# A Review on Carburizing temperature and the mechanical behaviour of mild steel

**Zeeshan Hyder Wani[1], Er. Neeraj Kumar[2]**
[1,] *PG SCHOLAR,DEPARTMENT OF MECHANICAL ENGINEERING, R N COLLEGE OF ENGINEERING & TECHNOLOGY, MADLAUDA, PANIPAT*
[2,] *ASSISTANT PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, R N COLLEGE OF ENGINEERING & TECHNOLOGY, MADLAUDA, PANIPAT*
Email id :- wanizeez787@gmnail.com

**Abstract**

*This paper investigates the impact of carburizing temperature on the mechanical behaviour of mild steel. Carburization is a heat treatment process in which steel or iron absorbs carbon when the metal is heated in the presence of a carbon containing material, such as charcoal or carbon monoxide. The heat treatment and carburization increase the mechanical and wear resistance. This process involves 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 in its stable crystal structure. This paper attempts to review the works related to the impact of carburizing temperature on the mechanical behaviour of mild steel. The objective of the study is to analyze the effect of cutting speed, feed rate and depth of cut on the surface roughness and the cutting forces generated during the turning operation. The investigation on the mechanical and wear properties of iron and steel component under different condition have been made by a number of workers. Most of these investigations had been made on analysis of wear properties a very few studies were made including both the mechanical and wear properties under the same parameters and conditions.*

***Keywords:****-carburization, heat treatment, cutting forces, investigation*

## 1. Introduction

Carburization of steel involves heat treatment of soft metallic surface using a source of carbon. Carburization is used to increase the surface hardness of low carbon steel, thus making outer surface hard and more resistant to wear and tear. In past carburization was done by application of charcoal around the sample to be treated (then referred to as case hardening), but modern techniques use carbon-containing gases or plasmas (such as carbon dioxide , carbon monoxide or methane). The process depends primarily upon surrounding gas composition and temperature of the furnace, which must be carefully controlled, as the heat may also impact the microstructure of the remainder of the material.

Use of plasma in carburization is nowadays increasingly being used to improve the surface characteristics such as wear, corrosion resistance, hardness, load-bearing capacity etc of various metals, like stainless steels. In comparison to gaseous or solid carburizing, this process is environmentally friendly. It also provides an even treatment of components with complex geometry as plasma can penetrate into holes and gaps, making it very flexible in terms of component treatment. Carburization works via the diffusion of carbon atoms into the surface layers of a metal. As metals are made up of atoms bound tightly into a metallic lattice, the carbon atoms diffuse into the crystal structure of the metal and at lower temperatures remain in solution dissolved within the metal crystalline matrix and at higher temperatures, due to the higher mobility of the metal atoms react with elements in the host metal to form carbides. If the carbon remains in solid solution, the steel is then heat treated to harden it. Both of these mechanisms strengthen the surface of the metal, the former by forming pearlite or martensite, and the latter via the formation of carbides. Both of these materials are hard and are resistant to abrasion.

### *A. Types of carburization processes*

Carburizing is normally the addition of carbon at the surface of low carbon steels at appropriate temperatures. There is not just one type of carburization process available. But, generally, there are four different methods of carburization that are used, each different process offers its own advantages and disadvantages.

• **Solid or pack carburization:** Pack carburization involves placing steel articles into a furnace in close proximity to high-carbon items which may include carbon powder, cast iron particles, charcoal and barium carbonate as catalyst. After these items are inserted, they are heated with carbon monoxide. The article to be carburized is placed in a carburizing box and surrounded by solid carbonaceous material after which, the boxes are sealed with clay to exclude air and are placed in an oven or furnace where they are heated to a temperature between 900-950°C for several days depending upon the desired extent of carburizing action desired. In this way, carbon from the carburizing compound diffuses into the surface of the hot- steel. After carburizing, steel is reheated to a temperature just above the critical point followed by quenching in water, brine or oil. The case depth is around 0.1 – 1.5 mm.

The residual air in the box combines with carbon to produce carbon monoxide gas. Carbon monoxide gas is unstable at the process temperature and thus decomposes on contact with the iron surface by reaction.

$$2CO = C + CO2$$

The atomic carbon enters the steel

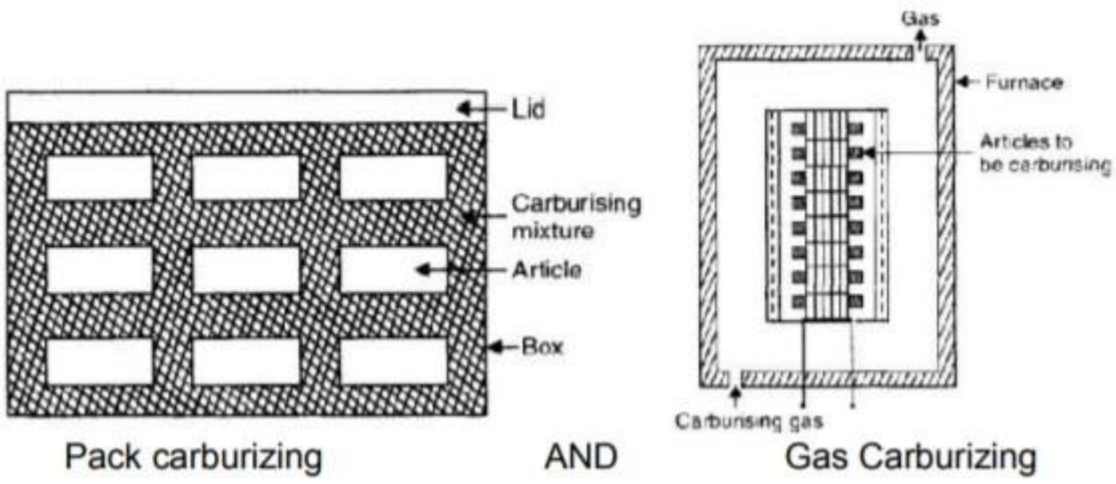
$$Fe + 2CO = Fe(C) + CO_2$$

The addition of $BaCO_3$ catalyzes the carburizing effect. $BaCO_3$ decomposes and evolves carbon dioxide which reacts with coal to form carbon monoxide.

$$C + CO_2 = 2CO$$

However, pack carburization is a time consuming process and requires very highly skilled labour, due to the temperature which is difficult to be maintained. Thus, it's unreliable and inconsistent. While it will allow for carbon diffusion, but this diffusion normally won't occur uniformly across an entire steel section.

• **Gas carburization:** Gas carburizing is theoretically similar to pack carburizing, in gaseous carburization, carbon monoxide gas is supplied to the heated furnace. The gaseous carburization is carried out at temperature of 900-950 degree Celsius. Carbon monoxide and various other hydrocarbons (methane, ethane) are used as carburizer. They decompose at the process temperature and form atomic carbon. The components are enclosed in a carbon bearing environment, thus a high carbon content environment is continuously maintained. High temperatures allow the carbon molecules to diffuse into the steel item which being hard cased. It is very important to accurately control the composition and flow rate of carburizing gas. Gas carburization is the main process in mass production of carburized steel, while the simpler solid carburization is economically more effective in small scale production.




• **Vacuum carburization:** In this method carburizing is carried in an oxygen-free environment at very low pressure thus the carburising temperature can be increased without worrying about oxidation. The higher temperature is necessary to increase the carbon solubility and the diffusion rate. A hydrocarbon gas such as methane is pumped into the environment, allowing carbon molecules to attach to the steel surface. In efforts required to simplify the atmosphere, this method has been explored and developed into a viable and important alternative.

The process is to be performed within a sealed furnace because unless the oxygen supply is entirely cut, the desired process cannot be carried out.

• **Liquid carburization:** in this process, the steel components are immersed in a liquefied and carbon rich environment (cyanide bath) or by using molten salt. The molten salt also helps in introducing carbon into the metal. The metal is then rapidly quenched producing a hardened case. The quality produced by this process is similar to the one in Gas Carburising, but with low nitrogen and high carbon content. If only selected portions of the component are to be carburized, then the remaining portions are covered through copper plating.

***B. Benefits of Carburized Steel***

There are various benefits which come with carburization of steel. Some of these benefits are

**Very Hard Exterior**

The steel which has been carburized will have a very hard exterior thus, allowing it to take on a great deal of physical abrasion without wearing down prematurely. Although there are steels out there with harder surfaces than carburized steel, but they are not as malleable or affordable as carburized steel. In also don't provide the desired combination of soft interior and hard exterior that carburized steel offers.

**Soft Interior**

Another benefit of carburized steel is that it possesses a soft interior due to soft interior, thus can easily be transformed into different shapes. This makes it useful especially in the manufacture of intricate metal items with hard surfaces (ie; internal machine components). Although some un-carburized steel alloys provide natural surface hardness but they don't provide the internal softness needed to be intricately shaped and formed. In essence, they do not provide the coveted combination of soft interior and hard exterior.

**Relatively Inexpensive**

Hard surface steel alloys are costly if a substance of greater surface hardness is required, carburized steel is most affordable option for this purpose. The process of carburization is much cheaper than the manufacture of certain steel alloys. In the manufacture hard steel surface products on a mass scale carburization is the most cost-effective option.

***C. Plain carbon steels***

Steel with carbon content of 0.05% to 2.1% by weight is called as carbon steel. The plain steels are generally classified broadly into following types.

- **Very Low Carbon Content Steels**

They contain very low carbon content (upto 0.05%C). These steels are malleable and ductile and have properties similar to that of iron. They normally cannot be modified by heat treatment. They are very cheap as compared to higher carbon steels, so, engineering applications are restricted to non-critical components.

- **Low or mild Carbon Content Steels**

Also known as plain-carbon steel, contains upto 0.30% of carbon. Due to relatively low price, mild steel is the most common form of steel used as it provides material properties that are acceptable for various applications. Normally, low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.30% carbon. Mild steel has a relatively low tensile strength, but it is cheap and malleable but the surface hardness can be increased through carburizing then heat treating the carbon rich surface. It is used where ductility or softness are important. Examples of low carbon steels are 080M15, 150M19, 220M07, AISI 1006, AISI 1009, AISI 1020.

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, domestic appliances etc.

- **Medium Carbon Content Steels**

They contain 0.30 to 0.60% of carbon. These are comparably less ductile but are harder and have a greater tensile strength than low carbon steel. It balances ductility and strength and also has good wear resistance. They have also better machining qualities. e.g. 070M20, 080M40, 216M44, AISI 1023, AISI 1030, AISI 1046. Most steels in this category contain small amounts of silicon and manganese, which are added as deoxidising and desulphurising elements during manufacture process.

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

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

- **High Carbon Content Steels**

They contain 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. Cold working is not possible with these types of steels, as they fracture even at very low elongation. They are also highly sensitive to thermal treatments. 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, high strength wires etc

***D.. AISI Classification***

As per AISI carbon steel is broken down into four classes based on carbon content

**Low-carbon steel:**

Having 0.05 to 0.25% carbon (plain carbon steel) content.

**Medium-carbon steel:**

They have approximately 0.3–0.6% carbon content. Balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components.

**High-carbon steel:**

Containing approximately 0.6 to 1.0% carbon content. Very strong, used for springs, edged tools, and high-strength wires.

**Ultra-high-carbon steel:**

Approximately have 1.25–2.0% carbon content. These steels that can be tempered to a great hardness. Used for special purposes like (non-industrial-purpose) knives, axles or punches. Steels with more than 2.5% carbon content are made using powder metallurgy.

***E. Case hardening***

Case hardening is a simple method used for hardening of steel surface. This technique is generally used for steels with low carbon content. Carbon is added to the surface layer of the steel, to a depth of approximately 0.03mm. This hardening process is carried out through various methods and techniques in order to improve the mechanical properties and wear resistance of parts without affecting the softer, tough interior. This combination of hard, abrasion resistant surface and along with a tough interior is used in various equipments subjected to surface abrasion and to resist the impact that occurs during operation. Further, the surface hardening of steels has a great advantage over through hardening as it is less expensive. Low-carbon and medium carbon steels can be surface hardened without the problems of distortion and cracking associated along with the through hardening of thicker sections. One advantage of this method of hardening steel is that the inner core is left untouched and so still processes properties such as flexibility and is still relatively soft.

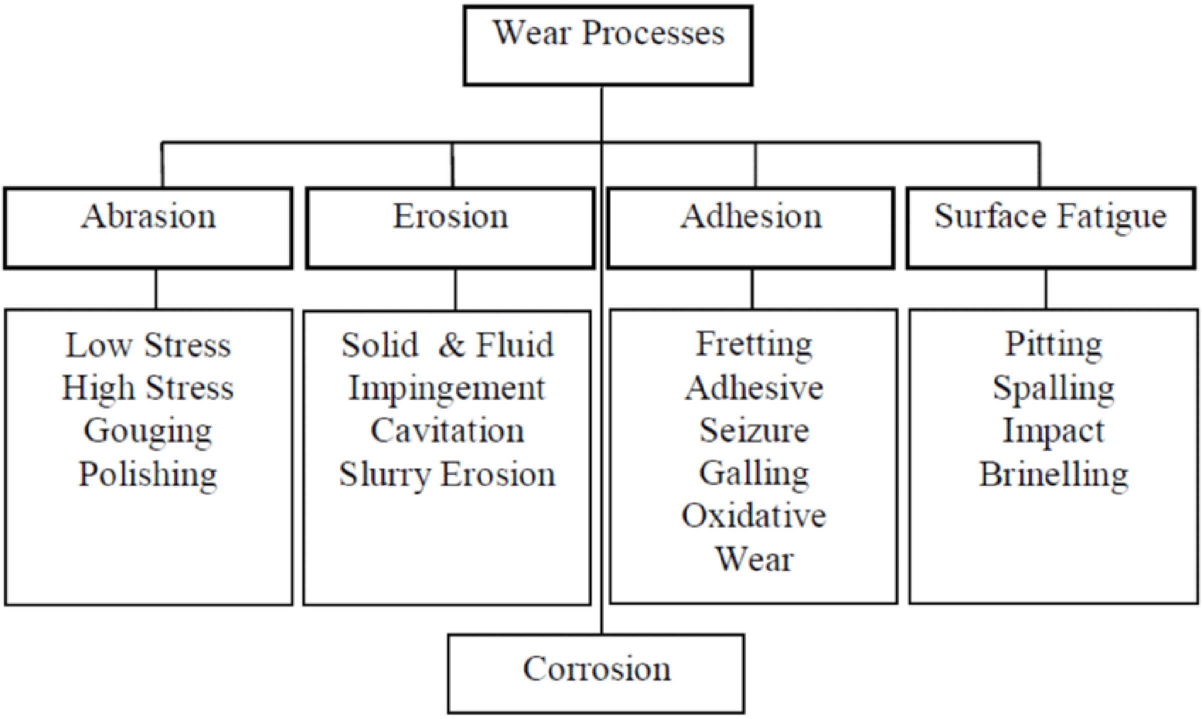
***F. Tempering***

Tempering is a heat treatment technique applied to iron based alloys, like steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. It is done to improve the hardness and elasticity of metal or steel by reheating and then cooling it. Tempering always follows the hardening operation and never precedes it. Tempering is usually performed after hardening to reduce the excess hardness and is done by heating the metal to a temperature below the critical point for a given period of time, after which it is allowed to cool in still air as normally, the rate of cooling has no effect on the steel properties. The temperature depends upon the specific composition of the alloy and on the desired properties in the finished product and it determines the amount of hardness to be removed. The purpose of tempering is to reduce the brittleness that is imparted by hardening and to produce definite physical properties within the steel based on its use. To get the steel to its critical temperature, heating devices like gas furnaces, electrical resistance furnaces, induction furnaces are used. Due to reduction in hardness there is an increase in ductility, thereby, it decreases the brittleness of the metal. Tempering thus alters the mechanical properties- ductility and hardness and relieves internal stresses of the steel. This heating is done usually in a vacuum or along with an inert gas to protect the steel from oxidation. Tempering allows carbon trapped in a martensitic microstructure to disperse, and thus enables the internal stresses to be released from the steel which might have been created from previous operations.

***G. Wear of material***

Wear is a process of gradual removal of material from the surface of one or both the solid surfaces which are in contact due to sliding or rolling motion together. Wear is the damaging, gradual removal or deformation of material at the surface of solid substance. The causes may be mechanical like erosion or chemical (eg; corrosion). Thus, it is caused by impact, erosion, metal-to-metal contact, abrasion, oxidation and corrosion, or a combination of these processes. The following shows the five main categories of wear and the specific wear mechanisms that occur in each category.




## 2. Review of Literature

*Luo et al* studied the effects of microstructure on the abrasive wear behavior of spheroidal cast iron and reported that the wear resistance of spheroidal grey cast iron was inferior to that of steel with a similar matrix. Quenched structures were more resistant to abrasion than the austempered structures. In addition, the wear performance of quenched iron and steel samples were reported to be better than austenitized at higher temperature.

*Celik et al* studied the high temperature abrasive wear behavior of an as-cast ductile iron and reported that the high temperature tensile properties were affected by dynamic strain aging. Serrated flow was observed in the temperature range between 100 and 300°C. In this temperature regime, tensile strength values were almost invariable. Above 400°C, increase of temperature decreased the tensile strength. Minimum ductility was observed at 500°C. At 600°C, higher ductility was observed than that of 500°C. he also concluded that after the increase in wear resistance at 50–100°C, abrasive wear resistance decreased with increasing temperature. Dynamic strain aging caused improvement of abrasion resistance. The highest resistance to abrasive wear is observed at temperature range between 50 and 100°C. At this temperature range ductile iron exhibited more than 15% higher abrasion resistance than room temperature.

*Izciler and Tabur* on his study of abrasive wear behavior of different case depth gas carburized AISI 8620 gear steel concluded that in respect with microstructures, samples subjected to longer periods of gas carburizing exhibit greater case depth The samples having greater case depth and surface hardness are more wear resistant than that with low case depth. The hardness of the abrasives in relation with the applied loads and wear distances had affected the wear resistance significantly. Comparing $Al_2O_3$ and SiC abrasive papers, $Al_2O_3$ abrasive papers lose their sharpness more than SiC papers do, especially under higher loads.

*Khusid et al* on his work studied the Wear of carburized high chromium steels and reported that Carburization raises the abrasive wear resistance and allows significant suppression of the adhesion phenomena under dry sliding. The results obtained determine the regime of surface hardening of high chromium steels required to produce the desired combination of wear resistance and bulk strength properties.

The results of an experimental investigation carried out by *Akdemir et al* on Impact toughness and microstructure of continuous steel wire-reinforced cast iron composite and reported that absorbed energy of the gray cast iron increases basically with adding the ductile reinforcement. Also absorbed energy of the composite decreases with decreasing test temperature since the steel wire in the composite loses its ductility and behaves as a brittle material as the test temperature was decreased. He also reported that Impact toughness of the gray cast iron was not improved with the increasing normalization temperature since there is no change in the morphology of graphite flakes in the gray cast iron with normalizing heat treatment. Normalizing heat treatment does not affect impact toughness of the cast composite significantly, because the partially dissolved region is very narrow due to insufficient volume fraction for the current work condition.

*Baldissera and Delprete* studied effects of deep cryogenic treatment (DCT) on static mechanical properties of 18NiCrMo5 carburized steel and concluded that The soaking time parameter shows a strong influence on the hardness increase induced by the pre-tempering DCT and, under the assumption that the microstructural mechanism involves the entire process further improvements could be possible with a prolonged DCT exposure. The unchanged tensile strength of the pre-tempering DCT groups could be related to a compensation effects due to the loss in residual stress, as it is reported by literature.

## 3. Types of wear processes and mechanisms

Abrasive wear occurs when a hard-rough surface slides across a softer surface. ASTM (American Society for Testing and Materials) define it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface [1]. There are two modes of abrasive wear two-body and three-body abrasive wear. Two-body wear occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface, when they remove the material from the surface. The common analogy is that of material being removed with sand paper. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear are:

- Plowing
- Cutting
- Fragmentation

Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridge adjacent to grooves, which may be removed by subsequent passage of abrasive particles. Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves.

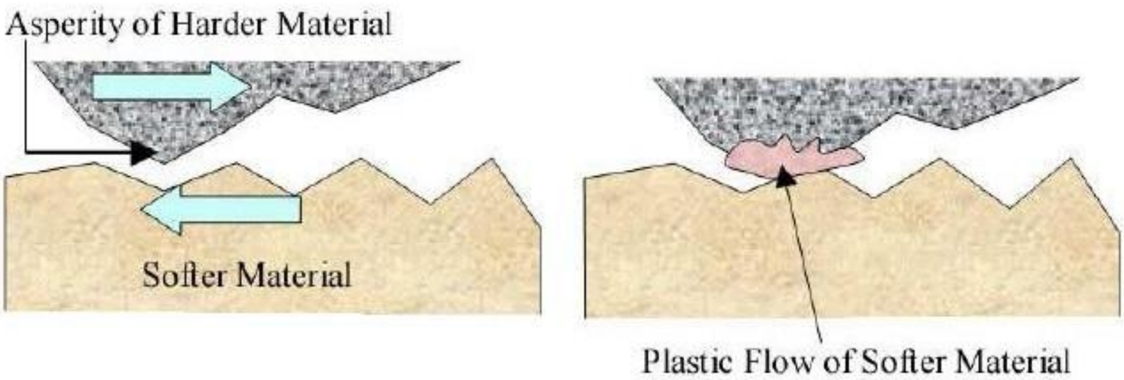



Figure 1: Abrasive wear [1]

This mechanism closely resembles conventional machining. Fragmentation occurs when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material. These cracks then freely propagate locally around the wear groove, resulting in additional material removal.

**Erosive** wear is caused by the impact of particles of solid or liquid against the surface of an object. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions. As shown in Figure 3 erosion occurs due to the impact of a solid particle A, on the solid surface B, resulting in part of the surface B been removed. It is a widely encountered mechanism in industry. A common example is the erosive wear associated with the movement of slurries through piping and pumping equipment. The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, and impact velocity and impingement angle are primary factors along with the properties of the surface being eroded.

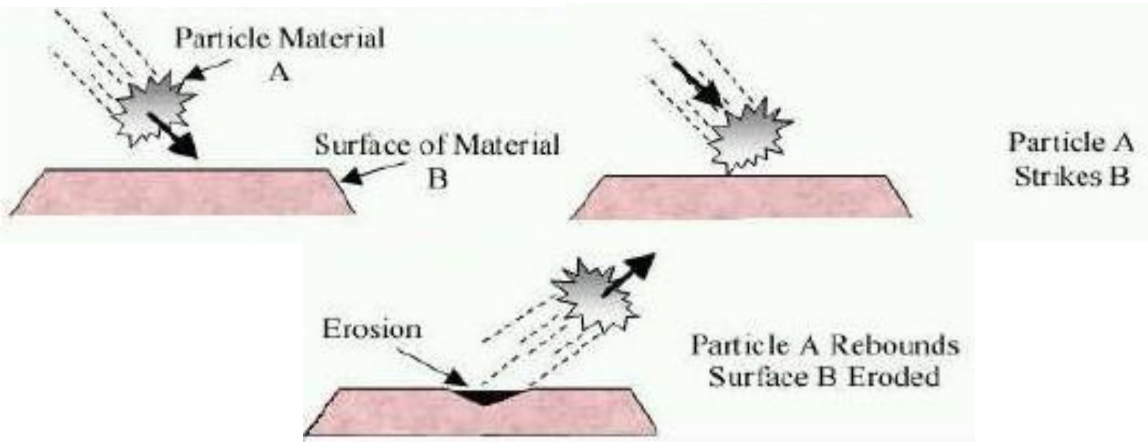



Figure 2: Erosive wear [1]

Adhesive Wear is often called galling or scuffing, where interfacial adhesive junctions lock together as two surfaces slide across each other under pressure. As normal pressure is applied, local pressure at the asperities become extremely high. Often the yield stress is exceeded, and the asperities deform plastically until the real area of contact has increased sufficiently to

support the applied load, as shown in Figure 4. In the absence of lubricants, asperities cold-weld together or else junctions shear and form new junctions. This wear mechanism not only destroys the sliding surfaces, but the generation of wear particles which cause cavitation and can lead to the failure of the component. An adequate supply of lubricant resolves the adhesive wear problem occurring between two sliding surfaces.

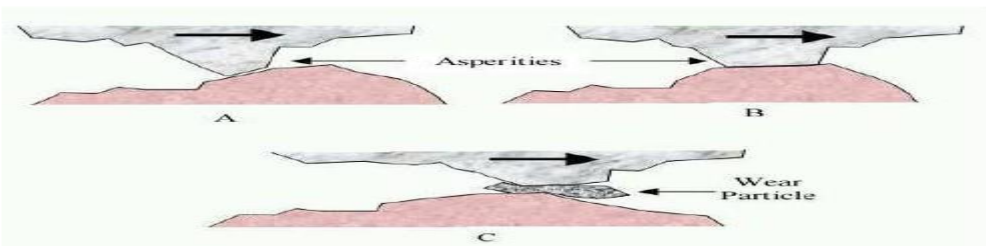



Figure 3: Adhesive wear [1]

Surface Fatigue is the phenomenon, when mechanical machinery moves in periodical motion, stresses to the metal surfaces occur, often leading to the fatigue of a material. All repeating stresses in a rolling or sliding contact can give rise to fatigue failure. These effects are mainly based on the action of stresses in or below the surfaces, without the need of direct physical contact of the surfaces under consideration. When two surfaces slide across each other, the maximum shear stress lies some distance below the surface, causing micro cracks, which lead to failure of the component. These cracks initiate from the point where the shear stress is maximum and propagate to the surface as shown in Figure 5.

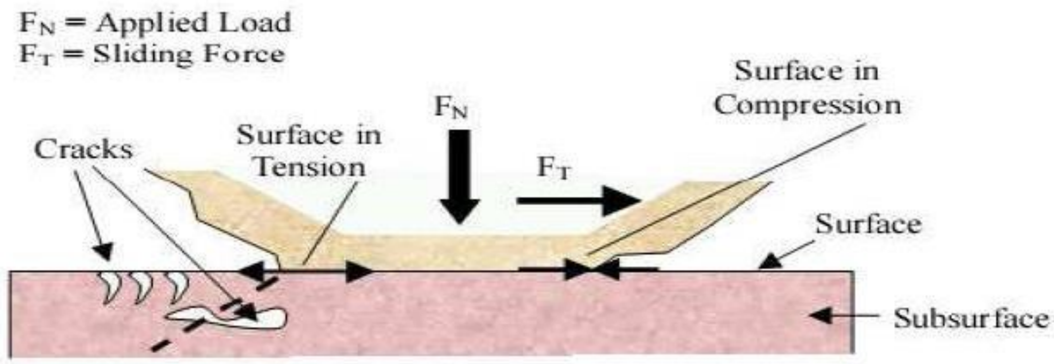



Figure 4: Surface Fatigue [1]

In Corrosive wear, firstly, the connecting surfaces react with the environment and reaction products are formed on the surface asperities. Attrition of the reaction products then occurs as a result of crack formation, and/or abrasion, in the contact interactions of the materials. This process results in increased reactivity of the asperities due to increased temperature and changes in the asperity mechanical properties.

The wear rate can be influenced by a number of factors as given below:

- Physico-chemical properties of materials, such as composition, microstructure, hardness, work hardening characteristics, corrosion resistance, wear strength, etc.
- Wear conditions such as contact areas, load applied, temperature, presence of lubricants, degree of lubrication, rotational/sliding speed, flow rate of liquid or gas, nature of environment, duration of wear etc.
- Characteristics of abrasive involving hardness, shape and size.
- Design properties involving transmission of load, type of motion, test geometry etc.

## 4. Conclusion

Thus in this paper a study on mechanical and wear properties of carburized mild steels samples. The mechanical and wear properties of mild steels were found to be strongly influenced by the process of carburization and carburizing temperature.The carburization treatment followed by the water quenching appreciably improved the hardness, wear resistance and tensile strength of mild steels

## References

[1] Chee Su Be, Ammar Al Shalabi and B. F. Yousif, “On the effect of counter face materials on tribo-behaviour of steel wire sliding under dry contact condition,” Surface Review and Letters, Vol.15, No. 4, 2008, pp. 355–360.

[2] Sanjib Kumar Jaypuria “Heat treatment of low carbon steel,” Project Report, National Institute of Technology, Rourkela, 2009, pp. 8.

[3] “Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus,” ASTM International, Designation: G 99 – 03.

[4] Horst Czichos, “Tribology a systems approach to the science and technology of friction, lubrication and wear,” Tribolgy Siries,1, Elsevier Scientific Publishing Company, 1978, pp. 57.

[5] Durbadal Mandal, B. K. Dutta and S. C. Panigrahi, “Dry sliding wear behavior of stir cast aluminium base short steel fiber reinforced composites,” Journal of Material Science, Vol. 42, 2007, pp. 2417–2425.

[6] Thanakrit Chotibhawaris, Tachai Laungwaranant and Sombun Charoenvilaisiri, “The Study of Powder Metallurgy Tin Bronze Wear Behaviour by Pin-On-Disk Method,” Journal of Metals, Materials and Minerals, Vol.18, No.2, 2008, pp.17-22

[7] Luo Q., Xie J. and Song Y. , Effects of microstructure on the abrasive wear behavior of spheroidal cast iron, Wear, 184 ( 1995 ) : pp. 133 – 137.

[8] Celik O. , High temperature abrasive wear behavior of an as – cast ductile iron, wear, 258 ( 2005 ) : pp. 189 – 193.

[9] Izciler M. and Tabur M. , Abrasive wear behavior of different case depth gas carburized AISI gear steel, Wear, 220 ( 2016 ) : pp. 90 – 98.

[10] Khusid B. M. and Khina B.B. , Wear of carburized high chromium steels, Wear, 165 (1993) : pp. 109 – 112.