CHAPTER I \hspace{1cm} INTRODUCTION

1.1 BACKGROUND OF THE STUDY

India is a vast country with 329.5 million hectares geographical area with agriculture still as a main occupation of over 70 per cent of Indian population. Agriculture is an important sector of the Indian economy, accounting for 14 per cent of the nation’s Gross Domestic Product (GDP) from which about 11 per cent contributes its exports. Also, about half of Indian population still relies on agriculture as its principal source of income. In addition, it is a source of raw material for several agriculture-based industries. Therefore, it is important not only for accelerating the growth of agriculture produce but also to achieve an overall GDP target of 8 per cent during the 12th Plan and meet the rising demand for food. It is also vital to increase the incomes of those, who depend on agriculture to ensure inclusiveness in our society (Anonymous, 2009).

In the last four decades there is a fast change in the scenario of improvement in agricultural mechanization. The application of tillage machinery in the agriculture sector has assumed importance for increasing agricultural production, productivity and profitability by timely farm operations, labour saving, as well as optimum utilization of resources. The newly developed appropriate technology of farm mechanization with improvement in existing designs, newer materials and production techniques will cater the needs of farms (Manian et al., 2002). In the Indian state of Punjab, the most widely accepted method of tilling land is ploughing with cultivator and mouldboard ploughs. During field operations, these implements inverts the upper soil layer, without proper mixing of soil. Hence, additional operations are needed such as rotavator and harrowing etc., to improve soil tilth on the ploughing. Further, the preparation of seed bed after
harvesting of rice crops is very difficult in heavy soils. Due to development of deep cracks in the soil, considerable difficulty is experienced with mould board plough, disc plough and cultivators. Clod formation in these types of soils necessitates many operations of conventional implements to be carried out. In addition, the rice stubbles after combine harvesting remain intact and create problems in subsequent sowing operation. The tractor mounted rotavator holds promise for overcoming these problems. In recent years, rotavator is becoming popular among the farmers for land preparation where two or more crops are taken in a year. The rotavator saves 30-35 % yield preparation time and 20-25 % in the cost of operation as compared to tillage by cultivator. Rotavator produces a perfect seedbed in fewer passes as compared to other implements (Anonymous, 2011).

1.2 ROTAVATOR

The rotavator (derived from rotary cultivator) or rotary tiller is a tillage tool primarily comprising a set of blades mounted on flanges, which are attached to a shaft that is driven by the tractor power-take-off (PTO) shaft. It is an active tillage tool that processes the soil at a speed that is different from the forward travel speed of the tractor. The entry of the rotavator in agriculture is relatively recent in comparison to hand tools and animal-drawn tillage tools. The delayed entry of rotavators is attributed to the lack of suitable sources of power, prior to the development of the steam powered tractor. The original rotavators were intended for deep land preparation as an alternative to the drawn or passive tillage tools. They were heavy machines that expended excessive energy per unit mass of processed soil at the intended depths of operation. These rotavators suffered frequent mechanical breakdowns during tillage operations specifically the breakdown associated with wear and tear of tines (Bernacki et al., 1972). Presently most of the farmers of the state use rotavator as tillage equipment for preparation of seedbed.
1.2.1 AXIS OF ROTATION

During tillage, rotavator rotor shafts either be rotated in vertical-axis or horizontal-axis as shown in Figure 1.1. The surface of soil produced after tillage by rotavator is depends upon the soil condition, soil flow dynamics and tine kinematics (Kinzel et al., 1981). The gesture of soil is depending upon, whether the rotor shaft of rotavator is rotating in vertical or horizontal axis; and on the direction of rotation of rotavator tines. Rotavator tines are rotated in up-cut or down cut direction, in horizontal rotation of rotor axis; while clockwise or anti-clockwise direction of rotation, in vertical rotation of rotor axis. In general, rotation of axis of rotavator rotor shaft is horizontal axis rather than vertical axis (Makange et al., 2015).

![Figure 1.1: Rotavator rotor axis](image)

When the direction of rotation of rotavator rotor shaft is up-cut direction, it provides the pulling force towards rearward to tractor while down-cut direction, it provides thrust or forward force to the tractor. The forward force generated by down-cut direction to the tractor, offers various advantages during tillage are as follows:

- The forward force generated by the rotavator tines, contributes significantly during tillage to reduce the rolling resistance of the tractor.
- The slippage of tractor tyres is reduced due to declined draught of rotavator, which improves the field productivity and efficiency.
➢ Lighter tractors are used for tillage due to reduced draught of rotavator, which reduced the soil compaction.

➢ Due to the reduced draught of rotavator, it permits to perform tillage operation in difficult traction conditions.

In addition to the above stated advantages, the rotavator is used for mixing fertilizer into soil, mixing manure, eradicating weeds, sowing seeds, to break up and renovate pasture for crushing clods resulting in a good clod size distribution etc. Rapid seed bed preparation and reduced draft are also the important advantages as compared to conventional tillage. To achieve the acceptable tilth quality, conventional tillage required number of equipment’s but rotavator provides the same tilth quality with a single pass (Salokhe et al., 2003).

1.2.2 ROTAVATOR ASSEMBLY

The complete rotavator assembly contains various components as shown in Figure 1.2 and details of the components as follows:

a) Independent top mast: - It is a shaft which is used to transmit power from tractor PTO to rotavator input shaft.

b) Single/Multi speed gear box: - It is a gear box unit having main shaft, heavy duty roller bearings, bevel gear and pinion shaft which is used to reduce the PTO rpm from 550 to 200 rpm. It is also used to rotate the direction of travel. The direction of rotation helps to prevent the clogging of rotavator, because it throws the soil behind the rotavator.

c) Chain/Gear cover part flange: - It is a flange which supports the chain and gears.

d) Tines: - For better manuring of trashes and weed killing, L-shaped tine is commonly used.

e) Chain/Gear cover part: - It is cover which protects the chain and gear from outside.
f) **Frame and Cover:** - The degree of pulverization of soil is controlled by adjusting the rear cover. To get acceptable or fine tilth quality, rear cover position is closed which pulverized the more clods by the rotating action of rotavator tines. If rear cover position is wide open, then large size clods thrown away and coarse tilth obtained.

g) **Adjustable depth skids:** - It is known as depth skid, means to adjust the gap between blade contact and soil.

h) **Offset adjustable frame:** - It is fixed support to cover the side parts mounted on rotor shaft of the rotavator.

![Rotavator with labelled parts](image)

**Figure 1.2: Rotavator with labelled parts**

### 1.2.3 TYPES AND SPECIFICATION OF ROTAVATOR TINES

The different types of rotavator tines are as follow: -

- Pick-Shape tine
- C-Shape tine
- I-Shape tine
- L-Shape tine
- J-Shape tine

Five different types of rotavator blades are as shown in Figure 1.3, which are designed & developed by different researchers. In the present study L-shaped tine was used as per the recommendations of Punjab Agriculture University, Ludhiana, Punjab. As this shape is most acceptable by the farmers as per the composition of the soil. Various
working parameters are namely cutting width ($B_w$), rotor radius ($R$), depth of tillage ($L_d$), rotational velocity ($N$), volume of soil tilled ($V_{st}$) and peripheral & traveling speed ratio, which affects the fuel consumption of the rotavator. The working range of these parameters suggested by the researchers (Tafesse et al., 2007; Sarasswat, 1987; Sakai, 2000; Beeny et al., 1970; Yatsuk et al., 1981 and Kataoka et al., 2002) and mentioned as Table 1.1.

![Figure 1.3: Various type of rotavator tine](image.png)

Table 1.1: Working range of various parameters of different rotary tines

<table>
<thead>
<tr>
<th>Types of Rotary Tines</th>
<th>Rotational Velocity ($N$) rpm</th>
<th>Rotor Radius ($R$) mm</th>
<th>Depth of Tillage ($L_d$) mm</th>
<th>Cutting Width ($B_w$) mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick-Shape</td>
<td>150 to 300</td>
<td>170 to 220</td>
<td>50 to 100</td>
<td>10 to 22</td>
</tr>
<tr>
<td>C-Shape</td>
<td>150 to 300</td>
<td>245 to 250</td>
<td>50 to 150</td>
<td>35 to 45</td>
</tr>
<tr>
<td>I-Shape</td>
<td>150 to 300</td>
<td>200 to 225</td>
<td>50 to 150</td>
<td>35 to 65</td>
</tr>
<tr>
<td>L-Shape</td>
<td>150 to 300</td>
<td>235 to 260</td>
<td>50 to 150</td>
<td>45 to 80</td>
</tr>
<tr>
<td>J-Shape</td>
<td>150 to 300</td>
<td>235 to 250</td>
<td>50 to 350</td>
<td>40 to 60</td>
</tr>
</tbody>
</table>

➢ **Pick-shaped tine:** - Pick-shaped tine which has been used for deep soil preparation in clean ground, wheat stubble and sod ground with cover crop removed, and should never be used in tall tough cover crops. Pick shape tine is most effective for cultivating upland fields or unsaturated soils that have little grass. The point of tine enters the ground at the angle and causes it to dig continually throughout its entire contact with
the untilled soil on the blade circle, much like the point of the plough. Thus, the action of blade is to dig itself in and pull the entire tilling units down.

➢ **C-Shaped tine:** - The C-shaped tine has a bent and curved knife structure of changing thickness from the base to the tip. The blade is free from hooking problems with plant residues. It provides sliding and cutting of the fibrous soil with minimum resistance and has self-cleaning characteristics when working in damp soils. These tines also have sufficient resistance to breakage and abrasive wear. From power consumption point of view these types of tools are as good as hoe tines. However, they are not as desirable as about the pulverization and their ability to chop surface organic matter, particularly when cultivating at shallow depths.

➢ **I-shape tine:** - These are applicable for loosening meadow sods, and for working new lands with moderate quantities of grassy vegetation and roots to a depth of 120 to 150 mm where ordinary ploughing may cause undesirable turning of the soil layers. Soil cutting with straight knives, small zones of deformation, comparatively low power consumption for cutting, and less chance of clogging with plant residue. These tines with small angles of attack are used to get good turning of the separated layer of soil and sufficient burial of plant residue.

➢ **L-Shaped tine:** - The L-shaped tine structure has a bend and the tine is not free from hooking. The cutting portion of the rotavator tine has pressed the uncut soil surface because of higher the curvature between the depth of cut and cutting width, and the lower clearance angle, the sweep clearance angle and the radius of curvature than the C-shaped tine as shown in Figure 1.3. Consequently, the power requirement of the rotavator tine and the amount of soil pulverizing, throwing, and mixing is considerably increased.
The specification of L-shape rotavator tine used in the present study is as shown in Figure 1.4. The data of tine details were collected from the test reports of rotavators being tested by Farm Machinery Testing Centre, Punjab Agricultural University, Ludhiana, India (Anonymous, 2011).

Figure 1.4: Details of a typical L-Shape tine of rotavator

➢ J-shaped tine: - The J-shaped (scoop type) of rotary tine has been used for counter spinning rotary tiller for reducing the potential requirement in rooted tillage. The maximum cutting depth is 350 mm and the tine rotation as 250 mm. The rotational direction of the tine is opposite to the rotation of the machine tires and the position of the rotary axle is the ground level. The tine consists of two components, one vertical and the other horizontal. The horizontal portion consists of the outside cutting edge and scoop surface. The scoop surface has an arc with a 60 mm of curvature spanning 50°. The horizontal portion occupies the main role of soil cutting and throwing, while
the vertical portion supports the horizontal portion. The rotary tine has a high backward throwing ability: provide pure soil clods with a single cut without re-tilling.

1.3 SOIL AND ITS DYNAMIC PROPERTIES

Soil can be defined as organic and inorganic materials on the surface of earth that provide the medium for plant growth. The physical and mechanical properties of a soil greatly influence the performance of rotavator. Therefore, the detail of soil and its properties are given below:

1.3.1 SOIL AND ITS TYPES

The various types of soil available in the different zones of the state. There are three categories of soil such as: sand, silt and clay. But most of the soil contains the composition of all the three.

a) **Sand**: The natural rock particles known as sand are mixed into the soil. The sand particles are loose and coarse, so they cannot hold the water and drained out easily. So sandy soil is not good for farming because it cannot hold nutrients and water.

b) **Silt**: Soil has one more type known as silt. Silt having a fine sand particle which hold better water as compared to sand. If silt is hold in our hand, it feels to hold like flour. If we add water to the silt, it holds water and feels like smooth and slick.

c) **Clay**: Another form of soil is clay which has fine grained soil. The clay particles are very fine as compared to silt, so very little space for water or air to circulate between these fine grains. Therefore, clay does not provide space to the roots of plant to grow easily and drained out water. For a farmer, optimum quantity of clay is required and good for agriculture. As a potter, rich quantity of clay soil is better. After water is added in clay soil, it can be easily moulded into any shapes like building bricks or bowl which are the desired properties of clay soil for potter.
The fourth type of soil is loam, even though it is really a combination of sand, silt and clay. Loam will vary depending on how much of each component is present, but generally if you are a gardener, this is the type of soil you want because it holds moisture, but also allows for good drainage. If you were to hold loam in your hand, you could mold it into a ball, but the ball would easily crumble when disturbed.

1.3.2 DYNAMIC PROPERTIES OF SOIL

The soil dynamic properties are those properties of the soil that become manifest through soil movement. From this definition, if a block of soil starts moving on a flat surface, the resultant friction angle is a dynamic property of soil as it does not appear unless soil starts moving over the flat surface (Gill et al., 1967). Another dynamic property of soil is shear strength, the shear strength and bulk density is increased by compacting the loose soil. The soil texture and water content are also affected the soil dynamic properties (Mc Kyes, 1985). The soil can be classified as non-frictional and frictional or non-cohesive and cohesive, which depends upon the soil texture.

By taking the dynamic component of the soil strength into account, the mathematical modeling was developed to maximize the shear strength of a soil under the influence of a tillage tool (Glancey et al., 1996):

\[
\tau_{\text{max}} = \tau_o + \tau_i V_f \tag{1.1}
\]

Where:

\( \tau_{\text{max}} \) = maximum shear stress at failure (kPa)

\( \tau_o \) = soil property related to static component of the static shear strength (kPa)

\( \tau_i \) = soil property related to the dynamic component of soil shear strength, proportional to the operating speed \( [\text{kPa (ms}^{-1})^{-1}] \)

\( V_f \) = forward travel speed of the tool \( (\text{ms}^{-1}) \)
1.4 WEAR AND ITS MECHANISM

Wear can be defined as the progressive loss of material from the operating surface of a body occurring due to relative motion at the surface. The primary cause that limits the persistence of many agricultural tool is wear. The wear of tillage equipment has their own characteristics, which are different from other types, since they interact with soil with unpredictable conditions in the field. Accordingly, various types of wear along with its mechanism must be understood. Various types of wear are described as follow:

1.4.1 ABRASIVE WEAR

The removal or plastic deformation of a material due to forced sliding of hard abrasive particles or bulges against the solid surface is termed as Abrasive wear. The solid surface of the target material was physically damaged and scratched by a counter body harder than the material itself. If the impact of harder material is normal, the abrasive particles generally bounced back or get imbedded into the softer material causing the plastic deformation followed by cutting. However, if the impact is tangential, then the ploughing and micro-cutting are the mechanisms responsible behind the material removal.

Abrasive wear is commonly classified according to the type of contact and the contact environment. The type of contact determines the mode of abrasive wear. There are two different situations, where abrasive wear may occur and are shown in Figure 1.5 (a) & (b) where abrasive wear may occur:

a) **Three-body abrasion** is one in which the harder abrasive particles get trapped between two solid surfaces sliding against each other, causing either removal of other or get imbedded into one followed by cutting of other. Such erosion is observed in milling machineries, mining industry, and grinding machines working in desert.
b) **Two-body abrasion** is one in which the two solid bodies are in direct contact and slides one over the other, the asperities of the harder surface ploughed or cut the material from the other surface. Further, the two-body abrasion can never be eliminated because even the smoother surface has peaks and valleys up to some extent. But it can be controlled by proper modification of the material. Also, in case of two-body abrasion, with the passage of time, work hardened wear debris and particles form contaminated lubricant get generated and being trapped between the surfaces and the wear may evolve into three body abrasion. Thus, two-body and three-body abrasions may exist together.

There are several factors which influence abrasive wear and hence the manner of material removal. Three different mechanisms already developed by researchers, which shows about the occurrence of wear are hereby mentioned as Figure 1.6.

**Plowing:** 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:** - 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. This mechanism closely resembles conventional machining.

➢ **Fragmentation:** - 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 by spalling.

### 1.4.1.1 Prediction of abrasive wear rate

Several models have been proposed to predict the volume loss in abrasive wear. A simplest one that is Archard equation involves the scratching of materials by a conical/angular hard particle, under an applied load of ‘P’, the hard particle penetrates the material surface to a depth of ‘h’ which is linearly proportional to the applied load ‘P’ and inversely proportional to the hardness ‘H’ of the surface being abraded. As sliding occurs, the particle will plough (cut) the surface producing a groove, with the material originally in the groove being removed as wear debris. If the sliding distance is ‘L’, the wear volume (V) can be expressed as:

\[
V = K \frac{PL}{H}
\]

(1.2)

In which, K is wear coefficient partly reflecting the influences of geometries and properties of the particles (or asperities), and partly reflecting the influences of many other factors such as sliding speed and lubrication conditions. Equation (1.2) indicates that wear loss can be reduced by

➢ decreasing contact load,
➢ reducing sliding distance,
➢ reducing K value by eliminating the presence of hard particles and reducing surface roughness of the counter face.

However, these changes are frequently impossible in practice if the function of a machine is to be maintained. Then, increasing hardness (H) by means of material selection, heat treatment and surface engineering will be the most effective and relatively easy way to solve an abrasive wear problem.

1.4.2 ADHESIVE WEAR

Adhesive wear occurs due to localized bonding or welding between contacting solid surfaces leading to material transfer between the two surfaces and loss from either surface.

Every material has peaks and valleys even after the polishing to a larger extent, no such surface exists which has complete flat surface. If the two such surfaces comes into surface contact, the actual contact occurs at valleys and peaks, which is approximately 1 % of the total apparent contact area. Further, due to sliding of these surfaces against each other, the inter-metallic adhesion will occur at the peaks and valleys, forming cold weld junctions. The strength of these junctions will depend upon the surface properties and mutual solubility of contact metals. In most of the metallic materials, there is high mobility and adhesion tendency is also appreciably high, which contributes to stronger junction.

Further due to sliding between these surfaces, the material gets tear out either from the cold weld junction or in the original softer material. The location of tear mainly depends upon the strength of the cold weld joint and the softer material. If the two materials have low solubility or the metallic surfaces separated by oxide film, the cold weld junction is weaker, and the material will get removed from the junction, causing
lesser material loss during wear. But if the softer material is weaker than the junction, the tearing will occur inside the softer material and the small chips of the softer material will be carried away and gets imbedded to the harder body, as a schematic shown in Figure 1.7. This process is known as material transfer.

![Figure 1.7 Adhesive wear occurs by material transfer](image)

### 1.4.2.1 Prediction of adhesive wear rate

Adhesive wear is dominated by material transfer and removal of the transferred material. The former is determined by the material properties and the strength of adhesion junction while the latter by the sliding conditions. Archard proposed that adhesive wear volume loss (V), can be expressed by the following equation

\[ V = K \frac{P}{3H} \]  

(1.3)

Where,

- P is the applied normal load,
- H is the hardness of the softer material of the two contact bodies,
- K is referred to as wear coefficient.

K is related to the possibility of generation of wear debris from each contact. K would be higher if two contacting materials have higher mutual solubility. K would also be higher when wear occurs in a vacuum or an inert atmosphere, such that adhesive wear
is one of the major problems for contacting components, e.g. bearing, in a spacecraft or satellite.

The adhesive wear resistance is to be improved as following:

➢ Improving mechanical properties (hardness and strength) of the contacting material, due to tearing is more likely to happen in adhesion junction.

➢ Material selection or changing the chemical nature of the surfaces, e.g. by surface engineering, will fundamentally reduce the possibilities of adhesion and reduce adhesive wear rate.

1.4.3 EROSiVE WEAR

In this type of wear, the harder solid particles impinge onto the solid surface either individually or accompanied by the liquid media. As a result of impact between the solid particles and surface, the material from the surface gets removed or deformed (Sarkar, 1980). Further in some cases, the embedment of solid particles may also occur. In erosive wear, the different type of forces acts onto the particle in contact with a solid surface (Stachowiak et al., 2005).

Erosive wear (or erosion) occurs when particles in a fluid or other carrier slide and roll at relatively high velocity against a surface. Each particle contacting the surface cuts a tiny particle from the surface. Individually, each particle removed is insignificant, but a large number of particles removed over a long period of time can produce staggering degrees of erosion. Erosive wear can be expected in metal parts and assemblies where the above conditions are present; common problem areas are found in pumps and impellers, fans, steam lines and nozzles, the inside of sharp bends in tubes and pipes, sand and shot blasting equipment, and similar areas where there is considerable relative motion between the metal and the particles.
1.4.4  FATIGUE WEAR

Surface fatigue wear or delaminating is the process of crack formation, crack growth and particle detachment of a surface caused by cyclic stress variations in the contact. It is characterized by an incubation period: the actual wear process only starts after some period of use. Typical applications that are subject to surface fatigue are ball bearings and railway wheels and tracks.

1.4.5  FRETTERING WEAR

In this type of wear the protrudes of two surfaces slides against each other, when subject to the normal load as seen in other tribological systems. The material loss in case of fretting wear increases with increase in surface roughness of the material. Further with decrease in amplitude of the projections, the fretting erosion will get similar to that of the erosion occurs during reciprocating sliding under comparable conditions of environment and load (Sarkar, 1980).

1.4.6  CHEMICAL WEAR

Chemical or corrosion wear is the chemical phenomenon where the deterioration of a metal occurs due to a chemical reaction between the metal and his surrounding environment. Such type of erosion occurs in both lubricated and un-lubricated surfaces during their functionality because of the chemical reaction between the wearing material and a corroding medium. In this erosion, the material in the form of thin film is removed, which is formed by chemical attack of contacting body (Stachowiak et al., 2005).

1.4.7  TRIBOCHEMICAL WEAR

Tribochemical wear occurs when one or both of the two surfaces chemically react with constituents in the lubricant or the environment. Once in contact, the layer of reaction products that is accordingly formed on the surface might be removed and a cycle of
continuous formation, removal and reformation of a layer of reaction products occurs, resulting in progressive material loss.

1.5 ABRASIVE WEAR TESTING MACHINES

Wear testing machines are used to measure wear resistance accurately during the laboratory testing. Since field testing of tillage tools is costly and time-consuming process, laboratory methods have been evolved by various researchers for the measurement of wear resistance. Tests conducted at different experimental stations like on field and laboratory test show that metal hardness cannot be alone taken as an index of resistance to wear of metals used in handling soil (Reed et al., 1951). Haworth (1949) developed different laboratory methods, same are presently used for abrasive wear studies. Brief description of the testing methods is described as following:

➢ Sand blast type
➢ Ball mill type
➢ Fixed abrasive type
➢ Abrasive lap type
➢ Rotating wheel type

Selection of a wear test unit not only depends on the mode of wear being investigated under simulated conditions but also on the objectives of the test. The sand blast and ball mill types are apparently not applicable to wear tests of materials used for tillage tools (Reed et al., 1951). Hence, the details of the remaining three types of wear testing machines described as following: -.

1.5.1 FIXED ABRASIVE TYPE

In fixed abrasive type wear testing machine, a metal specimen is made to rub against fine abrasive grains on the rotating disc under varying but controlled: loads, speed and sliding track. Such wear testing machines are represented by grinding wheels or rotating discs
with abrasive cloth paper fixed on flat surfaces of the disc with an adhesive. Pin-on-disc type is the common form of fixed abrasive type machine and has been used by many researchers. Pin abrasion wear testing simulates high-stress, quasi-two-body abrasive wear. The wear test is high stress because the abrasive grains are frequently fractured during the test. Many different pin abrasion wear testers have been developed over the years (viz. Pin-on-disk, Pin-on-belt, Pin-on-drum and Pin-on-table) with various geometries of wear track (viz. circular, spiral, linear, rectilinear and helical). All these devices expose the specimen to an environment where the abrasive grains are initially fixed to a substrate. ASTM G132-96 provides a useful guide to the general features of pin abrasion wear testing (ASTM, 2013a). The Pin-on-disc abrasion tester as shown in Figure 1.8, has been used to study the wear of materials. The load pressing a test specimen against a bonded abrasive paper, either low stress abrasion or high stress abrasion may be produced. Early results obtained from this type of apparatus were reported by Khruschov (1974) and Babichev. It was found that the wear resistances of any material like annealed pure metals and steels were substantially in direct proportion to their indentation hardness. The relevance of their work to the wear of agricultural implements has been discussed by Richardson. It was reported that in field tests of ground engaging tools for a wide range of soil conditions, the relative wear rates of a number of metals were in general agreement with the results obtained by (Ruff et al., 1993).

Apart from heat treated and untreated base materials, this test has extensively been used to study the wear behavior of hard-faced and thermally sprayed components fitted in aircraft, automobiles, constructions machinery, gas exploration and chemical processing equipment that are subjected to sliding and abrasive wear conditions (Thakur et al., 2014).
1.5.2 ABRASIVE LAP TYPE

In this type of testing machine, wear is caused by rubbing the specimen against loose abrasive mass, wet or dry and kept either in a container or in a soil bin. Necessary compaction of the medium may also be simulated in this type of test rig as shown in Figure 1.9.

1.5.3 ROTATING WHEEL TYPE

These machines use either dry or wet abrading medium, such as sand/soil, which are either fed or carried between the faces of abrading disc and test sample. Original unit of this type was developed by Brinell. Subsequent development and modifications were made by the investigators for their convenient use, but the working principle remained unaltered. Reed et al., (1951) built a wear testing machine that followed the principle
developed by Brinell and was later accepted as USDA. This is the basic principle of the test described by ASTM-G65 (ASTM, 2010a) and the test schematic is shown in Figure 1.10. The rubber wheel tester, which was standardized by ASTM, has been used to produce low stress three-body abrasion (Hawk et al., 1999). The test is widely used to rank materials for components that will be subjected to low stress abrasion in service like agricultural tools, chutes and hoppers in ore processing plant, and construction equipment (Swanson et al., 1981).

![Schematic diagram of dry sand rubber wheel abrasion test rig.](image)

This test has a longer history and has generated more data than other types of abrasion testing machines. However, this test configuration has some limitations. For example, the abrasive particles may get embedded in the rubber wheel and scratch the test specimen in a manner similar to two-body abrasion. In the test, a plane specimen is loaded against the rim of a rotating rubber wheel; sand is fed into the gap between the wheel and specimen and is carried past the specimen and thus abrades it. The behavior of a material in a rotating wheel abrasion test depends not only on the intrinsic properties of the test sample itself, but also on the conditions of the test, such as nature of the abrasive particle type, size, shape, brittleness, the wheel hardness, its stiffness and the nature of
the environment (Trezona et al., 1999; Shipway et al., 2004 & Fang et al., 1991). In such a machine, the test sample was held against the abrading disc at a uniform pressure applied by a weight. The screened sand/soil contained in a hopper is continuously pouring in the gap between the abrading disc and test sample. The standard test consisted of rotating abrading disc to give a linear motion of a point on its circumference. Results of the preliminary trials compared well with the field tests.

1.6 INFLUENCE OF VARIOUS PARAMETERS ON ABRASIVE WEAR

For earth engaging implement, the most dominant wear mechanism is abrasion. Nathan and Jones (1966) reviewed the work on abrasive wear study by different authors and assumed that the applied conditions which influence the wear are load, length of run, mean diameter of abrasive particles, velocity of the abrasive surface, types of abrasive particles, temperature and absolute humidity of the atmosphere etc. However, the results of earlier investigators as well as a preliminary investigation of their own showed that the changes in temperature and the humidity that occur in the laboratory have very little effect on the abrasive wear of metals. Based on the earlier studies, the following are crucial parameters to effect abrasive wear:

1.6.1 INFLUENCE OF ABRASIVE PARTICLE

The brief description about influence of abrasive particle is as under:

- **Abrasive particle shape:** The theoretical and experimental outcomes confirm that abrasive particle size has an adverse effect on rate of wear (Moore et al., 1983). Due to influence on critical size for fracture and change of transition load from elastic stage to plastic stage. The cross-sectional area of a groove from a contact will depend on the particle shape due to this ratio of cross-sectional area to projected area for contact of
spherical, conical and pyramidal shape increases by decreasing the radius, cone and included angle respectively (Moore et al., 1981). Generally, it is seen that above ratio is less for spherical as compared to pyramidal and conical shape. Thus, wear rate is higher for sharp pointed abrasive than blunt round abrasive shape in both of plastic and brittle mechanism of material removal (Deuis et al., 1998). 1/10th volume loss for low alloy steels and plain carbon with blunt shape using dry and wet sand rubber wheel abrasion test (Swanson et al., 1981).

- **Abrasive particle size:** Increase the particle size, it will increase the wear rate of material up to certain limit beyond that it becomes independent of particle size through all material and abrasive type is constant (Avery, 1961). The critical particle size is 100 Gm.

- **Abrasive particle hardness:** Abrasive particle hardness is also influence on the rate of wear. Higher hardness particle induces higher wear as compared to lesser hardness particle. The wear rate is also depending on the ratio of abrasive hardness $H_a$ to surface hardness $H_s$ (Richardson, 1968). It is seen that when the ratio of abrasive hardness $H_a$ to surface hardness $H_s$ is greater than 1.2 it shows a hard abrasion and when the ratio of abrasive hardness $H_a$ to surface hardness $H_s$ is less than 1.2 it termed as soft abrasion. The critical value of $H_a/H_s$ has been estimated as 1.2 and about at this critical value, plastic deformation in the form of scratches and grooves occurs (Hutchings, 1992; Laesen-Basse et al., 1979 & Tabor, 1956).

- **Abrasive particle strength:** When the load on the particle is increased but there is no deformation or crushing in the particle then the shows that there is permanent deformation has occurred in the particle which also relevant to strength and toughness of the abrasive particle. There are two abrasive particles having similar hardness i.e. chert and quartz, but in case of chert having two to three times higher wear rate as
compared to quartz after that chert having a higher fracture resistance (Gahlin et al., 1999).

1.6.2 INFLUENCE OF OPERATIONAL PARAMETERS

For testing degree of abrasion, one needs experimental set up and various parameters are required to be taken care of that affects the wear of components. Following are the prime parameters that effect degree of abrasion.

- **Length of abrasive path**: It is imperative from the above discussion that wear loss during abrasion of metal in an abrasive medium is affected by the length of travel and the loss of metal due to abrasion is proportional to the length of abrasive path it travels. Based on the recommendations of the past studies, wear loss due to abrasion may be expressed as the loss of metal due to abrasion that has occurred during unit distance travelled by the specimen in contact with the abrasive medium. This unit has been adopted to express the wear loss in the present study.

- **Load**: Equation 1.2 anticipate that the wear rate is directly proportional to the applied load because sudden transitions from low to high wear rate. Sometimes it reverses back due to increase load beyond the limit that corresponds to change in mechanism of material removal.

- **Speed**: In the field, the soil particles strikes on the blade of the rotavators under running condition due to high speed of soil particles more wear occurred at contact point because of more normal pressure is generated at that contact point.

1.6.3 INFLUENCE OF FIELD ENVIRONMENT

There are some field parameters which vary with change in location and surrounding environment, are discussed below:
• **Moisture content of abrasive particle:** - In dry conditions means moisture content between 0 to 5 %, there is a direct contact between sand/soil particles with surface of wearing out but less wear because of their relative sliding velocity and interaction between the soil particles is less so that only few particles is wearing out over the blade of the rotavators. Kurchania (1997) observed that at higher moisture content of 10 to 15 %, higher wear rate is occurred. Sevemev (1972) found that in sandy loam soil with moisture content of 10 to 12 % is increased the intensity of wear rate at the contact point.

• **Depth of operation:** - As the depth of operation increases, more surface area of blade comes in contact with abrasive particles which results in more wear rate and drastically increase the soil pressure at the nose of the blade which also responsible for higher wear rate. Generally, the depth of rotavators used is 15 cm.

1.7 **VARIOUS TECHNIQUES TO IMPROVE THE WEAR RESISTANCE OF MATERIAL**

The various techniques to improve the wear resistance of material are explained in the following paragraph:

1.7.1 **HARD FACING**

It is a metal working process where harder or tougher material is applied to a base metal. It is welded to the base material and is generally takes the form of specialized electrodes for arc welding or filler rod for oxyacetylene and TIG welding. Hard facing may be applied to a new part during production to increase its wear resistance, or it may be used to restore a worn-down surface. Hard facing by arc welding is a surfacing operation to extend the service life of industrial components, pre-emptively on new components, or as part of a maintenance program. The result of significant savings in machine down time
and production costs has meant that this process has been adopted across many industries such as Steel, Cement, Mining, and Petrochemical, Power, Sugar cane etc.

➢ **Arc welding method:** - The choice of arc welding method depends primarily upon the size and number of components, available positioning equipment and frequency of hard facing. The welding methods used for hard facing are as explained below:

- **Manual Welding using stick electrodes** requires the least amount of equipment and provides maximum flexibility for welding in remote location and all position.
- **Semiautomatic welding** uses wire feeders and self-shielded, flux-cored electrodes increasing, deposition rates over manual welding.
- **Automatic welding** requires the greatest amount of initial setup but provides the highest deposition rates for maximum productivity. It can be done with the following combinations:
  - Neutral flux and alloy wire.
  - Self-shielded flux-cored wire with or without flux.
  - Alloy flux and mild steel wire.

### 1.7.2 COATINGS

One of the most common forms of surface treatment of a material is the application of a coating. Even when one spray paints a bare piece of metal, it is treating the surface and improving its characteristics. This may be the basic example, but the idea is clear. When a coating is applied to a substrate, it can improve its resistance to corrosion, fatigue, and most importantly is wear. In recent days there are many different types of coatings that are being developed. The coatings that are most related to the improvement of wear are electroplating and thermal spraying.

a) **Electroplating:** - It is a plating process in which metal ions in a solution are moved by an electric field to coat an electrode. The process uses electrical current to reduce
cations of a desired material from a solution and coat a conductive object with a thin layer of the material, such as a metal. Electroplating is primarily used for depositing a layer of material to bestow a desired property (e.g. abrasion and wear resistance, corrosion protection, lubricity etc.) to a surface that otherwise lacks that property. Another application uses electroplating to build up thickness on undersized parts. The process used in electroplating is called electro deposition.

b) Thermal spraying: - It is the technique for coating in which melted (or heated) materials are sprayed onto a surface. The “feedstock” (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame). Thermal spraying can provide thick coatings (approx. thickness range is 20 micrometers to several mm, depending on the process and feedstock), over a large area at high deposition rate as compared to other coating processes such as electroplating, physical and chemical vapor deposition.

1.7.3 SURFACE LAYERS

To prevent hard rough asperities on a surface from penetrating into a softer counter surface, the softer surface can be covered with (a combination of) surface layers with a higher hardness than the asperities. A range of such hard surface layers is considered. All surface layers are commercially available. Based on the manufacturing process they can be divided into three classes:

➢ Physical vapor deposition layers: - In PVD processes the coating material (the reactant) is evaporated in a high vacuum chamber ($10^{-1}$-$10^{-4}$ Pa) at a temperature ranging between 200 °C to 500 °C. By means of plasma the reactant is transported to the substrate where it condenses. Using PVD processes it is possible to deposit atomically thin layers on a substrate. This layer is uniform in thickness, so the application of a PVD layer to a surface does not affect the surface roughness characteristics. Examples
of surface coatings that are deposited using a PVD process are Chromium Nitride (CrN), Titanium Nitride (TiN) and Metal-Carbon (MC) layers. Because of their high hardness the latter are also known as Diamond like Carbon (DLC) coatings.

Often these coatings are applied as duplex layers, consisting of at least two layers with different properties. A common example is the use of an intermediate layer to ensure proper adherence of the top layer to the substrate. More complex duplex layers can consist of as many as 20 thin layers. On relatively soft and ductile substrates the application of a duplex coating may be required in order to provide a gentler transition in physical properties and to prevent cracking of the thin hard coating due to the deformation of the substrate (the egg-shell phenomenon). This also applies to the EN-GJS-700-2 tool material used in this work as the material is ductile, but also because of the very soft carbon nodules. Some typical hardness values of PVD coatings are presented in Table 1.2.

Table 1.2: Typical properties of some hard surface layers

<table>
<thead>
<tr>
<th>Coating</th>
<th>Coating process</th>
<th>Hardness [GPa]</th>
<th>Thickness [μm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium Nitride (TiN)</td>
<td>PVD</td>
<td>28</td>
<td>1-5</td>
</tr>
<tr>
<td>Metal-Carbon (MC)</td>
<td>PVD</td>
<td>10-25</td>
<td>1-10</td>
</tr>
<tr>
<td>Chromium Nitride (CrN)</td>
<td>PVD</td>
<td>20</td>
<td>1-8</td>
</tr>
<tr>
<td>Hard Chromium (HCr)</td>
<td>Electroplating</td>
<td>8-11</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>Cobalt based alloy A (St6)</td>
<td>Laser cladding</td>
<td>4</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Cobalt based alloy B (Ult)</td>
<td>Laser cladding</td>
<td>3</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

Electrolytic layers: - In electrochemical deposition or electrolytic chrome plating the substrate is submerged into a chromium-acid solution and negatively charged. A high current flow from the inert anode to the work piece, resulting in deposition of the chromium from the solution to the cathode. Common current densities are in the order of $1.2 \times 10^4$ A/m$^2$. A large range of layer thicknesses is possible, from several
micrometers to more than a millimeter. An example of a surface layer deposited using an electrochemical process is a hard chromium layer.

➢ Laser clad layers: - In laser cladding the surface layer is composed of a powder that is fed onto the surface of the substrate. A laser beam melts both the powder and a top layer of the substrate, resulting in a good bond between the coating and the substrate and limited dilution. Common layer thicknesses range from tenths of millimeters for single layers to several millimeters for stacked layers. Typical powder materials are tungsten alloys and cobalt alloys. After application of the layer a surface finishing operation like grinding or polishing is required. Some properties for two commonly applied cobalt based clad layers are listed in Table 1.2.

1.7.4 CONVENTIONAL HEAT TREATMENT PROCESS

The heat treatment on steel material is one of the most important factors in determining how it will perform in service. The standard process of the conventional heat treatment for the steel material consists of; heating from room temperature to austenite temperature and then soaked at this temperature for a predetermined time period and followed by quenching in different mediums like: air, oil, water, ice, salt cool etc.

1.7.5 CRYOGENIC TREATMENT

The word cryogenic is derived from the Greek words “Kryos” (meaning cold) and “Genes” (meaning born). It is a modification of a material or component using cryogenic temperature. During recent year’s studies, interest has been shown in the effect of cold treatment on the steels. It is very useful to enhance the wear resistance. Cold treatment is generally classified as either so called “sub-zero treatment” at temperatures down to about (-80 °C) or “deep cryogenic treatment” at liquid nitrogen temperature (-196 °C). More recent evidence shows that the wear resistance is further enhanced by cryogenic treatment at liquid nitrogen temperature. Most researchers believed that there are two
mechanisms to improve the mechanical properties of the work that has been treated cryogenically. The first mechanism is attributed to the transformation of retained austenite to martensite. The second is to initiate the nucleation sites for precipitating many fine types of carbide in the matrix of martensite. Most scientific research on cryogenic treatment described the benefits in detail such as wear resistance and dimensional stability. However, many reports are not clear-cut understanding of the mechanisms by which how the cryogenic treatment improves the performance of the steels. Cryogenic treatment contributes to wear resistance due to fine η carbide precipitation rather than the removal of retained austenite only, however the study of the fine η carbide precipitation has been so sophisticated and there a lack of systematic study to clarify the microstructure change via cryogenic treatment. Two types of cryogenic treatment are generally applied:

- Shallow cryogenic treatment (SCT) which is performed between -75 °C to -95 °C.
- Deep cryogenic treatment (DCT) at liquid nitrogen temperature -196 °C.

From the above techniques, conventional heat treatment and cryogenic treatment are applied in the present research. Hence their details are discussed below:

**1.8 QUENCHING: CONVENTIONAL HEAT TREATMENT**

Heat treatment is a combination of heating and cooling operations, timed and applied to a metal or alloy in the solid state in a way that will produce desired properties. Heat treatment can be used to change the micro structure and enhance the properties of carbon steels. All basic heat treatment processes for steel involve the transformation or decomposition of austenite. The nature and appearance of these transformation products determine the physical and mechanical properties of any given steel. Various heat treatment techniques are available to improve hardness and wear resistance of steel.
1.8.1 QUENCHING

Maximum hardness that can be produced in any given carbon steel is that associated with a fully martensite microstructure. The hardness of the martensite is primarily decided by its carbon content as shown in Figure 1.12. The high hardness and associated high strength, fatigue resistance and wear resistance are the prime reasons for the quenching heat treatment that produce martensite.

Martensite is formed when there is no time for carbon atoms to diffuse out of the face centred cubic austenite to produce the body centred alpha ferrite with its Figure 1.11. Martensite is produced when an iron-carbon alloy is heated to austenitizing temperature (above A3 for hypoeutectoid steels) and subsequently cooled rapidly from the austenitic state as shown in Figure 1.12.

The minimum cooling rate that will give martensite is called the critical cooling rate. Cooling rates faster than this give a completely martensite structure but rates slower than this will not. The value of critical cooling rate depends on the percentage of carbon present, the smaller the percentage of carbon, higher the cooling rate. Below about 0.3 %
carbon, the rate of cooling needed to prevent the diffusion of the relatively small numbers of carbon atoms, is too high to be achievable by quenching the steel in cold water.

![Diagram showing heat treating temperature ranges for plain carbon steels](image)

**Figure 1.12: Heat treating temperature ranges for plane carbon steels**

### 1.9 DEEP CRYOGENIC TREATMENT

The cryogenic treatment is performed as an add-on process over the normal heat treatment process of the boron steels to enhance its properties. Cryogenic treatment is an extension of the conventional heat treatment to achieve 100% martensite. This treatment alters the material microstructure that enhances its strength and wear resistance. Cryogenic treatment is the process of cooling a material to extremely low temperatures to generate enhanced mechanical and physical properties. There are two types of cryogenic treatment, called “shallow cryogenic treatment”, treated at temperatures around 193 K (-80 °C), and “deep cryogenic treatment”, treated at temperature closer to the liquid nitrogen temperature (-196 °C). For maximum benefits cryogenic treatment should be introduced between the hardening and tempering processes (Vimal et al., 2008 & Bryson, 1999).

Cryogenic is done to make sure that there is no retained austenite during quenching in cryogenically treated steel. The transformation of austenite to martensite is shown in Figure 1.13. When steel is at the hardening temperature, there is a solid solution of carbon and iron, known as austenite. The amount of martensite formed at quenching is
a function of the lowest temperature encountered. At any given temperature of quenching there is a certain amount of martensite and the balance is untransformed austenite. This untransformed austenite is very brittle and can cause loss of strength or hardness, dimensional instability, or cracking (Reasbeck R. B., 1989).

Figure 1.13: Transformation of austenite to martensite (Khandey U, 2009)

A low-temperature environment is termed as cryogenic environment when the temperature range is below the point at which permanent gases begin to liquefy. Permanent gases are the elements that normally exist in the gaseous state and were once believed impossible to liquefy. Among others, they include oxygen, nitrogen, hydrogen, and helium. Some of important cryogen with their boiling points is listed in Table 1.3.

<table>
<thead>
<tr>
<th>Cryogen</th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>−183</td>
<td>−297</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>−196</td>
<td>−320</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>−253</td>
<td>−423</td>
</tr>
<tr>
<td>Helium</td>
<td>−269</td>
<td>−452</td>
</tr>
<tr>
<td>Neon</td>
<td>−246</td>
<td>−411</td>
</tr>
<tr>
<td>Argon</td>
<td>−186</td>
<td>−302</td>
</tr>
<tr>
<td>Krypton</td>
<td>−153</td>
<td>−242</td>
</tr>
<tr>
<td>Xenon</td>
<td>−107</td>
<td>−161</td>
</tr>
</tbody>
</table>

➢ **Deep cryogenic treatment:** - In order to achieve deep cold temperatures, materials cannot be directly kept in the freezer at -185 °C, because the temperature difference
is very high and fast cooling will lead to quench cracks. In the present investigation the boron steel material which has undergone the optimized conventional heat treated are slowly cooled from room temperature to -185 °C at a rate of 0.5 °C/min, soaked at -185 °C for 12, 24 & 36 hours, and finally heated back to the room temperature at a rate of 0.5 °C/min allowing the material to be stabilize. Then the samples were subjected to tempering cycles to relieve the stresses induced by cryogenic treatment. This was accomplished by increasing the temperature to tempering temperature and held at this temperature for a particular time then slowly reducing the temperature back to room temperature.

1.9.1 PROCEDURE TO CONDUCT DEEP CRYOGENIC TREATMENT

The procedure adopted to conduct the cryogenic treatment and the flow chart of cycle-run is shown in Figure 1.14 is as follow:

➢ **Ramp down:** - A typical cryogenic cycle will bring the temperature of the specimen down to -185 °C with a cooling rate of 0.5 °C/min. This avoids thermal shocking of the part. There is ample reason for the slow ramp down. Think in terms of dropping a cannon ball into a vat of liquid Nitrogen, which is near -196 °C. The inside wants to
remain at room temperature. This sets up a temperature gradient that is very steep in the first moments of the parts exposure to the liquid Nitrogen. The area that is cold wants to contract to the size it would be if it were as cold as the liquid Nitrogen. The inside wants to stay the same size it was at room temperature. This can set up enormous stresses in the surface of the part, which can lead to cracking at the surface. Some metals can take the sudden temperature change, but most tooling steels and steels used for critical parts cannot. So, ramp down prevents the thermal shocking of the parts.

➢ **Soaking Temperature:** - Soaking temperature is the temperature at which the samples are held to be cryogenically treated by using liquid nitrogen. Samples can be soaked to a minimum of −196 °C (77 K), the boiling temperature of nitrogen. Many researchers believe that depending upon the material, complete transformation takes place at the lowest temperature. With developments in cooling technology, it is known as cryogenic technology. However, references also exist, where the samples were soaked at -150 °C (123 K) improve the properties of the steel. Researchers have conducted experiments at various temperatures, according to the chemical composition of the material and the treatment on the material to finalise the soaking temperature.

➢ **Soaking period:** - Soaking period means the material is soaked (hold) at the cryogenic temperature i.e. -185 °C for a long time, specifically for 12 to 48 hours. During the soak segment of the process the temperature is maintained at a low temperature. Although things are changing within the crystal structure of the metal at this temperature, these changes are relatively slow and need time to occur. One of the changes is the precipitation of fine carbides. It is found that soaking time in the process also provides time for the crystal structure to react to the low temperature and for energy to leave the crystal structure (Yong A.Y.L., 2005). In theory a perfect crystal
lattice structure is in a lowest energy state. If atoms are too near other atoms are too far from other atoms, or if there are vacancies in the structure or dislocations, the total energy in the structure is higher. By keeping the part at a low temperature for a long period of time, it is found that some of the energy go out of the lattice and making a more perfect and therefore stronger crystal structure.

➢ **Ramp up**: - Ramp up means to bring the material back to room temperature from cryogenic temperature. It takes eight to fifteen hours as per the heating rate. It is very crucial step of the cryogenic treatment because when we increase the heating rate then material faces some problems like cracking.

➢ **Temper ramp up**: - Tempering ramp up is a cycle in which cryogenic treated materials are heat up to predetermined temperature above the room temperature. It plays an important role for ferrous material to regain its ductility on the sacrifice of hardness. Cryogenic treatment converts the retained austenite into martensite. This primary martensite increases the brittleness of the material. Tempering on cryogenic treated material reduces its brittleness and increase its toughness. Tempering temperatures range are to be selected as the per requirement of material, the tempering temperature range varies from 150 to 600 °C.

➢ **Temper hold**: - Tempering hold means to hold (soaked) the material at tempering temperature for a predetermined period to get the benefit of this cycle. The actual tempering soak (hold) period in the range of 1 to 3 hour, which depends upon the materials shape and size. It may be more than one tempering cycle to get the desired properties of the material.

The wear and tear of tillage equipment’s have their own characteristics, as they are interacting with soils of different moistures, textures and other unpredictable conditions in the field. The rotavator is an efficient equipment, which saves energy and
time as compared with other tillage equipment. The rotavator tine operates under dynamic loading, subjected to abrasive wear. The studies on wear of tine as well as wear resistance of different surface treatments are scarce, although wear is the most important factor for predicting service life of a tine. Therefore, there is a need to study these aspects carefully with some specific objectives. Accordingly, present research work was planned to execute. The complete organization of the thesis is described in the next section.

1.10 ORGANIZATION OF THE THESIS

To achieve all the set objectives, thesis has been organized in following chapters: introductory, literature review, design of experiment, methodology, experimentation, results & discussion, conclusions and recommendations for future work.

Chapter I covers the background of the rotavator along with different types of tines, soils and its dynamic properties. Various types of wear are described in brief, by which material deteriorates. Various types of abrasion wear testing rigs as well as different types of hard facing techniques are elaborated. Further conventional heat treatment and cryogenic treatment are also described. Complete organisation of the Thesis is mentioned in the present chapter.

Chapter II describes literature review on previous research conducted in rotavator tillage tool parameter studies, surface improvement studies, conventional and cryogenic studies and dry abrasive wear testing studies. Different test options for various types of wear assessment are described by using different types of hard facing techniques.

Chapter III summarizes the conceptual and practical elements of design of experiment along with various optimization techniques. Taguchi method has described in elaborated form, ANOVA, regression model, residuals etc are also described.
Chapter IV presents the methodology used for testing and their commissioning for the present work. The parameters, factors & their levels used for thermal cycle like conventional heat treatment and deep cryogenic treatment.

Chapter V describes the results obtained from different investigations on blade material for revealing and analysing different aspects like microstructure, impact, hardness and abrasion wear. The results are recorded under this chapter. The detailed discussion of each and every aspect was held in this chapter.

Chapter VI presents the conclusions obtained from the present research work and recommendations for the treatment on rotavator blade material in the field of dry sand abrasion test assessment.