Prospects of AISI 1055 Steel in Gearing Applications

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Abstract - *Solid particle erosion of a material plays a vital role in degradation of components, surface scratching and loss in useful life of a material structure. Erosive wear is governed by various parameters like particle impact velocity, impingement angle, applied load, contact area, particle size, and hardness. Erosion being progressive loss of material adds up to the woes of working machinery and equipments with quite uncertainty leading to premature failures. Therefore; these parameters needs to be effectively kept in the safe working range thereby reducing the unavailability leading to increased machine performance. This research work is the prospective study of AISI 1055 Steel under variable operating conditions. AISI 1055 is used in gearing applications like gear box assembly.*

***Key Words*: *Solid particle erosion, Structure, Wear, Unavailability, Gear box* etc…**

1. INTRODUCTION

Wear is a complex phenomenon involving loss of material found in various engineering equipments such as hydraulic machinery, oil and pipe lines, centrifugal pumps etc. due to presence of various variables such as target material, hardness, size, temperature and humidity. Elements such as ball or roller bearings, drive belts or gears may cause vibration when they are worn. A worn gear or a drive belt that is breaking down will produce vibration. The effects of vibration can be severe. Vibration of an uninspected machine can speed up wear rate and damage equipment. Vibrating machines can produce noise, cause safety problems and lead to degradation in plant working conditions. Vibration can cause machinery to consume too much energy and adversely affect product quality [23]. Impact velocity and particle size highly dependent on wear as compared to solid concentration [1]. Chemical composition of the AISI 1055 Steel is given in table 1:

Table-1: Chemical composition [18]

Element	Fe	C	Mn	P	S
Content (%)	98.65	0.5-0.6	0.6-0.9	0.040	0.050

AISI 1055 steel is a medium carbon steel that is supplied in a black hot-rolled or normalized condition. It has a tensile strength of 570 - 700 MPa and Brinell hardness of between 170 and 210 [20]. It is characterized by good machinability, good weldability, high strength and impact properties [21]. It is economical for industrial purposes. It is widely used in all industrial applications that require high wear-resistance and strength. AISI 1055 steels standard applications are gears, shafts, axles, studs, bolts, connecting rods and crankshafts.

Table-2: Physical properties [19]

Properties	Value
Tensile strength, ultimate	660 MPa
Tensile strength, yield	560 MPa
Modulus of elasticity	190-210 GPa
Poisson's ratio	0.27-0.30
Hardness, Brinell	197
Thermal expansion coefficient	11 µm/m°C
Thermal conductivity	49.8 w/mK
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1.1 Mechanism of Wear

The wear is caused by two main methods referred to as cutting and deformation [2,3].

• Cutting: It is associated with particles impacting the eroding surface at an oblique angle having sufficient energy and removes the material.

• Deformation: It is caused by particles which impact the eroding surface perpendicularly having sufficient kinetic energy to initiate plastic deformation or surface crack formation in the eroding material surface.

1.2 Types of Wear

Following are five main types of wear [4]:
(a) Abrasive wear
(b) Adhesive wear
(c) Erosive wear
(d) Corrosive wear
(e) Fretting wear

Abrasive wear, also referred to as three-body abrasion and can be termed as abrasion wear, by loose solid particles is a common problem in various industries and in agricultural work. It is estimated that about 50% of all wear related issues in industry are because of abrasion. It can be seen that the measured cost due to abrasive wear losses in the gross national product of an industrialized country is as high as 1 to 4%.. Surface wear causing failure and damage counts for high percentage of machinery components in the industry. There are many laboratory works have been observed over the abrasive wear behavior with a wide range of engineering material. When particles are in sliding movement, between hard and rough surface, and are able to move freely then the two-body abrasion wear often appears.

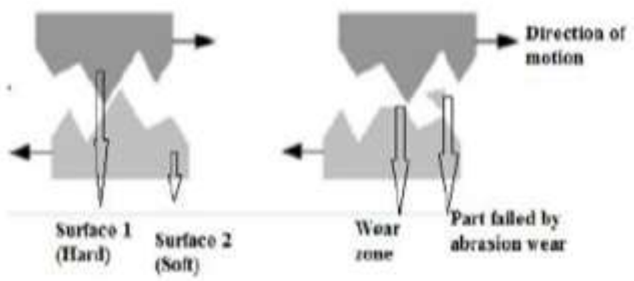

Fig- 1: Abrasive Wear [5]

Adhesive wear is measured by the contact from one solid surface to another solid surface, resulting in the formation of localized bond between the contact surfaces. This phenomenon of surface deterioration is usually observed in several components.

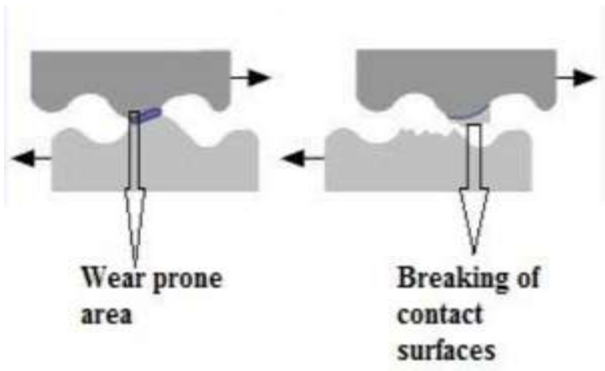

Fig- 2: Adhesive Wear [5]

Erosive wear can be described as a mechanism happen in a very short sliding motion and within a short time. When liquid or solid particles impacted on the surface of the material then erosive wear occurs. Material is removed slowly by impact particles from the surface through continuous deformations and cutting operations. It is a widely recognized mechanism in industry.

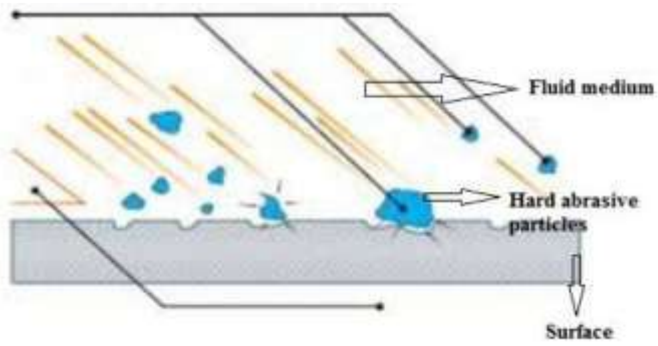

Fig-3: Erosive Wear [6]

Fretting wear is commonly perceived failure type in bearing assemblies. It takes place due to minor amplitude oscillatory motion among the surfaces of bearing races, rolling elements and many more, which are in higher pair position or in contact with each other. Number of parameters affects the fretting wear characteristics of engineering materials, for instance, material in mating combination, slip amplitude, normal load, frequency, surface treatment, surface form and environment are few of them.

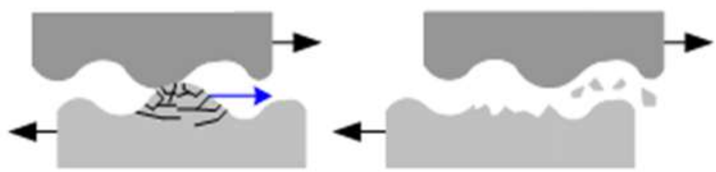

Fig- 4: Fretting Wear [5]

2. FACTORS AFFECTING WEAR RATE

The erosive action of particles depends on their hardness, strength, particle size, while the surface erosion by these particles depends on the surface nature, the number of particles that hit the surface, their velocity and their direction of impact.

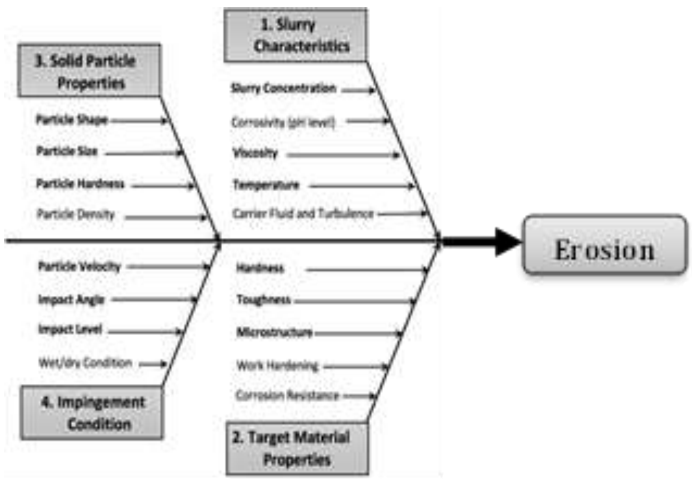

Fig-5: Important parameter influencing Erosion (Fishbone Diagram) [7]

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The main factors affecting wear are as follow:

(a)Impact velocity between all the material erosion influencing parameters, impact velocity is the most influential. J.E. Goodwin et.al [8] had performed experiments in this area to determine effect of impact velocity on erosion of different materials. They concluded that erosion depends on a simple power of velocity (V) shown in equation, i.e.

$$\text{Erosion} = \text{constant} \times (\text{velocity})^n$$

Where the exponent n varies from 2.0 for 25 μm to 2.3 for the saturation erosion occurring for 125 μm and more. Experiments were performed with 25 μm, 40 μm, 60 μm and 200 μm particle sizes. Similar efforts have been made by G.P. Tilly and Sage [9] for wide variety of materials and found excellent agreement with respect to exponent n, in each case. The test results are shown below in fig 6:-

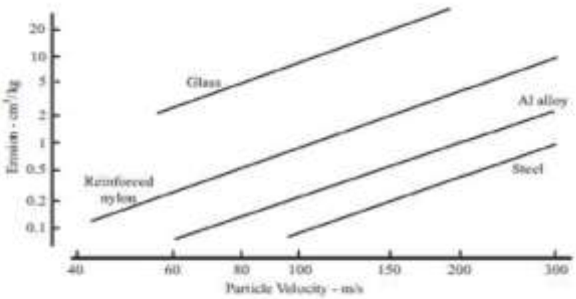

Fig-6: Influence of Velocity on Different Material [8]

(b) Impact angle A curve presented by G.P. Tilly and Sage [9] and shown in Fig 7 shows the effect of impact angle with erosion for two different materials and is typical of the previous work done to determine the effect of these variables. Both materials revealed a very important difference in both the erosion rate and the impact angle. These materials, in fact, reflect the now known behavioral models [10]. The aluminium alloy is one of the ductile materials. In this at impact angle around 20° erosion is maximum and provides better erosion resistance against normal impact. Glass is one of brittle materials. It encounters heavy erosion under normal impact but offers good resistance to erosion at low angle [22]. The different response to erosion shown by brittle and ductile materials demonstrated from fig 7, therefore there must be different mechanism for brittle and ductile materials.

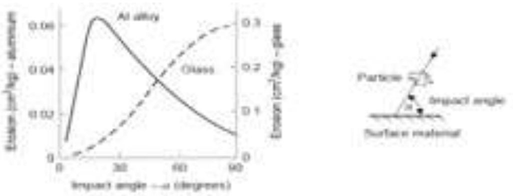

Fig-7: Influence of Impact Angle on Erosion [11]

(c) Abrasive particle size If one of the surfaces which are in contact, is hard and rough, it chips the surface which is in contact, due to the presence of motion between them. This type of wear is known as two- body abrasive wear. When the abrasive particles are amongst the two surfaces, the wear is known as three-body abrasive wear. Wear rate increases as the diameter of abrasive particles increases.

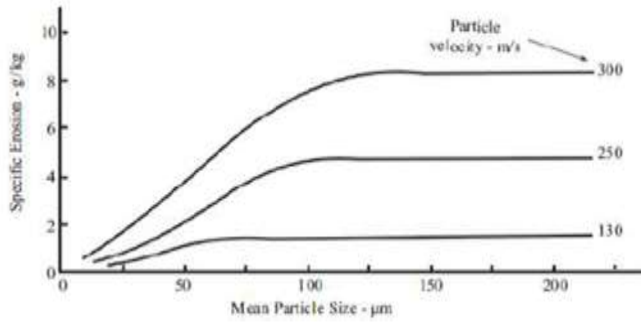

Fig-8: Influence of Particle Size and Velocity on Erosion [11]

(d) Abrasive particles hardness when hardness of material is more than abrasive particles, then the rate of wear is less. If abrasive particle are with more hardness, then the wear rate is on higher side, as abrasive particles easily penetrate the material while working [25]. Significant work in particle hardness is performed by J. E. Goodwin et al. [8] ,where they tested with natural dust were sieved into the size range 125 to 150 μm and their erosiveness measured by testing an 11 per cent chromium steel at 420 ft/s for normal (90°) impact. The research concludes that testing of a variety of abrasives confirmed that their erosiveness is dependent upon hardness (and sharpness by inference) as shown in the Fig. 9. The figure concludes that erosion increase with particle hardness [15]. They further found that erosion is related to hardness by the expression

$$\text{Erosion} = \text{constant} \times H^{2.4}$$

Where, H=Particle hardness.

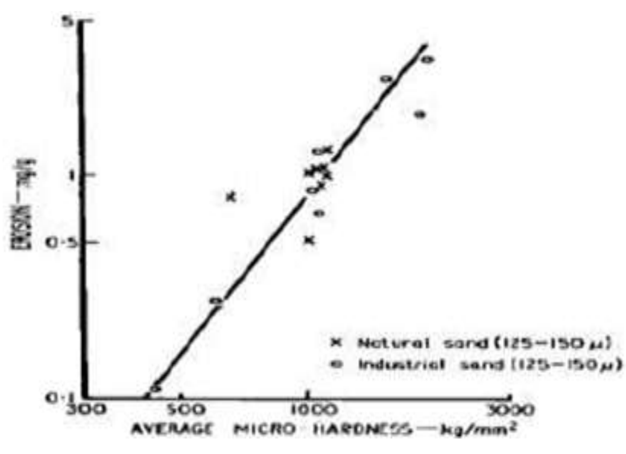

Fig-9: Effect of particle hardness on erosion of an 11 % Chromium steel at 420 ft/s and 90° impact angle [8]

(e) Contact area Contact area is inversely proportional with wear. When surface has only point contact with abrasive particles, friction coefficient value is high and wear is more.

When contact area is more, then friction coefficient value is less and wear rate is also lower [4].

(f) Applied load plays an important role on wear of materials. During working, there is significant increase in wear rate, when load increases from lower to higher value. When graduation in load, the friction coefficient also enhances and rate of wear also rises, as wear is directly proportional to frictional force [4]. Experiment on double phase (DP) steel and normal steel(N) shows variation in wear rate with loading in fig.10:

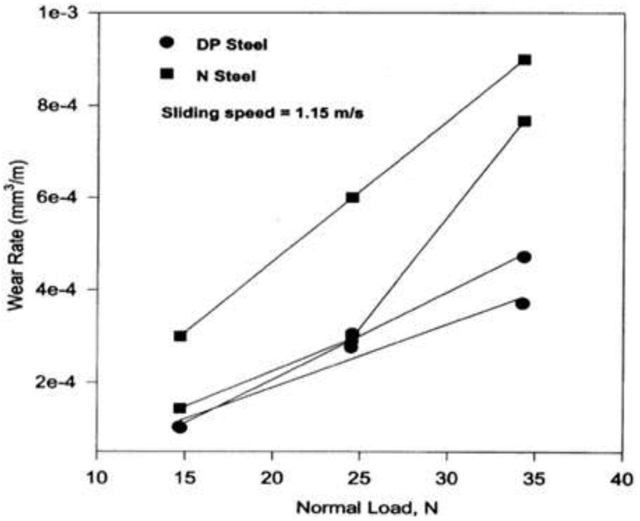

Fig- 10: Effect of loading on Wear Rate [12]

(g) Environment Environmental conditions effects the wear of material up to great extent [24]. Wear is less in wet conditions as compared to dry conditions. In moist conditions, moisture plays role of lubrication, hence reduces the frictional value and decreases the wear rate. In dry conditions, frictional force is higher and enhances the wear of materials.

(h) Material properties Material properties affect the wear of material up to greater extent. Generally when hardness of material is more, low wear occurs and when material is soft, then wear is on higher side. When microstructure is coarse, hardness is less and wear rate is higher. When microstructure is fine, hardness is more and wear rate is on lower side [4].

3. RESULTS AND DISCUSSIONS

Table-3: Results

Parameter	**Effect**
Impact Velocity	Erosion is dependent upon a simple power of velocity (V) shown in equation, i.e. Erosion = constant x $(\text{velocity})^n$
Impact Angle	For ductile materials erosion rate is maximum at 20-25° impact angle and then decreases. For brittle materials erosion rate increases continuously with increase in impact angle.
Particle Size	Wear rate increases as the diameter of abrasive particles increases.
Particle Hardness	When hardness of material is more than abrasive particles, then the rate of wear is less. If abrasive particle are with more hardness, then the wear rate is more.
Applied Load	When load increases there is significant increase in wear rate.
Contact Area	Contact area is inversely proportional with wear.
Test Time Duration	Wear rate increases with increase in test time duration.

4. CONCLUSIONS

AISI-1055 steel is a suitable material for heat-treated components in those applications where high impact strength and tensile strength are needed. This material is majorly used for compound gear-box of the rolling mill, roller, forming, moulding dies and blanking tools.

- Impact velocity and impingement angle are two main factors which influencing erosion.
- Impact velocity is one of the major parameter and contribution of it in erosive wear is as high as 60%.
- Impingement angle is the second most dominant parameter and contribution of it in erosive wear was almost 21%.
- Erosion behaviour of brittle and ductile material is different.

(a) For ductile materials erosion rate is maximum at 20-25° impact angle and then decreases continuously. Micro cutting is the reason behind increase in wear rate at low impact angle and it slows down at higher impact angle because of plastic deformation of surface erosion mechanism.

(b) For brittle materials erosion rate increases continuously with increase in impact angle and is maximum at 90°

- Particle size, hardness and concentration are other parameters influencing erosion.
- Wear rate increases with increase in test time duration.
- By increasing concentration of erodent wear rate increases.

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