechanical properties of hardening samples tempered at 250^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 378.23N/mm2, 290.00N/mm2, 53 HRC, 60.78J, 39.96 respectively. The mechanical properties of hardening samples tempered at 350^0C, showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 355.17N/mm2,355.17N/mm2, 49 HRC, 58.53J, 35.50 respectively. The mechanical properties of hardening samples tempered at 450^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were 343.80N/mm2,217.31N/mm2, hardness 44 HRC, 58.88J, 21.16respectively. The mechanical properties of hardening samples tempered at 550^0C showed that the tensile strength, yield strength, hardness, toughness and percentage of elongation were336.37N/mm2,265.74N/mm2,39HRC,70.29J, 47.01respectively.[5]

According to **Mr Swapnil R. Nimbhorkar et al**, research concerned it is basically concentrate on "To study the effect of case hardening treatment on the structure and properties of automobile gears, which consist of carburizing process which is a case hardening process." Case hardening is the process of hardening the surface of metal, often low carbon steel by infusing elements into the metal surface forming a hard, wear resistance skin but preserving a tough and ductile applied to gears, ball bearings, railway wheels. Comparative study of the following gears viz. grade of EN353, SAE8620 and 20MNCR5 are done in this research. The basic study in this research is Procedural study, Micro structure study, testing of hardness gradient of automobile gears, thus MrSwapnil R. Nimbhorkar et al, the procedure they followed and the result they got.

1. Heat treatment Procedure for EN353 Gear-

Pack, salt or gas carburize at 910˚C, holding for sufficient time to develop the required case depth and carbon content.

• Slow cool from carburizing temperature and re-heat to 870˚C, hold until temperature is uniform throughout the section, quench as required in water, oil or air cool.

TEMPERING:

• Re-heat to 780˚C - 820˚C, hold until temperature is uniform throughout the section, and quench in oil.

• Temper immediately while still hand warm.

• Heat to 150˚C - 200˚C as required.

• Soak for 1 - 2 hours per 25mm of section, and cool in still air.

Table 2-3 Experimental Result

St No	Sample ID	Distance	Hardness in VPN
1	EN353 GEAR	0.2	652
		0.3	636
		0.4	578
		0.5	533
		0.6	436

2. Heat treatment procedure for 20MnCr5 Gear:

• Carburizing process-Heating Gear up to 880^0c

• Cycle Time – According to Case Depth required.

• Hardening Temp. -Drop Down to 850^0c

• Oil Quenching

• Tempering-210^0C

Table 2-4 Experiment Result

St No	Sample ID	Distance	Hardness in VPN
1	20MNCR5 Gear	0.2	758
		0.3	727
		0.4	724
		0.5	686
		0.6	670
		0.7	627
		0.8	582

3. Heat treatment procedure for SAE8620 Gear

• CARBURISING

• Pack, salt or gas carburize at 900˚C holding for sufficient time to develop the required case depth and carbon content.

• Slow cool from carburizing temperature and re-heat to 840˚C, hold until temperature is uniform throughout the section, quench as required in water, oil or air cool.

TEMPERING:

• Re-heat to 780˚C -820˚C, hold until temperature is uniform, and quench in oil.

• Temper immediately Heat to 150˚C -200˚C as required.

• Soak for1-2 hours per 25mm of section, and cool in still air.

Table 2-5 Experimental Result

St No	Sample ID	Distance	Hardness in VPN
1	SAE8620 gear	0.2	621
		0.3	607
		0.4	570
		0.4	528
		0.5	506
		0.6	490

[9].

Belete Kefarge Azmite et al, the experiment of their study is to improve the mechanical properties and abrasion resistance of traditional farm implements. To achieve the intended objectives of the study, Investigation was conducted on the mechanical and wear characteristics of steel samples for better performance of farm implements.

Belete Kefarge Azmite et al, use for the experiment , packed carburization treatment using wood coal as the carburizer, carburized at850 °C, 900 °C and 950 °C, soaked at the carburizing temperature for 1:50 hrs followed by quenched with water. At the first the test specimen for analysis of different mechanical and wear characteristics of various local farming tools like toughness, tensile strength, abrasive wear and hardness were prepared as per ASTM standard.

The test specimens that was prepared for this purpose was subjected to destructive mechanical test before and after carburization process. From the data obtained, ultimate tensile strength, percent elongation, percent reduction in area, modulus of elasticity, Rockwell hardness, impact toughness, and abrasive wear were calculated. The destructive mechanical test results are compared before and after carburization process in order to see the impact of pack carburization and carburizing temperature on the performance (lifecycle) of the traditional farm implements. It was observed that the mechanical properties of steel samples were found to be strongly influenced by the process of carburization, carburizing temperature and soaking time at carburizing temperature. It was concluded that the sample carburized at 950 °C soaked for 1:50 hrs followed by water quenching gives best result than the other samples. Since pack carburizing enhance the hardness, tensile strength, abrasion resistance, the farm implement manufacturing company has been recommended to carburize these farm implement. [11]

According to **Mr Hazizi Azri Bin Ahmad Sabri,** project is experimental study of pack carburizing of carbon steels by using two parameters (holding time and carburizing temperature). This study was conducted by using furnace. This process is carried out at temperatures from 850°Cto 950°C for three various durations time which are 4, 8 and 16 hours. From the experiment, the surface hardness and thickness of carbon layer was different according to the parameters used. The quenching medium that He use in this experiment is water. For carburizing temperature at 950°C, the highest of surface hardness value is395.7 HV that carburized for 16 hours. For carburizing temperature at 900°C, the highest of surface hardness value is 373.4 HV that carburized for 16 hours and for carburizing temperature at 850°C which is the highest of surface hardness value is 345.5HV. The thickness of carbon layer for 950°C was between 40μm to 120μm. The thickness of carbon layer for 900°C was between 40μm to 80μm and for 850°C was between 20 μm to 60 μm. Activation energy was determined which is 142.55kJ/mol. The result indicates the carburizing process accelerates the diffusion of carbon atoms into the surface, thus increasing the thickness of carburized layer as well as the surface hardness. [12]

As a conclusion this literature reviews contains different technique to improve the mechanical property, some of them are.

Mr. Jaykant Gupta works his research on the mechanical and wear behaviors of mailed steels carburized at different temperature range of (850,900 and 950)^{0}c for 2 hours and tempered at 200^{0}c for 30 min and he get a good result at the temperature of 950^{0}c that is 57HRC, 32J toughness and 1960 Mpa tensile.

Ashish Verma et al, there investigation is on AISI 1040 it is one of medium carbon steel, they were heated the sample at 900^{0}c and hold for 120min and quenched in water then tempered at(650,450 and 250)^{0}c for 60,90 and 120min and the result they got is 685Mpa tensile at 250^{0}c and 60min.

Mrs P.O.offorl et al works on hot rolled steel the experiment they did is on heat treated from (750 to 810)^{0}c at 10^{0}c interval for 1hr in the furnace and quenching media they uses SAE 40 engine oil, water and brine. And the good result they got which is quenched in brine which is 708Mpa tensile at 810^{0}c and 233 BHN.

Saigeeta Priyadarshin et al the experiment they used on low carbon steel first carburized at 900^{0}c for 5hr then annealing, normalizing, hardening and tempering process they did at 150^{0}c for 30min and finally cooled in air. The result they got after carburized 69RHB, after quenching 104RHB, after tempering 82RHB after annealing 52RHB and finally after normalizing 74RHB.

CHAPTER 3. MATERIALS, METHODS AND CONDITION

3.1. FERROUS MATERIALS:-

The word “ferrous” usually refers to the materials that have a lot of iron in them. It is common for these materials to be strongly magnetic but not all of them are. Different type of iron and steel are more or less magnetic. High-chromium stainless steel is nearly non-magnetic, while pure iron tends to form magnets easily. Iron with impurities usually stays magnetic better than pure iron.

The material that is used for this experiment has the chemical composition shown from table below

Table 3-1 Chemical composition for ASTM A36 steel

Symbols	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Fe
ASTM A36	0.032	0.01	0.295	0.0072	0.015	0.085	0.01	0.006	0.02	0.0077	99.47

These ferrous materials are mainly classified in the two different types.

1. Steels: - Carbon contain up to 2%

a. Plain carbon steel

b. Alloy steel

2. Cast iron: - Carbon contain above 2% to 6.67%

a. Grey cast iron

b. White cast iron

c. Malleable cast iron

d. Ductile cast iron

3.1.1. Plain carbon steels:-

The plain carbon steels are the least costly and may be used for a variety of purposes.

The plain steels are generally classified in following 3 types.

1. Low carbon steel: - up to 0.30% of carbon.

Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.02–0.15% carbon and mild steel contains 0.16–0.30% carbon. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is used where ductility or softness are important. Properties: Malleable and ductile, and therefore bends fairly easily.

Uses: - It is used for nut, bolts, screws, automobile body panels, tin plate, wire product, tubes, girders etc.

2. Medium carbon steel: - From 0.30 to 0.60% of carbon.

These are less ductile but harder and have greater tensile strength than low carbon steel. It balances ductility and strength and has good wear resistance. They have also better machining qualities.

Properties: Harder, better tensile strength, good wear resistance.

Uses: - Shafts, connecting rods, spindles, gears, crank shaft, couplings, rail wheels, rail axle etc.

3. High carbon steel:- From 0.60 to 1.70% of carbon

They have higher tensile strength and harder than other plain carbon steels. They also readily respond to heat treatment. These steels can be tempered to great hardness. Used for special purposes like (non-industrial-purpose) knives, axles or punches. Most of these steels with more than 1.2% carbon content are made using powder metallurgy.

Properties: Tough rather than hard, and fairly ductile.

Uses :- Used for making hand tools such as wrenches, chisels, punches, files, cutting tools such

as drills, wood working tools, rail road wheels, springs, high strength wires etc.

This experiment is focus on low carbon steel since this low carbon has low cost and we can get easily in our country.

3.2. WORKING CONDITION:

3.2.1 Empirical Approach:-

Empirical Approach means derived from experiment and observation rather than theory.

Step 1 Literature Gap analysis & Conducting Industrial Survey for the selection of low carbon steel for experiment.

Step 2 Cutting and Machining of a low carbon steel material using shear machine and milling machine respectively.

Step 3 Heat Treatment Processes Such As Heating, Quenching, Hardening &Tempering of specimen.

Step 4 Hardness testing of untreated & treated sample steel.

Step 5 Composition testing of Untreated& treated steel material.

Step 6 Tensile strength test using universal testing machine untreated & treated sample steel.

Step 7 Impact testing for both untreated and treated steel material

3.2.2 Experimental Procedure:-

Literature gap analysis & conducting industrial survey for the selection of low carbon steel for experiment.

Literature gap analysis has been collected by referring various journals, books, papers etc. for the purpose of hardening process of steels material on which method that I was going to heat treatment will be carried out.

Another objective selection of place where to perform experiment, market availability of the recommended steel and their cost analysis, time analysis to complete the experiment etc. The purpose of selecting A36 steel is that they are mostly used in the manufacturing industry and it has low cost.

For this experiment the selected tempering temperature is 200^0c, 400^0c and 600^0c to see the clear effect of the mechanical property face change and tempering times vary with section size. Often, a time at temperature of 1 h per inch of thickness (minimum dimension of heaviest section) or per inch of diameter, with a minimum of 1 h, is used.[15]
From this idea I select 30min, 60min and 90min.

3.3. SAMPLE PREPARATION CONDITION

3.3.1. Selection of Material

ASTM A36 steel is selected for Experiment. These steel grades were suggested to be the best during machining process and it has low cost, for that objective we designed an industrial based experiment. The Carbon Composition is the same for each sample materials. We can easily identify between samples Prepared by punching the number before Heat Treatment.

These Materials are purchased From Material Shop. For defining the objective of study to be carried out more effectively and specific we designed Heat Treatment Performance

3.3.2. Cutting and Machining Condition

Sample Mark: ASTM A36 steel

Machine Used: shire machine

Amount of Sample Prepared: 77Sample is prepared

From this77 samples, 33 of the Samples prepared for tensile test, 11 samples are prepared first for microstructure next for composition and finally for hardness testing, 33 of the samples are for impact test.

Milling Machines

Sample Mark: ASTM A36 steel

Machine Used: Milling Machine

Work of Sample Prepared: 33 Sample is Machined

After preparation of 33 sample its dimension (20*200*5mm) using shire machine for tensile and 33 sample for impact it's size (55*10*10), the shape is finished in milling machine.

3.4. METHOD

Method for this experiment combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate the aim is to obtain a desired microstructure to achieve certain predetermined properties.

Heat Treatment Processes Such As Heating, Quenching, Hardening & Tempering of Sample Steels.

Place of Experiment: Mechanical Work shop.

Heat treatment process: Heating, Quenching, Hardening & Tempering.

Sample Mark: ASTM A36 steel

Instrument Used: Muffle Furnace.

3.4.1. Furnace

Electric furnace is used for heating purpose in various industrial production processes. Electric furnaces are used where more accurate temperature control is required. There are three types of electrical furnaces namely: (1) Induction Heating Furnace (2) Resistance Heating Furnace and (3) Arc furnace depending upon the method of heat generation.

Electric furnaces find its application in Engineering Industries, Food processing industries, Chemical processing Industries, Laboratories etc. The furnace is designed and constructed as per the requirement of the customer. The various parameters such as maximum attainable temperature dimension of the heating chamber, automatic or semi - automatic controlling of temperature etc. depends upon the requirement of the customer.

3.5. HEAT TREATMENT:-

The process of heat treatment is carried out first by heating the material and then cooling it in water. The purpose of heat treatment is to soften the metal, to change the grain size, to modify the structure of the material and to relieve the stress set up in the material after hot and cold working. The various heat treatment processes commonly employed in engineering practice as follows:-

3.5.1. Annealing:-

Tool steels usually are received from the supplier in the annealed condition. This condition allows the steel to be easily machined and heat treated. However, if they are subjected to hot or cold forming, often they must be fully annealed again before subsequent operations. If a tool is to be re hardened, it should first be thoroughly annealed. This procedure is important with the steels of higher alloy content; otherwise, irregular grain growth occurs and a mixed grain size (sometimes called fish scale or duplex grains) will result.

3.5.1.1. Spherodizing:-

Spherodite forms when carbon steel is heated to approximately 700^0c for over 30 hours. The purpose is to soften higher carbon steel and allow more formability. This is the softest and most ductile form of steel. Here cementite is present.

3.5.1.2. Full Annealing:-

The softest, most ductile and most workable condition of both non-heat-treatable and heat-treatable wrought alloys is produced by full annealing to the temper designated "O." Strain-hardened products in this temper normally become recrystallized, but hot-worked products may remain unrecrystallized. In the case of heat-treatable alloys, the solutes are sufficiently thoroughly precipitated to prevent natural age hardening. A higher maximum temperature than that used for stress-relief annealing, controlled cooling to a lower temperature, and additional holding time at the lower temperature generally are employed.

3.5.1.3. Process Annealing:-

As the hardness of steel increases during cold working, ductility decreases and additional cold reduction becomes so difficult that the material must be annealed to restore its ductility. Such annealing between processing steps is referred to as in-process or simply process annealing. It may consist of any appropriate treatment. In most instances, however, subcritical treatment is adequate and least costly, and the term "process annealing" without further qualification usually refers to an in-process subcritical anneal. It is often necessary to specify process annealing for parts that are cold formed by stamping, heading, or extrusion.

Hot worked high-carbon and alloy steels also are process annealed to prevent them from cracking and to soften them for shearing, turning, or straightening.

3.5.1.4. Diffusion Annealing:-

The process consists of heating the steel to high temperature (1100-1200)^{0}c. It is held at this temperature for 3 hours to 20 hours and then cooled to (800-850)^{0}c inside the furnace for a period of about 6 to 8 hours. It is further cooled in the air to room temperature. This process is mainly used for ingots and large casting. It is also called isothermal annealing.

3.5.2. Normalizing:-

Normalizing requires slow and uniform heating above the transformation range to dissolve excess constituents, then cooling in still air (see the article "Normalizing of Steel" in this Volume). Normalizing breaks up non uniform structures, relieves residual stresses, and produces greater uniformity in grain size thus counteracting undesirable results of unequal reductions for different sections during forging, differences in temperature between varying thicknesses of sections, and the subsequent irregular cooling rates. Normalizing also conditions the steel for subsequent spheroidizing, annealing, or hardening.

3.5.3. Hardening:-

The process of hardening consist of heating the metal to a temperature of 30-50 ^{0}c above the upper critical point for hypo-eutectoid steels and by the same temperature above the lower critical temperature for hyper-eutectoid steels. It is held this temperature for some time and then quenched. The purposes of hardening are to increase the hardness of the metal and to make suitable cutting tools.

3.5.4. Austempering:-

It is a hardening process. it is also known as isothermal quenching. In this process, the steel is heated above the upper critical temperature at about 875 ^{0}c where the structure consists entirely of austenite. It is then suddenly cooled by quenching it in a salt bath maintained at a temperature of about 250 ^{0}c to 525 ^{0}c.

3.5.5. Martempering:-

The martempering process is similar to austempering in that the work piece is quenched rapidly from the austenitizing range into an agitated bath held near the $M_s$temperature. It differs from austempering in that the work piece remains at temperature only long enough for the temperature to be equalized throughout the work piece. When the temperature has attained equilibrium but before transformation begins, the work piece is removed from the salt bath and air cooled to room temperature. Oils are used successfully for martempering, but molten salt is usually preferred because of its better heat-transfer properties.

Cooling from the martempering bath to room temperature is usually conducted in still air. Deeper hardening steels are susceptible to cracking while martensite forms if the cooling rate is too rapid. Alloy carburizing steels, which have a soft core, are insensitive to cracking during martensite formation, and the rate of cooling from the Martensite temperature is not critical.

Martempering does not remove the necessity for subsequent tempering. The structure of the metal is essentially the same as that formed during direct quenching.

3.5.6. Tempering:-

Tempering of Steel is a process in which previously hardened or normalized steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness, but also to increase the grain size of the matrix. Steels are tempered by reheating after hardening to obtain specific values of mechanical properties and also to relieve quenching stresses and to ensure dimensional stability.

Tempering usually follows quenching from above the upper critical temperature; however, tempering is also used to relieve the stresses and reduce the hardness developed during water quenching and to relieve stresses.

3.6. SURFACE HARDENING:-

In many engineering applications, it is desirable that steel being used should have a hardened surface to resist wear and tear. At this time, it should have soft and tough interior or core so that it can absorb any shocks. Case hardening is the process of hardening the surface of metal, often a low carbon steel by infusing elements into the metal surface forming a hard, wear resistance skin but preserving a tough and ductile interior. This type of treatment is applied to gears, ball bearings, railway wheels.

3.6.1. Induction Hardening

In induction hardening, a high-frequency current is passed through a coil surrounding the steel, the surface layers of which are heated by electro-magnetic induction. The depth to which the heated zone extends depends on the frequency of the current (the lower frequencies giving the greater depths) and on the duration of the heating cycle. The time required to heat the surface layers to above the Ac3 is surprisingly brief, frequently being a matter of only a few seconds. Selective heating (and therefore hardening) is accomplished by suitable design of the coils or inductor blocks. At the end of the heating cycle, the steel is usually quenched by water jets passing through the inductor coils. Precise methods for controlling the operation, that is, rate of energy input, duration of heating, and rate of cooling, are necessary. These features are incorporated in induction hardening equipment, which is usually entirely automatic in operation.

3.6.2. Flame Hardening

Flame hardening is a process of heating the surface layers of steel above the transformation temperature by means of a high-temperature flame and then quenching. In this process the gas flames impinge directly on the steel surface to be hardened. The rate of heating is very rapid, although not so fast as with induction heating. Plain carbon steels are usually quenched by a water spray, whereas the rate of cooling of alloy steels may be varied from a rapid water quench to a slow air cool depending on the composition.

3.7. CASE HARDENING

Case hardening is a process of hardening a ferrous alloy so that the surface layer or case is made substantially harder than the interior or core. The chemical composition of the surface layer is altered during the treatment by the addition of carbon, nitrogen, or both. The most frequently used case-hardening processes are as follows:

A. Carburizing
B. Cyaniding
C. Nitriding
D. Carbonitriding

3.7.1. Carburizing

Carburizing is a process that introduces carbon into a solid ferrous alloy by heating the metal in contact with a carbonaceous material to a temperature above the 880^0c of the steel and holding at that temperature. The depth of penetration of carbon is dependent on temperature, time at temperature, and the composition of the carburizing agent. As a rough indication, a carburized depth of about 0.6 to 1.27 mm. can be obtained in .about 6 hr at 900 °c depending upon the type of carburizing agent, which may be a solid, liquid, or gas. Since the primary object of carburizing is to secure a hard case and a relatively soft, tough core, only low-carbon steels (up to a maximum of about 0.25% of carbon) either with or without alloying elements (nickel, chromium, manganese, molybdenum), are normally used.

After carburizing, the steel will have a high carbon case graduating into the low-carbon core a variety of heat treatments may be used subsequent to carburizing, but all of them involve quenching the steel to harden the carburized surface layer. The most simple treatment consists of quenching the steel directly from the carburizing temperature; this treatment hardens both the case and core (insofar as the core is capable of being hardened).

There are following types of carburization processes exist

1. Solid carburization
2. Gaseous carburization
3. Liquid Carburizing
4. Vacuum carburization
5. Plasma carburization
6. Salt bath carburization

3.7.1.1. Solid carburization:-

Solid or PACK carburizing is a process in which ferrous metal is brought into contact with an environment of sufficiently high carbon potential to cause absorption of carbon at the surface and to enable diffusion as a result of the carbon concentration gradient between the surface and the interior of the metal.

The solid or pack carburization involves heating the steels parts embedded in powdery mixture of 85% charcoal and 15% energizers are used as carburizing media. The most commonly used energizers are sodium carbonate and barium carbonate, at a temperature in range 900 degree Celsius. The residual air in the box combines with carbon to produce Co gas. Carbon monoxide gas is unstable at the process temperature and thus decomposes upon contacting the iron surface by reaction.

$2CO = C + CO2$

The atomic carbon enters the steel through the following reaction.

$Fe+2CO = Fe(C) + CO2$

The addition of $BaCO_3$or $NaCo_3$enhances the carburizing effect. $NaCO_3$ decomposes and evolvesCO_2 which react with charcoal to form carbon monoxide.

$C+CO_2 = 2CO$

Solid carburization is a time consuming procedure. Typical carburizing time to obtain a case

Depth of 1-2 mm is around 4-8 hours. Higher speed can be obtained by carburizing in gaseous medium.

3.8. TESTING CONDITION

The experimental procedure for the project work can be listed as:

1. Specimen preparation
2. Heat treatment
3. Tensile strength test
4. Hardness measurement
5. Composition test measurement
6. Microstructure study
7. Impact test

3.8.1. Tensile Strength Test:-

Computer-Controlled Electro-hydraulic Servo Universal Testing Machine is suitable to test various metallic & non-metallic materials for tension, compression, bending and shearing strength. It is capable of testing the characters of materials on physical & technology properties. It is simple, easy to operate and widely used in works, laboratories and high schools for material properties research and quality control. Equipped with the computer & Software & printer, it can display, record, process and print the test results, and control test procedures as per the set program and can draw test curves automatically in real time. UTM machine Model WAW 600, precision grade 0.5, max load 600KN, serial No 16259, made in china.

3.8.1.1 Specimen Preparation:

The first and foremost job for the experiment is the specimen preparation. The specimen size should be prepared according to ASTM A370 standard test method and definition for mechanical test of steel on Fig 3-2.

The test sample was prepared from steel, ASTM A36: It is one of the American standard specifications of the low carbon steel having 0.032% of carbon.

3.8.1.2 Specimen preparation and testing for tensile strength

As we discussed in chapter 3, the sample is prepared from 5mm plate using shear machine and finished in milling machine.

Size of the sample will be, l=200mm, width=20mm, t=5mm

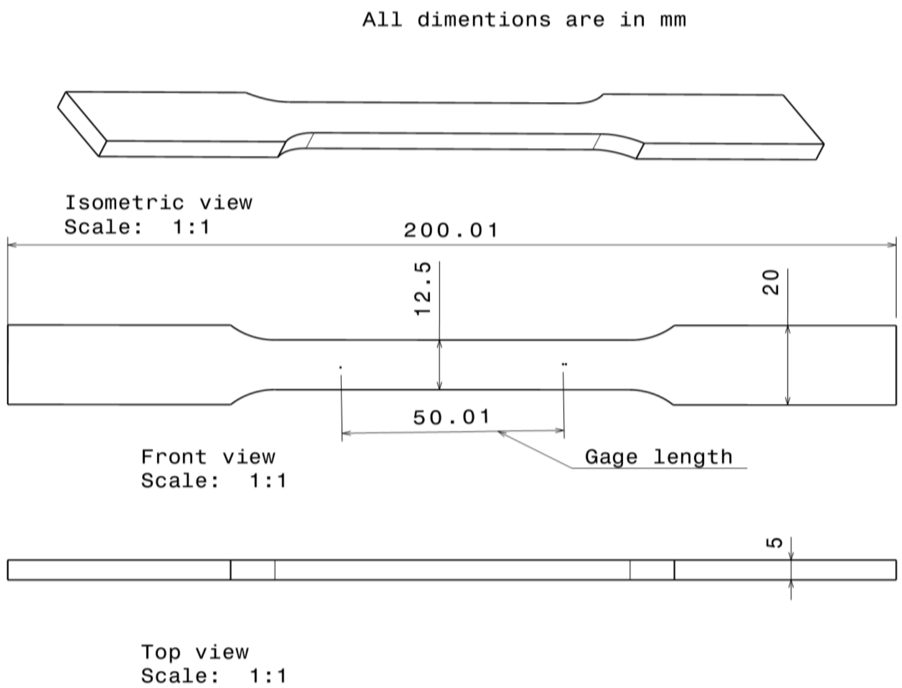


Figure 3-1 size of tensile strength sample

Number of sample prepared for tensile strength is 33pic

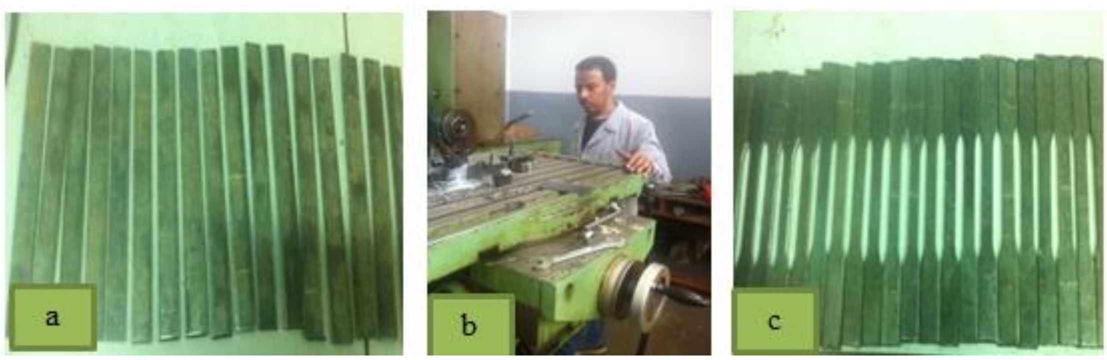


Figure 3-2 (a) Samples before machining. (b) Machining the samples (c). Samples after machining

Figure 3-3 (a) Tempered samples before testing. (b) Testing samples on U.T.M. (c) Samples after testing.

3.8.2 Hardness Testing

Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load F0 (Fig.3.5A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig.3.5B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig.3.5C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number. AVERY, Type 6402, Parte .No 512520, machines No 3530.

HR = E - e

F0 = preliminary minor load in kgf

F1 = additional major load in kgf

F = total load in kgf

e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm

E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number

D = diameter of steel ball

Steel hardness calculator used for conversion of values. Using that we calculated HRB value

& brinell Hardness HB,

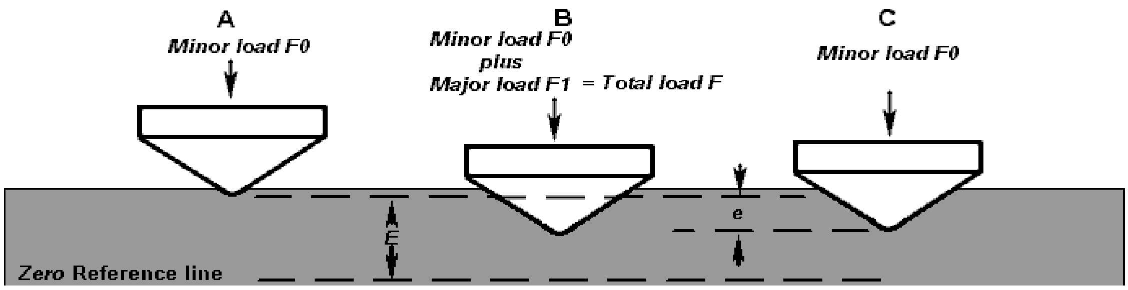


Figure 3-4 Rockwell Principle

Sample Mark:- ASTM A36 Steel.

Instrument Used:- Rockwell Hardness Test

Working type:- Hardness test

Place of Experiment:- Material testing Room, in Mechanical Work shop

3.8.2.1 Specimen preparation and testing for hardness

The specimen size should be prepared according to ASTM A370 standard test method and definition for mechanical test of steel. CFR Section 49 CFR 179.102-1(a)(1)[17].

The size of the sample should be Length = 50mm, width = 25mm , t = 5mm

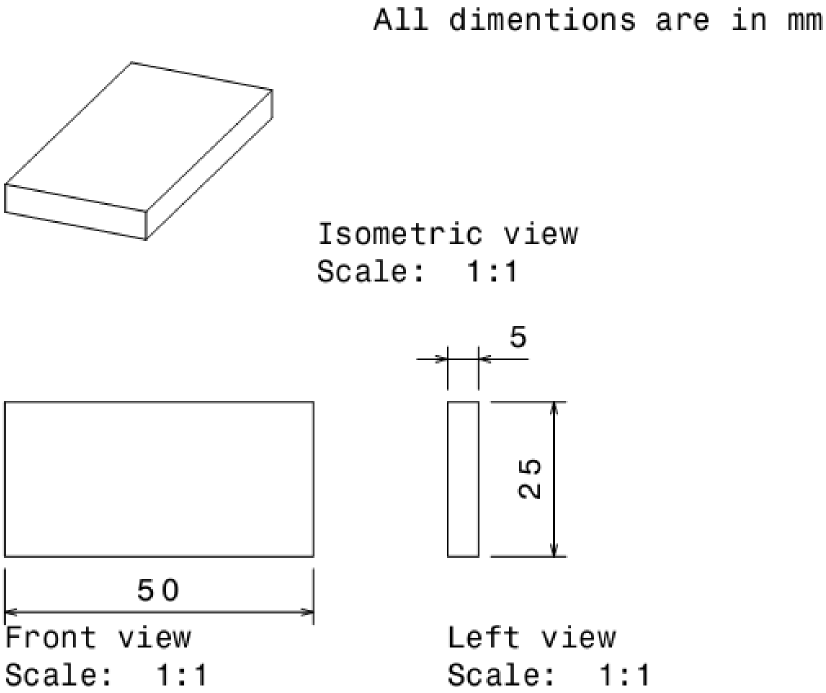


Figure 3-5 Size of Samples for Hardness Test

Number of sample prepared is 11pic

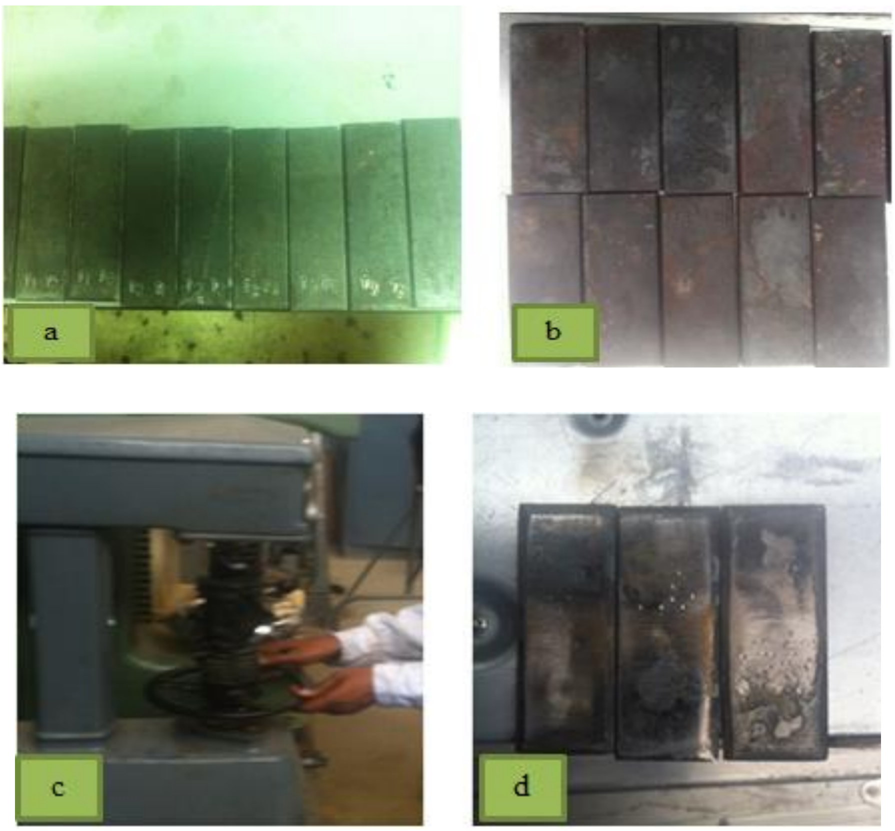


Figure 3-6 (a) preparation of samples before heat Treatment. (b). Samples after heat treatment (c). Testing Samples Using Rockwell hardness (d) After testing the Samples.

3.8.3 Composition Testing

Spectrometer

A spectrometer is an instrument for making relative measurements in the optical spectral region, using light that is spectrally dispersed by means of a dispersing element.

Basically, two things can happen when light hits a sample. We either have absorption or we have emission. In absorption, the sample absorbs some of the energy from the light, which is what happens when your sunglasses stop the ultraviolet rays in sunlight from getting to your eyes.

Emission occurs when we hit a sample with some light and it emits light of a different wavelength. This explains phenomena such as fluorescence, luminescence and phosphorescence. Emission is what happens when you wear a white shirt that has been washed in a detergent containing chemical brighteners. It absorbs ambient light and gives off a slight blue hue to make it look cleaner. A clever idea's from detergent manufacturers.

The effect of light on a sample depends on the wavelength of the light, the intensity of the light, and what it's doing to the molecules or atoms of the sample.

Here, in a very simple form, is a schematic of a spectrometer. First, we have a light source. Second, we have some sort of device that can select a specific wavelength for that light. It can be a monochromator, a polychromator, an interferometer, or even something as simple as a filter. Third, we have a means of presenting our sample to the spectrometer. T/C No ST 1058/s11/001c, matr/SN 27949 /0000/000, Item 03.

Sample Mark: ASTM A36 Steel

Instrument Used: spectrometer

Working type: composition test

Place of Experiment: Material testing Room, in Mechanical Work shop

3.8.3.1 Specimen preparation and testing for composition

This specimen size should be prepared according to ASTM A751 standard test method and definition for mechanical test of steel.

The size of the sample should be Length = 50mm, width = 25mm, t = 5mm

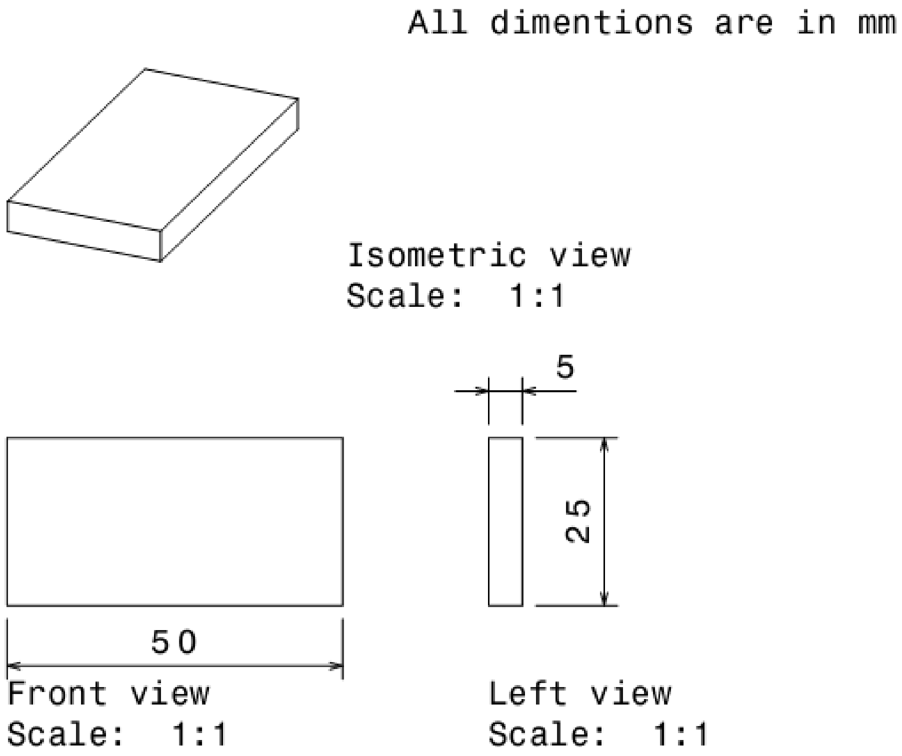


Figure 3-7 Size of Samples for Composition Test.

Number of sample prepared is 11pic

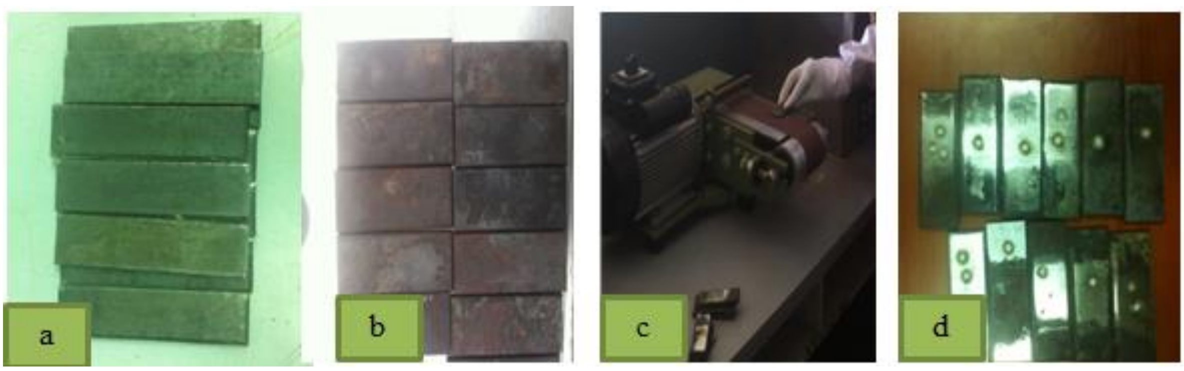


Figure 3-8 (a) Composition Testing (b) Samples After Heat Treatment (c) Polishing Samples (d) Samples After Composition Testing

3.8.4. Optical Microscope

The main principal of light optical microscopy (LOM) is to shine a light through (transmitted light) or onto the surface (reflected light) of a specimen and examine it under magnification. The main components of the LOM are the objective lens, eyepiece, condenser, and light source.

The basic components of a light microscope are:

• Objective lens - magnifies the object.

• Eyepiece - enlarges the image but does not increase the resolution.

• Condenser - focuses the light source onto the specimen for uniform illumination, eliminating stray light.

• Iris (which is associated with the condenser) - affects the resolution vs. the depth of field and contrast. Unfortunately, nature dictates that improvement in one result in the loss of another.

Standard light sources are often used in ordinary microscopes. The primary illumination sources found in modern LOMs are incandescent tungsten filament lamps. The tungsten filament emits light ranging from 300 to 1400 nm with a color temperature range of 2200 to 3400 K. The color temperature is the temperature of an ideal black-body radiator that radiates light of comparable color to that of the light source. The best light sources are those in which the light intensity is controlled by a voltage adjustment. Ref: ST 10 UN/s21/002c Holland.

3.8.4.1 Specimen preparation and testing for microstructure

For this specimen size should be prepared according to ASTM E 112-13 standard test method and definition for mechanical test of steel.

The size of the sample should be Length = 50mm, width = 25mm, t = 5mm

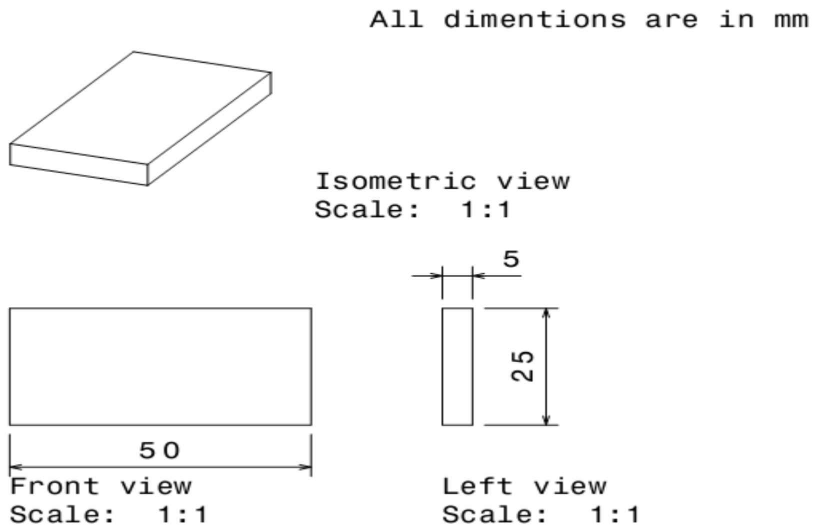


Figure 3-9 Size of Samples for Microstructure.

Number of sample prepared is 11pic

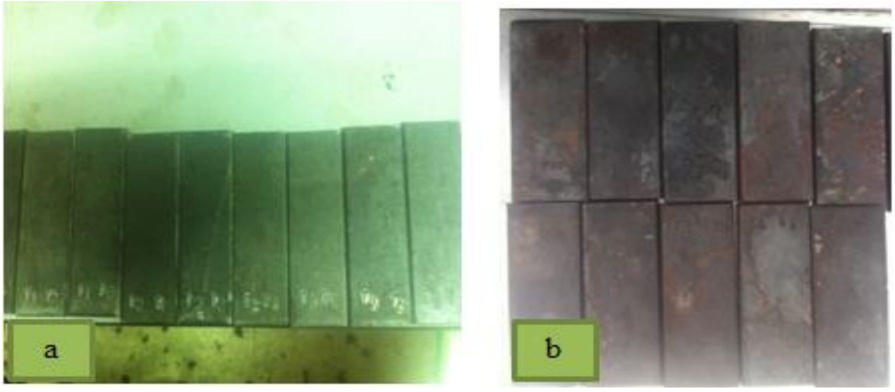


Figure 3-10 (a) Samples Before Heat Treatment. (b) Samples After Heat Treatment.

Grinding - removes saw marks and levels and cleans the specimen surface. Polishing removes the artifacts of grinding but very little stock. Grinding uses fixed abrasives—the abrasive particles are bonded to the paper or platen

Etching - The purpose of etching is to optically enhance microstructural features such as grain size and phase features. Etching selectively alters these microstructural features based on composition, stress, or crystal structure. The most common technique for etching is selective chemical etching and numerous formulations have been used over the years. Other techniques such as molten salt, electrolytic, thermal and plasma etching have also found specialized applications.

Chemical etching selectively attacks specific microstructural features. It generally consists of a mixture of acids or bases with oxidizing or reducing agents.

The nitric acid that is used for etching is 10% and the other 90% is alcohols

Figure 3-11 (c) Polishing Samples (d) Mixing of Alcohol and Nitric Acid (e) Observing Grain Structure.

3.8.5 Izod Impact Test:

In the Izod impact test, the test piece is a cantilever, clamped upright in an anvil, with a V notch at the level of the top of the clamp. The test piece is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed height, to give a blow of 120 ft lb energy. After fracturing the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount is read. Made in England by AVERY Capacity 17Kg/m , Type 6701 ,Number E5360.[17]

3.8.5.1 Specimen preparation and testing for Impact test

For the impact test the specimen size should be prepared according to ASTM A370 standard test method and definition for mechanical test of steel. CFR Section 49 CFR 179.102-1(a)(1)[17].

The size of the sample should be Length = 75mm, width = 10mm, depth = 10mm Which is simple beam impact test specimen Type A, which has 2mm V-grove

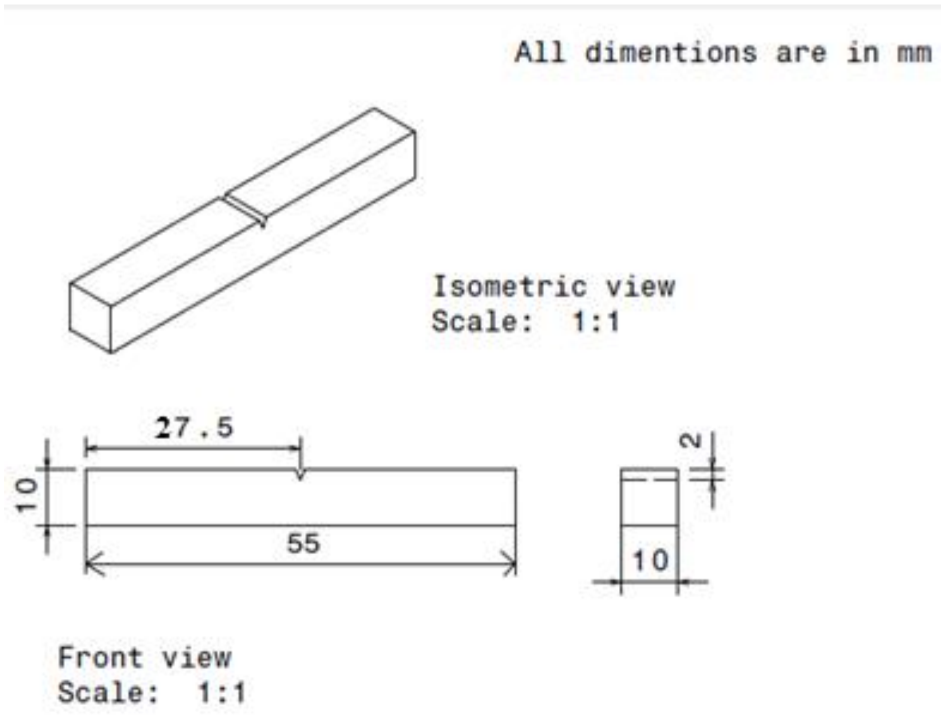


Figure 3-12 Size of Samples for Impact Test

Number of sample prepared for tensile strength is 33pic

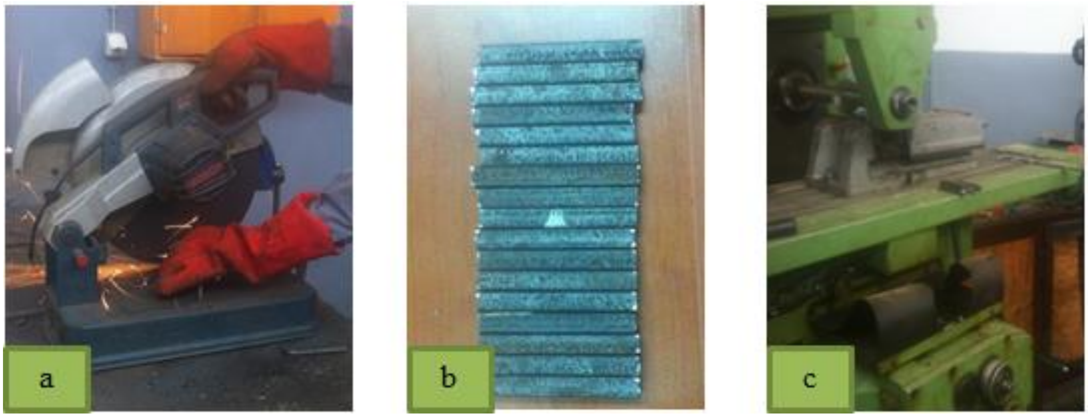


Figure 3-13 (a) Cutting Samples.   (b) Samples Before Machining. (c) Machining the Sample

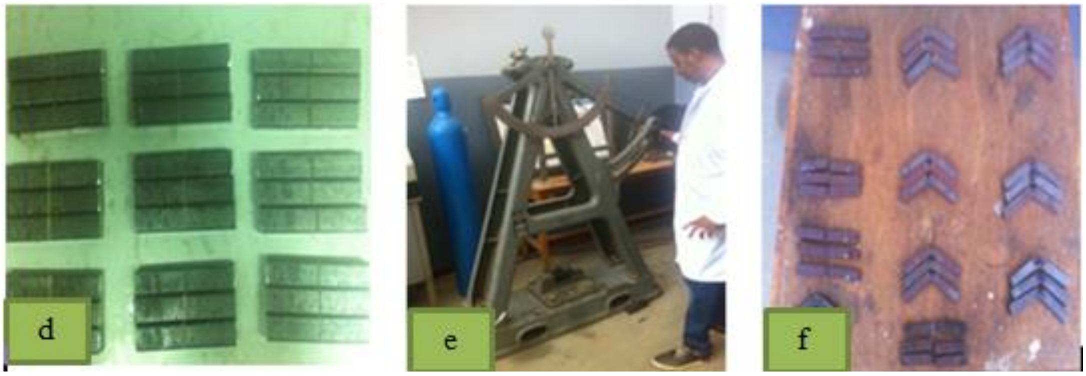


Figure 3-14 (d) After machining the samples. (f) Testing the samples   (g) After testing the samples.

3.9 CARBURIZATION PROCESS:

3.9.1 Carburization Container:-

The different test specimen samples made up of mild steel for mechanical and microstructural properties testing were subjected to pack carburization treatment. In this process the mild steel samples were placed on the thick bed of carburizer kept in two stainless steel container and fully covered from all sides, and it's dimension is 600mm*500mm*400mm. The top of the container was covered with a stainless steel plate. The container was then introduced into the muffle furnace and then maintained at the required carburization temperatures of , 900 ^{0}C with the soak time of 6 hours in this way the A36 steel samples gets carburized and then they were quenched in the Furness in order to stable the elements i.e. the hardening was effected immediately after carburization. By this carburization process the mechanical properties of mild steel samples increased considerably. The carburized steel samples were then tempered with different tempering temperature and tempering time finally different type of mechanical and microstructural test would be done.

3.9.2 Carburized Compounds:-

The common commercial carburizing compounds hardwood charcoal 85% and 15% of Sodium carbonate it is the principal energizer is used. The remainder of the energizer usually is made up of calcium carbonate, although barium carbonate and potassium carbonate also may be used. It should be noted that barium carbonate, now designated by government regulations as a health hazard due to its toxicity and the disposal problems it presents, is gradually being phased out by U.S. manufacturers as a catalyst in pack-carburizing operations. Hardwood charcoal is more reactive than coke as a source of carbon for pack carburizing Nevertheless; coke offers certain advantages, such as minimum shrinkage, good hot strength, and good thermal conductivity. More active carburizing compounds therefore contain both charcoal and coke, with typical compounds containing a greater percentage of coke.

The arrangement of the samples in the box is 50mm gape in order to equal distribution of carbon atom on the surface of the samples.[15]

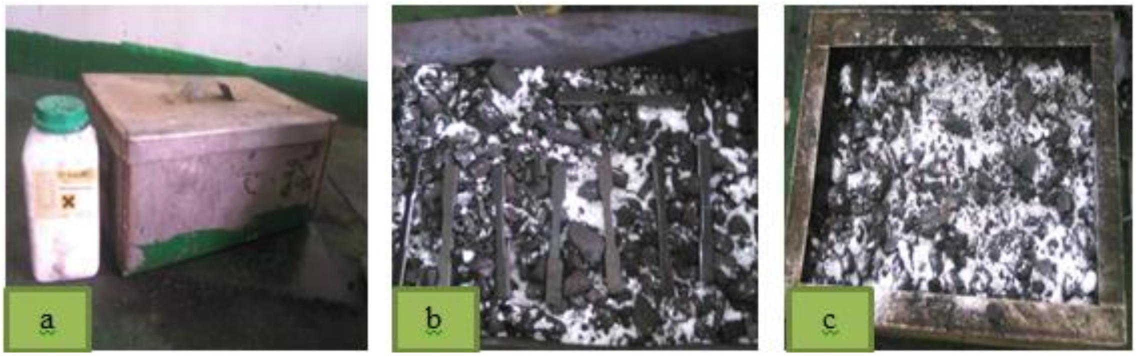


Figure 3-15 (a) NaCo3 and Carburizing Box. (b) Samples Arrangement. (c) Samples Paced in the Box.

3.9.3 Heat treatment Procedure:-

77 sample is prepared according to ASTM standard

From 77 sample prepared 7 sample has been test before heat treatment and 7 sample has been test after carburized the sample to check its Composition, Hardness value, Microstructure, tensile strength and impact test.

From the remaining 63 sample 27 for tensile strength 27 for impact and 9 sample for composition, hardness value and microstructure.

The 63 sample will have identification number'' Ti Tj'' the symbol Ti- stands for Temperature and Tj- stands for Time, for example T1T1 means the first temperature and the first time (i.e 200^0c and 30min) then carburized at the temperature of 900 ^{0}c for 6 hrs then all the sample has been cooled in the Furness then hardening process has been continued at a temperature of 830^0c and quenched in water.

The first 9 (i.e. T1 T1,T1 T2,T1 T3) sample is tempered at the temperature of 200^0c and holding for 30 min for the 1st sample, 60 min for the 2nd sample, 90 min for the 3rd sample respectively and quenched in air.

The second 9 (i.e.T2 T1,T2 T2,T2 T3) sample is tempered at the temperature of 400^0c and holding for 30 min for the 4th sample, 60 min for the 5th sample, 90 min for the 6th sample respectively and quenched in air.

The last 9 (i.e.T3 T1,T3 T2,T3 T3) sample is tempered at the temperature of 600^0c and holding for 30 min for the 7th sample, 60 min for the 8th sample, 90 min for the 9th sample respectively and quenched in air.

After all samples are cooled very well, we have to cline the sample to test and evaluate or compare the value between them after heat treatment or Harding process is completed.

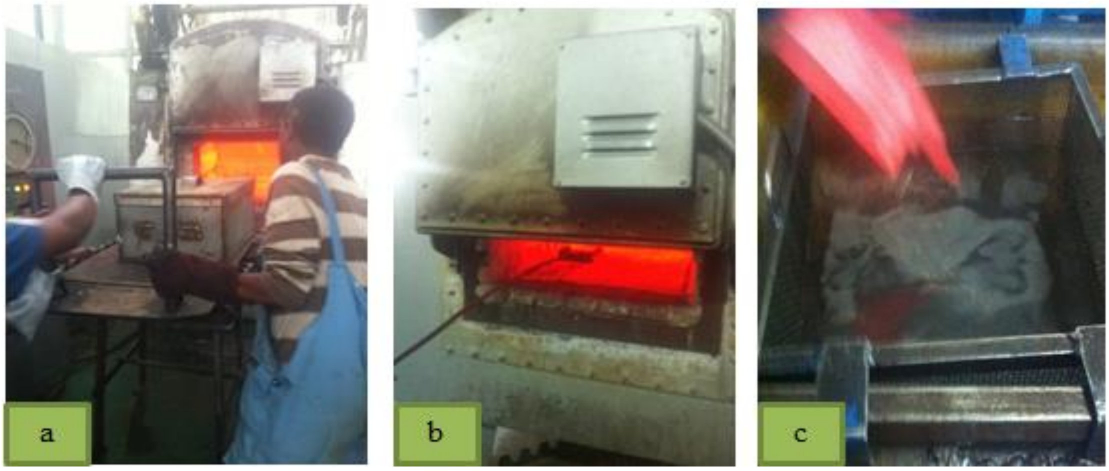


Figure 3-16 (a) Carburizing the Samples. (b) Hardening Process. (c) Quenching in water.

Tempering Process

Tempering of Steel is a process in which previously hardened or normalized steel is usually heated to a temperature below the lower critical temperature and cooled at a suitable rate, primarily to increase ductility and toughness, but also to increase the grain size of the matrix. Steels are tempered by reheating after hardening to obtain specific values of mechanical properties and also to relieve quenching stresses and to ensure dimensional stability.

Tempering usually follows quenching from above the upper critical temperature; however, tempering is also used to relieve the stresses and reduce the hardness developed during water quenching and to relieve stresses.

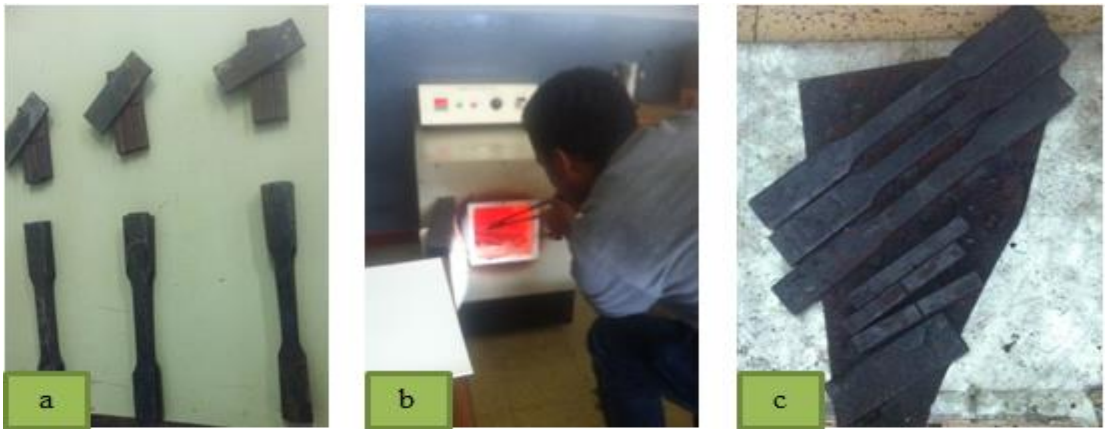


Figure 3-17 (a) Samples After Tempering. (b) Tempering Process. (c) After Tempering.

CHAPTER 4. RESULTS & DISCUSSION

4.1 EXPERIMENTAL RESULT

4.1.1 Tensile Strength Test:

After the sample was prepared according to ASME standard the heat treatment was done according to the paper, after that test was taken using U.T.M machine

The resale is tabulated and the graphed as follows.

4.1.2 Hardness Test:

The heat treated specimens it's hardness was measured by means of Rockwell hardness tester. The procedure adopted can be listed as follows:

1. First the indenter was inserted in the machine; the load is adjusted to150kg.

2. The minor load of a 10 kg was first applied to seat of the specimen.

3. Now the major load applied and the depth of indentation is automatically recorded on a dial gage in terms of arbitrary hardness numbers. The dial contains 100 divisions. Each division corresponds to a penetration of 0.002mm.The dial is reversed so that a high hardness, which results in small penetration, results in a high hardness number. The hardness value thus obtained in C scale. The test result is tabulated and graphed as follows.

Tabulation for Hardness Testing:

4.1.3 Izoid Impact Test

In Izoid Impact test each sample after heat treatment is done according to this paper the test was taken. The test result is tabulated and graphed as follows.

Table 4-1 Test Result for the Experiment

Sample Name	Material type	Carburizing Temp.(^{0}C)	Harding Temp.(^{0}C)	Tempering Temp.(^{0}C)	Tempering Time(min)	Max Tensile Stress (Mpa)	Elongation (%)	Hardness (HRC)	impact test (J)
Untreated	ASTM A36 steel					347.77	39.54	18.2	150
Hardened		900 (Quenching media is Furnace)	830 (for 30min and Quenching media is water)			572.71	4	82.1	9.8
T1T1				200	30	611.16	9.34	64	14.7
T1T2					60	550.9	12.94	61.7	37.6
T1T3					90	554.79	15.54	60.8	44.8
T2T1				400	30	473.27	29.14	44.2	95
T2T2					60	469.38	30.34	37.3	96.1
T2T3					90	445.93	32.14	36.3	100.7
T3T1				600	30	445.93	33.54	34	106.2
T3T2					60	440.06	28.2	32.3	116.7
T3T3					90	437.99	22.66	30.9	138.6

Notes: there is some uncertainty on the value of elongation this is because of sliding on machine griping and some ununiformed distribution of carbon atoms during carburizing.

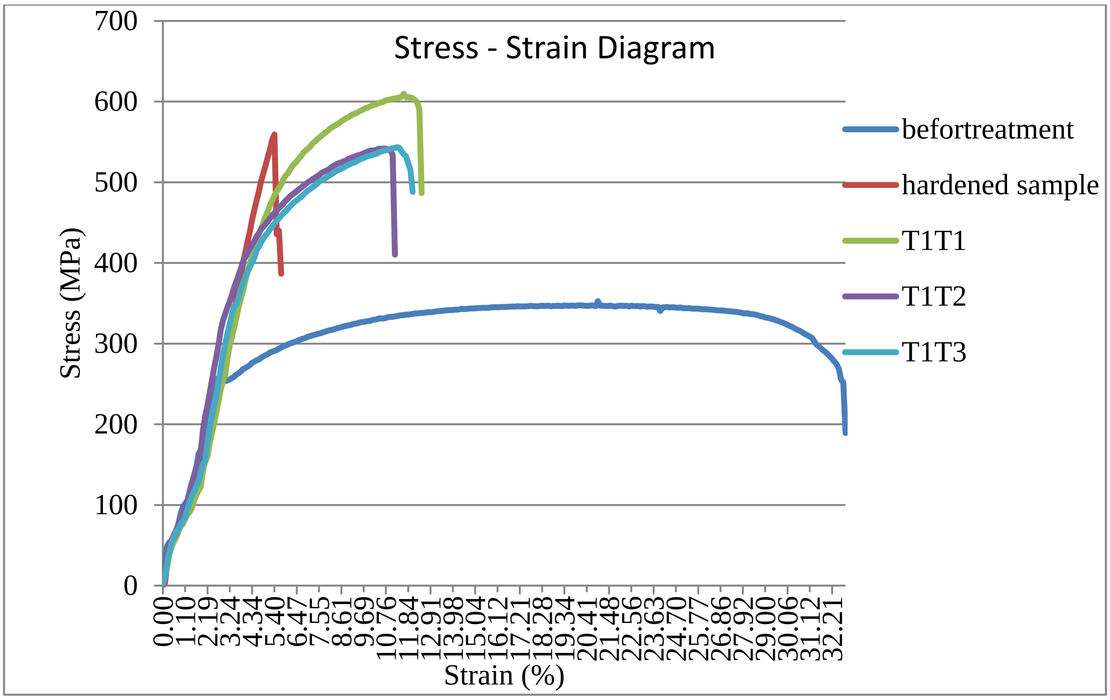


Figure 4-1 Stress-Strain Diagram at 200^{0}c with different tempering time

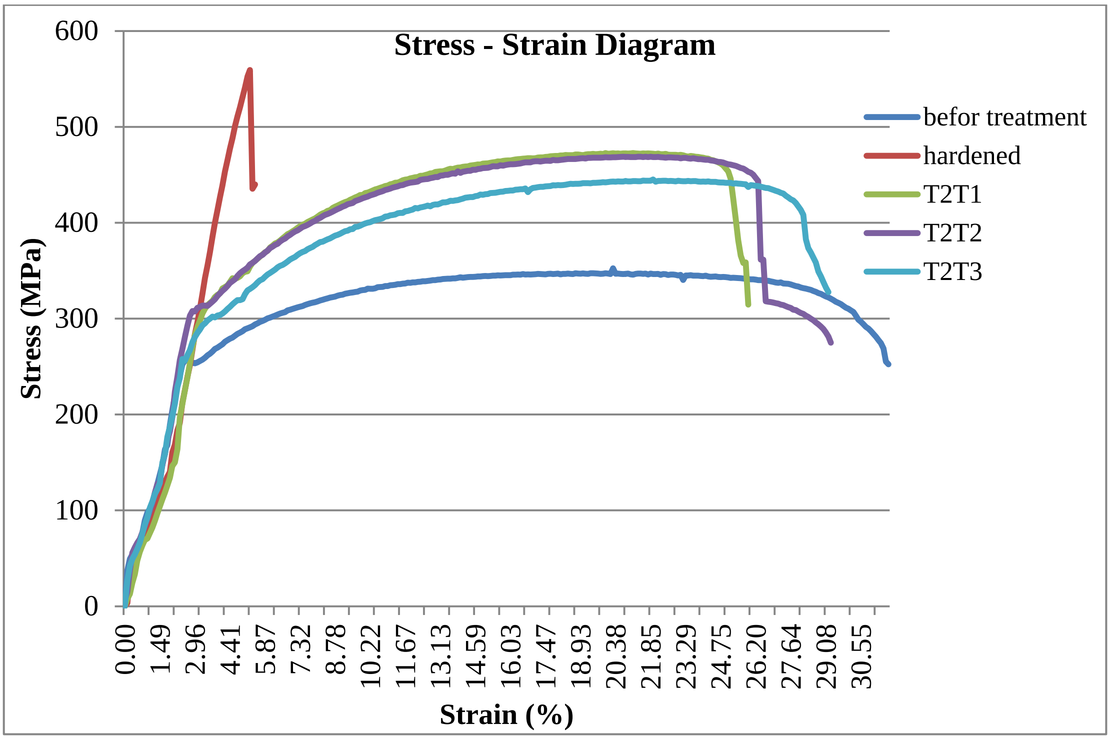


Figure 4-2 Stress-Strain Diagram at 400^{0}c with different tempering time

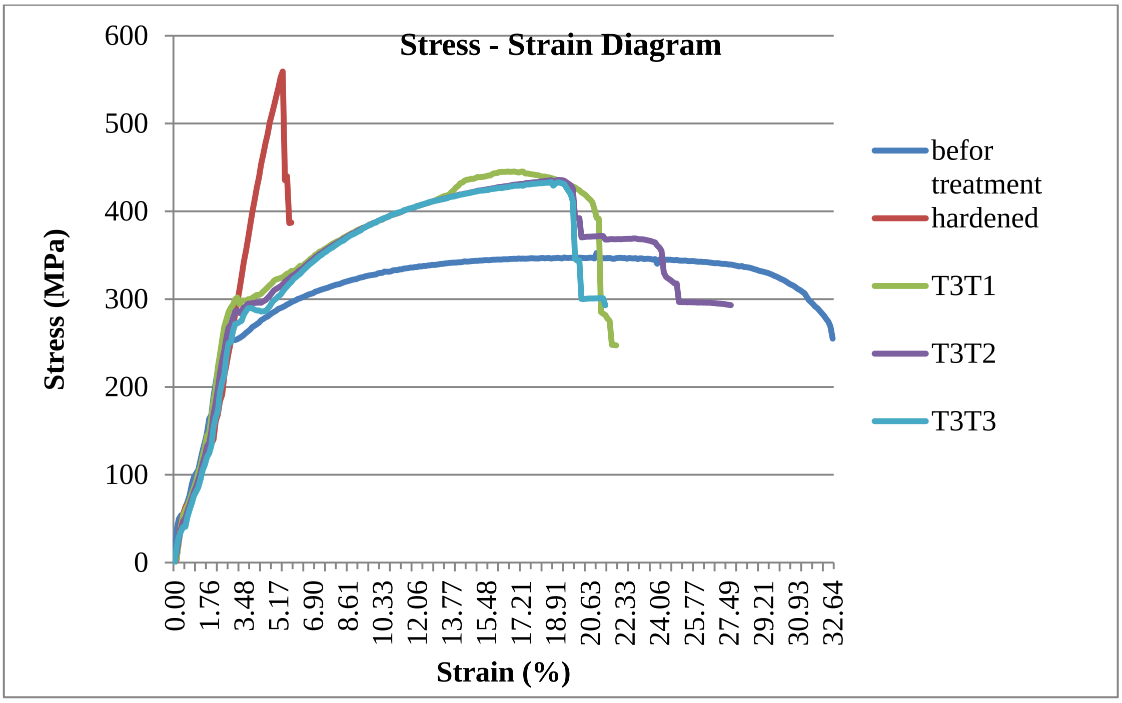


Figure 4-3 Stress-Strain Diagram at 600^{0}c with different tempering time

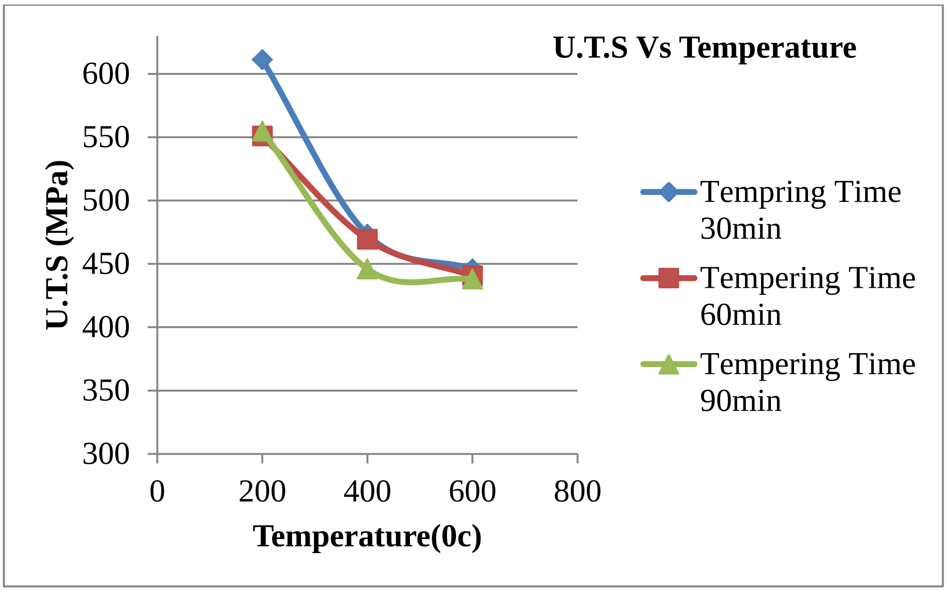


Figure 4-4 Stress v/s Tempering Temperature Using Constant Tempering Time Diagram.

The above fig show there is some uncertainty on the machine at value of 30min and 60min holding time.

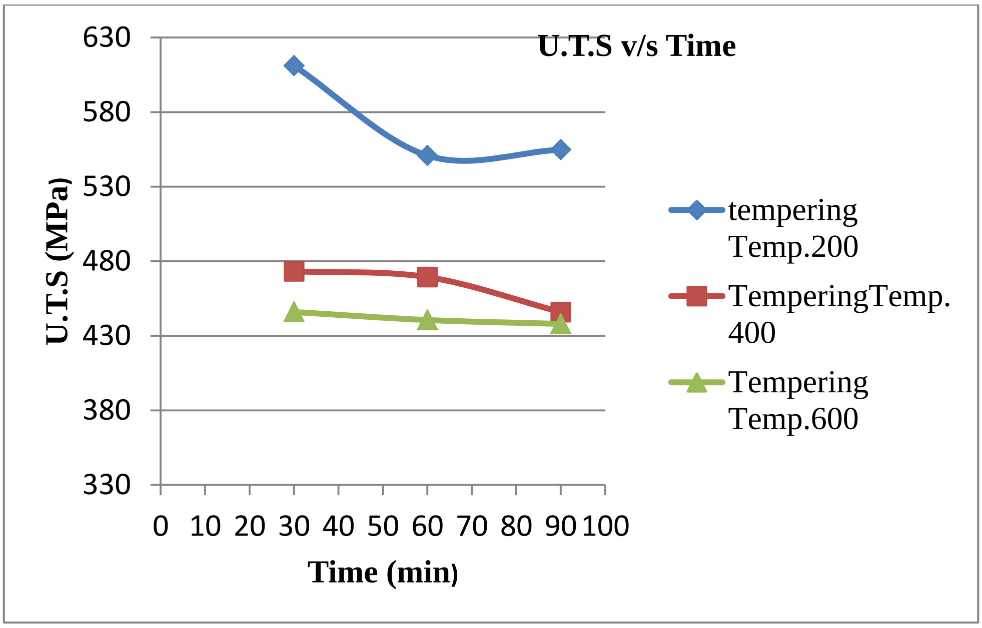


Figure 4-5 Stress v/s Tempering Time Using Constant Tempering Temperature Diagram.

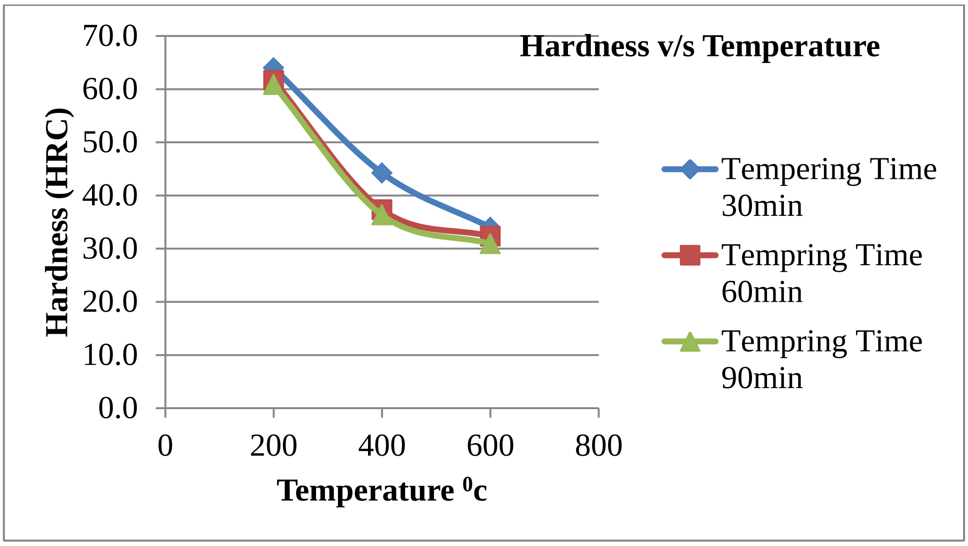


Figure 4-6 Hardness v/s Tempering Temperature Using Constant Tempering Time Diagram.

Notes: this shows it has little deferens between 60min holding time and 90min holding time.

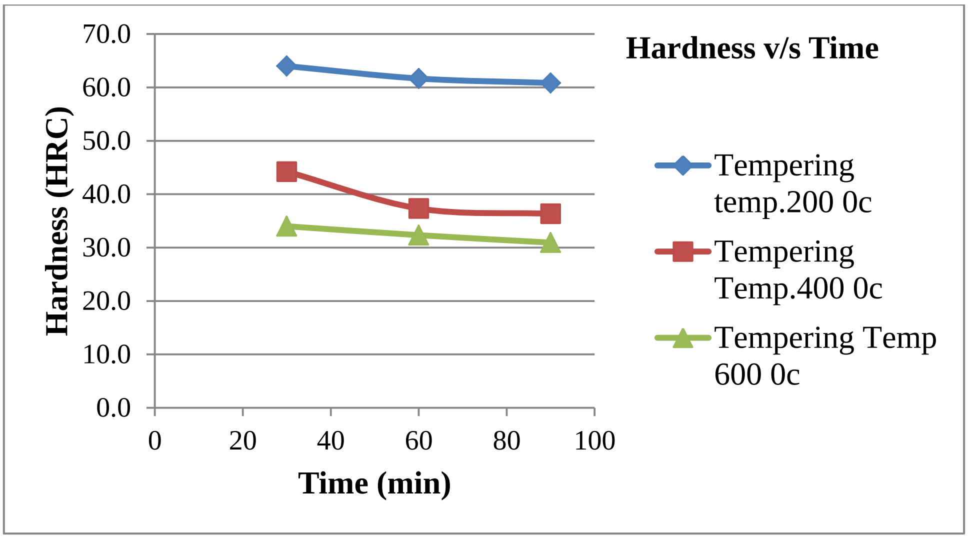


Figure 4-7 Hardness v/s tempering Time Using Constant Tempering Temperature Diagram.

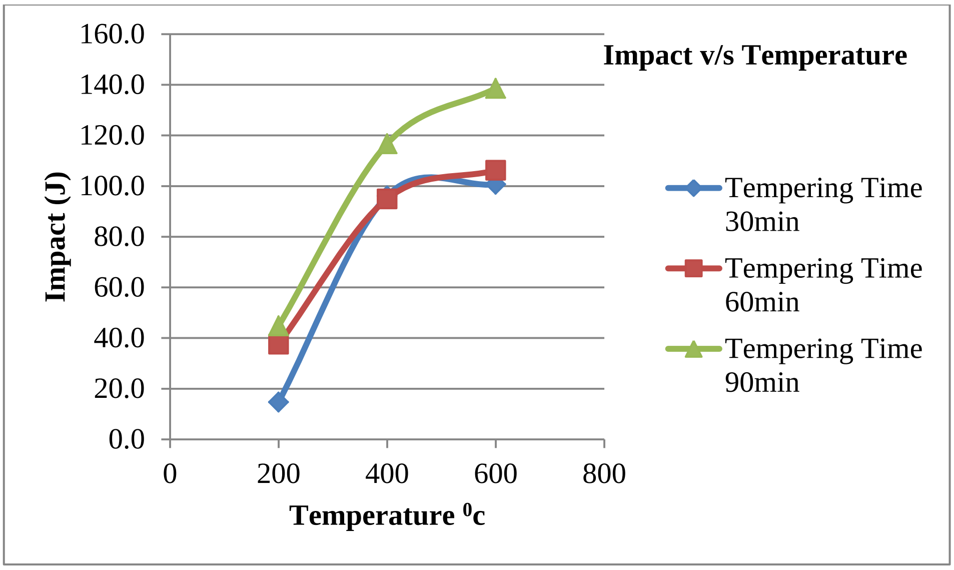


Figure 4-8 Impact v/s Tempering Temperature Using Constant Tempering Time Diagram.

The above fig show there is some uncertainty on the machine at value of 30min and 60min holding time.

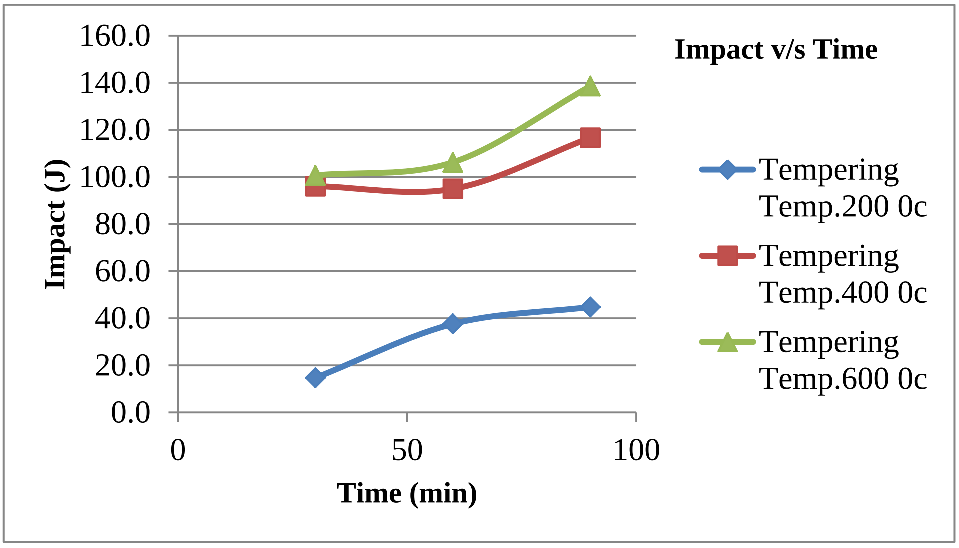


Figure 4-9 Impact v/s Tempering Time Using Constant Tempering Temperature Diagram.

4.1.4 Composition test

The composition test was done using spectrometer, before measuring we have to first polish to bring the sample street and Smooth.

Then open the argon gas and switch on the machine after waiting the machine for 15 to20 min then select low alloy steel. We can start pressing the pushbutton on the testing gun after the gun tip was contact with the sample.

Composition Test Result for All Samples

Table 4-2 Composition Test Result for All Samples

Symbols	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Al	Co	Nb	Ti	V	W	Fe
Untreated	0.032	0.01	0.295	0.0072	0.015	0.085	0.01	0.006	0.02	0.0077	0.005	0.005	0.003	0.0016	0.03	99.47
Carburized	0.533	0.01	0.271	0.0067	0.01	0.019	0.01	0.005	0.018	0.0038	0.005	0.005	0.003	0.0018	0.03	99.07
T1T1	0.768	0.01	0.287	0.011	0.012	0.01	0.01	0.011	0.023	0.005	0.005	0.005	0.003	0.0014	0.03	98.81
T1T2	0.78	0.01	0.286	0.0031	0.011	0.01	0.01	0.0071	0.019	0.0049	0.005	0.005	0.003	0.0018	0.03	98.81
T1T3	0.751	0.01	0.293	0.0077	0.016	0.01	0.01	0.0085	0.02	0.0053	0.005	0.005	0.003	0.0016	0.03	98.82
T2T1	0.711	0.01	0.283	0.0091	0.015	0.01	0.01	0.0093	0.021	0.0061	0.005	0.005	0.003	0.0017	0.03	98.87
T2T2	0.782	0.01	0.296	0.0092	0.012	0.01	0.01	0.0077	0.02	0.003	0.005	0.005	0.003	0.0016	0.03	98.79
T2T3	0.542	0.01	0.299	0.0068	0.014	0.01	0.01	0.0067	0.02	0.0066	0.005	0.005	0.003	0.0016	0.03	99.03
T3T1	0.689	0.01	0.289	0.0084	0.015	0.01	0.01	0.005	0.02	0.0057	0.005	0.005	0.003	0.0017	0.03	98.89
T3T2	0.484	0.01	0.291	0.0091	0.011	0.01	0.01	0.0065	0.02	0.0056	0.005	0.005	0.003	0.0016	0.043	99.08
T3T3	0.693	0.01	0.278	0.0096	0.008	0.01	0.01	0.0063	0.018	0.0063	0.005	0.005	0.003	0.0017	0.03	98.91

4.1.5 Microstructure Observation

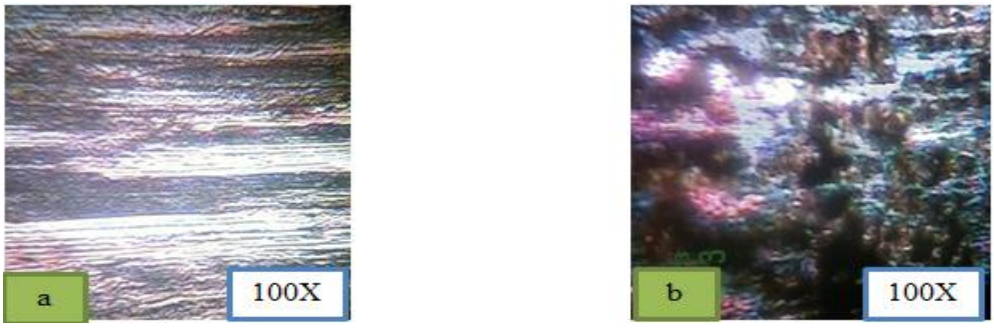


Figure 4 10 (a) Microstructure before Heat Treatment (b) Microstructure after Hardened

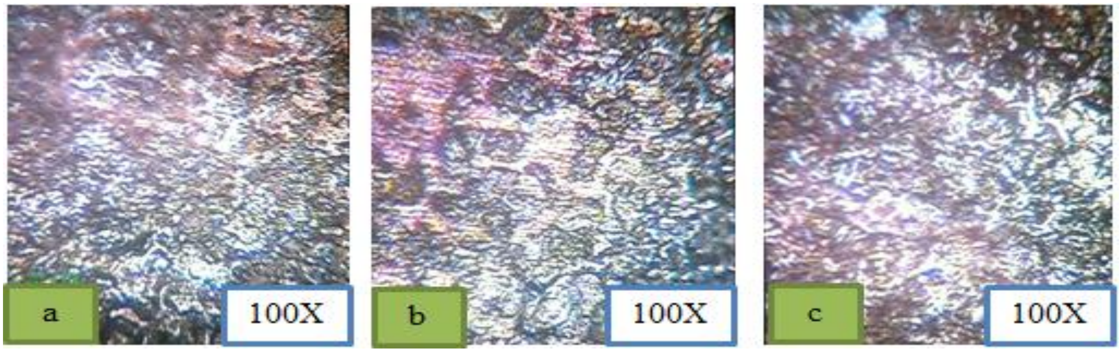


Figure 4-11 Microstructure at 200^0c and (a) at 30min tempering time, (b) at 60min tempering time,(c) at 90min tempering time

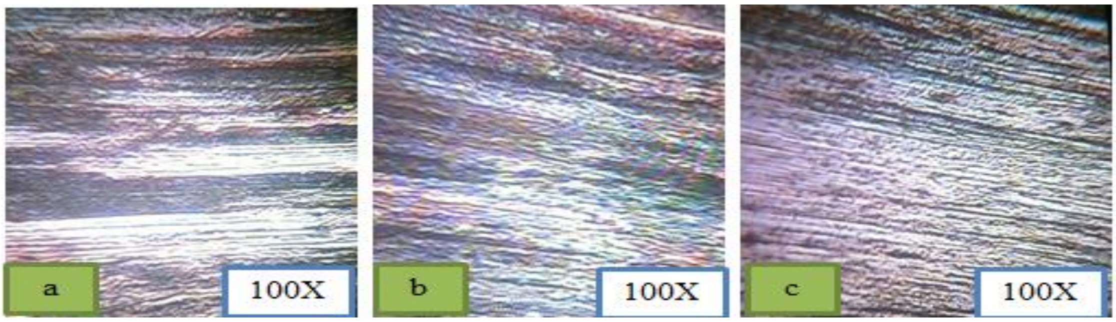


Figure 4-12 Microstructure at 400^0c and (a) at 30min tempering time, (b) at 60min tempering time,(c) at 90min tempering time

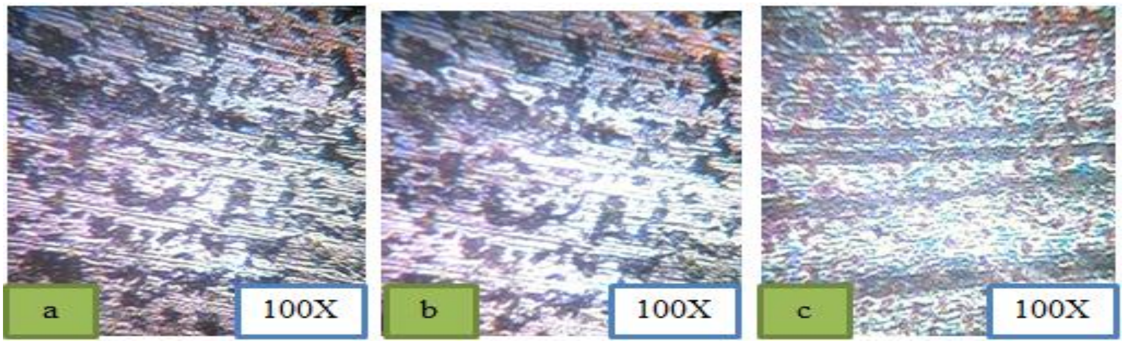


Figure 4-13 Microstructure at 600^0c and (a) at 30min tempering time, (b) at 60min tempering time,(c) at 90min tempering time

4.1.6. Discussion:-

4.1.6.1 Tensile strength and elongation

From table 4.1 the result I got the specimens is tempered at temperature 600^0c the phase transformation takes place from an unstable martensite to a mixture of ferrite and cementite. At this temperature further increase in tempering time and tempering temperature leads to develop sorbet structure, consist of ferrite and finely divided cementite which imparts high ductility and low hardness.

And its maximum value is during 200^0c tempering temperature and 30min tempering time that is 611.16Mpa tensile stress, 9.34% elongation 64HRC and 14.7J its impact and the smallest value from this experiment that I have got, during 600^0c and 90min tempering temperature and time respectively its value is 437.99Mpa tensile stress, 22.66% elongation 30.9HRC and 138.6J its impact

When the specimens are tempered at temperature 400^0c, phase transformation takes place from retained austenite to bainite. Bainitic structure consist of ferrite and epsilon carbide which are formed at temperature ranging between 400^0c−450^0c for each tempering time while maximum elastic properties has been developed during one hour tempering treatment.

When the specimens are tempered at the temperature 200^0c with the increase in tempering time the retained mixed austenite and carbide films that are decomposed from the lath boundary retained austenite are formed. The result that we got from this tempering temperature is increase in tensile strength and it's hardness but the elongation has been decrease.

4.1.6.2 Hardness test result

From table 4.1 the hardness of steel increases rapidly as tempering temperature and tempering time decreases with decreasing in it's elongation, since martensite percentage is increased because it is one of the most common strengthening phases in steel. In general, the micro hardness increases because of the refinement of the primary phases after rapid cooling

It is well known that the water quenching creates a supersaturated solid solution and increase locations with carbon content in quenched specimens. Thus high hardness correlates with high resistance to slip and dislocation.

4.1.6.3 Izoid Impact Test result

When a material is subjected to a sudden intense blow in which the strain rate is extremely rapid, it maybe have in a much more brittle manner than is observed in the tensile test. The Izod Impact test is often used to evaluate the brittleness of a material under these conditions. The test specimen should be notched, because V-notched specimens better measure the resistance of the material to crack propagation. The ability of a material to withstand an impact load is often referred to as the toughness. From table 4.1 the test result I got is as the tempering temperature and tempering time increase, it has better impact load resistance, since it's ductility is increase.

4.1.6.4 Composition test result

The Composition test result that I got from table 4.2 it has a big difference with carbon content before heat treatment we have 0.032%of carbon content after heat treatment this value increased 0.782% due to carburizing process because of this all the mechanical and microstructural property has to be changed.

The reduced of carbon content during testing on the sample carburized, sample T2T3 and sample T3T2 this is happed because of grinding to much the top surface before the sample has been tested.

4.1.6.5 Microstructures result

A study was conducted to evaluate the effect of surface carburization of test sample for the ASTM A36 steel. The metallographic test pieces used in this experiment were the top surface of the sample.

Before observing the microstructures carburized surface were, polished using well-established polishing machine which has different fine polisher surface. The prepared surfaces then etched using a combination of 10% nitric acid and 90% alcohol. Then using 100X magnified microscopic instrument the Preliminary visual examination confirmed the presence of the carburized case where tempered at 600^0c the microstructure consisted of martensite and retained austenite, and tempered at 400^0c from retained austenite to bainite. Bainitic structure consists of ferrite and epsilon carbide. And finally tempered at 200^0c with the increase in tempering time the retained mixed austenite and carbide films were observed.

CHAPTER 5. CONCLUSSION & RECCOMENDATION

5.1. CONCLUSION

1. The results show that the ultimate tensile strength and to some extent the yield strength decrease, whereas the elongation increases with increase in tempering temperature and tempering time.

2. For a given tempering time, the ultimate tensile strength and the yield strength decrease, whereas the elongation and hence the ductility i.e. elongation increases by increasing the tempering temperature.

3. Ultimate tensile strength decreases continuously by increasing tempering temperature and time. The ductility of the specimen is measured by the tensile test. The elongation increases with the increase in tempering temperature and time.

4. The higher is the tempering temperature, the lower is the hardness or the more is softness (ductility) induced in the previously quenched specimen.

5. The longer is the tempering time, the higher is the ductility induced in the specimen as a result of the grain re-arrangement.

Finally from this experiment the mechanical properties of the sample have been improved. Because of increasing the hardness and tensile strength, the weight must be decrease and it has better tempering temperature and tempering time at 400^0c and 30min because of both tensile strength and elongation.

5.2. SUGGESTIONS for the Future Work:-

After studying the Mechanical properties of carburized steel at 900 ^{0}c sample under the different tempering temperature of 200, 400 and 600 ^{0}C and different tempering time 30,60 and 90min. The following works are suggested to be carried out in the future.

1. The similar studies can be made for wear like adhesive wear, erosive wear, corrosive wear etc.
2. The similar studies can be made for other types of carburizing mixture.
3. The similar studies can also be made for other types of mechanical properties like elasticity, plasticity, compressive strength, ductility, brittleness and malleability etc.
4. The similar studies can be performed by changing the carburization temperature.
5. The similar studies can also be made by changing the soak time and the tempering temperature.
6. The similar studies can be performed for the heat treated low carbon steels.
7. The similar studies can also be performed by changing its quenching medium.
8. The similar studies can also be performed for other type of heat treatment process like nitriding, cyaniding, carbonitriding etc.

REFERENCES

1. **P. O. Offor1, C.C. Daniel2, D. O. N. Obikwelu3**," Effects Of Various Quenching Media On The Mechanical Properties Of Inter critically Annealed 0.15Wt%C – 0.43Wt%Mn Steel " Metallurgical and Materials Engineering Department, University of Nigeria, Nsukka
2. **J.K.Odusote,T.K.Ajiboye and A.B.Rabiu**."Evaluation of Mechanical properties of Medium carbon steel, Quenched in water and oil",Apr,2012.
3. **S.Hosseini and M.bagher."**Optimization of Heat Treatment to Obtain Desired Mechanical properties of High Carbon Hadfield steels" IDOSI Publication,2011.
4. **B.A.shaw,C.Aylott,P.O'Hara,and K.Brimble."**The Role of residual stress on the fatigue strength of high Performance Gear".2003.
5. **V.K.Murugan1, Dr.P.Koshy Mathews2** " Effect of Tempering Behavior on Heat Treated Medium Carbon (C 35 Mn 75) Steel" Vol. 2, Issue 4, April 2013.
6. **Ashish Verma,Pravin Kumar Singh."**Influence of Heat Treatment on Mechanical Properties of Aisi 1040 steel".Journal of mechanical and civil Engineering, volume 10,Issue2 Nov-Dec.2013.
7. **Saigeeta Priyadarshini1, Tripurari Sharma2 and Gaurav Arora3**." Effect of Post Carburizing Treatment on Hardness of Low Carbon Steel" ISSN 2250-3234 Volume 4, Number 7 (2014), pp. 763-766 Research India Publications.
8. **Jamiu Kolawole Odusote1, Tajudeen Kolawole Ajiboye2 and Abdulkarim Baba** Rabiu2 "Evaluation of Mechanical Properties of Medium Carbon Steel Quenched in Water and Oil" AU J.T. 15(4): 218-224 (Apr. 2012)
9. **Swapnil R. Nimbhorkar, 1 Prof.B.D.Deshmukh2.**" Effect of Case Hardening Treatment on the Structure and Properties of Automobile Gears" Vol.3, Issue.2, March-April. 2013 pp-637-641.
10. **Jaykant Gupta,** "Mechanical and Wear Properties Of Carburized Mild Steel Samples" May, 2009.
11. **Belete Kefarge Azmite1, *, Adhena Ayaliew Werkneh1, Asmamaw Tegegne Abebe2, Fekadu Gashaw Hone3** " An experimental study on the mechanical characteristics of low alloy carbon steels for better performance of traditional farm implements in Ethiopia" Published online January 19, 2015.

12. **Hazizi Azri Bin Ahmad Sabri,** " Experimental Study Of Pack Carburizing Of Carbon Steel", Bachelor Of Engineering University Malaysia Pahang ,2010.

13. **George Fillari, Thomas Murphy, Igor Gabrielov:**’’ Effect of Case Carburizing on Mechanical Properties And Fatigue Endurance Limits of P/M Steels’’ Hoeganaes Corporation Cinnaminson, NJ 08077 ,Borg Warner Automotive Livonia, MI 48150.

14. **Fatai Olufemi Aramide1,*, Simeon Ademola Ibitoye2, Isiaka Oluwole Oladele1 and Joseph Olatunde Borode1’’** Pack Carburization of Mild Steel, using Pulverized Bone as Carburizer:Optimizing Process Parameters’’ Metallurgical and Materials Engineering Dept., Federal University of Technology PMB 704, Akure, Ondo State, Nigeria. Issue 16, January-June 2010.
15. **ASM Handbook Committee** “Heat Treating” published in 1991 as Volume 4 of the ASM Hand book.
16. **Sanjib Kumar Jaypuria** “Heat Treatment of Low Carbon Steel” (Roll No 10503053) Session : 2008-09.
17. **ASTM A370** : “Standard Test Method and Definitions for Mechanical Testing of steel Products” CFR Section 49 CFR 179 .102-1(a)(1).

APPENDIX

All the samples shown in the same diagram

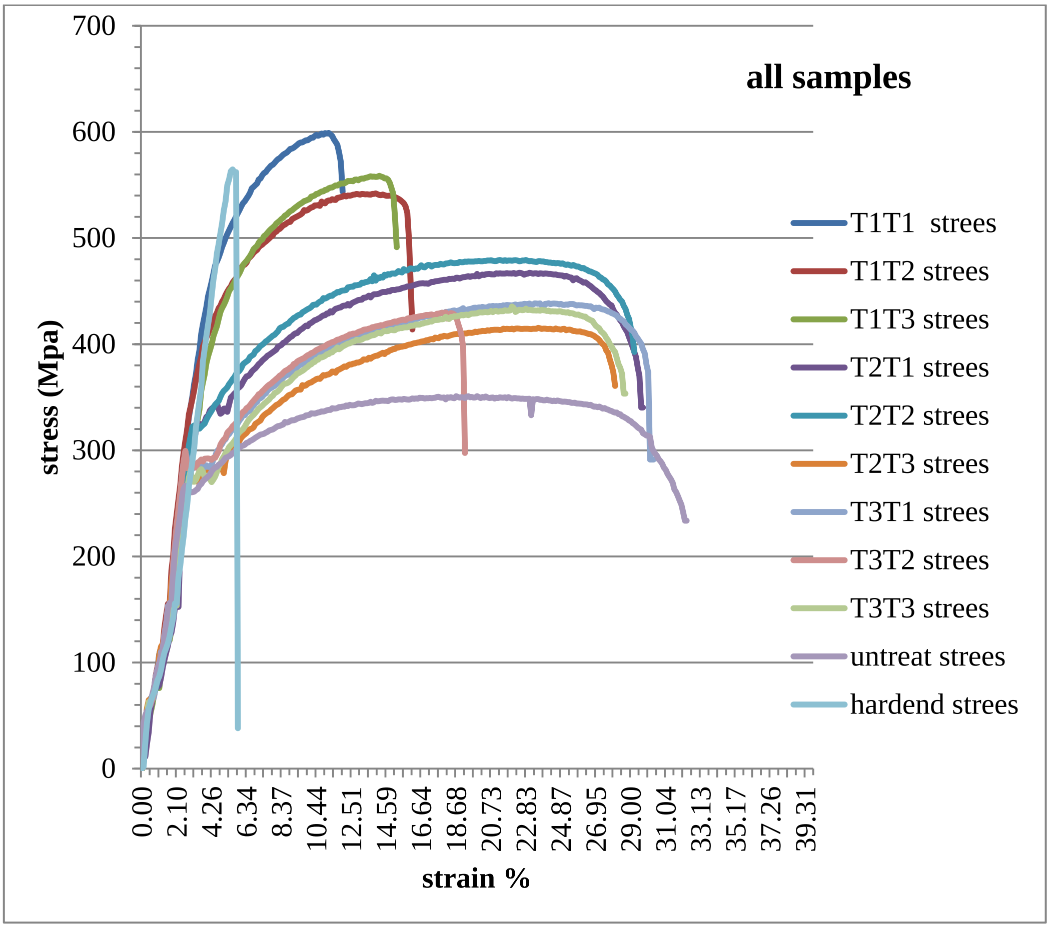


Fig 5.1 all samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. abiyu project untreat

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

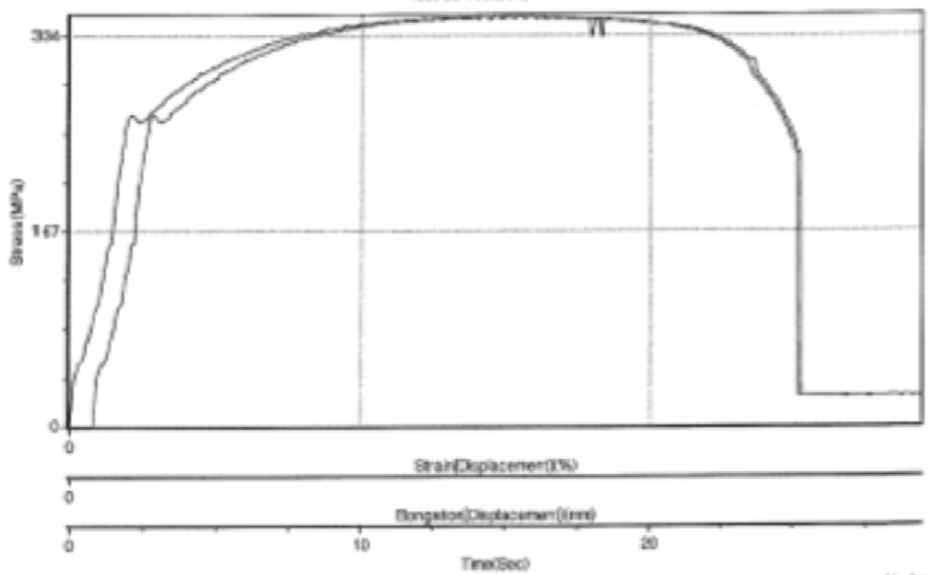
Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	21.94	16.66	16.27	70.00	351.00	266.51	260.37	
2	12.50	5.00	22.37	21.34	21.27	69.00	357.91	341.47	340.25	
3	12.50	5.00	20.90	15.52	14.94	70.30	334.41	248.39	239.02	
Average			21.74	17.84	17.49	69.77	347.77	285.46	279.88	
S.D.			.756	3.084	3.338	.681	12.08	49.35	53.36	
C.V.			3.477	17.29	19.08	.976	3.473	17.29	19.07	

Test Curve(No.:1)



Tester: Proofreader: No.1

Fig 5.2 before treatment samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. abiyu project harden

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-08-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	35.29				564.67			
2	12.50	5.00	36.94				591.09			
3	12.50	5.00	35.15				562.37			
Average			35.79			-	572.71			
S.D.			.998				15.96			
C.V.			2.781				2.787			

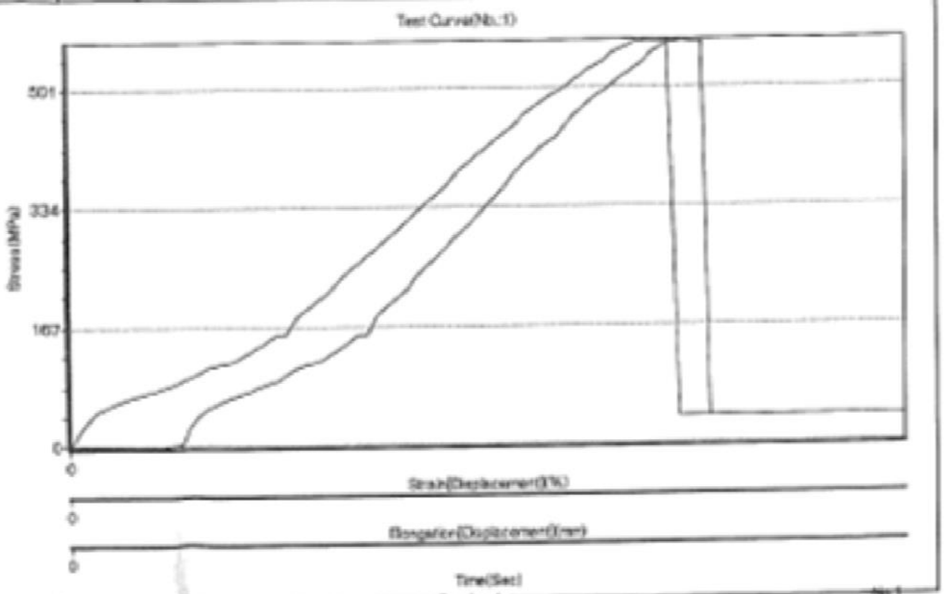


Fig 5.3 hardened samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. abiyu project temper T1T1

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

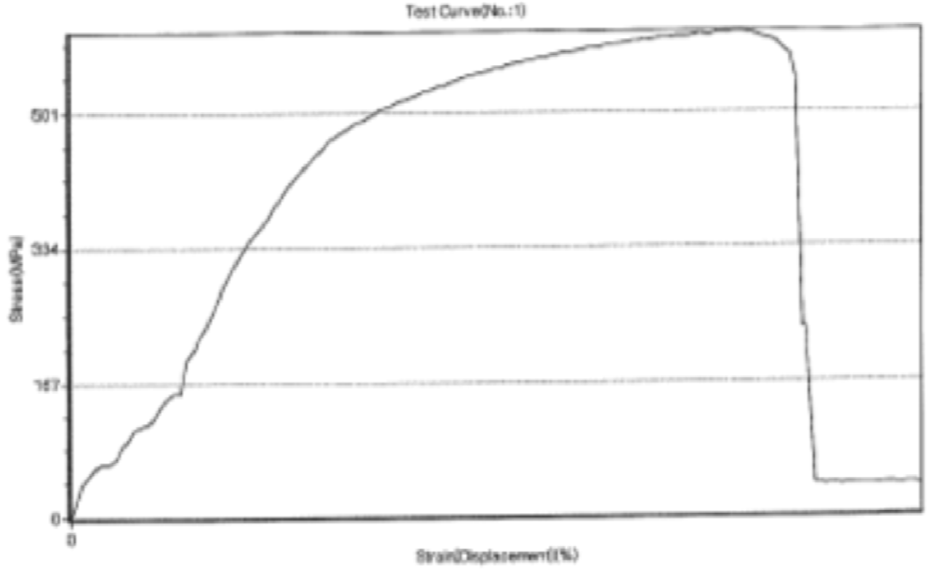
Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	37.44			54.00	599.08			
2	12.50	5.00	37.90			56.00	606.45			
3	12.50	5.00	39.25			54.00	627.96			
Average			38.2			54.67	611.16			
S.D.			.941			1.155	15.01			
C.V.			2.463			2.112	2.455			

Test Curve(No.:1)



Tester: Proofreader: No:1

Fig 5.4 T1T1 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

Report No. ablyu project temper T1T2

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

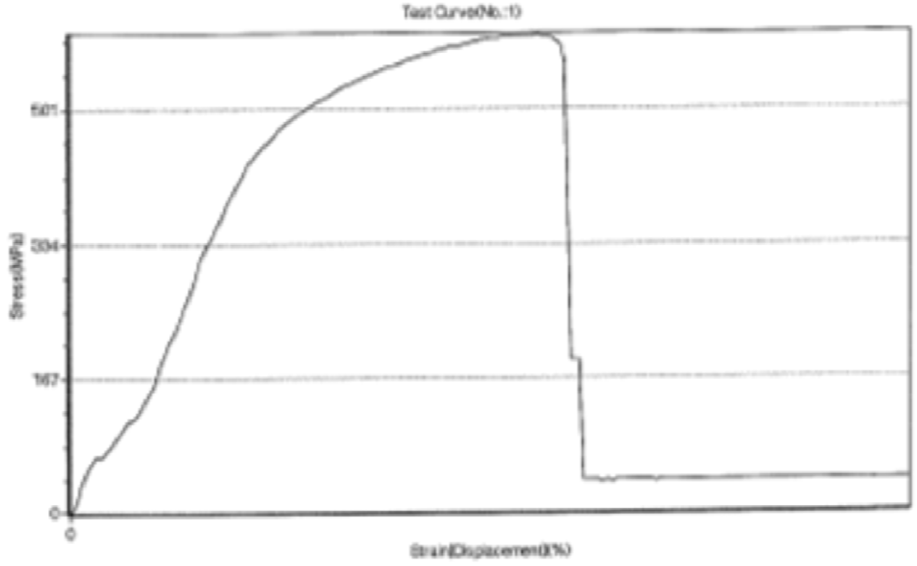
Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	37.11			54.50	593.70			
2	12.50	5.00	33.88			57.30	542.09			
3	12.50	5.00	32.31			57.60	516.90			
Average			34.43			56.47	550.9			
S.D.			2.447			1.71	39.15			
C.V.			7.108			3.028	7.107			

Test Curve(No.:1)



Tester: Proofreader: No:1

Fig 5.5 T1T2 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T₁T₃

Report No. abiyu project temper

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

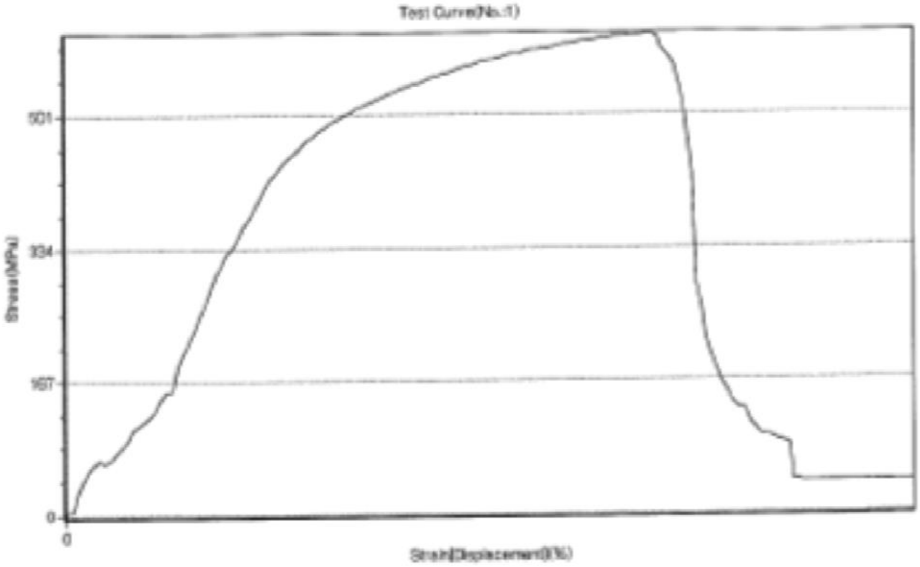
Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	37.56			56.30	600.92			
2	12.50	5.00	34.92			57.00	558.68			
3	12.50	5.00	31.55	21.97	21.08	60.00	504.76	351.46	337.33	
Average			34.68			57.77	554.79			
S.D.			3.012			1.966	48.2			
C.V.			8.687			3.403	8.688			

Test Curve(No.:1)



Tester: Proofreader: No 1

Fig 5.6 T1T3 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T2 T1

Report No. abiyu project tempor

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

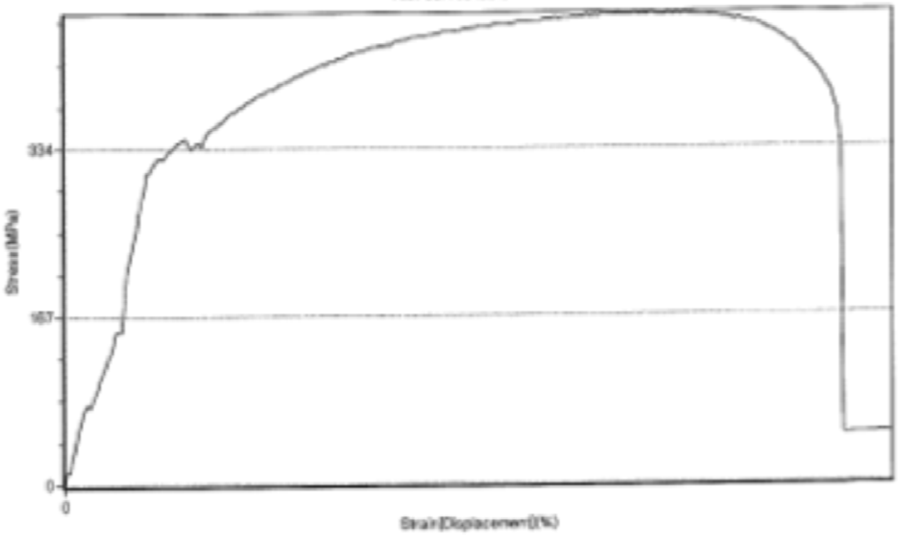
Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	29.21	21.52	21.02	66.60	467.28	344.39	336.25	
2	12.50	5.00	31.39			63.80	502.30			
3	12.50	5.00	28.14			66.30	450.23			
Average			29.58			65.57	473.27			
S.D.			1.656			1.537	26.55			
C.V.			5.599			2.345	5.609			

Test Curve(No.:1)



Tester: Proofreader: No:1

Fig 5.7. T2T1 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T2T2

Raport No. abiyu project temper

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	29.95	20.25	20.03	66.40	479.26	323.96	320.43	
2	12.50	5.00	28.33	18.64	17.88	64.60	453.30	298.31	286.02	
3	12.50	5.00	29.72			64.50	475.58			
Average			29.33	19.45	18.96	65.17	469.38	311.14	303.23	
S.D.			.876	1.138	1.52	1.069	14.05	18.14	24.33	
C.V.			2.988	5.855	8.02	1.641	2.993	5.829	8.024	

Test Curve(No.:1)

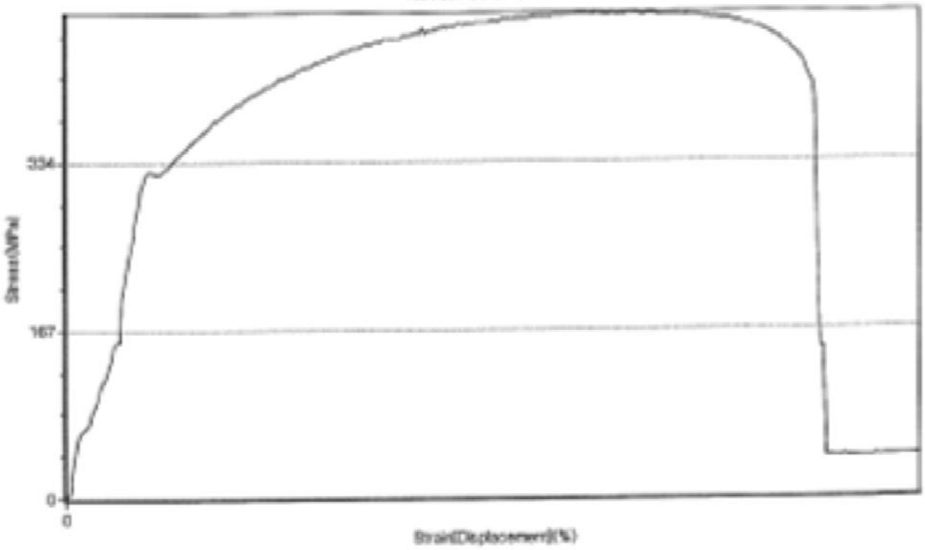


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Fig 5.8. T2T2 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T2 T3

Report No. abiyu project temper

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	25.96	17.12	16.91	64.20	415.36	273.89	270.51	
2	12.50	5.00	29.90	28.40	28.36	66.20	478.34	454.38	453.76	
3	12.50	5.00	27.76	20.64	19.29	67.80	444.09	328.57	308.60	
Average			27.87	22.02	21.52	66.07	445.93	352.28	344.29	
S.D.			1.972	5.784	6.042	1.804	31.53	92.55	96.7	
C.V.			7.076	26.27	28.08	2.73	7.071	26.27	28.09	

Test Curve(No.:1)

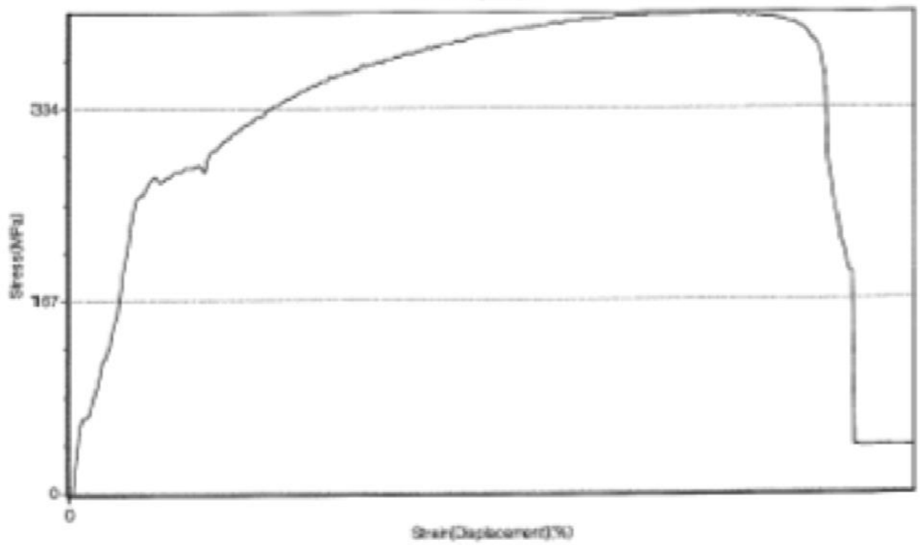

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Fig 5.9. T2T3 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T3 T1

Report No. abiyu project temper

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	27.41	18.64	17.61	66.70	438.56	298.31	281.72	
2	12.50	5.00	27.33	20.84	19.59	68.40	437.33	333.49	313.52	
3	12.50	5.00	28.87	18.18	18.00	65.20	461.90	290.94	288.02	
Average			27.87	19.22	18.4	66.77	445.93	307.58	294.42	
S.D.			.867	1.422	1.049	1.601	13.84	22.74	16.84	
C.V.			3.111	7.397	5.7	2.398	3.105	7.393	5.719	

Test Curve(No.:1)

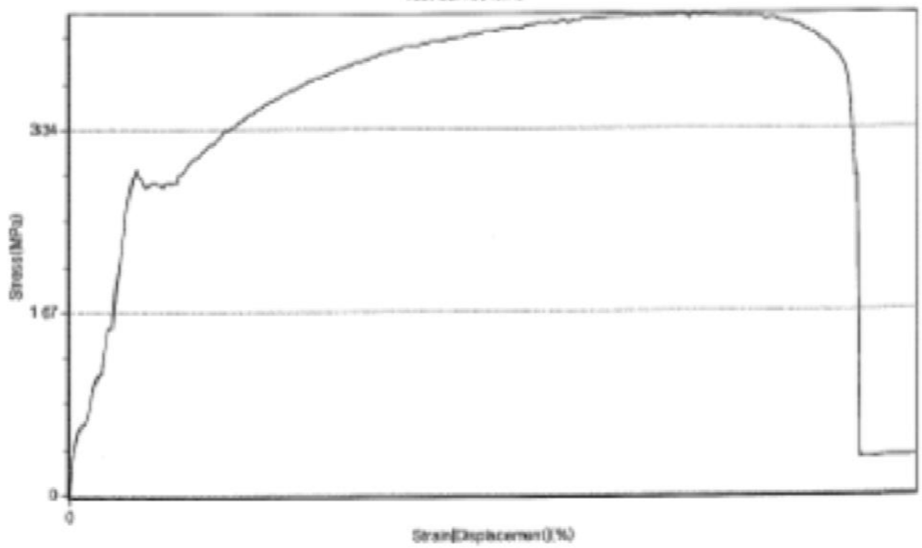

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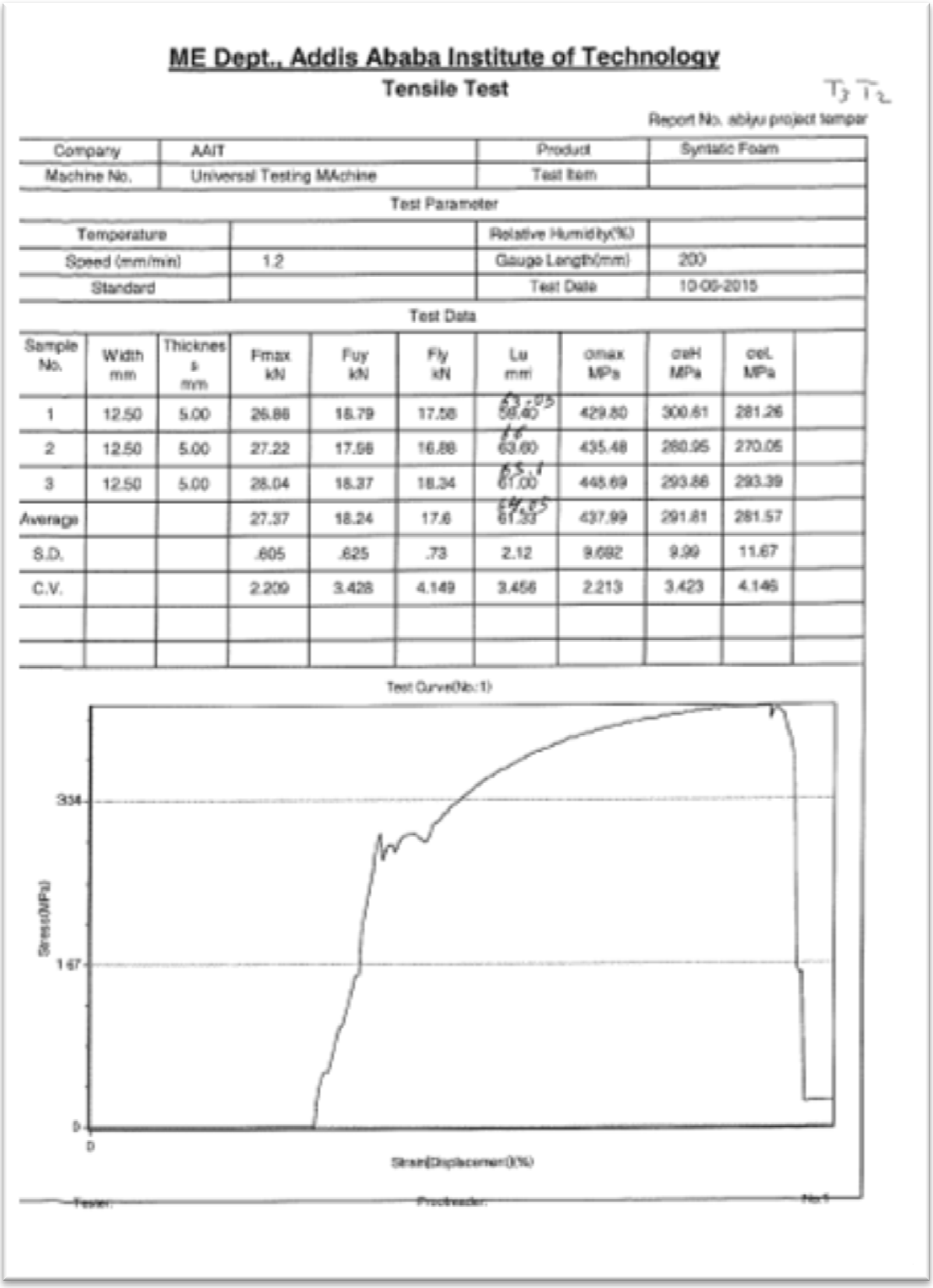
Fig 5.10. T3T1 samples graphs



ME Dept., Addis Ababa Institute of Technology

Tensile Test

T3 T2

Report No. abiyu project tempar

Company	AAIT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σeH MPa	σeL MPa	
1	12.50	5.00	26.86	18.79	17.58	59.40 (63.05)	429.80	300.61	281.26	
2	12.50	5.00	27.22	17.98	16.88	63.60 (66)	435.48	280.95	270.05	
3	12.50	5.00	28.04	18.37	18.34	61.00 (65.1)	448.69	293.88	293.39	
Average			27.37	18.24	17.6	61.33 (64.05)	437.99	291.81	281.57	
S.D.			.605	.625	.73	2.12	9.682	9.99	11.67	
C.V.			2.209	3.428	4.149	3.456	2.213	3.423	4.146	

Test Curve(No.:1)

Tester: Proofreader: No.1

Fig 5.11. T3T2 samples graphs

ME Dept., Addis Ababa Institute of Technology

Tensile Test

T3 T3

Report No. abiyu project temper

Company	AAiT	Product	Syntatic Foam
Machine No.	Universal Testing MAchine	Test Item	

Test Parameter

Temperature		Relative Humidity(%)	
Speed (mm/min)	1.2	Gauge Length(mm)	200
Standard		Test Date	10-06-2015

Test Data

Sample No.	Width mm	Thickness mm	Fmax kN	Fuy kN	Fly kN	Lu mm	σmax MPa	σsH MPa	σeL MPa	
1	12.50	5.00	26.86	18.79	17.58	59.40	429.80	300.61	281.26	
2	12.50	5.00	27.22	17.56	16.88	63.60	435.48	280.95	270.05	
3	12.50	5.00	28.04	18.37	18.34	61.00	448.69	293.86	293.39	
Average			27.37	18.24	17.6	61.33	437.99	291.81	281.57	
S.D.			.605	.625	.73	2.12	9.692	9.99	11.67	
C.V.			2.209	3.428	4.149	3.456	2.213	3.423	4.146	

Test Curve(No.:1)

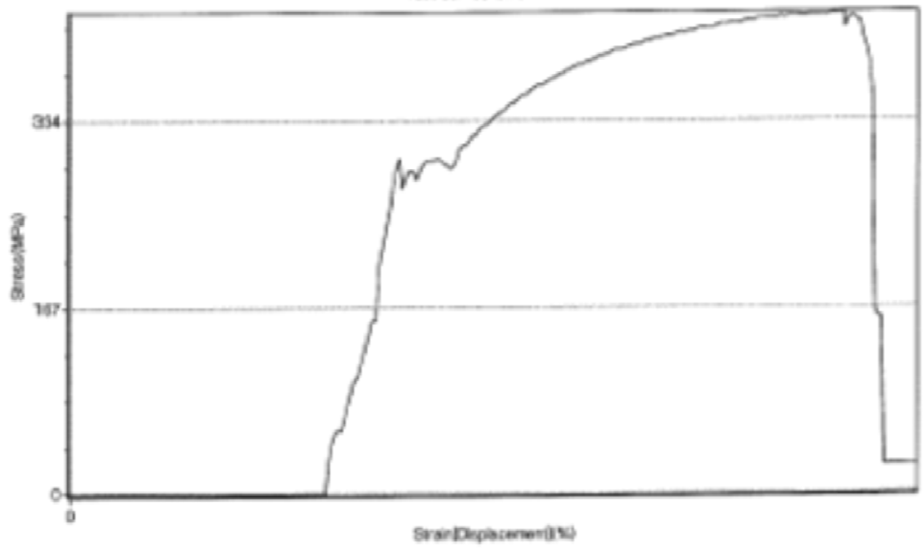


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Fig 5.12. T3T3 samples graphs