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Effect of Different Tempering Temperature and Different Load on Wear Behaviour and Mechanical Properties on Mild Steel

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Abstract — *Heat treatment is process to modify the mechanical, physical and somewhat chemical properties by heating or cooling at desired temperature. Carbon is absorbed in steel with help of coal material according to proper heating and tempering time and temperature in carburizing process. The mild steel specimens are made from standard sample size according to perform different test. The mild steel samples are carburized at 900^{0}C temperature and socking time up to 120 min. Then quenching in oil bath and tempered at different temperature like 200^{0}C, 250^{0}C, 300^{0}C for ninety minutes .These standard specimens perform under different test like 50N, 150N, and 250N load for wear test. Mechanical test performed on their standard dimension and size according to hardness, tensile and toughness test. During this test carburizing process improve the wear, hardness, tensile strength value and compromise in toughness at higher tempering process in mild steel material.*

Keywords- *Carburizing, Tempering, load, Wear test, Hardness test, tensile test, toughness test , carburizing time*

I. INTRODUCTION

Steel is an alloy of iron and carbon elements which containing less than 2% carbon and 1% manganese and small amounts of silicon, phosphorus, sulphur and rest of iron. Steel is the world's most important used material in engineering and construction. It is used in every aspect of our lives; in cars and construction products, refrigerators and washing machines, cargo ships and surgical scalpels [1].Heat treatment is the process of heating and cooling metals to achieve desired physical and somewhat chemical properties through modification of their crystalline structure. The temperature, length of time, and cooling rate are most affecting factors in heat treatment process. The most common reasons to heat treat is improved mechanical properties like increasing strength or hardness, increasing toughness, improving ductility and maximizing corrosion resistance[2].

Carburizing is a process of adding Carbon to the surface by exposing the part to a Carbon rich atmosphere at an elevated temperature and allows diffusion to transfer the Carbon atoms into steel. This diffusion will work only if the steel has low carbon content, because diffusion works on the differential of concentration principle. If steel had high carbon content to begin with, and is heated in a carbon free furnace, such as air, the carbon will tend to diffuse out of the steel resulting in Decarburization.

Pack Carburizing: Parts are packed in a high carbon medium such as carbon powder or cast iron shavings and heated in a furnace for 12 to 72 hours at 900 ºC (1652 ºF). At this temperature CO gas is produced which is a strong reducing agent. The reduction reaction occurs on the surface of the steel releasing Carbon, which is then diffused into the surface due to the high temperature. When enough Carbon is absorbed inside the part (based on experience and theoretical calculations based on diffusion theory), the parts are removed and can be subject to the normal hardening methods. The Carbon on the surface is 0.7% to 1.2% depending on process conditions. The hardness achieved is 60 - 65 RC. The depth of the case ranges from about 0.1 mm (0.004 in) up to 1.5 mm (0.060 in). In some case process is difficult to control the uniform temperature and sufficient heating.

Gas Carburizing: Gas Carburizing is conceptually the same as pack carburizing, except that Carbon Monoxide (CO) gas is supplied to a heated furnace and the reduction reaction of deposition of carbon takes place on the surface of the part. This process overcomes most of the problems of pack carburizing. The temperature diffusion is as good as it can be with a furnace. The only concern is to safely contain the CO gas. A variation of gas carburizing is when alcohol is dripped into the furnace and it volatilizes readily to provide the reducing reaction for the deposition of the carbon.

Liquid Carburizing: The steel parts are immersed in a molten carbon rich bath. In the past, such baths have cyanide (CN) as the main component. However, safety concerns have led to non-toxic baths that achieve the same result. [3]

II. LITERATURE REVIEW

Shristee Singh etal [4] studied the Mechanical and Wear behaviours of mild steels Carburized at 860⁰C temperature at different Soaking time 2 hour, 2 hour 30 minutes and 3 hour. The authors were examine the effects of these different Soaking Time and conditions on the Mechanical and Wear properties of the Carburized mild steels. Due to these experiment the carburization treatment improved the hardness, wear resistance and tensile strength of mild steel and the weight loses due to abrasion, while wear rate increases with the increase in the applied load.

Kalpana Sachan etal [5] studied the effect on wear behaviour of as received and carburized mild steel sample at different load like 75 N , 200 N , and 375 N and at different tempering temperature like 200 °C , 250 °C and 300 °C at carburized at 950 °C . Authors were observed that the sample with heat treatment improves the hardness, tensile strength and wear resistance of mild steel.

Jaykant Gupta [6] studied the mechanical and wear behaviours of mild steels carburized at different temperature range of 850, 900 and 950^{0}C have been studied that the simple heat treatment greatly improves the hardness, tensile strength and wear resistance of the mild steels. Author was observed that the mild steels carburized at the temperature of 950^{0}C gives the best results for the different kinds of mechanical and wear properties because it gives highest tensile strength, hardness and wear resistance for the required applications.

Sunil Patidar etal [7] studied the effect of various wear environments like 20% soil & 80% sand and 40% soil & 60% sand on as received and carburized mild steel sample at different load like 75N, 200N & 375N and at different tempering temperature like 200ºC, 250ºC & 300ºC and carburized at 950ºC. Authors observed that the sample with heat treatment improves the hardness, tensile strength and wear resistance of mild steel.

N.A. Astunkar etal [8] studied the carburizing process and its effect on wear properties at various types alloy steels. Carburizing is one of the processes of hardening on surface and sufficient toughness at the core according to the application.

Rashmi Ranjan Panda etal [9] studied that the mild steels carburized under different temperatures (850^{0}C, 900^{0}C and 950^{0}C) out of which the mild steels carburized at the temperature of 950^{0}C gives the better results for the different kinds of mechanical and wear properties like highest tensile strength, hardness and wear resistance.

Hesham Elzanaty [10] studied that the mild steels were carburized at temperature range of 850 to 950^{0}C and then it is tempered at 200^{0}C for thirty minutes after that it subjected for different kind of tests such as hardness, tensile and toughness. The authors were observed that carburization greatly improves the mechanical properties like hardness and tensile strength 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.

P. Tamil Arasu etal [11] studied that the heat treatment on En 353 steel is improved the ductility, toughness, strength, hardness and relive internal stress in the material. The authors were used the X-ray diffraction (XRD) method for analyze the composition and the phase of the alloy material.

Fatai Olufemi Aramide etal [12] studied that the the effects of the carburizing temperature and time on the mechanical properties of mild steel carburized with activated carbon, at 850, 900 and 950 °C, soaked at the carburizing temperature for 15 and 30 minutes, quenched in oil, tempered at 550 °C and held for 60 minutes. The authors were observed that the optimum combination of mechanical properties is achieved at the carburizing temperature of 900 °C soaked for 30 minutes followed by oil quenching and tempering at 550^{0}C for 60 minutes.

A.Oyetunji etal [13] have using palm kernel shell, animal bone (mammalian bones from cattle) and sea shell (oyster shell) materials as carburizers for case hardening of 0.078%C mild steel. The carburizing temperatures varied between 700 - 1100^{0}C while the holding time varied between 1-5 hrs and cool down to room temperature in the furnace after carburization.Authors were observed that the hardness values of the untendered samples are superior to the tempered ones at carburizing temperatures of 700^{0}C, 800^{0}C and 900^{0}C. On the other hand, the tensile strengths of the tempered samples are higher relative to the untempered samples at carburizing temperatures of 700^{0}C, 1000^{0}C and 1100^{0}C.

III. EXPERIMETAL DETAILS

1 **CHEMICAL COMPOSITION OF THE SPECIMEN (MILD STEEL):** The chemical composition of mild steel which is 0.199 (approx 0.2) % carbon compositions is shown as under.

Table 1. Chemical composition of the mild steel sample

Element	C	Si	S	P	Mn	Ni	Cr	Mo	V
Avg content	0.1999	0.1548	0.0594	0.0459	0.5826	0.131	0.1105	0.016	0.0013
Element	W	As	Sn	Co	Al	Cu	Ca	Zn	Fe
Avg content	0.0076	0.0051	0.0377	0.0098	0.0028	0.384	0.0001	0.0048	98.2476

2 Preparation of specimens:

The specimens were made for analysis of different mechanical and wear properties like abrasive wear, toughness, tensile strength and hardness were prepared as per standard

2.1 Specimen for abrasive wear and hardness test:

The abrasive wear and hardness test is determined from the standard specimen (80mm x 25mm x 6mm).

2.2 Specimen for toughness test:

A toughness test specimen dimensions are as under.
Length – 55 mm
Width – 10 mm
Thickness – 5mm
Notch depth – 0.4 mm

2.3 Specimen for tensile strength test:-

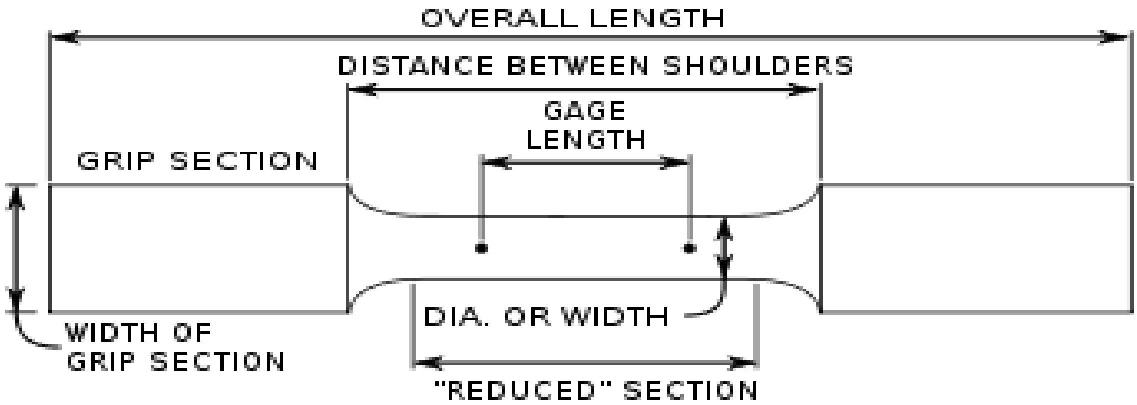

Fig 1 Specimen for tensile strength test

(Source:http://www.google.co.in/imgres?imgurl=https://upload.wikimedia.org/wikipedia/commons/thumb/8/8d/Tensile_specimen_nomenclature.svg/350px-)

Overall length=165mm
Distance between shoulders=120mm
Gauge length=55mm
Width of grip section =24mm
Reduction section length=63mm
Width=16mm

3 COAL PREPARATION:

Coal is used for the pack carburization of mild steel specimens, so it taken from local market for this purpose and crushed into smaller size with the help of crusher. Coal is checked by different method like moisture, volatile, ash and carbon content determination.

4 CARBURIZATION PROCESS

The mild steel samples for carburization process were cut from raw materials and measured according to their dimension. These specimen samples washed in acetone and dried and coated with clay to prevent the CO from escaping and prevent unwanted furnace gas from entering the steel pot during heating. In pack carburization process mild steel specimen samples put in stainless steel box. In stainless steel box, first make 30 mm thick layer of coal, charcoal and ash of compound then specimens and last thick layer of chosen compound then sealed to the box air tight and eliminate possibility of air ingress during pack carburization process in muffle furnace.

The furnace temperature was adjusted to the required temperature range and charged into the furnace. When the furnace temperature reaches the required carburizing temperature like 900 °C, then soaked for 120 minutes. After that, the steel box was removed from the furnace and the material was quenched in oil (which was initially at the ambient atmospheric temperature).The hardness of all the samples has been done using a Vickers hardness testing machine. Ten hardness readings are taken at different location to circumvent the possible effects of particle segregation. The impact tests were performed on various sample determine the impact strengths by using the Impact Testing Machine. Tensile properties of the alloys were analyzed by carrying out test on the universal testing machine. The test specimen for analysis of different mechanical properties (tensile strength, toughness and hardness test results) was prepared as per standards. [14]

5 TEMPERING OF CARBURIZED MILD STEEL SAMPLES:

After the carburization process, the steel is often harder than needed and is too brittle for most practical uses. Also generate severe internal stresses are set up during the rapid cooling from the hardening temperature [15]. To relieve the internal stresses and reduce brittleness, tempering process is done. In this tempering process the carburized steel samples were heated at the different temperature 200°C, 250°Cand 300°C for duration of 2 hours and then cooling it usually in the still air [16].

6 ABRASIVE TEST:

Abrasive wear occurs when hard surface or angular particles slide or impact against a softer surface. A soft material has more wear rate than compare to hard material. It depends upon particle size, hardness, distribution, velocity, surface hardness etc. It can find from below equation.

Wear Resistance = 1 / Wear Rate
Wear Rate = Wear Volume / Sliding Distance(s)
Sliding Distance (s) = (2 π R N / 60) x time
Where, R = radius of Abrasive Wheel (150mm)
N = R.P.M (300)
Π = 3.14 (constant)
Time=5min=300sec
Wear Volume = weight loss / density
Density of specimen = 7.85 g /cm3

7 TENSILE TEST:

A tensile test is the simplest, inexpensive, and standardized type of mechanical testing method for finding its strength and elongate [17]. During testing the material breaks or permanently deforms and dependent on the preparation of the specimen of the test environment and material [18]. It is a destructive test process that provides information about the tensile strength, yield strength and ductility of a material. In this methods top and bottom grips or left and right grips attached to the tensile or universal testing machine at one end if fixed and another is moving and it moved apart at a constant rate to stretch the specimen and proportional to check the load and plotted graph like stress-strain curve until failure occurs. After it check the final length and compare it to original length and to obtain the elongation. Also compare original cross section to the final cross section and to obtain reduction in area [19]. By measuring the force required to elongate a specimen to breaking point, material properties can be determined that will allow designers to predict how materials and products will behave in their intended applications. Tensile testing provides quality product, addition in design and production process, maintaining production, safety of materials, standards and reduction of costing [17, 18, 19].

8 .Hardness Test:

Hardness is a defined as the resistance to indentation and determined by measuring the permanent depth of the indentation by applying load [20]. It is also defined as the ability of a material to resist plastic deformation. The term may also refer to stiffness or temper or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied [21].

There are three types of tests used with accuracy by the metals industry like the Brinell hardness test, the Rockwell hardness test, and the Vickers hardness test. The hardness tests measure the metal's resistance to the penetration of a non-deformable ball or cone into metal under given load with specific time duration in to depth. The followings are the most common hardness test methods used in today`s technology [20, 21].

9.Rockwell hardness test method: The Rockwell test is generally easier to perform, more accurate than other types of hardness testing methods and used on all metals, except in condition where the test metal structure or surface conditions would introduce too much variations; where the indentations would be too large for the application; or where the sample size or sample shape prohibits its use. First, a preliminary test force or minor load is applied to a sample using a diamond indenter and this load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load and held for a predetermined amount of time (dwell time) to allow for recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number.

Test Method Illustration

A = Depth reached by indenter after application of preload (minor load)
B = Position of indenter during major load
C = Final position reached by indenter after elastic recovery of sample material
D = Distance measurement taken representing difference between preload and major load position

10 IMPACT TEST:

Impact toughness is the ability of a weld to permanently deform and absorb energy before fracturing when stress are rapidly .it's how much rapid impact energy a weld can take before it cracks[22] by striking two objects each other at high relative speeds. Impact resistance is suitability of a designated material for product liability and safety point of view. Impact Testing most commonly consists of Charpy and IZOD Specimen configurations [23].

A charpy impact test entails striking notched specimens with a swinging weight or pendulum at a series of temperatures to show the relationship of ductile to brittle transition in absorbed energy in specimens with standard size at specified temperature [24] and amount of energy measured in indicator. A brittle metal will absorb a small amount of energy when impact tested, a tough ductile metal a large amount of energy. The Charpy specimen may be used with one of three different types of notch, a 'keyhole', a 'U' and a 'V'. The keyhole and U-notch are used for the testing of brittle materials such as cast iron and for the testing of plastics. The V-notch specimen is the specimen of choice for weld testing and is the one discussed here [25].

IV. RESULT AND DISCUSSION:

The specimens of mild steel samples were carburized and different tempering temperature (200˚C, 250˚C, 300˚C) under the different load condition (50N, 150N, 250N) and then various kinds of test perform like abrasive wear test, tensile strength test, toughness test and hardness test. The results of all tests were shown below the table.

Table 2: Result of abrasive wear test for carburized mild steel, at load 50N

Carburization Data		Tempering Data		Weight loss ,g	Wear rate m^3 /m	Wear resistance m/m^3
Temperature (˚C)	Soak Time (min.)	Temperature (˚C)	Soak Time (min.)			
As received sample				0.912	0.000001690	589343.91
900 ˚C	120	200 ˚C	90	0.239	0.000000444	2248877.19
900 ˚C	120	250 ˚C	90	0.165	0.000000307	3257464.54
900 ˚C	120	300 ˚C	90	0.102	0.000000189	5269427.94

Table 3: Result of abrasive wear test for carburized mild steel, at load 150N

Carburization Data		Tempering Data		Weight loss ,g	Wear rate m^3 /m	Wear resistance m/m^3
Temperature (˚C)	Soak Time (min.)	Temperature (˚C)	Soak Time (min.)			
As received sample				3.812	0.0000044632	224052.42
900 ˚C	120	200 ˚C	90	1.23	0.0000014401	694380.36
900 ˚C	120	250 ˚C	90	0.852	0.0000009976	1002450.52
900 ˚C	120	300 ˚C	90	0.213	0.0000002494	4009802.11

Table 4: Result of abrasive wear test for carburized mild steel, at load 250N

Carburization Data		Tempering Data		Weight loss ,g	Wear rate m^3/m	Wear resistance m/m^3
Temperature (˚C)	Soak Time (min.)	Temperature (˚C)	Soak Time (min.)			
As received sample				5.321	0.0000062300	160512.66
900 ˚C	120	200 ˚C	90	2.13	0.0000024939	400980.21
900 ˚C	120	250 ˚C	90	1.562	0.0000018289	546791.20
900 ˚C	120	300 ˚C	90	0.789	0.0000009238	1082494.11

Table 5: Rockwell hardness of carburized mild steel at load 150 Kg

Carburization condition		Temperature condition		Hardness (Rc)
Temperature (˚C)	Soak Time (Hrs)	Temperature (˚C)	Soak Time (Hrs)	
As received sample				-------
900 ˚C	120	200 ˚C	90	29
900 ˚C	120	250 ˚C	90	34
900 ˚C	120	300 ˚C	90	44

Table 6: Tensile strength of carburized mild steel tempered at different temperature

Carburization condition		Temperature condition		Tensile strength (mpa)
Temperature (˚C)	Soak Time (Hrs)	Temperature (˚C)	Soak Time (Hrs)	
As received sample				404
900 ˚C	120	200 ˚C	90	493
900 ˚C	120	250 ˚C	90	543
900 ˚C	120	300 ˚C	90	597

Table 7: Toughness test of carburized mild steel tempered at different temperature

Carburization condition		Temperature condition		Toughness Joule(Nm)
Temperature (˚C)	Soak Time (Hrs)	Temperature (˚C)	Soak Time (Hrs)	

As received sample				59.32
900 ˚C	120	200 ˚C	90	38.23
900 ˚C	120	250 ˚C	90	32.76
900 ˚C	120	300 ˚C	90	29.60

The different kind of mild steel samples were carburized at 900^0 C, tempered for the soaking time and different temperature then tested for various kinds of test like abrasive wear test, tensile test, and hardness test.

1. The abrasion test was performed on carburized and un carburized mild steel material under three different loads (50 N, 150 N and 250 N). After the test, the weight loss is highest for the load of 250 N and it is lowest for the load of 50 N during the abrasion. The load increases proportionally the weight loss during abrasion is also increases.

2. During the abrasion test, Un carburized specimens of mild steel had highest weight loss and wear rate compare to carburized specimens of mild steel at 250 N load. Wear resistance was highest in carburized specimens of mild steel at tempering temperature at 300^0C compare to others like carburized specimens of mild steel at tempering temperature at 200^0C and 250^0C as well as un carburized specimens of mild steel. If the load was increase proportionally weight loss and wear loss increase in Wear test.

3. The hardness value of mild steel specimens was lowest at 200^0C tempering temperature and highest in 300^0C tempering temperature at carburized specimen in Rockwell hardness testing machine. The hardness value of un carburized mild steel was very low compare to carburized steel (at different tempering temperature) of mild steel specimen in Rockwell hardness testing machine.

4. The tensile value of mild steel is lowest value in un carburized specimen compare to carburized specimens at different tempering temperature. The tensile strength value of mild steel specimens was lowest at 200^0C tempering temperature and highest in 300^0C tempering temperature at carburized specimen in Tensile testing machine.

5. The toughness value of mild steel is highest value in un carburized specimen compare to carburized specimens at different tempering temperature. The toughness value of mild steel specimens was lowest at 300^0C tempering temperature and highest in 200^0C tempering temperature at carburized specimen in charpy impact test machine.

V. CONCLUSION:

From the above experiments concluded that:

- The wear volume and wear rate was depends upon carburizing process and load. The wear volume and wear rate was highest in received sample and proportionally decrease in carburizing process at tempering temperature from 200^0C, 250^0C and 300^0C.If load is increase proportionally the wear volume and wear rate increase. The highest value of wear volume and wear rate was at 250N load on sample specimen. The highest value of wear resistance was at 250N load on tempering temperature 300^0C in carburizing process.
- The hardness and tensile strength value was increases with proportional to increase in the tempering temperature of carburized mild steel sample.
- The toughness value was decrease with proportional to increase in the tempering temperature of carburized mild steel sample.

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