2.1 INTRODUCTION

Review of available published literature on any specific topic of research is the first valuable step to be taken to get an idea about the present status of that particular topic. In order to get familiarity with the established methods & procedures of conducting work, to avoid duplication of work & wastage of precious time; this stage of investigation must be carried out as comprehensively as possible. The available literature has been organized under the following topics for better understanding are:

➢ Rotavator studies
➢ Surface improvement studies
➢ Cryogenic studies
➢ Wear studies

2.2 ROTAVATOR STUDIES

Operating parameters of tool and other factors related to soil play significant role in abrasion. Soil properties that influences abrasion includes shape, hardness, and size of the soil particles etc. Literature review of some of these parameters are as follows:

*Yatsuk et al., (1981)* studied the relatively constant depth of tillage was observed in a pull type tillage implement that had straight cutting edges in a horizontal plane. Even after fixed depth setting was used in case of rotary tillage implements having horizontal axis, irregularities in tillage depth were detected. Some untilled ridges were found at the bottom of tillage layer of soil, during the rotary soil cutting process. Depth of tillage became nearly uniform when these ridges were small.
Murthy, (1987) was investigate the effect of various types of soil and the operational parameters selected, for abrasive wear behavior on cultivator shovel. Selected various grades of soil namely: loam sand, clay loam, sandy loam, sandy clay loam and light clay. It was noticeable that the wear rate (mg/km) of shovel was more, when a soil having higher concentration of sand was used. It was concluded that the wear rate of shovel is higher by using soil like sandy loam, pure sand and loam sand soil.

Kushwaha et al., (1989) designed and fabricated a centrifugal accelerated wear testing apparatus for determining wear characteristics of agricultural tool materials in sand and soil. Wear tests were carried out with seven different tool metals using the centrifugal wear tester. The results indicated a wide variation in wear characteristics of tool materials in sand and soil. The rate of wear was higher in sand than that obtained in soil.

Cruz et al., (1992) investigated the passes necessary for quality puddling of soil by employing rotary cultivator in a paddy field. They deciphered, single pass was required for the regions having fee weeds and area which have higher volume of weeds required at least two passes.

Niyamapa et al., (1994) performed the experiments in lab condition using optimum design parameters for a rotary cultivator in a soil bin having moisture content 23.26 % and bulk density 1.29 g/cm². The trials were carried out at different forward speeds of 0.16, 0.23, 0.35, 0.64 & 1.25 m/s, and variable rotor speeds of 140, 160, 180, 200 & 220 rpm at working depth of 12 & 18 cm. By increasing the tilling depth, rotor speed and forward speed at a given tiller width, power requirement for throwing and cutting soil increased. Soil breakage was also affected by these variables. High forward speed, low rotor speed and higher depth resulted in larger clod sizes. However, smaller clod sizes observed when rotor speed was high, and forward speed and tillage depth was low.
Rajaram et al., (1998) analyzed the seasonal wetting and drying of soils induces drying stresses that alter the soil physical state and its properties. The performance of vertical tine was investigated in a clay-loam soil subjected to three different levels of drying stress in a soil bin. The results showed that changes in most soil properties caused by tillage depended on drying stress. Soil bulk density decreased after tillage, although it was not significantly affected by drying stress. Soil shear strength, tine draft and aggregate size increased significantly with drying stress. Dried soils subjected to high drying stress broke in a less periodic manner and into larger masses than unwetted soil.

Rajaram et al., (1999) analyzed the agricultural soils are subject to seasonal wetting and drying cycles. Effect of drying stress, as influenced by one cycle of wetting and drying, on physical properties of a clay-loam soil was investigated in the laboratory. The physical properties studied were soil bulk density, cone penetration resistance, shear strength, adhesion, aggregate size and stability. Three drying stress treatments were made by wetting air-dried soil of initial moisture content of 12 % (on dry weight basis) to three different higher moisture contents, namely 27, 33 and 40 %, and then drying each of them back to their original moisture content of 12 %. The results showed that the soil strength indicated by cone penetration resistance and cohesion, and soil aggregate size, increased with the degree of drying stress. However, the soil bulk density did not change significantly with the drying stress.

Lee et al., (2003) investigated the effects of rotary blade shape, rotational direction, number of rotary blades around the periphery, with and without soil-cutting disc blades on soil break up and torque requirements. The tilling torque variation and the ratio of soil breaking as the shaft rotated through 180° during the up-cut and down-cut process. The torque requirements during the down-cut process were higher than those when the blade was cutting upwards. This result also shows good agreement with the results
reported by Hendrick et al., 1971a, that the torque requirements of a rotary shaft when cutting upwards was 20–30 % less than when cutting downwards. The ratio of soil breaking was 11.6 % during the up-cut process and 5.5 % during the down-cut process. Considering both the torque requirements and soil breaking ratio, the up-cut process would be advantageous for strip tillage by rotary tiller.

Salokhe et al., (2003) conducted experiments in a Bangkok clay soil to evaluate the performance of a rotary tiller equipped with reverse or conventional blades. The conventional rotary tiller was equipped with C-type blades whereas the reverse-rotary tiller had new type of blades. The tests were conducted on wet land as well as on dry land using tractor forward speeds of 1.0, 1.5 and 2.0 km/h. The results indicated that the PTO power consumption was less for the reverse-rotary tiller compared to the conventional tiller for all passes and forward speeds. For both rotary tillers, power consumption decreased as the number of passes increased, whereas power consumption increased when the forward speed was increased. At all forward speeds, the power consumption was the highest during the first pass and lowest during the third pass. The maximum difference of PTO power requirement was after the first pass at 1.0 km/h forward speed. The reverse-rotary tiller consumed about 34 % less PTO power under this condition.

Sharda et al., (2004) conducted the experiments on rotavator using L-type and C-type blades at two different rotor speeds 185 & 210 rpm for the study. The studies were conducted under four different field conditions, namely, manually and combine harvested paddy and wheat fields. It was found that the draft (negative) for L-shaped and C-shaped blades decreased (163 to 63 kgf) as the rotor speed increased (185 to 210 rpm) for the shield kept in the lowered (down) position. While operating the rotary tiller (rotavator) under different field conditions, it was observed that at a given rotary speed,
the rotary power requirement of C-shaped blades was 19 % less as compared to L-shaped blades because draft was about two and a half times more due to reduction in the rotor thrust. The power requirement of 24.2 kW was found to be the highest while operating the rotavator in the combine harvested paddy fields. The soil breaks up resulted from the action of L-shaped and C-shaped blades under selected field conditions was the lowest at 210 rpm of rotor speed while operating the rotavator in manually harvested wheat fields.

Tafesse et al., (2007) studied the mathematical model for fuel consumption, which was modified to evaluate the efficiency of different types of rotavator blades. Variables derived in this model includes cutting width, rotor radius, volume of soil tilled, rotational velocity, velocity ratio, depth of tillage and volume of soil tilled. Depth of tillage in case of “L” and “J” shaped blades was most prominent parameter that resulted in change of fuel consumption, amongst the type of blades tested. Fuel rate declined from 0.0843 to 0.0841% for “L” and 0.272 to 0.271 % for “J” shaped.

Celik et al., (2008) examined the height of ridges produced at the bottom layer of the tilled soil play an important role in determining the effective tillage depth. Small ridge height is indicator of nearly uniform tillage depth, it is also a desired condition as it avoids excessive power requirement of agricultural implements and good for crop. The various variations of rotor radius, forward speed, number of blades on one side of flange and rotor rotational speed were used to determine their effect on ridge height. The heights of ridges produced by horizontal axis rotary tiller could increase or decrease by varying the tiller parameters. By increasing the blade peripheral speed, number of blades on one side of a flange, rotor radius and ratio of blade peripheral speed to forward speed, the heights of ridges decrease. The height of ridges increases by increasing the tillage pitch and forward speed.
Chahar et al., (2008) conducted the experiments on shovels of tractor drawn cultivators wear out variably with change in moisture content present in the soil. The study of wear was conducted on cultivator shovels coated with EWAC 1002 ET surface hardening powder in sandy loam soil. The tests were conducted under indoor soil bin conditions for 100 h at three soil moisture contents in the ranges of 6 to 9, 9 to 12 and 12 to 15 %. Weight loss in each shovel due to wear was recorded at an interval of 20 h. Wear rate was found maximum at 9 to 12 % moisture content.

Chaudhary et al., (2008) conducted experiments to evaluate the influence of rotary blade and peg type puddlers on soil physical and dynamics properties and their subsequent effect on rice yield. The results revealed that the puddling index and hydraulic conductivity were better, in rotary blade as compared to peg type puddled field. The puddling index increased with increasing level of puddling. The bulk density of puddled field increased with the level of puddling as well as time after puddling in all the treatments. Hydraulic conductivity decreased after puddling. Cone index (0-15 cm depth) was found to decrease after puddling over that of initial saturated soil and the reduction was observed more in case of rotary blade as compared to peg type puddled field. Since, there was no significant difference in grain yield with reduced level of puddling, rotary and peg type puddler may be used with one pass to minimize the sedimentation period for transplanting operation.

Libin et al., (2010) stated that the power consumption in analytical model of a L-shaped blade for a small rotavator, which is suitable for soil cultivation of hills and mountainous areas of southern China, was deduced. Then a power requirement optimizing method with a multi-objective parameter design for rotavator soil tilling such as forward travel speed, power shaft rotation velocity and soil pulverizing effect, was developed, which is a probability parameter optimization method based on index
atlases, written in the MATLAB program. A rotavator power requirement optimization method was developed using a multi-objective parameter design to optimize forward travel speed, power shaft rotation velocity and soil pulverizing effect. This probability parameter optimization method is based on index atlases written in the MATLAB program. Moreover, other working speeds optimization cases for tilling various soils with a small rotavator were also carried out. The results show that the proposed models and methods are valid and available.

Sharma et al., (2010) measured the moisture content in agricultural soil by means of an on-site, easy to use and real-time acoustic wave system. The method is based on the propagation of an acoustic continuous wave (CW) with frequencies below 900 Hz through the soil. Speed of these acoustic waves enables estimation of water content and degree of saturation in the agricultural soil. It is argued that the change in the speed of sound in relation to the moisture content of the soil can be used for a continuous monitoring and control of irrigation of crops, thus leading to minimum use of irrigation water for optimal crop growth and to other associated advantages. The agreement between the experimental results obtained from the laboratory prototype and those obtained theoretically from Brutsaert’s model for elastic wave propagation in soil-air-water system is presented.

Singh et al., (2011) studied to identify suitable material and heat-treatment process to produce high quality wear resistant rotavator blade with affordable cost for the Indian farmers. Twelve different blades were selected for the study, out of these six were selected for their chemical composition, mechanical & micro-structural studied. The study revealed that there was a wide variation in chemical composition and mechanical as well as micro-structural properties of these rotavator blades. It was found that
rotavator blades contained boron (50B50 steel) or some alloying elements was best wear resistance.  

*Kaur et al., (2013)* conducted the experiments in rotary soil bin in loamy and sandy loam soil. L-Shape blades of four different makes were mounted on the two flanges and their speed was varied from 140-150 rpm. Two rollers along their stand were mounted on soil bin for compressing the soil up to 4.5-5.0 kg/cm² compaction. The width of rotary blades was measured before and after the wear test. The profile change of rotary blades was also determining, for wear characteristics of tillage tools. The decrease in width of blade T1, T2, T3 and T4 at starting point of blade section were 10.65, 13.95, 3.68 & 4.36 % respectively in loam soil while 15.10, 17.10, 13.50 & 18.65 % respectively in sandy loam soil.

*Parkash et al., (2013)* studied the performance of rotavator using “L”-shaped blades being manufactured by different manufacturer in Punjab. The reduction in labour and shorter window period between two successive crops of wheat and paddy requires effective mechanization to increase the production. A large amount of energy is required for seed bed preparation and a small fraction of improvement in tillage equipment can save a significant amount of energy. Rotavator (or rotary tiller) is such a tool that can prepare the seed bed in a single operation thus saving time and energy. The data was collected from the test reports of rotavators of 20 different makes and model tested by Farm Machinery Testing Centre, Punjab Agricultural University, Ludhiana during the period 2006–2011. Great variation for pulverization index was observed. Fifty percent machine has puddling index in the range of 65–70 %. And for mixing of crops for green manuring into the soil, 70% machines have mixing index 80 %.

*Azadbakht et al., (2014)* performed the experiments based on a randomized complete block with 18 treatments; three different velocities 2.2, 3.5, 6.1 km/h; three different
depths of 5, 10, 15 cm and with two rotary ploughs horizontal axis and vertical axis with three replications were used. Result showed that maximum MWD in 6.1 km/h and 15 cm of depth were 55.6 and 52.5 mm for horizontal axis rotavator, respectively. The minimum MWD in 2.2 km/h and 5 cm of depth for vertical axis rotavator were 34.9 & 35.1 mm, respectively. The values of cone index 1861.1 & 2339.5 kPa and cross-sectional area disturbed 687 and 497.2 cm$^2$ for vertical axis rotavator and horizontal axis rotavator were obtained, respectively.

Makange et al., (2015) analyzed the performance of vertical and horizontal axis rotavators in terms of tilling quality of soil and energy requirement in the field at two different moisture contents (11.78 % and 10.51 %). The effects of two operating parameters namely tilling depth and operating speed on the physical properties of soil like mean weight diameter, penetration resistance, bulk density and disturbed area were evaluated. The average values of soil mean weight diameter, cone index, bulk density and the percentage of soil disturbed area by using vertical and horizontal axis rotavators were found to be 4.00 & 4.72 mm; 53.00 & 56.20 kPa; 1.18 & 1.22 g/cm$^3$ and 94.43 & 91.19 % respectively. The average values of fuel consumption and energy requirement were found to be 15.60 & 13.20 l/ha; 958.23 & 816.47 MJ/ha for vertical and horizontal axis rotavators respectively. Based on tilling quality of soil, vertical rotavator was found better while through economic point of view, the horizontal rotavator was found better. The optimum tilling depth and operating speed were found to be 10 cm and 2.71 km/h respectively for both the rotavators.

Korucu et al., (2016) conducted the experiment for soil surface roughness (SSR), which is strongly influenced by soil tillage implements, soil condition, properties and climate. The effects of two different operating conditions were established: sub-soiler with blade coulter (SBC) and sub-soiler without blade coulter (SWBC) at three different
working depths (0.25, 0.30 and 0.35 m), and with either a vibratory (V) or non-vibratory (NV) operation. The maximal SSR in both the applications to the direction of tillage was obtained at the sub-soiling without blade coulter-non-vibratory (SWBC-NV) (34.66 %) application at 0.35 m depth. The minimal SSR with perpendicular direction of tillage was occurred at sub-soiling with blade coulter vibratory (SBC-V) application at 0.30 m tillage depth.

Pal et al., (2016) performed the experiments to analyze the performance of various parameters of rotavator under actual field conditions. Moisture content (11.27, 17.04 & 22.87 %) was recorded in the different field conditions. The rear shield position was adjusted at full down, full up and middle positions and three different forward speeds of the tractor 2.5, 3.0 & 3.5 km/hr and three types depth of cut 5, 8 & 12 cm were used for the study. The study was undertaken to examine the influence of forward speed, depth of cut at different moisture content fields with dependent parameters such as draft, fuel consumption, power consumption, field efficiency, and residue incorporation by rotavator. The results indicated that as the forward speed, shield position full down and depth of cut increased, the value of draft, fuel consumption and power consumption also increased.

Jakasania et al., (2017) evaluated the performance of vertical rotary plough on fallow and cultivated land. The observed experimental variables are: moisture content of soil, bulk density of soil, cone index, soil mean weight diameter, wheel sleep, theoretical field capacity, effective field capacity, field efficiency, fuel consumption and weeding efficiency. The results were: soil moisture content 8.19 & 11.74 %, bulk density of soil 1.99 & 1.90 gm/cm³, cone index 0.236 & 0.144 kg/cm², soil mean weight diameters 4.17 & 3.86 mm, fuel consumption 6.30 & 5.76 l/hr, field capacities 0.17 & 0.23 ha/hr and field efficiency 71.53 & 82.14 % in case of fallow land and cultivated land.
respectively. It shows that the time required for rotary plough operation in fallow land was more than the time required for the cultivated land.

2.3 SURFACE IMPROVEMENT STUDIES

To improve the wear resistance of a material, its surface properties can be altered in accordance with the application. Several research papers were reviewed in order to become familiar with surface improvement techniques such as welding, coating and heat treatment; which are discussed below:

Salokhe et al., (1999) compared the power requirement and performance for quality of work by enamel coated and uncoated rotavator tines. The moisture content of the selected clay soil was 21.6 % (db). Enamel coated tines saved maximum power of 22 % during the first pass at a 1.5 km/h speed as compared to uncoated tines. Enamel coated tines also saved more power during the second pass with better soil inversion. On comparing enamel coated and uncoated tine based on mean weight diameter of soil, cone index and bulk density, the quality of work was nearly the same. The soil inversion produced by enamel coating was higher during the second and third pass by 30 & 50 % respectively than uncoated tines. Better soil inversion attained during second to third pass required slightly more power, but the wear rate of enamel coated tines is less than uncoated tines.

Murthy et al., (2001) worked on abrasive wear behaviour of WC–Co Cr and Cr3C2–20 (Ni Cr) deposited by HVOF and detonation spray processes. Abrasion tests were done using a three-body solid particle rubber wheel test rig using silica grits as the abrasive medium. The results showed that DS coating performs slightly better than the HVOF coating possibly due to the higher residual compressive stresses induced by the former process and WC-based coating has higher wear resistance in comparison to Cr3C2-
based coating. Also, the thermally sprayed carbide-based coatings have excellent wear resistance with respect to the hard chrome coatings.

Buchely et al., (2005) compared the microstructure and abrasion resistance of hard-facing alloys reinforced with primary chromium carbides, complex carbides or tungsten carbides. The hard-facing alloys were deposited onto ASTM A36 carbon steel plates by a shielded metal arc welding (SMAW) method. Three different commercial hard-facing electrodes were employed to investigate the effect of the microstructure. The abrasion tests were carried out in a dry sand-rubber wheel abrasion machine according to the procedure A of ASTM G65 standard. Microstructure characterization and surface analysis were made using optical and scanning electron microscopy. The wear resistance of material depends upon the shape & size of carbide formation and their chemical composition & symmetrical distribution in a microstructure matrix. Best wear resistance was achieved by a material having primary M7C3 or MC carbides with eutectic matrix in a microstructure, while mass loss was higher in a material having completely eutectic structure.

Bhakat et al., (2007) implements conventionally manufactured from high carbon (~0.70 C) steel is unsuitable for harsher applications (desert areas and harder soil condition) as after heat treatment it can produce hardness of HRC 38-45 only against a requirement of 50-60 HRC. Therefore, medium carbon (~0.30 C) steels with micro-alloy additions of boron/chromium are being selected to achieve higher hardness and better wear resistance in the steel. The increase in hardness is due to faster cooling rate (water quenching) and increased hardenability is attributed to micro-alloy additions of boron/chromium in the steel. The wear pattern, as measured from weight loss, clearly established the superior performance of boron/chromium steel. In fact, compared to mild steel, high carbon, boron steel and chromium steel were 2.28, 2.50 and 2.53 times
more wear resistant, respectively. The wear characterization gives a concrete direction to customers about the required quality, properties and grade of steel for agricultural tillage discs in their specific soil condition, which is cheaper and durable.

*Horvat et al., (2008)* analyzed wear for mould board plough shares of steel EN 10027 (HF-1), EN 50Mn7 (HF-2) and regular share. The hard facing was done by a combination of two welding techniques likely high frequency induction welding (HFIW) and shielded metal arc welding (SMAW). The sandy clay soil was selected for abrasive wear analysis, results were analyzed based on weight loss and dimensional changes of plough share. Lesser dimensional changes and weight loss was reported in hard-faced shares as compared to regular shares. Hard faced shares produced better quality of work and minimum fuel consumption as compared to regular share. At the end it was concluded that hard faced shares provided efficient solution for wear resistance.

*Kirchgaßner et al., (2008)* compared the abrasive wear behavior of as received material and the iron-based alloy by using metal arc welding (GMAW). The material under study are Fe-Cr-W-Mo-Nb alloy having more boron content and low alloyed Fe-Cr-B-C with 50 % tungsten carbides and fine precipitated Niobium carbides with crack less martensitic Fe-Cr-C alloy. Besides these a conventional hypereutectic Fe-Cr-Nb-C alloy was integrated in the program serving as standard. In order to simulate real field conditions on a lab scale, tests were performed with a standard ASTM G65 dry-sand rubber-wheel tester (3-body abrasion). A specially designed impeller-tumbler apparatus enabled investigation of impact abrasion wear tests (combined impact and abrasion wear). The evaluation of wear behavior was supported by micro and macro-structural investigations and by hardness tests.
Singh et al., (2008) investigated the synergic effect of heat-treatment and shot-peening on medium carbon steel with a small percentage of Boron (50B50 steel). Three heat treatment cycles (annealing, inter critical annealing, quenching and tempering) were done to obtain different material property combinations. Shot peening was done at different intensities (0.17 to 0.47 A) on heat-treated specimens. Low stress abrasion wear behavior of these steel specimens was investigated by rubber wheel dry sand abrasion tester confirming to ASTM G-65 standards. The results indicated that shot peening operation decreased the wear rate of soft as well as hard surfaces and improved the wear resistance when the peening intensity was restricted to a critical value of 0.37A.

Chahar et al., (2009) compared the effect of three surface modification techniques i.e. surface hardening, thermal spraying and electro deposition on wear characteristics of reversible cultivator shovels. The practical was conducted in laboratory circular soil bin of 1010 mm effective width under controlled conditions. For abrasive wear analysis, the selected abrasive sand having a moisture content of 10 to 15 %. The shovels were operated for 100 hours at a speed of 1 m/s and depth of 100 mm for wear test. The weight loss in each shovel was recorded at an interval of 20 hour. Maximum weight loss of 10.85 g was observed in the shovels hardened with chrome plating. Shovels hardened with surface powder coating of EWAC 1002 ET powder resulted in minimum wear as compared to other processes.

Kima et al., (2009) concluded that abrasive wear resistance of the hard-facing alloys increased up to 50 % compared to that of boron-free alloys with increasing boron concentration. The mechanism of the abrasive wear resistance changed at 0.6 % wt. boron. Below 0.6 % wt. boron concentration, the abrasive wear resistance was improved almost linearly, and strain-induced martensitic transformation was considered as the
controlling factor for improving the resistance. Above 0.6 % wt. boron, it was observed that the primary borides started to precipitate. Further increase in boron concentration was not able to enhance the resistance due to the negligible change of primary borides size and volume fraction. With these results, it was concluded that two different effects of boron on the wear resistance of the austenitic Fe-Cr-C-Si-B hard-facing alloys existed depending on the boron concentration.

Saxena, (2009) performed to undertake metallurgical up-gradation on rotavator blades to enhance its service life. Two grades of spring steel material one that has boron and second boron free is selected. Before wear analysis all the selected materials are conventional heat treated (quenched and tempered). These conventional heat-treated materials are compared with two popular brands of rotavator blades for abrasive wear analysis. These materials are analyzed under three different conditions namely: laboratory test using dry sand rubber wheel test rig, circular soil bin in a lab and the actual field run. The conventional heat treated 50B50 (with boron steel) is least mass loss of material and ranked first as wear resistance, but it put second as compared on cost analysis. The cost of boron steel much higher as compared to boron free steel in the Indian market. The SAE-6150 has been selected best replacement of boron steel after CHT on the benefit of cost ratio.

Saxena et al., (2010) studied the appropriate material, production technology & bulk hardening of rotavator blades results into inferior quality and short service life. Central Institute of Agricultural Engineering, Bhopal has developed the production technology of these blades which results into enhanced service life. The production package includes material, production aids for cold and hot forging technology and bulk hardening cycles. The economic viability of the unit adopting this package at different level of production has also been worked out for aspiring entrepreneurs.
Kang et al., (2012) conducted a similar comparative study on wear behaviour of thermal spray coatings on high tensile steel rotavator blades. The high tensile steel rotavator blades with three different detonation gun sprayed coatings for comparison i.e. WC-Co-Cr, Cr3C2NiCr and Stellite-21 were used. The study showed that the wear rates of Cr3C2NiCr and Stellite-21 coated blades significant superiority over the uncoated blade, but not as much as shown by WC-Co-Cr coated blade.

Singh et al., (2011) performed abrasive wear rate of medium carbon steel like SAE 6150 is tested using dry sand abrasion test rig after heat treatment (annealing, inter-critically annealing and quenched and tempered) and shot peening (ranging 0.17- 0.47 A at an interval of 0.1 A). The hardness and abrasive wear resistance of as-received and annealed steel were significantly lower in irrespective of peening intensity. The peening intensity reduced the wear rate, if limited to a critical value of 0.17 A. The functional relationship between wear rate and the factors influencing it was found statistically significant and could be used for prediction of abrasive wear at a given level of factors.

Yazici et al., (2011) investigated the effects of gaseous carbonitriding processes on wear characteristics of 30MnB5 steel. The matrix of the carbonitride treated samples has a better wear resistance compared to the substrates of the conventionally heat-treated sample in laboratory conditions. The carbo-nitriding treatment condition giving rise to the lowest wear weight loss with the pin-on-disc wear machine was selected in order to harden plough share specimens to be tested in field experiments. The carbonitriding process at 860 °C, with 0.9 % C, and 0.6 m³/h NH₃ for 105 min and quenched in 60 °C oil followed by a 60 min tempering process at 140 °C decreased 14.65 % of total wear weight loss and 26.47 % of total wear dimension loss of the ploughshare specimens in comparison to the conventional heat treatment process in field operational conditions.
Choteborsky, (2013) performed the destabilization heat treatment and air & furnace cooling respectively to enhance hardness, fracture toughness and abrasive wear resistance. Destabilization treatment of materials by furnace cooling caused higher secondary carbides in the dendritic austenite whilst by air cooling it showed smaller particles of secondary carbide. Also, it was found that destabilization temperature at 1,000 °C improves hardness compared with hard-facing after weld depositing. The study, however, indicated that Palmqvist fracture toughness method is a useful technique for measuring the fracture toughness of high chromium hard-facing compared to Vickers hardness method.

Kang et al., (2014) compared the wear characteristics of hard faced blades of rotary tiller. Tungsten inert gas arc welding was used for hard facing by employing four different types of electrodes that have variable amount of Cr. Hard faced and non-hard-faced blades were compared in field and laboratory test. For field test, 50-acre land after combine harvest with rice stubbles of dry and sandy soil was selected for wear test. Weight loss of hard faced blades produced with electrodes 5, 7.5, 8 & 12 HCr was 5.02, 4.3, 4.22 and 2.84 gm/acre respectively which was much lower as compared to non-hard faced that was 7.08 gm/acre.

Singh et al., (2014) performed the experiment for abrasive wear response of medium carbon steel used for soil working components of agricultural implements i.e. rotavator blade, cultivator sweep, plough share etc. under three heat treatment processes and three load conditions. Medium carbon SAE-6150 steel was used by annealing, inter-critical annealing and quenching and tempering heat-treatment processes. The laboratory analysis of wear rate was done at 75, 200 and 375 N loads. This technique of wear measurement is very similar to working condition of soil working components of agricultural implements. The study revealed that under low load (75 N) condition, both
the inter-critically annealed and quenched and tempered SAE-6150 medium carbon steels gave identical wear resistance. However, inter-critically annealed material under medium load (200 N) condition and quenched and tempered material under high load (375 N) condition exhibited supremacy in terms of abrasive wear resistance.

2.4 CRYOGENIC STUDIES

In addition to surface treatments, cryogenic treatment was used to change the behavior at the core of the material, which may influence the steel under operating conditions. Some studies related to cryogenic treatments are discussed here:

Huang et al., (2003) conducted experiment to improve wear resistance of certain steels and has been implemented in cutting tools, autos, barrels etc by cryogenic treatment. Although it has been confirmed that cryogenic treatment can improve the service life of tools, the underling mechanism remains unclear. The microstructure changes of M2 tool steel before and after cryogenic treatment. Cryogenic treatment can facilitate the formation of carbon clustering and increase the carbide density in the subsequent heat treatment, thus improving the wear resistance of steels.

Aggarwal et al., (2008) optimized the multiple characteristics of CNC turning AISI P-20 tool steel namely tool life, cutting force, surface roughness and power consumption by using liquid nitrogen as a coolant during turning. The controllable turning process parameters like: depth of cut, nose radius, feed, and cutting speed were studied. The design matrix was developed for experimentation by face centered central composite design. Response surface methodology was used for modelling the responses. For optimization a single and multiple response, desirability function was used.

Darwin et al., (2008) improved the wear resistance of 18 % Cr martensitic stainless steel (SR34) made piston rings. Taguchi method is used to optimize the various factor and their level of deep cryogenic treatment. This method is used in two times to
optimize the process parameters of DCT. In the first iteration, $L_{16} (2)^{15}$ OA is used to finalize the factors of DCT. Then in the second iteration, $L_9 (3)^4$ OA is selected to optimize the effect of four factor and their three level of DCT to enhance the properties of selected material. Treated material was analyzed by weight loss on reciprocatory friction and wear monitor (RFWM) as per the ASTM standard (G-181 & G-133). A set of combination of process parameters and their levels of DCT are finalized by using the ANOVA and response values based on maximum S/N ratio. The confirmation test was run and compared, to be found within the confidence limits.

*Das et al., (2009)* suggested that refinement of carbide particles by cryo-treatment is often proposed as a major factor for the improvement of wear resistance in tool steels. The report has been examined by (i) detailed micro-structural analyses of the nature, volume fraction, size, population density and distribution of carbide particles, (ii) XRD and EDX micro-analysis on the bulk samples and electrochemically extracted carbides, and (iii) measurement of hardness and wear rate of a series of differently cryo-treated AISI D2 steel. It is concluded that the precipitation of finer carbides with increased volume fraction are more symmetrical distributed in deep cryogenic treated than conventional heat treated. The formation of secondary carbides and their population increases with the holding time increases at the cryogenic temperature (77 k). The latter observation indicates the pioneering direction towards optimization of cryo-treatment design for techno-economic benefit.

*Liu et al., (2009)* investigated the effects of cryogenic treatment on the microstructure, and abrasion resistance of CrMnB high-chromium cast iron subjected to sub-critical treatment by optical microscopy (OM), scanning electron microscopy (SEM), X-ray diffraction (XRD) and wear test. The results show that cryogenic treatment makes the alloy present a more refined and homogeneous matrix. In the course of sub-critical
treatment followed by cryogenic treatment, the amount of precipitated secondary carbide was more than that in air cooling. Cryogenic treatment can further reduce the austenite content but cannot make retained austenite transform to martensite completely. After cryogenic treatment, the hardness and abrasion resistance of CrMnB high-chromium cast iron can be improved obviously due to the precipitation of carbides, the martensite transformation and a refined microstructure resulting from cryogenics treatment.

*Jaswin et al., (2010)* optimized the DCT process parameters by using the combination of Taguchi method and Grey relational analysis. L9 (3)4 OA was used to enhance the mechanical properties of En52 valve steel namely wear resistance, hardness and tensile strength. Grey relation analysis was used to optimize the DCT process parameters. ANOVA and response values were used to find out the most significant DCT parameters i.e. soaking period for the selected material. The confirmation run was conducted and compared, to be found within the optimal range. It was reported that there is improvement in the wear resistance, hardness and tensile strength at the optimized set of process parameters of DCT is 46.51, 11.16 and 7.84 % respectively as compared to without DCT material.

*Kalsi et al., (2010)* stated that cryogenic treatment (CT) of materials has shown significant improvement in their properties. Various advantages like increase in wear resistance, reduced residual stresses, increase in hardness, fatigue resistance, toughness imparted by transformation of retained austenite to martensite, precipitation of carbides, eta-carbide formation, perfect distributed/homogenous crystal structure, better thermal conductivity, and reduced chemical degradation. Moreover, this technology is an eco-friendly, nontoxic, and non-explosive. Different approaches have been applied for CT to study the effect on different types of steel and other materials. The comprehensive
analysis of the strategies followed in CTs and their significant effects on properties of materials by differentiating CT from cryogenic conditioning of the process. The final part of the paper discusses the developments and outlines the trends for further research in this field.

*Bensely et al., (2011)* compared the effect of deep cryogenic treatment (DCT), shallow cryogenic treatment (SCT), and conventional heat treatment (CHT) on impact properties was also made by means of Charpy impact test as per ASTM standard designation: 23-02a. There is no reduction in toughness accompanied with increase in hardness and wear resistance due to DCT. Also the improvement in toughness due to DCT was marginally higher than CHT. The scanning electron microstructural examination of fractured surface indicates the occurrence of extensive crack branching and noticeable plastic deformation in the SCT and DCT specimens in comparison with CHT.

*Dogra et al., (2011)* compared the performance of cubic boron nitride (CBN) inserts was compared with coated carbide and cryogenically treated coated/uncoated carbide inserts in terms of flank wear, surface roughness, white layer formation, and microhardness variation under dry cutting conditions for finish turning of hardened AISI H11 steel (48-49 HRC). The flank wear of CBN tools was observed to be lower than that of other inserts, but the accumulated machining time for all the four edges of carbide inserts were nearer to or better than the PCBN inserts. Results showed that tool life of carbide inserts decreased at higher cutting speeds. The surface roughness achieved under all cutting conditions for coated-carbide treated/untreated inserts was comparable with that achieved with CBN inserts and was below 1.6 μm. The white layer formation and microhardness variation is less while turning with cryogenically treated carbide inserts than the CBN and untreated carbide. At low to medium cutting
speed and feed, the performance of carbide inserts was comparable with CBN both in terms of tool life and surface integrity.

*Gill, et al., (2012)* analysed the mechanical and metallurgical characterization of cryogenically treated AISI M2 high speed steel (HSS). First samples of AISI M2 HSS are conventionally heat treated and tempered, further they are subjected to cryogenic treatment at two levels -110 °C (shallow treatment) and -196 °C (deep treatment) of temperature. The metallurgical properties are compared of cryogenic treated samples on conventional heat treated and tempered, there is improvement due to the nature, size, and distribution of carbides. The mechanical properties such as hardness and wear rate of the specimens have also been compared by performing Rockwell C hardness test and pin-on-disc wear test, respectively. Microstructures, hardness, wear rate and analysis of worn surface reveal the underlying metallurgical mechanism responsible for the improving mechanical properties of the AISI M2 HSS.

*Mehtedi et al., (2012)* investigated the heat treatment response and the microstructure of high-chromium steel alloyed with nitrogen. Deep cryogenic treatment after quenching and prior to tempering was confirmed to be crucial in order to maximize the hardness of the steel. The different contributions to hardness of the various constituents (martensite, retained austenite, carbides and carbo-nitrides) were quantified by an equation based on the composite model. The model was able to describe the experimentally observed variation in hardness as a function of the austenite temperature and could also be used to estimate the volume fraction of the different constituents for a given austenite temperature.

*Panchakshari et al., (2012)* investigated the effect of cryogenic parameters such as cryogenic temperature (-100, -150 and -196 °C), duration of cryogenic treatment (0, 25 and 50 hr.) and wt. % of reinforcement (0, 10 and 20 % wt.) on wear behavior of
Al/Al$_2$O$_3$ metal matrix composites (MMCs). The Al$_2$O$_3$ particulate reinforced MMCs were fabricated by liquid metallurgy technique. Specimens so prepared were treated for different cryogenic temperatures for different treatment duration using liquid nitrogen. Both untreated and cryogenic treated specimens were tested on pin-on-disc for constant load 20 N, sliding speed of 1.5 m/s and sliding distance of 3 km. Taguchi method is applied for predicting the optimum cryogenic treatment parameter that gives the lowest wear rate to the castings. The experimental and analytical results showed that the Taguchi method was successful in predicting cryogenic parameters that give the lowest wear rate and the wt. percentage.

Mahesh et al., (2014) studied the cryogenic treatment has significant influence on the tribological performance of tool steels. It is a one-time permanent treatment process affecting the entire section of the part, unlike coatings. Enhancing the wear resistance and service life of the steel tools subjected to rubbing condition is of important concern. Literature provides information about the investigations performed on some high-speed steels which reveal remarkable improvement in wear resistance from 92 to 817%. Furthermore, the studies conducted on conventional D3 tool steel reveals the betterment of certain tribo-mechanical properties such as hardness and wear resistance. In the present investigation the effect of cryogenic treatment on austenitic ductile iron type D3 tool steel is studied by sliding the test specimen against the same mating material. The study reveals increase in hardness, reduction in friction coefficient and enhancement in wear resistance.

Amini et al., (2015) investigated the effects of the deep cryogenic heat treatment on the microstructural changes, wear resistance, and hardness of carburized DIN 1.7131 grade steel. The result shows that cryogenic heat treatment reduced the retained austenite and increased the carbide amount. In addition, after the cryogenic heat treatment, carbide
shows a more uniform distribution, as compared to the conventionally treated ones. It was also clarified that the hardness of the cryogenically treated samples was improved, but the relative improvement decreases with the distance as the surface increases. It has been shown that the wear resistance improves due to the cryogenic heat treatment, and the predominant wear mechanism is a combination of the adhesive and tribo-chemical wear.

2.5 WEAR STUDIES

For majority of earth handling tasks, the primary wear mechanism is abrasion. The wear of any material is depending upon the three major factors are as follows:

➢ Condition of soil: type of soil, moisture content, compactness, root and trashes.
➢ Material properties; composition, hardness, strength, plastic deformation, heat treatment, surface finish, geometry etc.
➢ Operating parameters: speed, feed, depth of cut, load etc.

Rigney, (1994) studied that hardness is one of the key factors which influence the sliding behavior of different materials combinations. However, in many discussions the only hardness value considered is that of the softer of the two materials in a tribological pair. This is usually the case when a simple linear wear equation (Holm, 1946; Archard, 1953 & Khruschov, 1965) is cited. Observations on many materials combinations demonstrate that the effects of hardness are much more complex. Hardness varies with position and time. It can depend on temperature, sliding speed and the chemical environment. The sign of hardness gradients adjacent to the sliding surface affects sliding behavior. Transfer and subsequent mechanical mixing strongly influence local hardness. The changes in hardness can affect transitions in friction and wear. Relative hardness values also help to explain differences in debris and in smooth and rough
sliding. They can also help us to understand geometric effects such as those noted when materials are interchanged in a test system.

Stevenson et al., (1996) has been designed and characterized a rubber wheel abrasion tester with some advantages over the design described in ASTM G65. In the new design the specimen was held horizontally. Therefore, it was possible to determine the actual mass flow rate of abrasive abrading the specimen and actual amount of abrasive in contact with specimen and rubber wheel during testing and load carried by each in contact particle. The abrasive feed system was designed to improve control over the conditions in the contact region. The performance of the apparatus was evaluated in tests on low carbon (AISI 1020) steel, with wheels made from cast polyurethane and chlorobutyl rubber. The influences of load, sliding speed and rubber hardness were investigated. Temperature rises of wheel, specimen and sand, and the friction force were measured; the main mechanism of heat dissipation was through the continual flow of fresh abrasive past the specimen.

Wirojanupatump et al., (1999) studied that environment had significant parameter in the abrasive wear rate of mild steel by using silica and alumina abrasive over a particle size and load. Wear rate is significantly less in wet conditions than in the dry, with the greatest differences being observed for small and/or rounded abrasives. Wear in dry conditions occurred predominantly by a three-body mechanism, whilst wear in wet conditions occurred mainly by a two-body mechanism. The water may affect the wear test in a number of ways, but it is proposed that it is its role as a lubricant which is most significant. Since wear rates and mechanisms are so dependent on the test environment, care needs to be exercised in choosing the correct test type to simulate service conditions.
Stachowiak et al., (2001) characterized the effects of abrasive particle, especially shape and hardness, on three-body abrasive wear of metallic samples. The experimental tests were carried out on a modified pin-on-disc tribometer using dry abrasive particles and on a ball-on-plate tribometer using slurry. Spike parameter quadratic fit (SPQ) was used in the characterization of particles angularity. Better correlation between wear rates and particle angularity was found in ball-on-plate tests. The noted exception was quartz that generated less wear in all the tests than could be expected from its high SPQ value. Additional characteristics such as particle toughness, orientation in the contact, and embedment in the worn surfaces affected the wear results. Damage due to rolling (indentation) wear prevailed on the plate samples from ball-on-plate tests, whereas both sliding and rolling wear was found on the cylindrical samples from modified pin-on-disc tests. The morphology of worn surfaces correlated well with the shapes of abrasive particles. Rounded particles generated round craters and smooth grooves while angular particles produced sharp indents and narrow cutting grooves.

Uthayakumar et al., (2013) enhanced the wear resistance properties of hybrid metal matrix composites consist of a metal or an alloy matrix with strongly embedded multiple hard reinforcements. The dry sliding wear behaviour of aluminum reinforced with 5% SiC and 5% B4C hybrid composite using a pin on disc tribometer. Wear performance of the hybrid composites were evaluated over a load ranges of 20-100N, at the sliding velocities from 1 to 5m/s. Detailed metallurgical examination and energy dispersive analysis were carried out to assess the effect of SiC and B4C particles on the wear mechanisms. The Focused Ion Beam (FIB) technique is used to characterize the tribo layers that have been formed at the worn surfaces of composites. The experimental results show that the hybrid composites retain the wear resistance properties up to 60N
load and sliding speed ranges 1-4m/s. The enhancement of wear resistance with small amount of SiC and B4C is achieved by the cooperating effect of reinforcement particles. Sharma et al., (2015) investigated the effect of graphite particles on the dry sliding wear behaviour of Al6082 alloy composites produced by conventional stir casting method. The percentage of reinforcement was varied from 0% to 12% in a step of 3. The result showed that with the addition of graphite particles micro- and macro-hardness reduced by 11.11% and 10.44%, respectively. The tribological behaviour of composites was investigated by pin on disc apparatus. Percentage reinforcement, load, sliding speed and sliding distance were taken as the process variable. Response surface methodology has been used to plan and analyze the experiment. Results showed that sliding distance is the most influential factor and load is the factor which affects the wear least.

2.6 PROBLEM FORMULATION AND OBJECTIVES OF THE RESEARCH

Under this section, research gaps of the previous investigations are discussed, and the main research gaps are identified, which is followed by objectives of the present work.

2.6.1 RESEARCH GAPS IDENTIFIED

After reviewing the literature some research gaps have been found in the area of increasing the hardness of rotavator blades to improve its wear properties. The following lines present the research gaps in this field.

➢ Cryogenic treatment has not been applied to enhance the properties of rotavator blade.

➢ The effect of thickness variation of rotavator blades (due to hard facing techniques) on fuel consumption, strength, impact and abrasion has not been investigated.
➢ The comparison of various cryogenic techniques to improve the wear characteristics of rotavator tine has not been reported.

### 2.6.2 OBJECTIVES OF THE RESEARCH WORK

The work proposed here will be delivered through the completion of several well-defined objectives. The major objective of this study is to improve the performance using conventional heat treatment that in turn improves the characteristics of rotavator tine material. Following are the proposed objectives of the present study:

1) To study the role of heat treatment on mechanical and metallurgical properties of rotavator blade material boron steel (30MnCrB4).

2) To investigate the effects of cryogenic treatment on heat treated blade material for improving mechanical performance.

3) To investigate the effects of post tempering on cryo-treated rotavator blade material with respect to mechanical and metallurgical properties.

4) Investigation on abrasive wear behavior of rotavator blade material subjected optimum thermal cycle by using different soils.