Effect of Carburizing and Normalizing on Mechanical Properties and Machinability of AISI 1018 Low Carbon Steel

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ABSTRACT: The carburization and heat treatment have been recognized by some means of improving the several properties of metals and alloys. The existence of low carbon steel, 80% of all metals formed in the most important engineering and construction material. In the present experimental study undergone to the carburization treatment used wood charcoal as the carburizer, carburized at 860 °C, 900 °C, 940 °C, carburizing temperature followed by quenched with water then tempered at 200 °C for half an hour and another normalizing heat treatment at 910 °C, temperature for followed by air cooling at room temperature. Subsequently, this the carburized and normalized low carbon steels are applied for numerous kind of mechanical test such as hardness test, tensile test, toughness test and the machinability test. From the experimental data obtained, tensile strength, Rockwell hardness, impact toughness, and machinability rate were calculated. The mechanical and machinability test results are compared before and after carburization and normalization treatment process in sequence to perceive the effect of pack carburization with rare carburizing temperatures and normalization on the performance (life cycle) of the manufacturing, engineering applications and metal fabrication implements. Test data was analyzed and experimentally found that the mechanical properties and machinability rate of low carbon steel samples to be profoundly influenced by the process of carburization and normalization. It was concluded that the low carbon steel samples at the temperature of 940 °C give the excellent test results for the diverse kinds of mechanical properties because at this temperature it demonstrates the most superior tensile strength, hardness whereas the low carbon steel at normalization temperature of 910 °C gives best results for toughness and machinability rate in comparing to carburization temperatures.

KEYWORDS: Carburization, Mechanical test, Machinability rate, Normalization, Engineering applications, etc.

1 INTRODUCTION

Low carbon steel, presence the most important engineering and construction material details for about 80% of all metals produced. This grade of importance is achieved by the steel because it combines strength, ease of fabricability and machinability into many shapes, and a broad range of properties along with reasonable cost. Carburizing as work remain concerned heat treatment of low carbon steel is an experimental task which for the most part achieves carburizing process. Carburizing present the accumulation of carbon to the surface of low carbon steels at temperatures
regularly between 850 °C and 950 °C, at which austenite, with its additional solubility for carbon. Carburizing, additionally referred to as case hardening, is a heat treatment process that delivers a surface which is resistant to wear, while keeping up durability and quality of the center. Carburizing steels for case hardening frequently have base carbon contents of about 0.2%, with the carbon content of the carburized layer commonly actuality controlled at between 0.8 and 1% C. Carburizing is one of the furthermost extensively used surface hardening processes. The custom process typically includes diffusing of carbon into a low carbon steel alloy to a high carbon steel surface. Carburizing steel attend extensively practice as a material of automobiles, agro implements, machines, gears, springs and high strength wires, etc. which are required to have the excellent strength, toughness, hardness and machinability, etc. because these parts are generally subjected to high load, impact and machining. Normalizing heat treatment, the material is heated to the austenitic temperature range and this is followed by air cooling at room temperature. This treatment is usually carried out to acquire a mainly pearlite, which results into strength and hardness greater than in as received condition. Normalized steels improves their mechanical properties and machinability particularly their strength. The failure of engineering materials is undesirable for several reasons, which include loss of human lives, injuries, economic losses and interference with availability of products and services. Through mechanical testing, causes of failure and behavior of materials may be identified, prevention of failure. Material testing is measurement of the properties and behavior of materials such as metals, ceramics, or plastics under various conditions. Materials testing classify into five key categories: mechanical testing, testing for thermal properties testing for electrical properties, testing for resistance to corrosion, radiation, and biological deterioration and non destructive testing. Such national and international bodies have established standard test methods as the American Society for Testing and Materials (ASTM), Philadelphia. And the International Organization for Standardization (ISO), Geneva.

1.1 AISI 1018 Low Carbon Steel

In this study AISI 1018 Low carbon Steel has been designated due to its importance in industry. AISI 1018 low carbon steel has excellent weldability, machinability and produces a uniform and harder case and it is considered as the mildest steel for carburized parts. AISI 1018 mild/low carbon steel deals a favourable balance of toughness, strength and ductility. Provided with more significant mechanical properties, AISI 1018 hot rolled steel additionally includes improved machining characteristics and mechanical properties. Low carbon steel comprise the most conventional form of steel as it provides material properties that are acceptable for many engineering applications. It is neither brittle nor ductile justified to its lower carbon content. It has more limited tensile strength and malleability. As the carbon content increases, the metal becomes harder and stronger but decreases ductile. In steel designation of AISI 1018, the first two digits shows it is a nickel, chromium, alloy steel and last two digits shows the percentage of carbon, that is 0.18 %.

1.2 Case Hardening

These methods is practised for steels with a low carbon content. Carbon is included to the exterior surface of the steel, to a depth of approximately 0.03 mm. This hardening process includes an extensive variety of methods is used to improve the mechanical properties and optimization machinability of parts without affecting the softer, tough interior of the part. Further, the surface hardening of steels has a lead over through hardening because less precious low carbon and medium carbon steels can be surface hardened without the complications of distortion and cracking related with the through hardening of thick sections. One benefit of this technique of hardening steel is that the inner core is left untouched and so still processes properties such as flexibility and is still relatively soft.
1.3 Carburization

Carburization is directly defined as the addition of carbon to the surface of low carbon steel at temperature generally between 850-950 °C. Carburization is the most extensively used process of surface hardening. Carburizing process is a metal treatment process that includes carbon to the surface of metal that has a low carbon content to increase the hardness of the metal. The metal is heated at a raised temperature in atmosphere of carbon. The heat will source carbon atoms to diffuse into the metal outer surface. The method is implemented lower the melting point of the metal being carburized. Carburizing process is one of the most usually performed steel heat treatments. For perhaps three thousand years it was performed by packing the low carbon wrought iron parts in charcoal, then raising the temperature of the pack to red heat for several hours. The whole pack, charcoal and all, was then dumped into water to quench it. The surface developed significantly hard, while the inner or “core” of the part retained the toughness of low carbon steel.

1.3.1 Solid or Pack Carburization

Solid or pack carburizing the process remain the process of addition carbon element (C) into the metal, particularly on the surface of the material, so that increasing the hardness number metal surface. The carbon element is acquired from materials containing carbon like that wood charcoal. Metal surface hardening can be done by totaling specific elements to the base metal such as carbon, calcium carbonate, nitrogen, and others. To rapidity the process then added barium carbonate (BaCO₃) calcium carbonate (CaCO₃) or sodium carbonate (NaCO₃) as energizers. The charcoal, energizer and specimen are put into the carburizing box then heated in the electric furnace. On pack carburizing usage of charcoal mixed with 10-40% CaCO₃, NaCO₃ or BaCO₃ steel is combined into this mixture, placed in a carburizing box and then heated at 850-950 °C.

The residual air in the box combines with carbon to produce carbon monoxide gas (CO) is unstable at the process temperature and thus decomposes upon contacting the iron surface by reaction.

\[ 2\text{CO} = \text{C} + \text{CO}_2 \]

The atomic carbon pass in the steel through the following reaction.

\[ \text{Fe} + 2\text{CO} = \text{Fe(C)} + \text{CO}_2 \]

The C element formed in the form of carbon atom, which actively arrives diffuses into the austenite phase of the steel. With the energizer the process will be steadier because even the air trapped in the box is very small, but the energizer delivers the CO that will instantly begin activating the next reactions. The decomposition reaction of CaCO₃:

\[ \text{CaCO}_3 = \text{CaO} + \text{CO}_2 \]

Depth of carburizing (thick carburization) is the under-surface distance that ranges the total thickness of carbon penetration. As with any other diffusion process, this carburization thickness depends on the temperature and time.

1.4 Tempering

Tempering consists of heating the steel to a specific temperature (below its hardening temperature), holding it at that temperature for the required length of time, and then cooling it, usually instill air. After the hardening treatment is implemented, steel is often harder than desired and is too brittle for utmost practical usages. In addition, severe internal stresses are developed during the rapid cooling from the hardening temperature. To relieve the internal stresses and reduce brittleness, tempering is needed for the steel after it is hardened. The
consequential strength, hardness, and ductility depend on the temperature to which the steel is heated during the tempering process. Considerably, reducing brittleness, tempering softens the steel. Tempering is always piloted at temperatures below the low-critical point of the steel. Typically, the rate of cooling from the tempering temperature has no effect on the steel. Steel parts are generally cooled in still air after being removed from the tempering furnace. Tempering remain the process of conveying toughness at the cost of its hardness to an already hardened piece of steel by reheating it to a definite temperature and then cooling it rapidly. The temperature of heating depends on the toughness to be conveyed and hardness to be reduced.

1.5 Normalizing

Heating a ferrous alloy to a temperature over the transformation range and then cooling in air to a temperature under the transformation range. The process of air cooling at room temperature of the specimen is addressed normalizing process. Normalizing reports both hardness and strength to iron and steel components. In addition, normalizing supports reduce internal stresses induced by such processes as forging, casting, machining, forming or welding. Normalizing also improves microstructural regularity and response to heat treatment (e.g., annealing or hardening) and enhances stability by imparting a thermal memory for following lower temperature processes. Parts that need maximum toughness and those subjected to impact are often normalized. When extensive cross sections are normalized, they are also tempered to further decrease stress and supplementary closely control mechanical properties.

1.6 Mechanical properties

Strength, hardness, toughness, elasticity, plasticity, brittleness, ductility and malleability are mechanical properties applied as measurements of how metals behave under a load. These properties are defined in terms of the types of force or stress that the metal essential withstand and how these are resisted.

1.7 Machinability

Machinability is defined as the easiness with which a material can be machined to intended geometry and purpose at a suitable cost. The machinability often considered as the work piece material property, however, the ease of machining also depends on other aspects such as rigidity of the cutting tool. Good machinability correlated to removal of material with moderate forces, good surface finish, intenser amount of chip, good chip formation and with the minimum tool wear. Machinability can be defined as ability to undesirable deterioration of a component by removal of material from the work piece surface in required dimension with minimum cost, low power consumption and high production rate. The tool wear, surface roughness and cutting temperature and other effecting characteristics on machinability. The change in work piece properties and cutting parameters represent break off the machinability by variations in characteristics as mentioned prior. The most machinable metal is one which certifies the removal of material with satisfactory finish at lowest cost. The machinability of the steel, determined by standard drilling tests (which are typical in industry labs), is a function of microstructure, which is determined, by the state in which the steel is received and/or heat treatment prior to carburizing.

1.8 Machinability Rating (MR)

A kind of machinability tests has been established, regularly to assess specific cutting environments, while others are employed for more general machining assessment. Machinability data is expressed in the form of a single index such as a “standard” material being ranked as 100% with others having values relative to it. The ratings can be dependent on the type of test as well such as the drilling test. Here the tests have index values on a 100 “scale” In general a machinability test assess the speeds and lapse time which are varied by trial and error and with specified constraints. These experiments
consider only the MR index, which is based on the amount (volume) of material removed under constant cutting forces, and may therefore be directly proportional to power consumption during machining. Other features such as tool life, surface finish and/or developed edge formation should be evaluated for specific machining operations.

1.9 Objectives of Present Work

The present work aims to improve the machinability characteristics and mechanical properties of low carbon steel by using wood charcoal as a carburizer and developing an economically feasible, less energy consuming carburization technique and normalizing condition. Moreover, the present work is applicable for the engineering implements like material of automobiles, machines, gears, springs, high strength wires and metal fabrication, etc. The following investigation were pointed to be carried out:

1. Carburization of low carbon steel samples at different temperatures and under various conditions using economically feasible carburization techniques.
2. Tempering of these carburized low carbon steel samples at a specific temperature for a particular period of time.
3. Normalization of low carbon steel samples at specific temperature for the particular period of soak time.
4. Determination of mechanical properties like hardness, tensile strength and toughness of these carburized and normalized low carbon steel samples.
5. Study of machinability characteristics of these low carbon steel samples.
6. Analysis of the results obtained.
7. Made conclusions from investigation results.

2. LITERATURE REVIEW

A lot of investigators have worked on mechanical properties and machinability characteristics on iron and steel component under different circumstances to evaluate its importance in various fields. Some of them are mentioned at the end:

Verdeja et al. [2] studied the machinability improvement through heat treatment in 8620 low-carbon alloyed steel and concluded that drill tests may be used to analyze and determine machinability of heat treated low alloyed steels. Also, the drilling test demonstrates to be an efficient process to evaluate machinability, especially in those cases where production requires rough machining. A very good selection of high quality drills is indispensable to obtain good statistical results, and applicable data for industry, where better machinability is needed to reduce production costs. Treatments at temperatures higher than 650 °C maintain or improve machinability of the 8620 steel compared to the as-received cold drawn state.

The results of an experimental investigation demonstrated by Adetunji et al. [4] on effect of normalizing and hardening on mechanical properties of spring and reported that the normalized spring had more strength, was harder and was much tougher than as received springs. The water quenched springs were the hardest of all the heat treated springs, were very brittle and had the lowest percentage elongation. Their strength was also lower than that of the normalized and as received springs. The tempered water quenched springs had better mechanical properties required for spring making, they had the optimum combination of hardness, strength and toughness when compared with the other heat treated springs.

Elzany et al. [8] on his study of effect of carburization on the mechanical properties of the mild steel concluded that the results of the process of 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. The mild steels carburized at the temperature of 950 °C gives the best results for the mechanical properties because at this temperature it gives the highest tensile strength and hardness, so it must be preferred for the required applications.

Tanwer et al. [12] experimentally found the effect of various heat treatment processes on mechanical properties of mild steel and stainless steel. The research pointed out that Tensile strength, yield strength and elongation have best results in normalized heat treated mild steel specimen than all other specimens of mild steel and stainless steel. Without heat treated stainless steel specimen shows better results for Tensile strength and yield strength than heat treated stainless steel specimens. In Testing of without heat treated specimens of mild steel and stainless steel, Tensile strength and yield strength are more and elongation is less for stainless steel than mild steel specimen. In stainless steel specimens, Annealing heat treatment gives better results than other heat treatment process. In mild steel specimens, normalizing heat treatment gives better results than other heat treatment process.

Akanji et al. [14] on his work examines the influence of particle size and soaking time on surface hardness of carburized AISI 1018 steel and reported that from results significant increase in the carburization rate of low carbon steel by the addition of seashell to charcoal. The 100% charcoal samples had lowest hardness values than the energized samples. The optimal carburizing effect was achieved at 90% charcoal and 10% seashell for 212 μm particle size at 8 hrs. soaking time when quenched with water. It implies hardness increases with decreasing particle size. It indicates the best condition under which sea shell should be used as an energizer for the carburization of mild steel.

Jha et al. [20] studied on investigation of micro-structure and mechanical properties of three steel alloys. The analysis of the result was conducted based on the variation and effect of the chemical composition of the alloying elements added to the steel on the mechanical behaviour. The experimental result showed that EN 8 steel had the highest ultimate tensile strength of 882 N/mm² followed by the mild steel of 666 N/mm² and carbon steel has the lowest value 420 N/mm². The tensile and impact strengths and hardness of carbon steel, EN 8 steel, and mild steel were evaluated and compared based on the chemical composition and macrostructural observation.

Supriyono [23] studied on the effects of pack carburizing using charcoal on properties of mild steel and findings the carburizing process using charcoal of unused wood changes the properties of the mild steel. The changes in this research represented by the changes of microstructure, hardness and tensile strength. The microstructure of the carburized mild steel can be divided into two zones i.e., case zone and core zone. The case zone consists of hypereutectoid, eutectoid, and hypoeutectoid sub-zone. The core zone is the same as raw material. The longer the holding time will result in the deeper the case zone and the stronger the material.

3. MATERIALS AND METHODS

3.1 Material Selection

The material selected for this research work is AISI 1018 low carbon steel. Flat and square bar type low carbon steel samples of the required dimensions were purchased from Shri Krishna Industries and Lakshmi Metals, Urla Industrial Area, Raipur, Chhattisgarh, India. The chemical composition of low carbon steel by (Wt %) is given as C-0.18, Si-0.04, Mn-0.4, P-0.03, S-0.05, Ni-0.08, Cr-0.06, Cu-0.02 and Fe.
3.2 Preparation of Test Specimens
The test specimen for analysis of different mechanical properties and machinability characteristics were prepared as per ASTM standard and its description is given below:

3.2.1 Specimen for Machinability and Hardness Test
The machinability rate and hardness is determined from the same specimen as per ASTM E18-17. A standard specimen of dimensions (81 mm x 35 mm x 9 mm) of low carbon steel is prepared for the same purpose.

Fig. 3.1 Specimen for machinability and hardness test

3.2.2 Specimen for toughness test
A toughness test specimen as per ASTM E23-07a standard is prepared for the same purpose acquiring the following dimensions. Length-55 mm, Width-10 mm, Thickness-10 mm, Notch depth-2 mm.

Fig. 3.2 Specimen for toughness test

3.2.3 Specimen for Tensile Strength Test
A tensile test specimen as per ASTM E8-13a standard is prepared for this purpose is based on the following equation,

\[ L_o = 5.65\sqrt{A_o} \]

Where, \( L_o \) = Gauge Length, \( A_o \) = Cross sectional area

Fig. 3.3 Specimen for tensile strength test
3.3 Coal Selection and Preparation
Locally available wood charcoal was selected due to its low cost and easy availability in the country. About 6 kg of wood charcoal was purchased from the Abdul Enterprises, Lucknow. It is crushed with help of crusher into -30 mesh size test sieve and test sample is prepared. This wood charcoal is employed for the pack carburization of low carbon steel samples as carburizer.

![Fig. 3.4 Prepared wood charcoal for pack carburization](image)

3.3.1 Proximate Analysis of Coal
Analysis for moisture, volatile matter, ash and fixed carbon contents in coal were carried out on samples ground to pass through -30 mesh U.S. test sieve by the method given below.

3.3.2 Moisture Determination
One gram of air dried coal powdered sample of size -30 mesh was taken in a borosil glass crucible and then kept in the air oven maintained at the temperature 110°C. The sample was soaked at this temperature for one hour and then put out from the furnace and cooled. Weight loss was recorded using an electronic balance machine. The weight loss in percentage gave the percentage moisture content in the sample.

3.3.3 Volatile Matter Determination
One gram of air dried coal powdered sample of size -30 mesh was taken in a volatile matter crucible (made of silica) and kept in the muffle furnace maintained at the required temperature of 925°C. The sample was soaked at this temperature for seven minutes and then crucible was taken out from the furnace and cooled in air. Weight loss in the sample was recorded by using an electronic balance. The weight loss percentage in moisture present in the sample gave the volatile matter content in the sample.

3.3.4 Ash Determination
One gram of air dried powdered sample of size -30 mesh was taken in a shallow silica disc and kept in the muffle furnace maintained at the temperature of 775-800 °C. The sample was brought forwarded in the furnace till complete burning. Weight of ash made was noted down and the percentage ash content in the sample was determined.

3.3.5 Fixed Carbon Determination
The fixed carbon content in the sample was calculated by using the following formula:

Fixed Carbon Content (Wt. %) =100 – Wt. % (Moistness +Volatile matter + Ash)
3.4 Carburization Process of Low Carbon Steel Samples
The different test specimen samples made up of low carbon steel for mechanical properties and
machinability characteristics testing were subjected to pack carburization treatment. In this process
the low carbon steel samples were placed on the thick bed of carburizer kept in a stainless steel
container and fully covered from all sides, the top of the container was tightly sealed with clay cover
to prevent the carbon from escaping and unwanted furnace gases from entering the steel box during
heating. The specimens were placed in a stainless steel box and arranged at least 3 mm distance
among the specimens. The stainless steel container was then introduced into the muffle furnace and
then maintained at the different required carburization temperatures of 860, 900 and 940 °C with the
soak time of 2 hours by this way the low carbon steel samples gets carburized and then they were
quenched in water i.e., the hardening was achieved instantly after carburization.

3.5 Tempering Process of Carburized Low Carbon Steel Samples
After the carburization process, the steel is often harder than required and is much brittle for most
practical procedures. Furthermore, severe internal stresses are produced during the speedy cooling
from the hardening temperature. To relieve the internal stresses and decrease brittleness, we should
temper the steel after it is hardened. So in this tempering process the carburized steel samples were
heated at the temperature of 200 °C for duration of 0.5 hour and then cooling it usually in the serene
air. The carburized and tempered low carbon steel specimens are then subjected to various kind of
mechanical and machinability tests.

3.6 Normalizing Heat Treatment Process of Low Carbon Steel Samples
At the distinct beginning the specimen was heated to the temperature of 910 °C. There the specimen
was reserved for 2 hours. Then the muffle furnace was switched off and the specimen removed from
the furnace taken out. Promptly the specimen is allowed to cool in the traditional environment i.e.,
the specimen is air cooled to room temperature. Meanwhile another set of the sample specimens
which were not heat treated were taken directly for the mechanical and machinability test to serve as
control samples.

Fig 3.5 Muffle furnace for carburizing and normalizing process

3.7 Hardness Test
Rockwell hardness testing is a wide-ranging technique for determining the bulk hardness of metallic
and polymer materials. Hardness testing is widely used for material calculation due to its easiness
and low cost relative to direct measurement of various properties. This testing method comprises 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 10 kg. When equilibrium has been
established, an indicating device, which follows the travels of the indenter and accordingly responds
to changes in depth of penetration of the indenter, is set to a datum position. While the preliminary minor load is still placed an additional major load is applied with subsequent increase in penetration. When equilibrium has once more been reached, the additional major load is removed but the preliminary minor load is still sustained. Removal of the additional major load permits a partial recovery, so decreasing the depth of penetration. The constant increase in depth of penetration, subsequent from the application and removal of the additional major load is used to calculate the Rockwell hardness number. In present experimental work the hardness was measured on carburized and normalized low carbon steel samples which are carburized under different temperature range of 860, 900, 940 °C and normalized at temperature of 910 °C measured by means of Rockwell hardness tester. For each of the sample, test was conducted for five times and the average of all the samples was considered as the observed values in each event. The procedure accomplish in determining the Rockwell testing can be listed as follows:

1. First, the diamond indenter was introduced in the machine, and the load is adjusted to 150 kg.
2. The minor load of a 10 kg was first applied to surface of the specimen.
3. Then the major load applied and the depth of indentation is automatically recorded on a dial gauge in terms of arbitrary hardness numbers.

![Fig. 3.6 Rockwell hardness testing machine](image)

3.8 Tensile Test

The tensile strength is measured by the tensile test which is carried out on a Justy JUTM-20 machine. This involves the preparation of a test specimen as per ASTM standard as shown in fig. 3.7 and this test specimen is based on following relation. At this place the key parameters are the gauge length \(L_0\) and the cross sectional area \(A_0\) then a uniformly increasing load is applied on the specimen. As the load increases the specimen primarily gets elastically elongated. On additional elongation, the specimen starts necking at some points when the material goes beyond the elastic range. The reduced width of the specimen would further be reduced under the force of the load and ultimately grows fractures when the test is completed. It can be experimental that there is a limit up to which the applied stress is directly proportional to the prompted strain, the end of this linear portion is the yield point of the material above which the material gets starts plastically deforming and when the force applied load goes beyond the limit that can allowed by the material, the specimen breaks. The maximum stress gets hold of in a material before the fracture is termed as the ultimate tensile strength. In present experiment the tensile test was carried out on carburized and normalized low carbon steel samples which are treated under different temperature range of 860, 900, 940 °C and 910 °C the following condition were taken during the tensile test in Justy JUTM-20 machine. Following dimensions parameters of specimen for tensile test:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>6 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>6 mm</td>
</tr>
<tr>
<td>Gauge length</td>
<td>25 mm</td>
</tr>
<tr>
<td>Grip distance</td>
<td>100 mm</td>
</tr>
</tbody>
</table>
3.9 Toughness (Charpy Impact) Test

The test is conducted for the three diverse samples carburized under the three numerous temperatures of 860, 900, 940 °C and normalized under temperature of 910 °C. The test consists of measuring the energy absorbed in breaking a ASTM standard V-notched specimen by striking a single blow by swinging hammer. The specimen is placed as simply supported at both ends. As the velocity of striking hammer is changed, there must happen a transfer of energy, work is done on the parts receiving the shock. The mechanics of impact comprise not only the question of stresses tempted, but also a concern of energy transfer and of energy absorption and dissipation. The capacity of material to absorbed energy and distort plastically before fracture is called “toughness”. It is typically measured by the energy absorbed in a notched impact test like charpy or izod tests. In present work for each of the sample, test was conducted for three times and the average of all the samples was taken as the observed values in each case.

3.10 Machinability test by drilling

The materials considered for this experiment is carburized low carbon steel samples which are carburized under different temperature range of 860, 900, 940 °C and a normalized low carbon steel sample under normalizing temperature at 910 °C, which dimensions have 81 mm x 35.0 mm x 9 mm. The test was conducted on a machine assembled bench drilling machine ASTM as shown in fig. The heat treated samples were prepared by grinding, polishing finishing with various series of emery paper as per ASTM standard. The sample was mounted on a standard stationary bench. In order to determine the Machinability Rate (MR) index in different steel samples, controlled drilling tests were performed using a standard bench drill specially prepared for the test. The results were based on the amount of material removed during drilling. The tests were performed using HSS twist 9 mm diameter drills operating a new drill (as-received) for each sample to be measured, and always using drills from the similar supplier in order to maintain the test repeatability. These
experiments consider only the MR index, which is based on the amount of material removed under constant cutting forces, and may therefore be directly proportional to power consumption during machining. Other features such as tool life, surface finish and/or developed edge formation should be evaluated for precise machining operations. In this experiment the test can be directed with the following parameters: (1) Cutting speed (2) Spindle Speed (3) Time

In the present experimental work spindle speed, cutting speed, feed rate kept constant and drill bit used same. Parameters that remained constant during all the experiments are provided in table:

Table 3.1 Parameter taken constant in machinability test

<table>
<thead>
<tr>
<th>Speed of drill spindle (RPM)</th>
<th>1040</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting speed (m/min)</td>
<td>29</td>
</tr>
<tr>
<td>Lapse (sec)</td>
<td>20</td>
</tr>
<tr>
<td>Drill bit type</td>
<td>Twist</td>
</tr>
</tbody>
</table>

The machinability of each sample was calculated from the amount of chip is determined by weighing the specimen chip amount before and after the carburizing and normalizing conditions by drill test using precession electronic weighing machine.

![Fig. 3.9 Pillar drilling machine for machinability test](image)

4. EXPERIMENTAL RESULTS

4.1 Results of proximate analysis of coal

The results of proximate analysis of coal is performed to find out the percentage (Wt %) of moisture, volatile matter, ash and carbon content in the given coal sample. From the analysis we found that coal content 75% of carbon, 5% of moisture, 15% of volatile matter and 5% of ash.

4.2 Results of mechanical properties

The tests results of different mechanical properties like tensile strength, toughness and hardness under the different carburization temperature of 860, 900, 940 °C and a specific normalization temperature of 910 °C are shown in Table 4.1 to 4.3
4.2.1 Rockwell hardness test results for carburized and normalized low carbon steel samples

Fig. 4.1 Experimented carburized and normalized steel samples by hardness test

Table 4.1 Results of Rockwell hardness of carburized and normalized samples, at load 150 kg

<table>
<thead>
<tr>
<th>Carburization condition</th>
<th>Tempering condition</th>
<th>Hardness (HRC)</th>
<th>Normalization condition</th>
<th>Hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
</tr>
<tr>
<td>As-received</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>As-received</td>
</tr>
<tr>
<td>860</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>910</td>
</tr>
<tr>
<td>900</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>940</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>-</td>
</tr>
</tbody>
</table>

4.2.2 Tensile test results for carburized and normalized low carbon steel samples

Fig. 4.2 Experimented carburized and normalized steel samples by tensile test
Table 4.2 Results of tensile strength of carburized and normalized samples

<table>
<thead>
<tr>
<th>Carburization condition</th>
<th>Tempering condition</th>
<th>Tensile Strength (MPa)</th>
<th>Normalization condition</th>
<th>Tensile Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
</tr>
<tr>
<td>As-received</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>As-received</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>488</td>
<td></td>
</tr>
<tr>
<td>860</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>1800</td>
</tr>
<tr>
<td>900</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>1888</td>
</tr>
<tr>
<td>940</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>2000</td>
</tr>
</tbody>
</table>

4.2.3 Toughness (Charpy impact) test results for carburized and normalized low carbon steel samples

Table 4.3 Results of toughness of carburized and normalized samples

<table>
<thead>
<tr>
<th>Carburization condition</th>
<th>Tempering condition</th>
<th>Toughness (Joules)</th>
<th>Normalization condition</th>
<th>Toughness (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
<td>Soak time (hrs.)</td>
<td>Temp. (°C)</td>
</tr>
<tr>
<td>As-received</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>52</td>
<td>As-received</td>
</tr>
<tr>
<td>860</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>35</td>
</tr>
<tr>
<td>900</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>31</td>
</tr>
<tr>
<td>940</td>
<td>2</td>
<td>200</td>
<td>0.5</td>
<td>29</td>
</tr>
</tbody>
</table>
4.3 Results of machinability test by drilling

The total amount of material removed was considered and compared to the amount extracted in the as-received sample, for which a 100% machinability rate was assigned. For each carburization and normalization temperature described. At least two times of samples were drilled to confirm the results. The test result of machinability characteristics like machinability rate under the carburization temperature 860 °C, 900 °C, 940 °C and normalization temperature 910 °C of low carbon steels samples. In general carburization and normalization of low carbon steels results of machinability test for lapse 20 secs, spindle speed 1040 RPM and cutting speed 29 m/min is recorded in Table 4.4

![Fig. 4.4 Experimented carburized and normalized steel samples by machinability test](image)

Table 4.4 Result of machinability test result of carburized and normalized samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tempering condition</th>
<th>Amount of chip (g)</th>
<th>Machinability rate (%)</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp. (°C)</td>
<td>Soak time (hr.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As-received</td>
<td>-</td>
<td>-</td>
<td>22.46</td>
<td>100</td>
</tr>
<tr>
<td>Carburized at 860 °C</td>
<td>200</td>
<td>0.5</td>
<td>14.73</td>
<td>65.58</td>
</tr>
<tr>
<td>Carburized at 900 °C</td>
<td>200</td>
<td>0.5</td>
<td>10.24</td>
<td>45.59</td>
</tr>
<tr>
<td>Carburized at 940 °C</td>
<td>200</td>
<td>0.5</td>
<td>3.94</td>
<td>17.58</td>
</tr>
<tr>
<td>Normalized at 910 °C</td>
<td>-</td>
<td>-</td>
<td>18.37</td>
<td>81.78</td>
</tr>
</tbody>
</table>
**Fig. 4.5** Effect of temperature on hardness of steel samples

**Fig. 4.6** Effect of temperature on tensile strength of steel samples

**Fig. 4.7** Effect of temperature on toughness of steel samples
Fig. 4.8 Effect of temperature on amount of chip of steel samples

Fig. 4.9 Effect of temperature on machinability rate of steel samples
Fig. 4.10 Effect of hardness on the amount of chip of steel samples

Fig. 4.11 Effect of hardness on machinability rate of steel samples
Fig. 4.12 Variation of tensile strength with hardness of steel samples

5. CONCLUSION

Literature gap investigation and industrial study conduction are found to represent beneficial approach for selection of low carbon steel grade which will be more useful for industrial opinion. After performing all the operations, following conclusions were made:

- The mechanical properties and machinability characteristics of low carbon steels were found to be strongly influenced by the process of carburization and normalization temperature.
- The carburization treatment followed by the water quenching appreciably improved the hardness, and tensile strength of low carbon steels.
- The carburization process decreases the toughness of the low carbon steels. Concluded that toughness decreases with increasing in the carburization temperature.
- Normalizing heat treatment at followed by air cooling at room temperature increases the toughness and machinability characteristics while decreases tensile strength and hardness in compare to carburization process.
- The amount loss of chip due to machining, machinability rate increases with the increase in amount of chip.
- Hardness, and tensile strength increasing with increase in the carburization temperature while machinability rate and toughness decreases.
- Machinability rate and toughness escalations on normalization temperature.
- Finally the net conclusion is that the low carbon steel carburized under the different temperature range of 860 °C, 900 °C, and 940 °C. The low carbon steels carburized at the temperature of 940 °C shows the best combination of higher hardness, higher tensile strength and normalized temperature 910 °C shows highest machinability rate and toughness.
REFERENCES


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