

**SOME STUDIES ON WEAR CHARACTERISTICS OF
ROTAVATOR BLADES**

M.Tech. (Agril. Engg.) Thesis

by

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**DEPARTMENT OF FARM MACHINERY AND POWER
ENGINEERING**

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AGRICULTURAL ENGINEERING AND TECHNOLOGY**

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ROTAVATOR BLADES**

Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Chelpuri Ramulu

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FOR THE DEGREE OF**

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in

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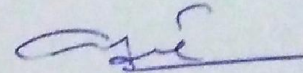
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No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published/ published part has been fully acknowledged. All the assistance and help receive during course of the investigation have been duly acknowledged by him.


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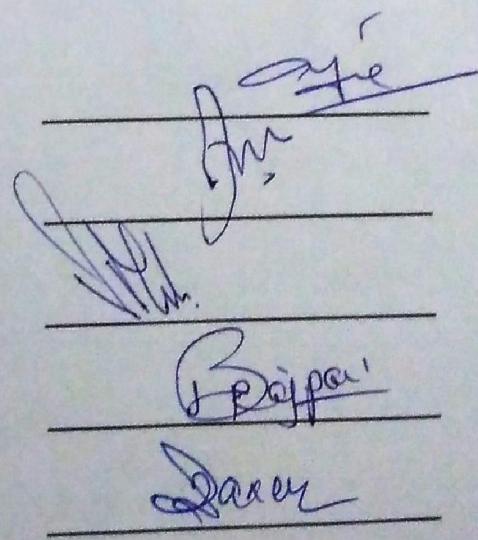
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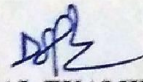
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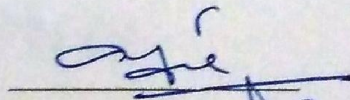
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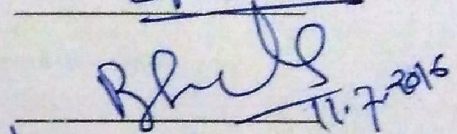
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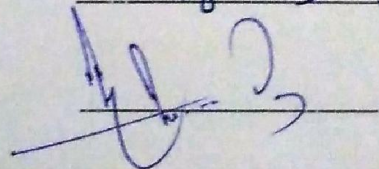


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Date: 30th June 2016
Place: Raipur

Ch. Duf.
(Chelpuri Ramulu)

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LIST OF ABBREVIATIONS AND SYMBOLS

%	percent
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
ASAE	American Society of Agricultural Engineers
avg.	Average
CIAE	Central Institute of Agricultural Engineering
C.G.	Chhattisgarh
cm	Centimeter
cm ²	Square centimeter
cm ³	Cubic centimeter
dia.	Diameter
db	Dry basis
<i>et al.</i>	Et alibi
Engg.	Engineering
EFC	Effective field capacity
FAE	Faculty of Agricultural Engineering
Fig.	Figure
g	Gram
g/cm ³	Gram per Cubic centimeter
ICAR	Indian Council of Agricultural Research
h	Hour
h/day	Hour per day
ha	Hectare
hp	Horse power
ICP	Inductively coupled plasma
C	Carbon
Mn	Manganese
S	Sulphur
P	Phosperous
Mo	Molybdenum
Sq.inch	Square inch
A	Ampere
V	Volt
Gpa	Giga pascal
CRIDA	Central Research Institute for Dryland Agriculture
Rpm	Rotations per minute
Lit	Litre
HRA	Rockwell hardness number
SEM	Scanning Electron Microscope
TEM	Transmission Electron Microscope
EDS	Energy dispersive X-ray spectrometer
Kev	Kilo electron volt
Å ⁰	Angstroms

CRT	Cathode ray tube
X	Magnification
θ	Theta
MB	Mould board
Kw	Kilo watt
pto	Power take off
max	Maximum
KHz	Kilo hertz
$^{\circ}\text{C}$	Degree centigrade
HVOF	High velocity oxygen fuel
ESC	Electro spark coating
QT	Quenching and tempering
Mpa	mega pascal
HRC	Vickers hardness number
SAE-6150	Low alloy high strength
EN-45	Plain carbon steel
w.r.t	with respect to
A	Almen
J	Joul
N	Newton
Fe	Iron
Cr	Chromium
WC	Tungsten carbide
FESEM	Field Emission Scanning Electron Microscope
ESD	Electro spark deposition
Vol.	Volume
μm	Micro meter
h/ha	Hour per hectare
IGKV	Indira Gandhi Krishi Vishwavidyalaya
IS	Indian Standard
i. e.	That is
kg	Kilogram
kg/cm^2	Kilogram per square centimeter
kg/ha	Kilogram per hectare
km / h	Kilometre / hour
kW	Kilowatt
m ²	Square meter
MMD	Mean mass diameter
MT	Million tonne
mm	Millimetre
MS	Mild steel
XRD	X-ray diffractro meter
m.c.	Moisture content
m/s	Meter per second
M. Tech.	Master of Technology
No.	Number
Rs	Rupees
Rs/h	Rupees per hour
Rs/ha	Rupees per hectare

S	Second
θ	Theta
viz.,	Namely
Wt.	Weight
@	At the rate of
TFC	Theoretical field capacity
ANOVA	Analysis of Variance

THESIS ABSTRACT

Title of the Thesis : Some Studies on Wear Characteristics of
Rotavator Blades

Full Name of the Student : Chelpuri Ramulu

Major Subject : Farm Machinery and Power Engineering

Name and Address of the :Dr. A.K. Dave

Major Advisor : Professor, FMPE, SVCAET & RS. Faculty of
Agricultural Engineering, IGKV, Raipur (CG)

Degree to be Awarded : M.Tech (Agricultural Engineering)

Signature of the Student

Signature of Major Advisor

Date: _____

Signature of Head of the Department

ABSTRACT

Tillage is the most important unit and more energy consumption operation in agriculture. The most widely accepted method of tilling land is ploughing with plough and cultivators. These invert the upper soil layer, without proper mixing of soil, hence these needs additional operations of rotavator and harrow to improve soil tilth on the ploughed land. The tractor mounted rotavator holds promise for overcoming these problems. Rotavator saves 30-35 % of time and 20-25 % in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30 %) than as cultivator. Rotavator under dynamic loading, blades are subjected to fatigue and abrasive wear. Abrasive wear has been emerged as a serious problem in rotavator blades. It increases the down time and maintenance

cost. The objective of this study was to increase the wear resistance and reduce the down time by strengthening the rotavator blades by surface modification. In this study coating of 3 material (Tungsten carbide, Stellite-21 and Chromium Carbide) have been done on different makes of L- type rotavator blades using electro spark coating, with 3 modes for each material. Out of this study, the coating material Tungsten carbide was found better in reference to wear loss compared to rest of the coated materials. The wear loss was minimum in T2 (Tungsten carbide 4th mode) treatment of blade 2 compared to other treatments on the basis of weight and volume. The hardness of the treatment C2 (Chromium carbide 4th mode) (58.33 HRA) of blade 2 was higher compared to the rest of the treatments in both blade 1 and blade 2. The study concluded that Tungsten carbide may be a material coating material for reducing wear loss in rotavator blade. However better hardness was achieved under chromium carbide coating.

षोध सारांष

षोध षीर्षक	– रोटलवेटर ब्लेड क्षरण क्षमता पर अध्धयन
छात्र का नाम	– चेल्लुरि रामुलु
मुख्य विशय	– कृशि यंत्र एवं षक्ति अभियांत्रिकी
मुख्य सलाहकार का नाम व पता	– डॉ. ए. के दवे (प्रमुख वैज्ञानिक) एस. वी.सी.ए.ई.टी. एवं अनुसंधान केन्द्र, एफ.ए.ई कृशि महाविद्यालय, इंदिरा गांधी कृशि विष्वविद्यालय, रायपुर (छ.ग.)
उपाधि का नाम	– एम.टेक. (कृशि) अभियांत्रिकीय

प्रमुख सलाहकार के हस्ताक्षर

छात्रा का हस्ताक्षर

दिनांक

विभागाध्यक्ष के हस्ताक्षर

सारांष

कृशि के क्षेत्र में जुताई सबसे महत्वपूर्ण एवं अधिक उर्जा खपत किया है। सबसे व्यापक रूप से भूमि जुताई हेतु हल एवं कल्टीवेटर को स्वीकार्य किया गया है। इस किया से भूमि की उपरी सतह पलटती है परन्तु उचित मिश्रण नहीं होता है। इस कारण से जुताई की हुई भूमि की दषा सुधारने हेतु रोटलवेटर एवं हेरो की द्वारा अतिरिक्त संचलन कराया जाता है टैक्टर चलित रोटलवेटर के द्वारा रज समस्या का कि दान किया जा सकता है कल्टोवेटर रोटलवेटर जुताई के मुकाबले 30–35 प्रतिषत समय की एवं 20–30 प्रतिषत जुताई की लागत दिया में बचत करता है रोटलवेटर से 25–30 प्रतिषत उच्च गुणवत्त की कार्य क्षमता कल्टीवेटर की तुलना में प्राप्त होती है। रोटलवेटर से कार्य के दौरान उसकी ब्लेड में अत्यधिक क्षरण एवं फेटिक की किया होती है।

ब्लेड की घिसाव क्षरण एक गंभीर समस्या है, इसके कारण समय–समय पर मरम्मत कराने से अतिरिक्त मरम्मत लागत आती है। इस अध्धयन का मूल उद्देश्य रोटल वेटर की ब्लेड की क्षरण प्रतिरोधक क्षमता में वृद्धि ब्लेड की सतह में परिवर्तन कर मजबूती कर प्राप्त करना है।

इस अध्ययन में रोटार्वेटर की एल ब्लेड की सतह पर तीन प्रकार के धातुओं का (टंगस्टन कार्बाईड, स्टेलाइट-21 एवं क्रोमियम कार्बाईड) इलेक्ट्रो स्पार्क कोटिंग विधि से तीन मोड पर परत चढ़ाई गई है। इस अध्ययन से टंगस्टन कार्बाईड धातु परत से क्षरण प्रतिरोधक क्षमता में वृद्धि अन्य धातुओं की तुलना में पाया गया। वजन एवं औसतन के पैमाने पर ब्लेड में न्यूनतम क्षरण T2 (टंगस्टन कार्बाईड 4 मोड) के अन्दर पाया गया। क्रोमियम कार्बाईड धातु का लेपन करनेपर C2 (क्रोमियम कार्बाईड 4 मोड) को कठोरत अन्य सभी की तुलना में अधिक पाया गया। इस अध्ययन के आधार पर यह कहा जा सकता है कि टंगस्टन कार्बाईड धातु का लेपन इलेक्ट्रो स्पार्क कोटिंग विधि से करने पर ब्लेड की क्षरण प्रतिरोधक क्षमता में वृद्धि का जा सकती है।

CHAPTER- I

INTRODUCTION

India is a vast country with 329.5 million hectares geographical area with agriculture still as a main occupation of 70 per cent of Indian population. In the world's, India accounts about 2.4 per cent of the geographical area and 4 per cent of its water resources but has to support about 17 per cent of the world's human population and 15 per cent of the livestock. 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 a large number of industries. Therefore, it is not only to accelerate 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, and also to increase incomes of those dependent on agriculture to ensure inclusiveness in our society, Anonymous (2013).

The scenario of agricultural mechanization has been increasing during last four decades. The application of machinery in of Indian agriculture has assumed importance for increasing agricultural production, productivity and profitability by timely farm operations, labour saving, as well as maximizing input efficiency by effective and proper utilization. The newly developed appropriate technology of farm mechanization with improvement in existing design, newer material and production techniques will cater the needs of farms (Manian et al 2002). The growth in large scale adoption of agricultural machinery in the country has been possible due to efforts not only by organized sectors but also by village craftsmen and small scale industries.

This large scale adoption leads to contributes to increase in production, due to its timeliness of operation and as well as potential of input saving, quality of work, the requirement of power for certain operations like seedbed preparation, cultivation and harvesting becomes so great that the existing human and animal power is becoming inadequate. As well, tillage is the most important unit and more energy consumption operation in agriculture. It is done mainly to loosen the soil, to

mix with fertilizer and to remove weeds. As a result of this processing the water-air, thermal and nutrient regimes of the soil are improved in the interest of the growth and development of crops.

The most widely accepted method of tilling land is ploughing with mould board ploughs. In this process of ploughing, mould board plough inverts the upper soil layer, without proper mixing of soil. Hence additional operations needed such as discing, rotavator and harrowing etc., to improve soil tilth on the ploughing. 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 taken in a year. Result shows that rotavator saved 30-35 % of time and 20-25 % in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30 %) than as cultivator. Rotavator produces a perfect seedbed in fewer passes. It is well known that one operation of rotavator equal to one MB plough and 2 harrow operations.

The primary cause that limits the persistence of rotavator is wear of blade. The wear of agricultural soil cutting tools have their own characteristics, which are different from other types, since they interact with soils of various textures, moistures and other unpredictable conditions in the field. Among the soil-cutting agricultural tools currently used, the rotavator is one of the most proficient equipment, saving operating time and human effort. The rotavator is energy and time efficient pieces of equipment, under dynamic loading, rotavator blades are subjected to fatigue and abrasive wear.

Abrasive wear has been emerged as a serious problem in the field of engineering particularly for the metallic surface of working components in machines. Important shortening of service life by abrasive wear appears on parts of

machines working in soil. Various efforts are going on to reduce abrasive wear rate by changing the chemical composition, microstructure, and mechanical properties.

The chemical composition of the steels to be used for the manufacture of rotavator blades shall be as follows: Carbon steel: Carbon 0.70 to 0.85 percent, Silicon 0.10 to 0.40 percent, Manganese 0.50 to 1.0 percent, Sulphur 0.05 percent, Max Phosphorus 0.05 percent, Max. Silica Manganese Steel: Carbon 0.50 to 0.60 percent, Silicon 1.50 to 2.00 percent, Manganese 0.50 to 1.00 percent, Sulphur 0.05 percent, Max Phosphorus 0.05 percent, Max.

Das et al. (2008) studied the several techniques developed over the year to increase the abrasive wear resistance of soil tools in order to improve the efficiency of agricultural equipments for the help of electro deposition, vapor deposition, thermal spraying surface, hard facing, cladding, ion implantation and heat treatment. Several heat treatment processes are often carried out to enhance the service life of the high tensile steel rotavator blade and hence, reduce the total cost of agricultural production. In harsh field conditions, the heat treated blade may not provide satisfactory protection from the abrasive action of soil particles. High wear rate is still observed, resulting in routine blade replacement during tillage (Karoonyboonyanan et al, 2007). Surface modification techniques have emerged as an alternative processes to curb wear resulted from abrasive action of soil particles. These modification methods improve the surface properties like hardness and wear resistance of tiller blades. A pertinent review of the literature has revealed that very few researchers have provided some techniques to enhance the abrasive wear resistance of earth engaging tools in agricultural sector such as surface coatings by Karoonyboonyanan et al., (2007), Kang et al.,(2014) and hard facing by Bayhan(2006).

The rotary tiller has been increasingly used in other agricultural fields. When abrasion conditions become too severe for ground engaging tools, or when the cost of equipment downtime requires more frequent parts replacement. However, studies on wear of its blade as well as wear resistance of different surface treatments are scarce, although wear is the most important factor for predicting service life of a blade. Therefore, there is a need to study these aspects carefully. The combinations of hardness and wear resistance properties are the

primary requirement of agricultural implements for reduction in wear rate and long lasting (Bhakat et al., 2007). The surface of the tiller blade, which is normally heat treated by the manufacturer, can be further improved to achieve higher wear resistance and strength by surface engineering techniques, HVOF (High Velocity Oxygen Fuel) thermal spray coating, Gas Tungsten Arc Welding, and Electro Spark Coating. Electro Spark Coating is a deposition process replaced the detonation-gun or HVOF processes and provided orders of magnitude increase in wear and damage resistance, a five-fold improvement in corrosion performance, lower friction, and more than a 50% saving in cost, with the same material.

It uses consumable electrodes made of stainless steel, nickel, other metals, sintered tungsten carbide, metal-ceramics or ceramics. It generates electric sparks between a rotating electrode and a base metal. It is also known as a micro-welding process, which uses electrical pulses frequencies in the 0.1... 2 kHz range and thus allow substrate heat dissipation over ~99% of the duty cycle, while heating only ~1%. The result is cooling rates of 10^5 to 10^6 °C/sec, and generation of nano-structures, amorphous for some alloys, with corrosion and tribological benefits. This also eliminates thermal distortions. This kind of feature of coating selection will improve the wearing resistance property quality of rotavator blade. No study has been conducted with ESC (Electro Spark Coating). There is need to study the effect of ESC on wearing properties of rotavator blades which will helpful for minimizing maintenance cost and reduces the downtime.

In view of this, the study was planned to know this performance of rotavator blades coated with hardened material with the following objectives.

Objectives:

1. To study the wear characteristics of commercially available rotavator blades.
2. To find out suitable materials for electro spark coatings to increase the wear life of the rotavator blades with a special reference to soil type.
3. To work out the cost economics for the system.

CHAPTER- II

REVIEW OF LITERATURE

The present chapter deals with the critical review of work that has been carried out related to the wear characteristics of rotavator blades and methods to reduce wearing. The review of literature is presented under the following headings:

2.1 Studies on Rotavator Blades

Kaur *et al.* (2011) conducted a study to know wear performance of different materials of rotary blades. For this study, rotary soil bin with loamy soil and sandy loam soil. The study was conducted on T1 (Low carbon steel), T2 (Low alloy steel), T3 (High carbon spring steel) and T4 (Low carbon steel). The blade was operated for 150 h duration. The performances of blades were noted on the basis of weight losses and width losses in percentage. The reveals that the loamy soil maximum average weight loss was 6.76% in blade T2 having 0.280% carbon content and minimum average weight loss was 0.86% that occurred in blade T3 having carbon content 0.64%. In sandy loam soil maximum average weight loss was 10.02% that occurred in blade T4 having carbon content of 0.250% and minimum average weight loss was 4.09% that occurred in blade T3. The width of worn out blades decreased with operational hours. In loam soil maximum average loss in width was 13.20% in blade type T2 and minimum average width loss was 3.18% in blade. In sandy loam soil maximum average width loss was 14.68% in blade type T4 and minimum average width loss was 8.27% in blade type T3.

Nage *et al.* (2011) developed an animal drawn rotary tiller at Faculty of Agricultural Engineering, IGKV Raipur, India. The effective field capacity of animal drawn rotary tiller (18 blades) was found to be 0.12 ha/h at a forward speed of 2.5 km/h. The field efficiency of 62.85% was observed during the field performance. The draft requirement of the developed animal drawn rotary tiller is 378 N. Mean Mass Diameter (MMD) of soil clod size was found 28.42 mm. The operational cost was found 384 Rs / ha.

Singh and Saxena (2011) conducted study for characterization of materials used for rotavator blades. The blades were collected from twelve leading manufacturers/dealers of five states of India. Rotavator blades were made from

steels and were heat-treated differently (Quenching and tempering in all four Steels and Austempering in case of boron contained steels) in order to achieve varying microstructures. Plain carbon steel (EN-45), low alloy high strength steel (SAE-6150) steel and two boron containing steels (50B50 and 30MnCrB4) were used for the study. That the formation of tempered martensitic structure with fine laths leads to higher mechanical properties like hardness (45-49 HRC), ultimate tensile strength (1195-1485 MPa), and percentage elongation (8-12%) in case of QT boron steels (50 B 50 and 30 MnCrB4 steels) similarly in high strength low alloy steel (SAE-6150steel). There is wide variation also observed in chemical composition of the steels used for making rotavator blades. During characterization it as observed that the Carbon, was most influencing alloying element of steel varies from 0.3 to 0.53%. This study also revealed that boron steels and low alloying high strength steels containing chromium and vanadium were also taken in consideration for the study. The wear rate of rotavator blades during three stages were found in same order i.e. Local 1>EN45 (QT)>Local 2>30MnCrB4 (Au) >50B50 (Au)>30MnCrB4 (QT) >SAE-6150 (QT) >50B50 (QT).

Kang *et al.* (2014) studied the wear behavior of hard facings on rotary tiller blades. The aim of the study was to observe the effect of the hard facings on the extent of wear and the wear characteristics of the tiller blades. The influence of Cr studied by hard facing of leading edge of tiller blades made of high tensile steel by gas tungsten arc welding using four different electrodes. The average wear rate of the un-hard faced blade was found as 7.08 gm/acre, while those of 5HCr, 7.5HCr, 12HCr and 8HCr hard facings were 5.02, 4.3 2.84 and 4.22 gm/acre respectively as indicated by field test results. A significant improvement was observed in the wear protection provided by hard facings over the un-hard faced blade.

Mahal *et al.* (2014) studied the blade characteristics of commercially available rotavators in Punjab. All the rotavator under study were of L-type blades only. The results obtained are maximum number of machines (57.14%) has hardness of blade in the range of 35-45 HRC. In most of the rotavators used, placement & angle of blades on flange w.r.t. blades on consecutive flanges are helical manner & angle varies from 13 to 32°. Diameter of hole for fixing blade to

flange was also not uniform. The weight of one blade is in the range of 750-1150 g. From the survey it was observed that the blade sharpening angle in the range of 15-20°.

Ozge ACARBAS BALTASI et al. (2014) examined characterization of agricultural machinery blades. In this study domestic blade and foreign blade were used. According to chemical analysis it was observed that the main element carbon as well as chromium molybdenum, nickel, copper and boron contents were higher in foreign blades than domestic blades. Foreign blade's surface hardness was higher than the domestic blade. On the other hand cross sectional hardness of domestic blade was higher than the foreign blade's. Advantage of this property can be seen on wear test. Domestic blade has higher wear resistance than foreign blade. They concluded that if domestic blades have suitable chemical composition and suitable heat treatment it will provide better results in the wear point of view.

Punamchand *et al.* (2016) reviewed influence of surface hardening processes on wear characteristics of soil working tools. They have concluded that wear resistance of agriculture implements can be increased by process of heat treatments of substrate material and by the surface modification of the implements. Heat treatment techniques used by various researchers are annealing, tempering, water quenching, oil quenching, case hardening, precipitation hardening, etc. Many researchers have also suggested surface modification techniques like electro deposition, vapor deposition, shot peening, hard facing, diffusion coating and Thermal spraying for wear resistance. Material hardness, moisture content, abrasive particle size, length of abrasive path, speed and normal load play significant role on abrasive wear of soil working elements.

2.2 Methods to Reduce Wearing

There are different methods are available for reducing wear by modifying surface of wear bodies. Out of which important and effective methods those have been studied, are detailed below:

2.2.1 Quenching and heat treatment

Abbas and Alwan (2014) were analyzed the effect of quenching media on the mechanical properties and abrasive wear resistance of steel blade (34cr4) with the soil texture was used as like as agricultural lands. It was observed that the wear

resistance increases with increase in hardness. Hardness of blade was increased with varying quenching media as follows; 38HRC, 56.6 HRC, 58.3 HRC and 60.6 HRC for as-received sample, caustic Soda(10%),engine oil and flaxseed oil respectively. It was also observed that the wear resistance increases with decreasing toughness to values 48.3J, 45J, 40.2J and 27J respectively. From this study, it was found that wear resistance depends upon the hardness, toughness and mechanical properties such as microstructure which consists of martensitic structure and some amount of carbide particles.

Singh *et al.* (2014) studied the work effect of heat treatment under changeable applied load on wear response of agricultural grade medium carbon steel. The treatments were SAE-6150 steels has undergone different heat treatment processes like Control 86% pearlite and remaining ferrite annealed 80 % pearlite and remaining ferrite Inter-critical annealing 85% tempered martensite and remaining ferrite quenching & tempering. After study it was observed that under low load (75N) 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 (200N) condition and quenched and tempered material under high load (375 N) condition exhibited supremacy in terms of abrasive wear resistance.

2.2.2 Shot peening

Rautaray and Sharma (1996) conducted a study on shot peening to reduce fatigue and wear in tillage implements. The results of this study showed that the specimens being shot peened after carburizing, hardening and tempering have given improved fatigue and wear performance with overall economy as compared to other treatments tested in the study. It was observed that the shot peening surface offered more abrasive wear resistance as compared to un-peened surface. The loss of weight of shot peened specimens reduces by 20-30% than of the virgin and strength of shot peened samples were higher under corrosive environment without agitation as well as under agitation. This Study suggests that shot peening may be considered for minimizing corrosion effects.

Sharma and Modi (2005) examined the effect of metal-spraying and shot peening on abrasive wear of carbon steel. The treatments used in this study were

virgin sample (SAE-1022), virgin and shot peened, virgin and coated with material - 1 (i.e. self fluxing alloy of Ni-Cr-Fe-3-6), virgin and coated with material II (i.e. ceramic material which is a combination of Al₂O₃ - TiO₂), virgin and coated with material III (i.e. super performance stainless steel), virgin, coated with material I and again shot peened, and actual blade material sample (En42). It was found that the mass wear of the virgin blade (SAE-1022) was the maximum of 6.25% followed by virgin - shot peened (5.84%), virgin - coated with stainless steel (0.9802%), virgin coated with ceramic material (0.07127%), virgin-coated with self fluxing alloy (0.06728%) and virgin-coated with self fluxing alloy and again shot peened (0.03217%). The use of ceramic materials (alloy of Al₂O₃ - TiO₂) for coating in this study has also improved surface hardness and reduced wear considerably. Similarly the use of stainless steel coating has also increased the surface hardness, improved wear resistance but it was not as harder as the other coating material so its wear is pronounced than other coating materials.

Singh *et al.* (2009) carried out a research on advantages of shot peening on abrasive wear resistance of agricultural grade steel. For this study surface of agricultural grade steel modified by using shot peening operation at various peening intensities varying from 0.17A to 0.47A at an interval of 0.1A. This study stated that the wear resistance improved considerably at mild peening (0.17 A), but further increase in peening intensity led to formation of cracks at surface and sub-surface level that decreased the wear resistance. The study reveals that the soil working components should be re-shot peened after a certain sliding distance (1.7 km) at 200 N loads for better abrasive wear response.

Chouhan and Saxena (2012) were examined that the shot peening technique to resist wear of critical components of agricultural machinery. They were observed that in-depth about shot peening techniques to resist abrasive wear of these components. It was concluded that wear intensity of soil engaging parts of agricultural machine depends upon the soil physio-mechanical properties of the environment such as adhesion, compaction, resistance to shear, coefficient of friction, intensity of load and contact pressure, and the construction and heat treatment of the material of soil engaging parts of agriculture machine. Surface

treatment and use of appropriate material are used to enhance wear resistance of these critical components.

Singh *et al.* (2012) studied the effect of shot peening on low stress abrasive wear behaviour of SAE-6150 steel at various intensities varying from 0.17A to 0.47A. It was concluded that abrasive wear test on un-peened and peened specimens by dry sand abrasion tester revealed that shot peening reduced abrasive wear considerably, when it was restricted up to 0.17A, but over peening led to higher abrasive wear rate. In critical period, the peened and un-peened samples exhibited comparable wear rate. This phenomenon indicates that peening was required on regular interval to maximize wear resistance. It was also observed that the wear rate decreased with sliding distance irrespective of peening intensities and applied loads. It increases monotonically with increase in applied load, irrespective of peening intensity. Study suggested that this technology would be useful for manufacturer of agricultural implements in India, due to its simplicity and cost effectiveness.

2.2.3 Thermal spray coating

Mohanty *et al.* (1996) reported that the manner of processing in thermal spraying inevitably leads to inhomogeneities, such as unmelted particles, oxide inclusions and porosity, in the sprayed deposits resulting in a structure markedly different from that of cast, wrought or even powder metallurgy materials. It is expected that thermal spray coating behavior would be even more complicated than that of homogeneous, uncoated bulk materials. The objective of this study was to investigate the effects of some wear test variables on high velocity oxy-fuel (HVOF) sprayed Cr.₂C/NiCr coatings using a pin-on-disk tribometer. The results showed tribological behavior of HVOF sprayed Cr.₂C/NiCr coatings is significantly affected by its microstructural constituents such as splats, porosity and form and dispersion of second phases. It was also showed that changes in imposed sliding wear test conditions varied the friction and wear behavior of thermally sprayed coatings considerably. The break-in sliding coefficient of friction is found to be more significantly affected by load than other test parameters. Results also indicate that friction decreased with increasing velocity but wear decreased then increased with increasing velocity.

Salokhe *et al.* (1999) examined the effect of enamel coating on the performance of a tractor drawn rotavator. In this study the power requirement and quality of work of uncoated and enamel-coated tines was compared under similar working conditions. It was observed that the enamel coating affected the power requirement; maximum saving in power of 22% was obtained at 1.5 km/h speed during the first pass of enamel-coated tines compared to that of uncoated tines. It was also observed that the power requirement of the enamel-coated tines was higher than the uncoated tines in the second pass, but it gave better soil inversion, the quality of work in terms of bulk density, cone index and mean weight diameter of soil mass were almost the same for both tines and soil inversion by enamel-coated tines was higher than the uncoated tines by 30 and 50% during the second and third pass, respectively. This study was concluded that rate of wear of enamel-coated tines was found to be less than that of the uncoated tines.

Schwetzke and Kreye (1999) conducted study on microstructure and properties of tungsten carbide coatings sprayed with various high-velocity oxygen fuel spray systems. The experiments in this study were a series of experiments with various high-velocity oxygen fuel spray systems (Jet Kote, Top Gun, Diamond Jet (DJ) Standard, DJ 2600 and 2700, JP-5000, Top Gun-K) using different WC-Co and WC-Co-Cr powders. The microstructure, phase composition of powders & coatings were analyzed by optical and scanning electron microscopy and x-ray diffraction. It was stated that the coatings of high hardness and wear resistance can be produced with all HVOF spray systems when the proper spray powder and process parameters were chosen.

Wang *et al.* (2000) produced Cr –Ni Cr detonation spray coating. It was observed that the produced coatings process was dense with good bonding to substrate as well as high resistance to high temperature oxidation and wear. It was stated that reports from the in-service test at Bao Shan steel company indicate that the Cr₃C₂-NiCr detonation spray coating produced by authors has at least doubled the roll life.

Krishna *et al.* (2002) examined the microstructure and properties of flame sprayed tungsten carbide coatings. The treatments in this study were first series of experiments all the coatings were produced with the same powder, i.e., mono

crystalline WC, with a particle size of 150–180 μm for rods and 40–50 μm for powder feeding. The free carbon content of the mono crystalline WC powder was 0.1 wt.% and the total carbon content was 6.26 wt.%. A second series of experiments were carried out with plasma transferred arc synthesized, fused and crushed WC (mixture of WC + W₂C) powder. All the coatings were sprayed on machined and degreased mild steel substrates. The thickness of the coatings was between 1.0 and 1.5 mm. In addition, powder particles were sprayed into water (quenching) and collected in a container (air cooling) to study their melting behaviour by scanning electron microscopy (SEM), X-ray diffraction and optical microscopy. It was concluded that the coatings with higher wear resistance can be produced by using fused WC than conventional WC, it was also stated that the most commonly used spray techniques like HVOF, Detonation Gun, etc. will give much more improved wear resistance than in the present technique.

Murthy and Venkataraman (2004) worked on abrasive wear behavior 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.

Karoonboonyanan *et al.* (2007) conducted a study on wear resistance of thermally sprayed rotary tiller blades. The main objective of this research was compared two different thermal spray coatings, namely HVOF-sprayed WC/Co and plasma-sprayed Al₂O₃–TiO₂/NiAl, on carbon steel rotary tiller blades. In this a test was conducted on a 3.2-ha area of sugarcane field after harvesting, the soil condition during the time of the test was dry, hard and sandy. The coated test blades were arranged in the rotary tiller using a randomized complete block design pattern to compensate for the blade position sensitivity in order to achieve meaningful data. The conducted test results the average wear rate of the uncoated blades was 0.86 cm³/ha, while those of the WC/Co and the Al₂O₃ coatings were

0.02 and 0.90, respectively. After study it was found that wear rates of the WC/Co-coated blades were significantly lower than those of the uncoated blades, indicating a great improvement in the wear protection provided by the coatings, however the Al₂O₃-coated blades, , did not show superiority over the uncoated reference blades. Some chipping of the Al₂O₃ coating was observed, which greatly contributed to the high wear rate.

Kang *et al.* (2011) conducted a similar comparative study on wear behavior of thermal spray coatings on high tensile steel rotavator blades. In this study 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.

Kripal *et al.* (2011) examined that the wear behavior of ferrous based thermal spray coatings on A356. This study stated that thermal spray coatings are one of the solutions for improving poor tribological properties of aluminium alloys. Two kinds of ferrous coated layers were deposited on A356 substrate, by HVOF spraying, and their microstructure and tribological properties were investigated. The pin and disc tribometer was used to carry out these tests under dry sliding conditions, sliding speed of 1 m/s and 2 m/s, sliding distance of 5000 m and normal load between 9.8 N-73.5 N. X-ray diffraction analysis showed the presence of elemental iron (Fe), FeNi, α -Fe₃O₄, α -Fe₂O₃, FeO, α -FeCr, Cr₂O₃ phases in coating C-1 and elemental iron (Fe), α -Fe₂O₃, γ -Fe₂O₃, FeO, Fe₃Ni, α -FeCr phases in coating C-2. It was concluded that the hardness of C-2 coating was higher than of C-1 coating and that had great influence on their tribological properties.

Kumar *et al.* (2013) investigated the wear resistance of al-sic coatings on steel substrate. The wear behavior of these coatings in this study has been tested using the Pin-on-Disc technique under dry sliding conditions. The wear resistance of the aluminum coatings was greatly enhanced by the incorporation of the SiC reinforcement. The wear rate of the coating was found increased with increase in load. The co-efficient of coating was found decreased with increased SiC particle.

The worn surfaces were examined using SEM (Scanning Electron Microscope), and it was found that the main wear mechanism was due to adhesion, abrasion and deformation.

Milanti *et al.* (2014) investigated the micro structural characteristics and tribological behavior of HVOF-sprayed novel Fe-based alloy coatings. Micro structural investigation (field-emission scanning electron microscope FESEM and X-Ray diffractometry XRD) reveals that HVOF Fe-based coatings have high density and low oxide content. Particle melting and rapid solidification resulted in a Meta stable austenitic phase with precipitates of mixed carbides and borides of chromium and iron which lead to remarkably high nano hardness. Tribological performances were evaluated by means of the ball on-disk dry sliding wear test, the rubber-wheel dry particle abrasion test, and the cavitation erosion wear test. From this study it was found that Fe-based coatings as a future alternative to the more expensive and less environmentally friendly Ni-based alloys.

Mruthunjaya and Parashivamurthy (2014) conducted microstructural study and tribological behavior of Wc-co coatings on stainless steel produced by HVOF spray technique. WC-Co coating was developed on the stainless steel AISI 304 by High Velocity Oxy-Fuel spray technique. It was observed that tungsten carbide (WC) coatings exhibit high wear resistance at low and high temperatures and WC - Cobalt coatings has demonstrated anti-resistive and wear characteristics better than those of conventional materials. The study concluded that service life of the WC-Co coatings depended on varying compositions of tungsten and cobalt. The grain size of WC varied in three ranges of 10-40 μm , 15-63 μm and 45-90 μm . WC coatings exhibit increased in hardness and resistance to wear. It was also concluded wear rate of tungsten carbide of sample C mesh size (45 to 90 μm) is less compare to two remaining samples by considering different loads.

2.2.4 Electro spark coating

Johnson and Sheldon (1986) conducted study on advances in the electro spark deposition coating process. It was stated that The ESD process is a pulsed arc micro -welding process that can apply metallurgically bonded coatings with such a low heat input that the bulk substrate material remains at or near ambient temperatures. It eliminates thermal distortions or changes in metallurgical structure

of the substrate. When properly applied, the ESD coatings can provide exceptional wear and damage resistance to materials that otherwise would be subject to galling or excessive wear or friction. The process may also be used to modify surface compositions of materials for a variety of other applications.

Ruijun *et al.* (2004) carried out study on interface behavior study of WC92–Co8 coating produced by electro spark deposition. The main objective of this study was comparing the behavior of the interface between the WC92–Co8 coating and the substrate. It was also concluded that the WC92–Co8 coating produced by electro spark deposition effectively improves the surface performance of the substrate, the high-melting-point WC92–Co8 was deposited onto the surface of Ti alloy, and the coating was usually more than 50 mm thick and the surface of the coating is mainly composed of TiC and W₂C besides a small amount of W, and its micro hardness reaches HV1129. It was stated that the coating dramatically improves the performance of the substrate.

Verbitchi *et al.* (2011) introduced electro-spark coating with special materials. It was examined that the electro-spark coating is a deposition process, with consumable electrodes used were made of stainless steel, nickel, other metals, sintered tungsten carbide, metal-ceramics or ceramics. The results of this study showed that the thickness of the coating is 0.01...0.5 mm, there is no distortion of the base metal and the operator has full control on the process, the deposition rate depends on the power of the device (0.160...1.6 kVA).

Sergey *et al.* (2013) investigated on electrospark coatings based on WC-CO alloys with aluminum oxide and carbon additives. It was observed that the structure and properties of coatings based on WC-Co alloys containing additives of 1% - 5% Aluminium oxide and 2.5% - 4.5% carbon. It was stated that this type coating depending on the duration and frequency of the discharge pulses, the ratio between WC and W₂C in the coatings was different. The additives in the hard alloy allowed us increase the microhardness and wear resistance of the coatings by a factor of 2 - 3 in comparison to coatings created using a conventional WC-10%Co alloy or carbon additives on steel 35. The size of Crystallites of tungsten carbide observed that 1 - 20. The surface layer had a nano structured construction with increasing carbon content in the anode material, the amount of tungsten

carbide WC increased. The additives of alumina in the electrode materials based on tungsten carbide allowed us to increase the wear resistance of the coatings. If carbon additives were applied, the microhardness and wear resistance became even greater. This is because with increasing carbon concentration in the anode materials, the decarburization of the tungsten carbide decreased.

Krzysztof *et al.* (2015) conducted study on Microstructure of electro-spark coatings for sliding friction pairs. The objective of this study was to investigate the microstructure of coatings made from bearing alloys on the bronze substrate. It was stated that this process is used for slide bearing bushings to improve break-in parameters.

The review of literature has revealed that very few researchers have provided some techniques to enhance the abrasive wear resistance of soil engaging tools. Although, the surface coating techniques have been suggested for improving the wear resistance in tools. In view of importance of surface coatings for enhancing wear life, the study has been planned by selecting spark coating techniques with three coating materials to improve the life of rotavator blade.

CHAPTER- III

METHODS AND MATERIALS

This chapter deals with detailed information on selection of rotavator blades, determination of chemical composition of rotavator blade, coating material, coating method and treatments used in this study. This chapter also deals with the different methods used for determining dependent parameters i.e. wear loss and relevant techniques used for characterization of the coating i.e. microstructure study, coating build up height, hardness and phase analysis. The field conditions during the field test such as moisture content and bulk density was also measured. The detailed information regarding material used and procedure followed for evaluation of blade wear characteristics explained under following subheading.

3.1 Selection of rotavator blades

3.2 Determination of composition of selected rotavator blade

3.3 Selection of different coating materials for ESC and their compositions

3.4 Properties and applications of electro spark coating machine

3.5 Details of treatments used in study

3.6 Determination of wear loss

3.7 Determination of soil parameters.

3.8 Determination of coating characteristics

3.9 Design of experiment

3.10 Economic analysis

3.1 Selection of Rotavator Blades

A preliminary survey was conducted in the region to know the popularity of rotavator and types of blades being used by farmers. The review was also done to have the stock of situation in reference to type of blades. It was found that L types of blades are more in numbers in the region with the two make of rotavators (Italian and Shaktiman make). In whole of the thesis, to avoid the name of make of rotavator blade, it is being presented as Blade 1 (Italian) and Blade 2 (Shaktiman) respectively. Therefore both the rotavators having L blades were selected for the study. The blade2 i.e. Shaktiman and blade1 i.e Italian are shown as a and b in the plate 3.1.

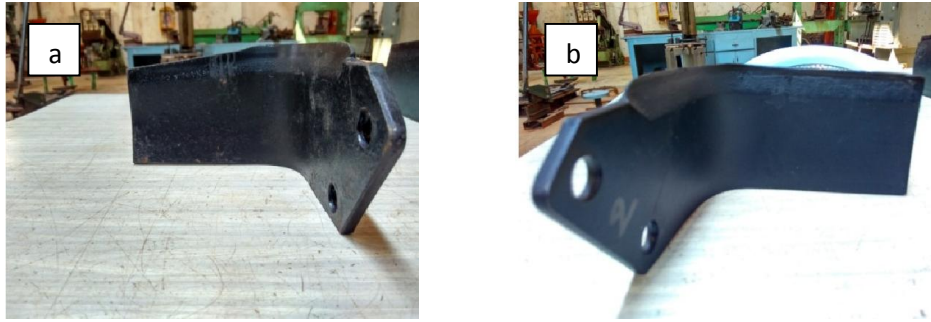


Plate3.1: Selected rotavator blades

3.2 Determination of Element Composition of Selected Rotavator Blades

In this study two types of rotavator blades were selected from two different manufacturing companies i.e. Blade 1 and Blade 2. Study was focused on L-shaped blades only. The composition of these blades was determined by using optical emission spectrometer (plate 3.2). As per the standard methodology, it is necessary to have a sample piece of blades having at least 1 sq inch area for the purpose of element analysis.

The optical emission spectrometer (plate 3.2) helps in determining all the elements utilized in the metal industry, including trace analysis of sulfur, phosphorous, nitrogen and carbon. All operating parameters are monitored by the spectrometer, which calculates the measurement time needed depending on the properties of the given sample. It also informs when the spark stand has to be cleaned depending on the kind of sample being inspected.

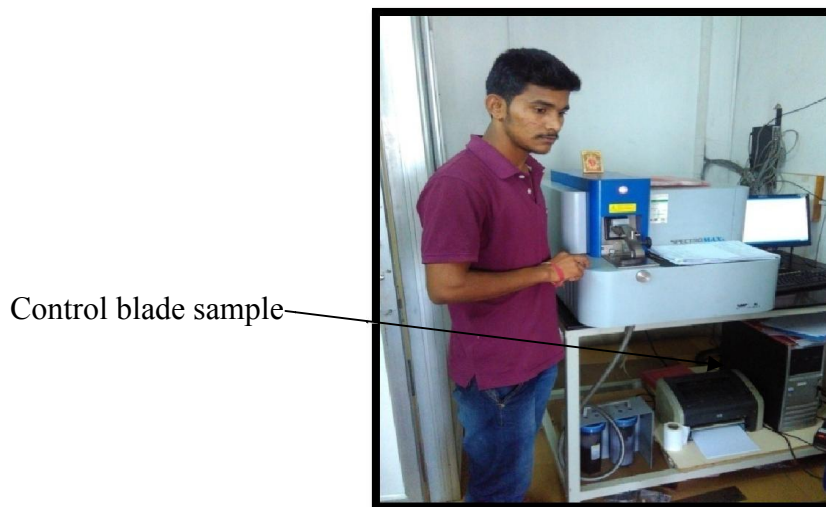


Plate 3.2: A view of optical emission spectrometer

Optical emission spectrometry involves applying electrical energy in the form of spark generated between an electrode and a metal sample, whereby the vaporized atoms are brought to a high energy state within so called “discharge plasma”. These excited atoms and ions in the discharge plasma create a unique emission spectrum specific to each element, as shown at right. Thus, a single element generates numerous characteristic emission spectral lines. Therefore, the light generated by the discharge can be said to be a collection of the spectral lines generated by the elements in the sample. This light is split by a diffraction grating to extract the emission spectrum for the target elements. The intensity of each emission spectrum depends on the concentration of the element in the sample. Detectors (photomultiplier tubes) measure the presence or absence or presence of the spectrum extracted for each element and the intensity of the spectrum to perform qualitative and quantitative analysis of the elements.

In the broader sense, optical emission spectrometry includes ICP optical emission spectrometry, which uses inductively coupled plasma (ICP) as the excitation source. The terms "optical emission spectrometry" and "photoelectric optical emission spectrometry," however, generally refer to optical emission spectrometry using spark discharge, direct current arc discharge, or glow discharge for generating the excitation discharge. The optical emission spectrometer offers rapid elemental analysis of solid metal samples, making it indispensable for quality control in steel making and aluminum metallurgy processes.

3.3 Selection of Different Coating Materials for Electro Spark Coating (ESC) and their Compositions

From the review of literature it appears that ESC is a suitable coating method for enhancing the wearing resistance and mechanical strength up to some extent. In this study, three types of coating materials Viz., 1.Tungsten carbide 2.Chromium carbide and 3.Stellite-21 have been selected. The ESC coating was done by using these electrodes on the working surface of the both Blade 1 and Blade 2 blades as per the standard methodology. The properties of all selected coating materials and their compositions are explained below.

3.3.1. Tungsten carbide

Tungsten carbide (chemical formula: WC) is a chemical compound containing equal parts of tungsten and carbon atoms. In its most basic form, tungsten carbide is a fine gray powder, but it can be pressed and formed into shapes for use in industrial machinery, cutting tools, abrasives, armor-piercing rounds, other tools and instruments, and jewelry. Tungsten carbide is approximately two times stiffer than steel, with a Young's modulus of approximately 530–700 GPa and is double the density of steel nearly midway between that of lead and gold. It is comparable with corundum ($\alpha\text{Al}_2\text{O}_3$) in hardness and can only be polished and finished with abrasives of superior hardness such as cubic boron nitride and diamond powder, wheels, and compounds. Tungsten carbide is extremely hard, ranking about 9 on Mohs scale, and with a Vickers number of around 2600. It has a Young's modulus of approximately 530–700 GPa, a bulk modulus of 630–655 GPa, and a shear modulus of 274 GPa. It has an ultimate tensile strength of 344 MPa, ultimate compression strength of about 2.7 GPa and a Poisson's ratio of 0.31.

Table 3.1 Composition of Tungsten carbide

S.No	Element	Composition (%)
1	Tungsten , W	75.0
2	Nickel, Ni	11.5
3	Carbon, C	5.6
4	Chromium, Cr	5.6
5	Iron, Fe	0.5
6	Others	0.8

3.3. 2. Stellite-21

Stellite alloys are a group of cobalt-chromium 'super-alloys' consisting of complex carbides in an alloy matrix predominantly designed for high wear resistance and superior chemical and corrosion performance in hostile environments. The combination of Cobalt and Chromium also results in an extremely high melting point making them perfect for a range of intriguing applications from extreme cutting tools to hot section alloy coatings in gas turbines. They may also contain molybdenum or tungsten and a small amount of carbon to offer even greater performance for specific applications. Carbon content

influences hardness, ductility, and resistance to abrasive wear. Tungsten also plays an important role in these properties.

Table 3.2 Chemical composition of Stellite 21

S.No	Element	Composition (%)
1	Cobalt, Co	59.0
2	Chromium, Cr	29.0
3	Molybdenum, Mo	6.0
4	Nickel, Ni	3.7
5	Silicon, Si	1.0
6	Manganese, Mn	1.0
7	Carbon, C	0.3

3.3.3 Chromium carbide

Chrome Carbide is a high temperature and wear resistant surfacing Cr_3C_2 with Binders of Ni/Cr. One of its most significant benefits is its wear resistance in higher temperature environments. Chrome carbide can be an excellent choice as an alternative to tungsten carbide, depending on operating conditions. While chrome carbide has less wear resistance than tungsten carbide, chrome carbide coatings along with nickel/chrome binder chemistry has heat resistance and oxide resistance characteristics at higher temperatures and under corrosive or oxidizing conditions. The properties of chrome carbide coatings can be further enhanced when the metal alloy matrix is made from Nichrome alloy, which has high corrosion resistance. Chrome Carbide coatings for applications that require resistance for wear by abrasion, hard surfaces, fretting, and particle erosion.

Table 3.3 Composition of Chromium Carbide

S.No	Element	Composition (%)
1	Chromium, Cr	58.5
2	Nickel, Ni	34.0
3	Carbon, C	7.5

3.4 Properties and Applications of Electro Spark Coating Machine

The review suggests that ESC is a better option for coating purpose. It helps in reducing wear. In the study, electro spark coating (ESC) has been used as

a coating method. The details of sample preparation prior to coating for ESC, details of ESC, applications, technical specifications and electrodes being used are given below under different sub headings

3.4.1 Sample preparation for coating

Prior to ESC coating the proposed coating surface of rotavator blade was polished by using mechanical polisher with blade grit 36 and diameter 127mm.



Plate 3.3: A view of polishing of coating surface of rotavator blade

3.4.2 Details of electro spark coating machine

The method of electro-spark deposition is particularly useful for anti-wear coatings. Due to a wide range of the materials which can be used and the control of the environment of the electrodes, the method can be employed to alter, to a major extent, mechanical, thermal, electrical, thermo emissive, and other properties.

In particular, the electro-spark deposition of the coating can be applied locally, yet strong adhesion to the substrate can be achieved and the materials are prevented from being heated in the process. Another distinguishing feature of the method is the possibility of using both pure metals and alloys, and also metalceramic composites and high-melting alloys. Finally, while using this method, it is possible to supplement the cathode (here the workpiece) with the anode components (the electrode) by means of diffusion, which can be achieved without altering the size of the work piece. The method does not involve any special preparation of the workpiece, and the equipment needed to perform the operation does not have large dimensions, making it easily portable. The method

drawbacks include the following: increase in surface roughness, tensile stress formation in the surface layer, and a decrease in fatigue resistance. The Components of ESC machine was shown below plates 3.5, 3.6, 3.7 and 3.8.



Plate 3.4: A view of Electro Spark Coating machine

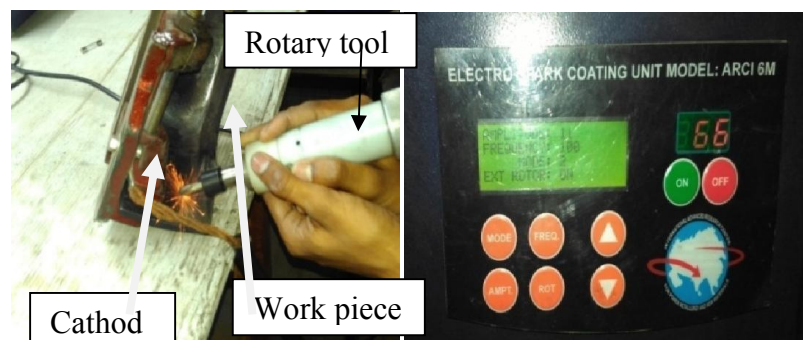


Plate 3.5: A view of ESC coating during working



Plate 3.6: A view of electrode holder



Plate 3.7: A view of drive box Plate 3.8: A view of vibratory tool

3.4.3 ESC process characteristics

Electrospark coating is a thin film coating technique where accumulated energy in a bank of capacitors is released in a controllable burst as brief as 1/1000

of a second or even less. The coating material is in the form of a bare rod of dia. 1 to 8 mm and a length of 50 mm. When the electrode is brought near the work piece, an electric arc is struck generating temperatures in the range of 10,000 to 12,000 °C. Size of the area of discharge is only 0.0001 sq.inch. The power supplies produces a variable direct current upto 50A and voltage is 25V, maximum achievable coating thickness is 130 microns with carbide materials and 1 mm with Co and Ni based alloys. The ESC has the following advantages:

- a) Easy to operate
- b) Low equipment cost
- c) Low process cost
- d) Extremely versatile
- e) No distortion of component
- f) Low risk of rejection
- g) Excellent bonding
- h) Intricate shapes can be coated

The ESC has following applications.

- a) Cutting tools
- b) Shearing and extrusion dies
- c) Wear parts
- d) Hot gas corrosion resistance applications

The range of electrodes that can be used with ESC, specifications of ESC and the parameters recorded during coating are mentioned in Table 3.4 to 3.6.

Table 3.4 Range of electrodes that can be used

S.No	Electrode name	S.No	Electrode name	S.No	Electrode name
1	Tungsten carbide	8	Chromium	15	Calmonoy
2	Chromium carbide	9	Copper	16	Wallex
3	Titanium carbide	10	Nickel	17	Deloro 40
4	Tantalum carbide	11	Stellite	18	Triballoy 400
5	Nickel aluminide	12	FeCrAlY	19	Silver
6	Titanium diboride	13	Palladium	20	Gold
7	Molybdenum	14	Zirconium alloys	21	Other composites

Table 3.5 Technical specification of electro spark coating unit

S. No	Nomenclature	ESC Equipment Model ARCI 6M
1	Power Capacity, kW	0.50
2	Voltage, V	220
3	Working current, A	0.5-60
4	Weight of generator, Kg	15
5	Thickness capacity	50-130 μm – with carbide electrode Up to 1 mm – with Ni and Co based electrodes
6	Productivity cm^2/Min	1.0-2.0

Table 3.6 Electro Spark Coating sprayed coating parameters

Parameters	Coatings		
	Tungsten Carbide	Stellite-21	Chromium Carbide
Amplitude	11	11	11
Frequency, Hz	100	100	100
Mode	2,4,6	2,4,6	2,4,6
Voltage, V	220	220	220
Current, A	0.5	0.5	0.5
Productivity, cm^2/Min	1.0	1.0	1.0

3.5 Details of Treatments Used

In this study two rotavator blades of two different manufacturers i.e. Blade 2 blades and Blade 1 were selected. ESC using three different hardened electrodes i.e. Tungsten carbide, Stellite-21 and Chromium carbide on Blade 2 and Blade 1 blades with three modes for each electrode were considered. Each mode has different coating build up heights or thickness. Two Control blades were also taken in this study which was without coated on their surface i.e. Blade 2 control blade and Blade 1 control blade. Therefore for Blade 1 and Blade 2 separately, there were 10 treatments and are mentioned in Table 3.7.

Table 3.7 Details of treatments for blade 1 and blade 2

S.No	Treatment Name	Description
1	T1	Tungsten carbide 2 nd mode
2	T2	Tungsten carbide 4 th mode
3	T3	Tungsten carbide 6 th mode
4	S1	Stellite-21 2 nd mode
5	S2	Stellite-21 4 th mode
6	S3	Stellite-21 6 th mode
7	C1	Chromium Carbide 2 nd mode
8	C2	Chromium Carbide 4 th mode
9	C3	Chromium Carbide 6 th mode
10	Control	Without coating

3.6 Determination of Wear Loss

An area of 9.20 ha in CRIDA Hyderabad was selected for testing of coated blades. The field was free from any cultivation. The whole field was divided in two parts for testing of Blade 1 and Blade 2 rotavator coated blades separately. The rotavator was operated with coated and non coated blades for three different durations i.e. 2, 7.5 and 10 hour. The time period was selected looking to field condition which was fully dried, which allows to judge the coating performance. The same time of duration was also suggested in review of literature, if field is fully dried. By doing so, the wear characteristics of coated blades in field conditions were observed. The general condition of soil in this area was hard, dry and clay loam soils with stones. The bulk density of soil was 1.35g/cm³. The high abrasiveness of the soil and high impact load on the blade surface results in a significant acceleration of the wear of the blades. The experiments were conducted on February 2016. The rotavator was driven by a tractor (5245 DI Massey Ferguson, Planetary drive, 47 HP, 3-cylinder, Forced water cooled) through its power take-off (PTO) shaft at the speed of 540 rpm@1790Erpm. Average traveling speed was about 1.21 km/h, yielding theoretical field capacity of about 0.72 acre/h. The average depth penetrated in the soil about 7.4cm and fuel consumption was 2.65lit/hr.

Table 3.8 Independent parameters

Parameters	Level	Details
No. of blades	2	Blade 1 and blade 2 blade
No. of treatments	10	T1, T2, T3 S1, S2, S3 C1, C2, C3, Control

Table 3.9 Dependant parameters

S.No	Parameter	Unit
1	Wear loss a. Weight based b. Volume based	% per hour
2	Hardness	HRA

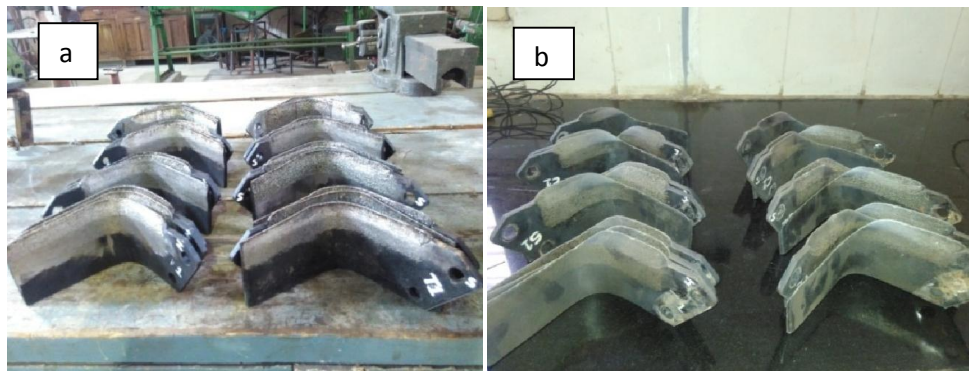


Plate 3.9: A view of ESC coated Rotavator blades before (a) and after (b) field operation

This test blades were fitted onto the tractor mounted rotavator in place of the standard blades randomly (plate 3.12) and the field experiment was carried out on a test field for a 10h. In this study the readings were taken at different time intervals i.e. 2.0h, 7.5h and 10h for measuring wear loss on weight and volume based. The weight readings were taken by using electronic weigh machine before operation and after operation.

The wear of the blades was assessed by weighing each blade before and after each experimental period to determine the wear loss. The percentage of wear (weight based) loss defined as the ratio of differences of rotavator blades weights before and after experimental period divided by weight of rotavator blades before experimental period.



Plate 3.10: A view of measurement of weight and volume of blade

Wear loss (weight based) (%) =

$$\frac{\text{weight before the operation} - \text{weight after the operation}}{\text{weight before the operation}} \times 100$$

..... (3.6.1)

Volume losses of blade were also assessed by measuring the volume of each blade before and after each experimental period to determine the volume loss. For measuring volume of the blades one bucket of 20 litres capacity with scaled on it was taken. Then it was filled up to 5litres of water. After this we kept the blade into that bucket. Then the volume of that bucket would be increased. Then taken the reading after volume increased. The volume of blade would be the volume of water after keeping blade minus the volume of water before keeping blade. Likewise we have measured the volume of all the treatments before and after field operation.

Percentage of wear loss (volume based) was defined as the ratio of differences of rotavator blades volume before and after experimental period divided by volume of rotavator blades before experimental period. Percentage of wear loss was used as indicator of amount of wear or performance of blade. Lower the percentage of wear, the performance more or lesser amount of wear.

Wear loss (Volume based) (%) =

$$\frac{\text{volume before the operation} - \text{volume after the operation}}{\text{volume before the operation}} \times 100$$

..... (3.6.2)



Plate 3.11: A view of measuring depth of operation



Plate 3.12: A view of rotavator after assembled of coated blades

3.7 Determination of Soil Parameters

The soil parameters like bulk density, soil moisture content, soil texture and depth were determined in this study.

3.7.1 Bulk density

The bulk density of a given sample is the ratio of dry weight of sample and the volume of that sample at same time.

Bulk density (Formula):

$$\text{Bulk density} = \frac{\text{Dryweight of sample}}{\text{Volume of sample}} \dots\dots\dots(3.7.1)$$

3.7.2 Soil moisture content

The Measurement of soil moisture was measured by gravimetric method. It was expressed by weight as the ratio of the mass of water present to the dry to the dry weight of the soil sample, or by volume as ratio of volume of water to the total volume of the soil sample.

Procedure

1. Auger or tool was taken to collect soil samples
2. Taken collected sample in aluminum weigh cans
3. Weighed aluminum can, and recorded this weight.
4. Placed a soil sample in the tin and recorded this weight as fresh weight.
5. Placed the sample in the oven 105°C, and dry for 24 hours or overnight.
6. Weighed the sample, and recorded this weight as dry weight (dry soil weight +can weight)

Repeat this step 5 until there is no difference between any two consecutive measurements of the weight of dry weight.

Computations

The moisture content in dry weight basis may be calculated using the following formula:

$$\text{Soil moisture (\%)} = \frac{\text{Fresh wt} - \text{Dry wt}}{\text{Dry wt} - \text{Can wt}} \times 100 \dots\dots\dots (3.7.2)$$

$$\text{Fresh wt} = \text{Can weight} + \text{Soil sample weight}$$

3.7.3 Soil texture (Hydrometer Method)

The percentage of sand, silt and clay in the inorganic fraction of soil was measured with hydrometer method. This method is based on Stoke's law. In this method following apparatus and materials was used.

- Glass cylinders, 500ml or 1000-ml capacity
- Thermometer, Fahrenheit
- Hydrometer, Bouyoucos
- Mechanical Agitator
- Stirrer
- Balance sensitive to $\pm 0.01\text{g}$

Reagents

Dispersing solution, 5%: Dissolve 50 g of sodium hexametaphosphate, $\text{Na}_6(\text{PO}_3)_6$ in deionized water and dilute to 1 liter.

Procedure method

1. Placed 50g or 100 g of soil in the cup.
2. Filled cup with 400 ml of water.
3. Added 5 ml of 1 N hexametaphosphate.
4. Mixed thoroughly with mechanical agitator:
 - a) For high clay soils- allow to soak for 15 minutes
 - b) For sandy soils- mix for 5 minutes
 - c) For finely textured soils- mix for 15 minutes
5. Transfer soil suspension to the sedimentation cylinder, use water to remove the entire sample from the cup.
6. Filled the sedimentation cylinder with 1 litre of water.
7. Carefully added the hydrometer, by gently placing it inside the cylinder.
8. Filled the sedimentation cylinder to 1150 mark.
9. Carefully removed the hydrometer.
10. Wrapped the top of the sedimentation cylinder in parafilm; make sure that seal is the secure.
11. Gently tilted the cylinder back and forth for thorough mixing, several times.
12. Carefully set the cylinder on a stable surface and removed the parafilm.
13. Return the hydrometer to the cylinder and begin the 40 seconds timing immediately, this 40 second reading can be repeated several times to improve accuracy.
14. After the final 40 second reading, remove the hydrometer and allow the cylinder to stand undisturbed. Begin to record the time in which you will start the 2 hour settling period.
15. Recorded the temperature, by lowering a thermometer into suspension and record the temperature (in $^{\circ}\text{C}$)
16. Taken a hydrometer reading at 2 hours.
17. Made up blank cylinder with water and 5ml of 1N sodium hexametaphosphate. Recorded the blank hydrometer reading.



Plate 3.13: A view of mechanical agitator

Calculations

1. Temperature Correction Factor

$$T = (\text{Observed temperature} - 20^{\circ}\text{C}) \times 0.03$$

2. Corrected 40 second reading

$$40 \text{ second (Corrected 'c')} = 2 \text{ hour reading} - \text{Blank reading} + T$$

3. Corrected 2hour reading

$$2 \text{ hour (Corrected 'c')} = 2 \text{ hour reading} - \text{Blank reading} + T$$

4. Particle percentages

- a. %sand (2-0.05)

$$= \frac{[\text{oven dry soil weight} - 40 \text{ second reading (c)}]}{[\text{oven dry soil weight}]} \times 100 \dots \dots \dots (3.7.3.1)$$

- b. % clay (<0.002mm)

$$= \frac{[2 \text{ hour reading (c)}]}{[\text{oven dry soil weight}]} \times 100 \dots \dots \dots (3.7.3.2)$$

- c. % silt (0.05-0.002)

$$= 100 - (\% \text{sand} + \% \text{clay}) \dots \dots \dots (3.7.3.3)$$

3.7.4 Determination of depth of operation

The depth of operation was measured by steel scale putting vertically with a lesser hand force into the soil behind the rotavator while it is field operation. Likewise take the 10 or more readings at different places. The average reading will be the depth of operation. The units are mm or cm.

3.7.5 Determination of speed of tractor during field operation

The speed is defined as the ratio of distance traveled divided by time taken for that travelled distance.

Procedure

1. Take the 30m steel tape
2. Select the 50m length of strip of field where field test was done and mark it
3. Take the time reading of tractor to cross this 50m strip
4. Repeat this above procedure for 4 or 5 time
5. Distance travelled divided by time will give the speed

3.8 Determination of Coating Characteristics

The coating characteristics include hardness, microstructure, coating build up height and phases presented were determined with different methods which were explained as follows;

3.8.1 Determination of hardness

Hardness means resistance to penetration. In this study the hardness was measured by using Rockwell hardness tester.

3.8.1.1 Sample requirements

Testing is typically performed on flat or cylindrical samples. Smooth parallel surfaces, scale and gross contamination, are required for testing. The size of samples about 1 inch dia and 7.5mm thick were tested. Samples 6 in. (150 mm) thick or larger can be accommodated. The minimum sample size depends on the sample hardness and test scale. Cylindrical samples are as small as 1/8 in. (3 mm) in diameter, and thin sheets 0.006 in. (150 μ m) thick, are the minimum size for testing.

Description of technique

Rockwell hardness testing is an indentation testing method. The indenter is either a conical diamond (brale) or a hard steel ball. Different indenter ball diameters from 1/16 to 1/2 in. are used depending on the test scale.

To start the test, the indenter is “set” into the sample at a prescribed minor load. A major load is then applied and held for a set time period. The force on the indenter is then decreased back to the minor load. The Rockwell hardness number

is calculated from the depth of permanent deformation of the indenter into the sample, i.e. the difference in indenter position before and after application of the major load. The minor and major loads can be applied using dead weights or springs. The indenter position is measured using an analog dial indicator or an electronic device with digital readout. The various indenter types combined with a range of test loads form a matrix of Rockwell hardness scales that are applicable to a wide variety of materials. Each Rockwell hardness scale is identified by a letter designation indicative of the indenter type and the major and minor loads used for the test. The Rockwell hardness number is expressed as a combination of the measured numerical hardness value and the scale letter preceded by the letters, HR. For example, a hardness value of 80 on the Rockwell A scale is reported as 80 HRA Its typical applications are quality control for metal heat treatment, weld evaluations in steels and other alloys, grade verification for hard plastics and Failure analysis.



Plate 3.14: A view of Rockwell hardness tester

3.8.2 Determination microstructure

Metallography consists of the study of the constitution and structure of metals and alloys. Much can be learned through specimen examination with the naked eye, but more refined techniques require magnification and preparation of the material's surface. Optical microscopy is sufficient for general purpose

examination; advanced examination and research laboratories often contain electron microscopes (SEM and TEM), x-ray and electron diffractometers and possibly other scanning devices.

3.8.2.1 Scanning Electron Microscope (SEM)

Description of technique

Scanning electron microscopy (SEM) is a method for high-resolution imaging of surfaces. The SEM uses electrons for imaging, much as a light microscope uses visible light. The advantages of SEM over light microscopy include much higher magnification (>100,000X) and greater depth of field up to 100 times that of light microscopy. Qualitative and quantitative chemical analysis information is also obtained using an energy dispersive x-ray spectrometer (EDS) with the SEM. (Handbook section on EDS analysis.)

The SEM generates a beam of incident electrons in an electron column above the sample chamber. The electrons are produced by a thermal emission source, such as a heated tungsten filament, or by a field emission cathode. The energy of the incident electrons can be as low as 100 eV or as high as 30 keV depending on the evaluation objectives. The electrons are focused into a small beam by a series of electromagnetic lenses in the SEM column. Scanning coils near the end of the column direct and position the focused beam onto the sample surface. The electron beam is scanned in a raster pattern over the surface for imaging. The beam can also be focused at a single point or scanned along a line for x-ray analysis. The beam can be focused to a final probe diameter as small as about 10 Å. The incident electrons cause electrons to be emitted from the sample due to elastic and inelastic scattering events within the sample's surface and near-surface material. High-energy electrons that are rejected by an elastic collision of an incident electron, typically with a sample atom's nucleus, are referred to as backscattered electrons. The energy of backscattered electrons will be comparable to that of the incident electrons. Emitted lower-energy electrons resulting from inelastic scattering are called secondary electrons. Secondary electrons can be formed by collisions with the nucleus where substantial energy loss occurs or by the ejection of loosely bound electrons from the sample atoms. The energy of secondary electrons is typically 50 eV or less.

To create an SEM image, the incident electron beam is scanned in a raster pattern across the sample's surface. The emitted electrons are detected for each position in the scanned area by an electron detector. The intensity of the emitted electron signal is displayed as brightness on a cathode ray tube (CRT). By synchronizing the CRT scan to that of the scan of the incident electron beam, the CRT display represents the morphology of the sample surface area scanned by the beam. Magnification of the CRT image is the ratio of the image display size to the sample area scanned by the electron beam.



Plate 3.15: A view of SEM Plate 3.16: A view of Optical Light Microscope

Two electron detector types are predominantly used for SEM imaging. Scintillator type detectors (Everhart-Thornley) are used for secondary electron imaging. This detector is charged with a positive voltage to attract electrons to the detector for improved signal to noise ratio. Detectors for backscattered electrons can be scintillator types or a solid-state detector. The SEM column and sample chamber are at a moderate vacuum to allow the electrons to travel freely from the electron beam source to the sample and then to the detectors. High-resolution imaging is done with the chamber at higher vacuum, typically from 10^{-5} to 10^{-7} Torr. Imaging of nonconductive, volatile, and vacuum-sensitive samples can be performed at higher pressures.

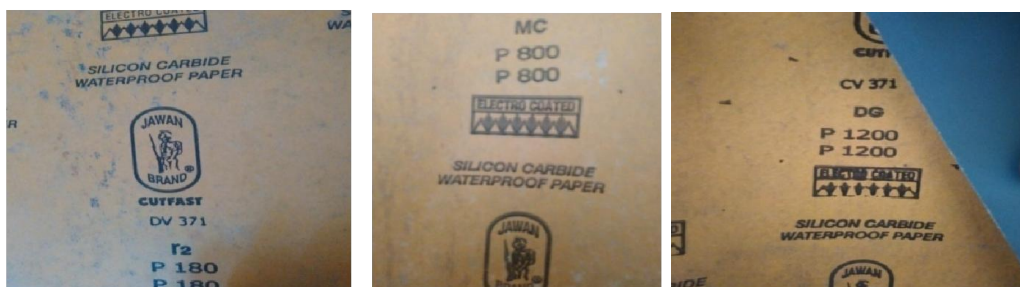


Plate 3.17: A view of SiC Papers of different grits

3.8.2.2 Sample preparation for analysis of microstructure with SEM

The size of samples used for measurement of microstructure is about 10x15x7mm³

Grinding

The purpose of the coarse grinding stage was to generate the initial flat surface necessary for the subsequent grinding and polishing steps. Course grinding was accomplished by using 80 to 180 grit SiC papers. The grinding was done till obtain a flat surface free from all previous tool marks and cold working due to specimen cutting.

The sample was washed thoroughly before proceeding from one grinding stage to the next.

Medium and fine grinding

Medium and Fine Grinding of metallurgical samples were closely allied with the Coarse Grinding which precedes them. Medium grinding was done by using successive 240, 320, 400, 600, 800, 1000 and 1200 grit SiC. The rotation of the sample between stages was must be held constant during the grinding at any on stage.

Mechanical polishing

Polishing involves the use of abrasives, suspended in a water solution, on a cloth-covered electrically powered wheel. Proceeding to the first polishing stage, wash the specimen carefully and also operator's hands. Beginning with 25-micron suspended aluminum oxide particles (suspended in water) on a Nylon-cloth, the final fine-grinding surface layer resulting from the previous grinding procedure was completely removed with a rotation rate of 150-200 rpm.

The specimen is initially held at one position on the wheel by using moderate pressure, without rotation, until most of the previous grinding marks were removed. It was rotated slowly, counter to the wheel rotation, until only scratches from the 25-micron aluminum oxide are visible. Entire stage was taken 1 or 2 minutes.

After carefully washing the specimen, proceed to the 5-micron stage where a separate polishing wheel with 5-micron particles; repeat the procedure outlined above using lighter pressure and a gradual rotating motion across the polishing cloth.

The final polishing stage with 1-micron suspended aluminum oxide particles was carried out on a separate polishing wheel at a slower speed of 100 - 150 rpm using a napped cloth. After 1 or 2 minutes the polished specimen was attained mirror-like surface free of scratches.

For precision work, extremely fine grades of diamond abrasives may often be used for the final polishing sequence. Cerium Oxide is especially excellent for the final polishing of aluminum and other soft metals and alloys.



Plate 3.18: A view of Mechanical Polishing Plate 3.19: A view Sample after polishing

Etching

Microscopic examination of a properly polished (plate 3.19), unetched specimen will reveal only a few structural features such as inclusions and cracks or other physical imperfections. Etching is used to highlight, and sometimes identify, microstructural features or phases present. Etching occurs when the acid or base is placed on the specimen surface because of the difference in rate of attack of the various phases present and their orientation. The etching process is usually accomplished by merely applying the appropriate solution to the specimen surface for several seconds to several minutes.



Plate 3.20: A view etching of sample

Nital was used for etching. It was dripped onto the specimen using an eye-dropper or cotton swab. Ten seconds time was taken for etching one sample. The sample was immediately washed under running water, rinsed with alcohol and dried in an air blast. The composition of Nital was given below.

Table 3.10 Different etchants for different material compositions

Materials	Composition	Application procedure
Iron & Steel	1-5 Parts Nitric Acid 100 Parts Alcohol	Immerse/Swab
	1 Part Ammonium Hydroxide 1Part3% Hydrogen Peroxide 1 Part Water	Swab
Stainless Steels	10 g Oxalic Acid 100 ml Water	Use
	5 ml Sulfuric Acid 100 ml Water	Electrolytically Use Electrolytically

3.8.2.3 Microscopic Examination

The specimen was placed on the stage of the microscope such that its surface is perpendicular to the optical axis. Detailed viewing is done with a SEM. It has a system of lenses (objectives and eyepiece) so that different magnifications (25X to 1000X) can be achieved. The important characteristics of the microscope are: (1) magnification, (2) resolution and (3) flatness of field. Scanning Electron Microscopes (SEMs) are capable of magnifications up to 20,000X.



Plate 3.21: A view of sample holder for SEM

3.8.3 Determination of coatings builds up height

Samples used in this study were coated on one side with Different types of coating materials, using an Electro Spark Coating Machine. The coating Materials

are Tungsten Carbide, chromium carbide and satellite-21. For measurement of these coatings build of height SEM instrument was used. Sample preparation was same as sample need for microstructure measurement. In this measurement the cross sections were prepared for the analyses of sample coated. These samples were placed vertically as coated side as front faced position, instring holders and put in a mould. Then observed with the microscopic where the coating has presented.

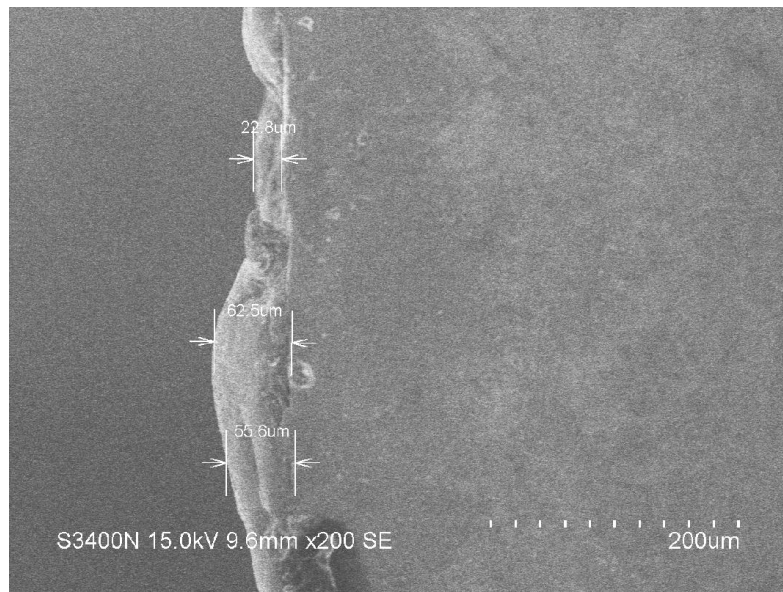


Fig 3.1 Observation of Coating Build up height of Sample with SEM

3.8.3.1 Sample requirements

Samples of size about 10mmx10mmx7.5mm were used for this study. Samples up to 8 in. (200 mm) in diameter can be readily analyzed in the SEM. Larger samples, up to approximately 12 in. (300 mm) in diameter; can be loaded with limited stage movement. A maximum sample height of approximately 2 in. (50 mm) can be accommodated. Samples must also be compatible with a moderate vacuum atmosphere (pressures of 2 Torr or less).

3.8.4 Determination of phases presented

For determining phased presented in coated materials and powders X-ray powder diffraction method is used. The instrument used for XRD method was X-ray diffractometer. X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide

information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined.

3.8.4.1 Fundamental principles of x-ray powder diffraction (XRD)

X-ray diffraction is based on constructive interference of monochromatic X-rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda = 2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through a range of 2θ angles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to spacings allows identification of the mineral because each mineral has a set of unique spacings. Typically, this is achieved by comparison of spacings with standard reference patterns. All diffraction methods are based on generation of X-rays in an X-ray tube. These X-rays are directed at the sample, and the diffracted rays are collected. A key component of all diffraction is the angle between the incident and diffracted rays. Powder and single crystal diffraction vary in instrumentation beyond this.

3.7.4.2 X-ray powder diffraction (XRD) Instrumentation

X-ray diffractometers consist of three basic elements: an X-ray tube, a sample holder, and an X-ray detector. X-rays are generated in a cathode ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced. These spectra consist of several components, the most common being $K\alpha$ and $K\beta$. $K\alpha$ consists, in part, of $K\alpha_1$ and $K\alpha_2$. $K\alpha_1$ has a slightly shorter wavelength and twice the intensity as $K\alpha_2$. The specific wavelengths are characteristic of the target material (Cu, Fe, Mo, Cr). Filtering, by foils or crystal monochromators, is required to produce monochromatic X-rays needed for diffraction. $K\alpha_1$ and $K\alpha_2$ are sufficiently close in

wavelength such that a weighted average of the two is used. Copper is the most common target material for singlecrystal diffraction, with $\text{CuK}\alpha$ radiation = 1.5418\AA . These Xrays are collimated and directed onto the sample. As the sample and detector are rotated, the intensity of the reflected Xrays is recorded. When the geometry of the incident Xrays impinging the sample satisfies the Bragg Equation, constructive interference occurs and a peak in intensity occurs. A detector records and processes this Xray signal and converts the signal to a count rate which is then output to a device such as a printer or computer monitor.

The geometry of an Xray diffractometer is such that the sample rotates in the path of the collimated Xray beam at an angle θ while the Xray detector is mounted on an arm to collect the diffracted Xrays and rotates at an angle of 2θ . The instrument used to maintain the angle and rotate the sample is termed a goniometer. For typical powder patterns, data is collected at 2θ from $\sim 5^\circ$ to 70° , angles that are preset in the Xray scan.

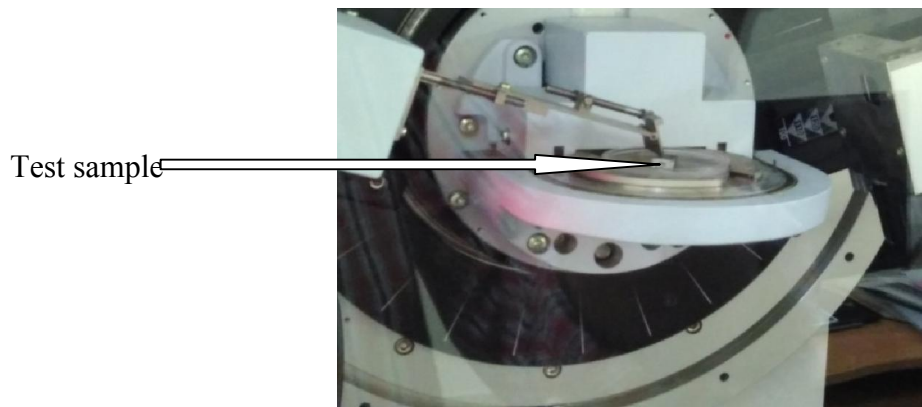


Plate 3.22: A view of X-Ray Diffractometer

3.8 Design of Experiment

Two different experiments were evaluated with 10 treatments and three replications by using randomized block design. The statistical analysis has been done as per standard procedure.

3.9 Economic Analysis

The economic analysis of the study also been done by using prevailing market rates and standard procedure.

CHAPTER- IV

RESULTS AND DISCUSSIONS

This chapter deals with the results and discussion of the experiment conducted in order to fulfill the objectives of the study. To determine the effect of different coating materials on wear loss of two rotavator blades manufactured by two different companies i.e. Blade 2 and Blade 1 both type of blades coated by ESC machine using three types of electrodes i.e. Tungsten carbide, Stellite-21 and Chromium Carbide, with three different modes. The study comprises 10 treatments for each blade type including control blade i.e. combination of coating materials with modes. The experiment was carried out in hard and dry clay loam soils at CRIDA, Hyderabad research farm during the season 2016-17. The effect of different coated materials on wear loss of controlled blades Blade 2 and Blade 1 was observed on the basis of weight and volume. The effect of different coated materials on hardness of controlled blades Blade 2 and Blade 1 was also observed. To strengthen the study surface characterization of coating i.e. microstructure analysis, phase analysis and measurement of coating builds up height was also done. The observed result during experiment and its discussion explained under the following subheading.

- 4.1 Chemical composition, wear characteristics, hardness and microstructure of selected rotavator blades
- 4.2 Effect of coating treatments on wear loss of selected rotavator blades on weight basis (% per hour)
- 4.3 Effect of coating treatments on wear loss of selected rotavator blades on volume basis (% per hour)
- 4.4 Effect of coating treatments on hardness of selected rotavator blades
- 4.5 Effect of coating treatments modes on coating builds up height of selected rotavator blades
- 4.6 Comparison of microstructures of coating treatments on selected rotavator blades
- 4.7 Comparison of phase analysis of coating treatments on selected rotavator blades

4.8 Cost economics of coating treatments on selected rotavator blades

4.1 Element Composition, Wear Characteristics, Hardness and Microstructure of Selected control Rotavator Blades

In this study two types of rotavator blades namely Blade 1 and Blade 2 were selected for determination of element composition, hardness and wear characteristics having no coating. The same has been quoted as control blades. The study was limited to L blades. The composition of these blades was determined by using optical emission spectrometer. The chemical composition is shown in Table 4.1. The control blades were used for tillage operations and the wear loss on weight and volume basis were recorded. The results of control blades are shown in Table 4.2. The hardness of blades was also measured to know the wear characteristics the results were shown in Table 4.3. However, their comparative analyses with coated blades are described in further sub sections.

Table 4.1 Element composition of selected rotavator blades

Blade / Parameter	Unit, %								
	C	Si	Mn	S	P	Cr	Mo	Ni	Fe
Blade 1	0.29	0.22	1.30	0.012	0.024	0.37	0.05	0.19	97.544
Blade 2	0.28	0.32	1.33	0.014	0.038	0.38	0.03	0.14	97.468

Table 4.2 Wear loss of selected rotavator blades on weight and volume basis

Blade	Wear loss, % per hour	
	Weight basis	Volume basis
Blade 1	1.810	5.660
Blade 2	1.802	3.729

Table 4.3 Hardness of selected rotavator blades

Blade	Rockwell hardness, HRA	Vickers hardness, Hv
Blade 1	44.66	438
Blade 2	45.33	448

4.1.2 Microstructure study of Blade 1 blades

The microstructures of Blade 1 and Blade 2 were shown in Fig.4.1 and Fig.4.2. The both rotavator blades have martensitic structure on their surface, it was shown in Fig.4.1(a) and Fig.4.2(a). Rough wear tracks also observed in both blades, it was shown in Fig.4.1(b) and Fig.4.2(b).

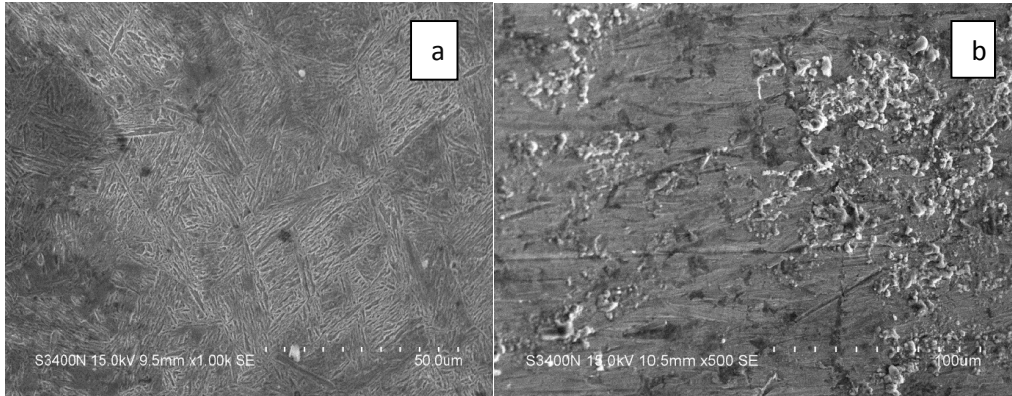


Fig 4.1: Micro structure of control Blade 1 before and after operation

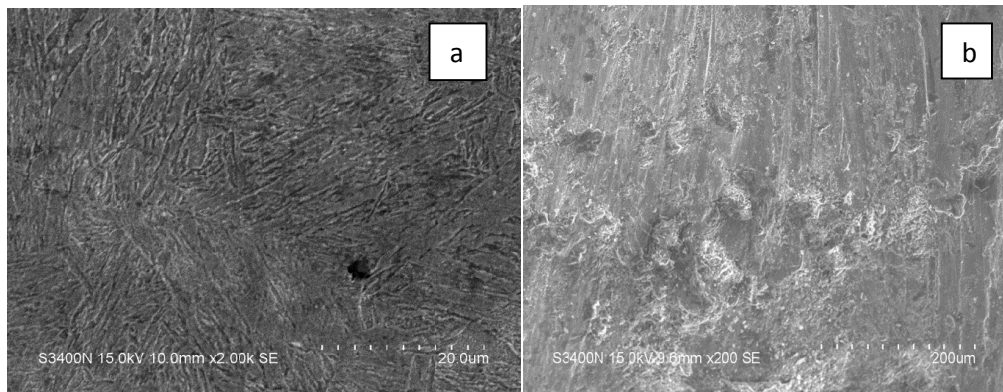


Fig 4.2: Micro structure of Control Blade 2 before and after operation

4.2 Effect of Coating Treatments on Wear Loss of Selected Rotavator Blades on Weight Basis (Wear loss % per hour)

The highest wear loss was obtained in case of control treatments and it was 1.810 per cent per hour for blade 1 and 2.0060 per cent per hour for treatment S2 blade 2 as shown in Table 4.4. In case of Blade 1 blade, the lowest wear loss 0.829 per cent per hour was recorded in T1 treatment i.e. Tungsten carbide 2nd mode. It was 2.04 times lower than that of control treatment. The treatments T1 (Tungsten carbide 2nd mode), S1 (Stellite-21 2nd mode), T2 (Tungsten carbide 4th mode), C1 (Chromium carbide 2nd mode), T3 (Tungsten carbide 6th mode) and S3 were having significant difference with control blade treatment. These treatments S1, T2, C1, T3 and S3(Stellite-21 6th mode) showed less wear loss i.e. 1.002%, 1.126%, 1.131%, 1.152%, and 1.275% respectively in comparison with S2, C3(Chromium carbide 4th mode) and C2(Chromium carbide 6th mode). However, these treatments do not have significant difference with each other. The treatments S3, S2 (Stellite-21 4th mode), C3 and C2 do not have any significant difference

with each other. But they were having lower wear loss compared to control blade treatment. The wear loss of treatments C2 & C3 was very close to control treatment and those were significantly at par to each other. It is well known that, theoretically the strength of treatment C2 and C3 is more than T1. However, blades having treated with C2 and C3 observed more wear loss may be due to the less bonding of base metal and coating material. It may be possible that position of blade also one of the parameter caused the more wear in treatments C2 and C3.

In case of blade 2, the lowest wear loss 0.8067 per cent per hour was recorded in T2 treatment i.e. Tungsten carbide 4th mode as shown in Table 4.4. It was 2.23 times lower than that of control treatment. The treatments C3, T3, C2 and S2 were having more wear loss compared to control blade treatment, however these treatments do not have significant different each other. The treatments C1, S3, T1 and S1 showed less wear loss i.e. 1.4116%, 1.4993%, 1.7007% and 1.7453% respectively in comparison with control blades. However, these treatments do not have significant difference with each other. The wear loss of treatments T1, S1, C3 and T3 was very close to control treatment and those were significantly at par to each other. The treatments C3, T3, C2 and S2 observed more wear loss may be due to the less bonding of base metal and coating material. It may be possible that position of blade also one of the parameter caused the more wear in treatments C3, T3, C2 and S2.

The rotavator blades were under field operation for 2, 7.5 and 10 hours and it was observed that more wear loss (% per 1 hour) was recorded during initial duration i.e. 2 hour operation. Although the blades were continuously used for 10 hour operation also, but the wear loss (% per hour) was lower in value. It means that the increase in hours of use reduces the wear loss (% per hour) in the tested treatments. The pattern of wear loss (% per hour) over different duration for Blade 1 blade and Blade 2 blades are depicted in Fig 4.3. and 4.4.

Table 4.4 Effect of coating treatments on wear loss of selected rotavator blades on weight basis

Treatments	Wear loss, % per hour	
	Blade 1	Blade 2
T1	0.829	1.7007
T2	1.126	0.8067
T3	1.152	1.8624
S1	1.002	1.7453
S2	1.377	2.0660
S3	1.275	1.4993
C1	1.131	1.4116
C2	1.679	2.0264
C3	1.649	1.8560
Control	1.810	1.8020
CD	0.453	0.307
SEM \pm	0.1526	0.103

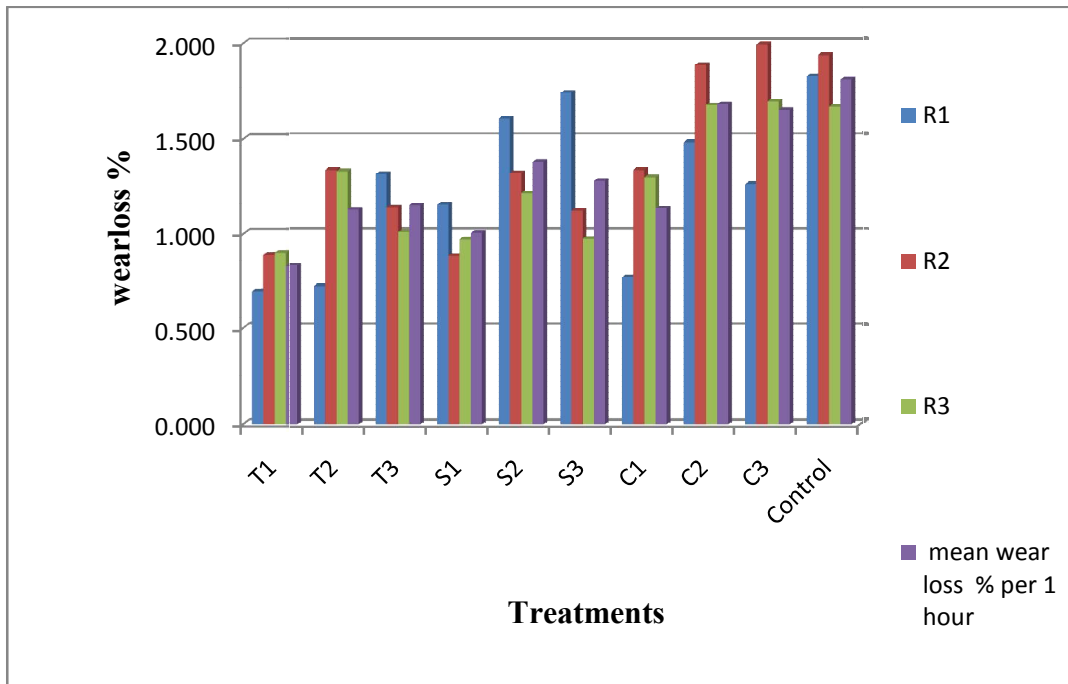


Fig 4.3: The effect of coating treatments on wear loss of Blade 1 (weight based)

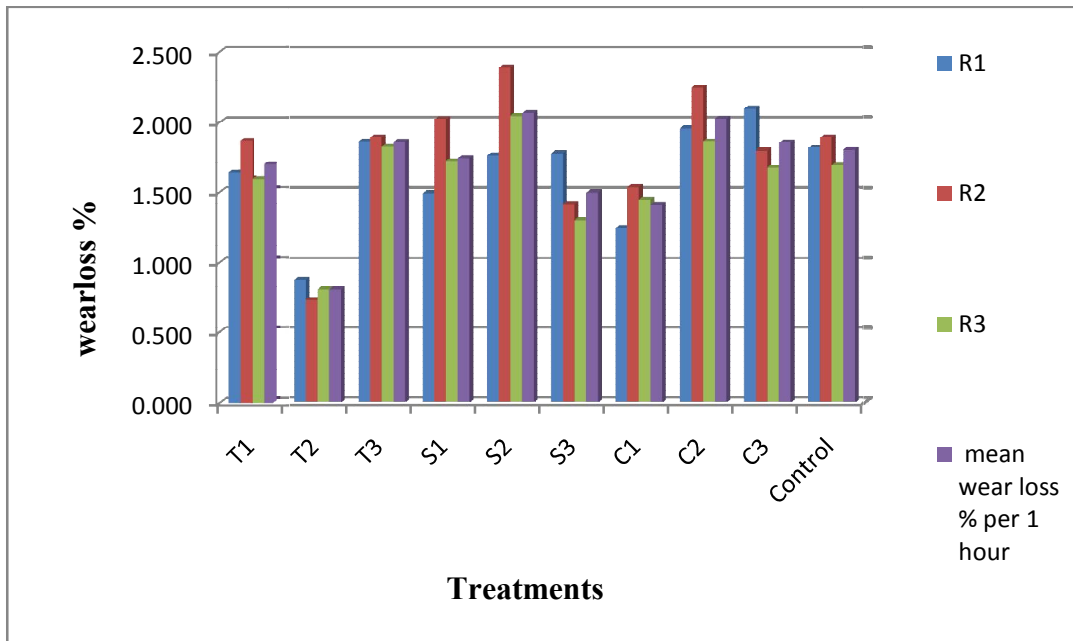


Fig 4.4: The effect of treatments on wear loss of blade 2 (weight based)

4.3 Effect of Coating Treatments on Wear Loss of Selected Rotavator Blades on Volume Basis (Wear loss % per hour)

The highest wear loss was obtained in case of control treatment (5.6608 % per hour) in case of blade 1 and treatment T3 (5.0296 % per hour) in case of blade 2 rotavator blade as shown in Table 4.5. In case of blade 1, the lowest wear loss 3.8634 per cent per hour was recorded in C1 treatment i.e. Chromium carbide 2nd mode. It was 1.46 times lower than that of control treatment. The treatments T1, S3, C2, S2, T3, C3, T2, S1 and control were having do not have significant difference with treatment C1. These treatments T1, S3, C2, S2, T3, C3, T2, S1 and control showed less wear loss i.e. 3.9350%, 4.0489%, 4.0556%, 4.2287%, 4.2667%, 4.8691%, 5.0711%, 5.1792% and 5.6608% respectively. However, blades having treated with T1 and S3 observed wear loss little close to the treatment C1. The wear losses are more in treatments T2, S1 and control was due to soil was very tough, dry soils with stones and during the operation of rotavator, it is under the dynamic loading then heat generated between the blade and soil cause the more wear. The maximum wear loss observed in control blade then after treatment S1.

In case of Blade 2 rotavator blade the less wear loss observed in treatment T2 (2.3296) shown in the Table 4.5. The treatment T2 was showed significantly

less wear loss than rest of the treatments. The wear loss of treatment T2 was 2.15 times lesser than that wear loss of the control treatment. The treatments C1, S3, S1 and C2 were having less wear loss after the treatment T2, however these treatments do not significance difference each other. Following treatments C3, S2, T1 and T3, were having more wear loss than the control treatment, these treatments do not have significance difference each other. These results were occurred due to uneven soil condition and different loads are acting on treatments C3, S2, T1 and T3.

Table 4.5 Effect of coating treatments on wear loss of selected rotavator blades on volume basis

Treatments	Wear loss, % per hour	
	Blade 1	Blade 2
T1	3.9350	4.2302
T2	5.0711	2.3296
T3	4.2667	5.0296
S1	5.1792	3.3213
S2	4.2287	4.0833
S3	4.0489	2.6738
C1	3.8634	2.5697
C2	4.0556	3.4439
C3	4.8691	4.0509
Control	5.6608	3.7297
CD	1.847	1.031
SEM \pm	0.621	0.347

The rotavator blades were under field operation for 2, 7.5 and 10 hours and it was observed that more wear loss (% per 1hour) was recorded during initial duration i.e. 2 hour operation. Although the blades were continuously used for 10 hour operation also, but the wear loss (% per hour) was lower in value. It means that the increase in hours of use reduces the wear loss (% per hour) in the tested treatments. The pattern of wear loss (% per hour) over different duration for Blade 1 blade is depicted in Fig 4.5. and Fig 4.6.

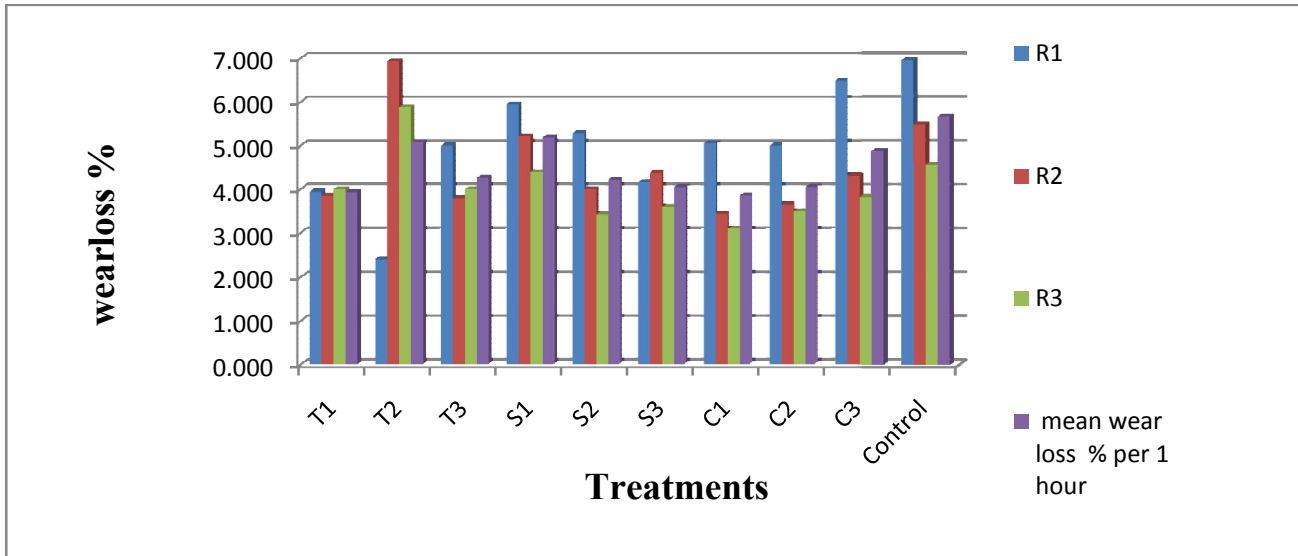


Fig 4.5: The effect of treatments on wear loss of Blade 1 (volume based)

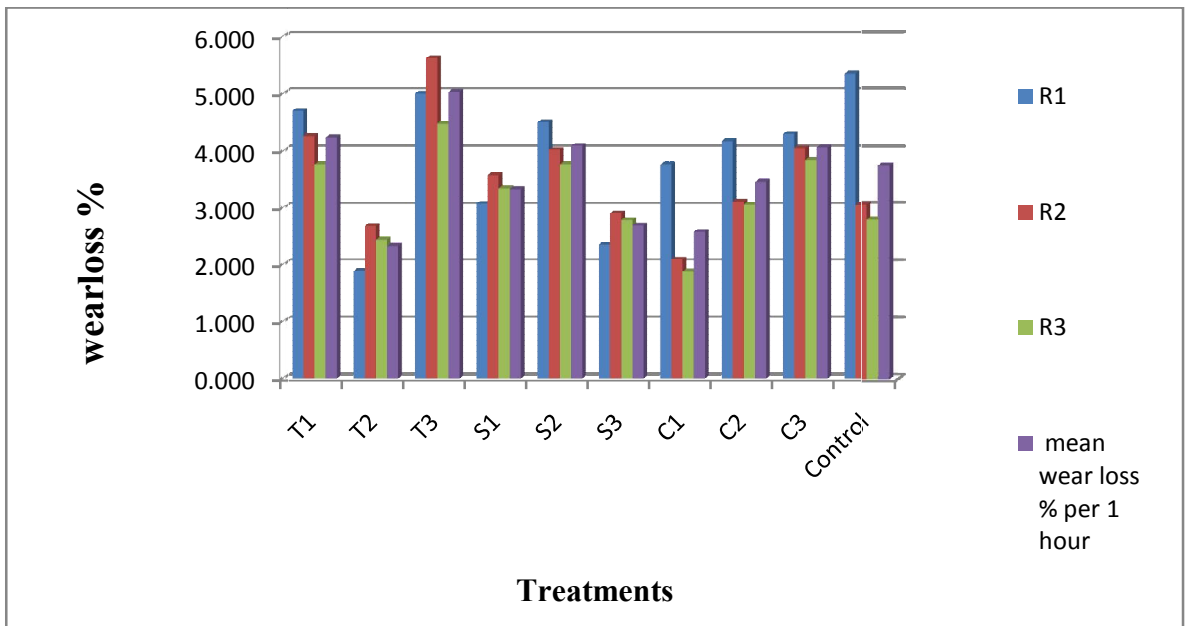


Fig 4.6: The effect of treatments on wear loss of Blade 2 (volume based)

4.4 Effect of Coating Treatments on Hardness of Selected Rotavator Blades

The hardness was observed more in treatment T1 (55.33 HRA) in case of Blade 1 rotavator blades and treatment C2 (58.33 HRA) in case of Blade 2 rotavator blades as shown in Table 4.6.

In case of Blade 1 rotavator blade hardness of treatment T1 was showed significantly higher than hardness of rest of all the treatments. The treatments C1

and control treatment were having less hardness i.e. 42.66 HRA and 44.667 HRA respectively; however these treatments do not have significant different each other. The treatments S2, C2, T3, T2, S1, S3 and C3 were having higher hardness after the hardness of treatment T1; these treatments do not have significance difference each other. The hardness of this treatment T1 was about 1.23 times more than hardness of the control treatment.

In case of Blade 2 rotavator blade hardness of treatment C2 was showed significantly higher than hardness of rest of all the treatments. The treatment T1 was having less hardness i.e. 26.0 HRA. The treatments S1, S3, T2 and C1 were having higher hardness after the hardness of treatment C2; these treatments do not have significance difference each other. Hardness of the treatment T3 was close to hardness of the control treatment; however these treatments do not have significant difference each other. The hardness of this treatment C2 was about 1.49 times more than hardness of the control treatment. These results were observed because theoretically the hardness of chromium hardness higher than tungsten carbide and Stellite-21.

Table 4.6 Effect of coating treatments on hardness of selected rotavator blades

Treatments	Hardness			
	Blade 1		Blade 2	
	Rockwell, HRA	Vickers, Hv	Rockwell, HRA	Vickers, Hv
T1	55.333	649	39.000	376
T2	48.000	490	49.667	497
T3	48.000	490	39.667	376
S1	48.000	490	51.000	531
S2	49.000	497	45.333	448
S3	47.667	474	50.667	505
C1	42.667	406	48.667	490
C2	48.333	490	58.333	746
C3	47.333	474	45.667	448
Control	44.667	438	39.000	376
CD	3.971		4.03	
SEM ±	1.336		1.359	

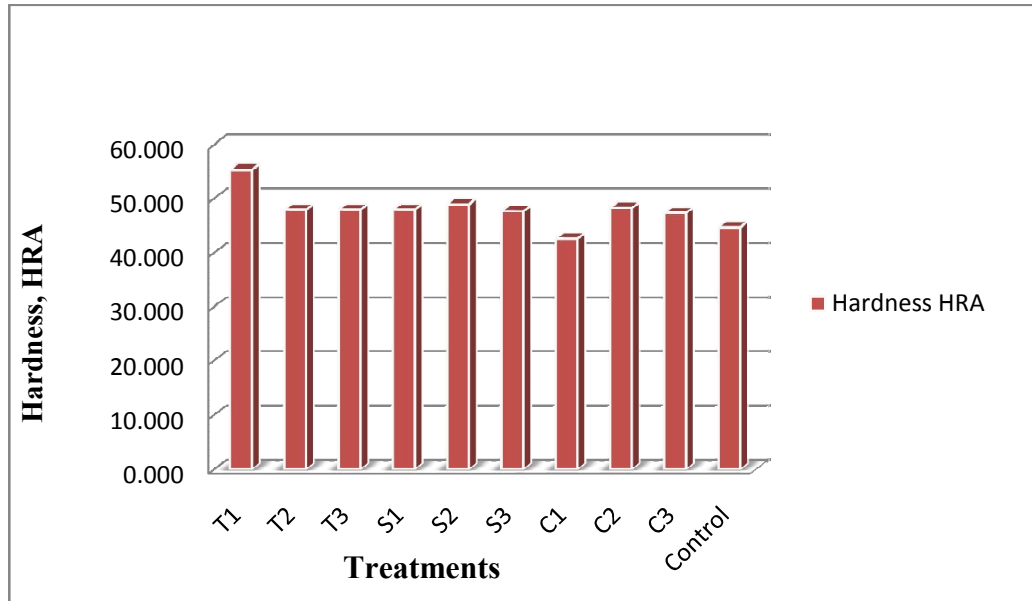


Fig. 4.7: Effect of hardness on coating treatments of blade 1 rotavator blade

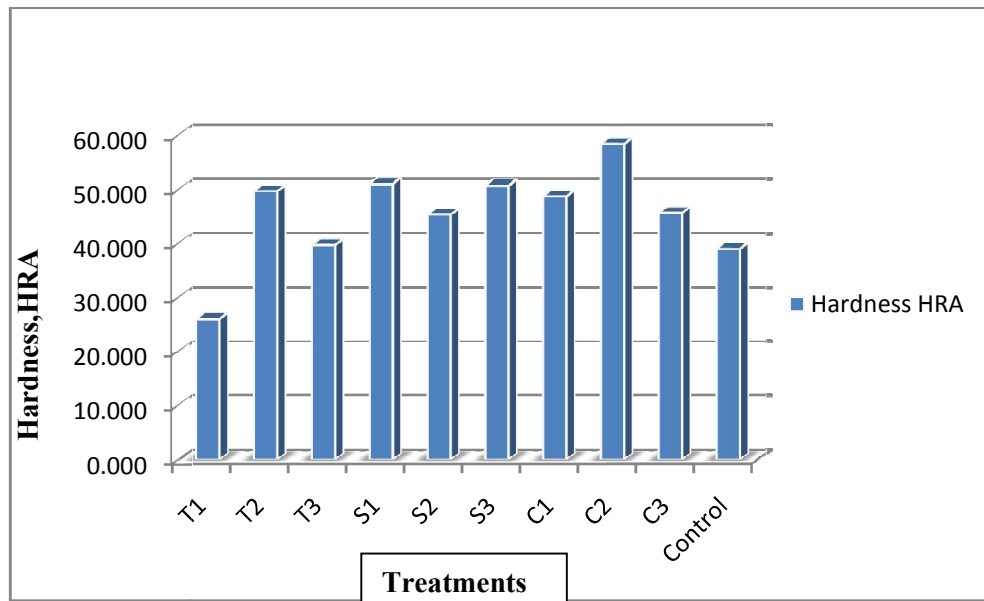


Fig. 4.8: Effect of hardness on coating treatments of blade 2 rotavator blade

4.5 Effect of Coating Treatments Modes on Coating Builds up Height of Selected Rotavator Blades

The effect of different coating modes on coating builds up height of blade 1 shown in the Table 4.7 it showed that the coatings buildup height varies from 72 μm to 157.019 μm . The treatment C3 has the more thickness of coating than the other treatments. Then the treatment S1 has the lesser thickness of coating.

The effect of different coating modes on coating builds up height of blade 2 shown in Table 4.7 which revealed that the coatings buildup height varies from 33.125 μm to 160.8 μm . The treatment C3 has the more thickness of coating than the other treatments. Then the treatment C1 has the lesser thickness of coating.

Table 4.7 Effect of coating treatments modes on coating builds up height of selected rotavator blades

Treatments	Coating buildup height, μm	
	Blade 1	Blade 2
T1	95.88	79.70
T2	105.6	95.80
T3	150.3	143.3
S1	72.00	70.30
S2	95.30	90.05
S3	143.2	140.9
C1	36.87	33.12
C2	93.40	142.5
C3	157.0	160.8

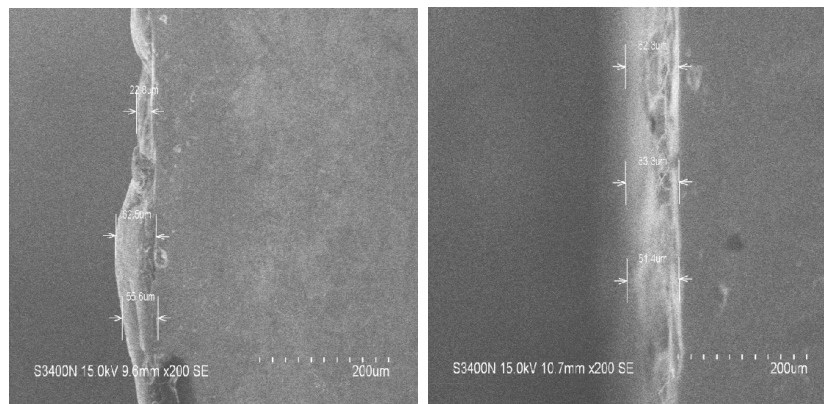


Fig 4.9: Coating thickness of treatment C1 Blade 1

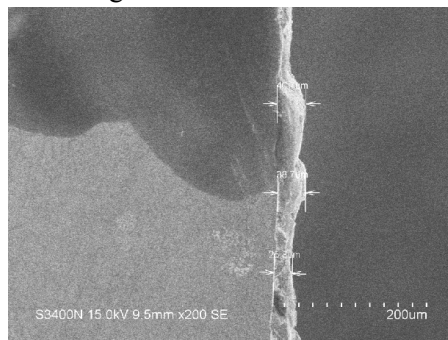


Fig 4.10: Coating thickness of treatment C1 Blade 2

4.6 Comparison of Microstructures of Coating Treatments on Selected Rotavator Blades

4.6.1 Microstructure study of Blade 1 blades

The SEM Micrograph of Fig 4.13a shows that the large pore spaces and non uniformity size of coating particles. The particle sizes are varies irregularly. Fig 4.13b clearly showed that the smoothed wear tracks, pulled of the carbide particles and also the small indentations. The 4.14a showed that the different sizes of coating particles it indicating the less bonding created between base metal and coating material. The Fig 4.15a shows that the pore spaces are more in T1 compared to C1, but C1 has the pore size more than the T1. The Fig 4.14b showed that the T1 has the rough wear tracks with small indentations. The Fig 4.15b showed that the big wear grooves with small indentations.

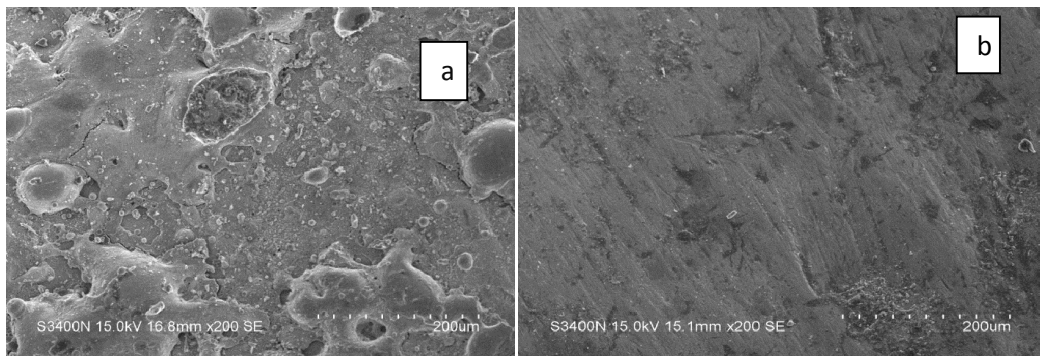


Fig 4.11: Micro structure of treatment C1 Blade 1 before and after operation

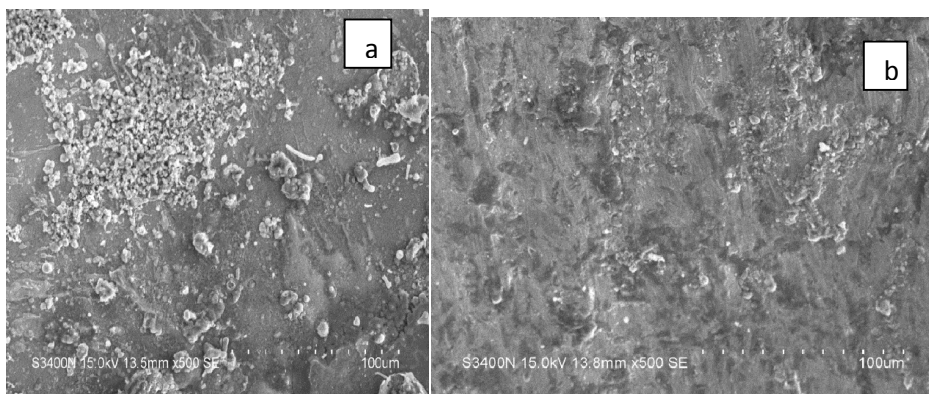


Fig 4.12: Micro structure of treatment S2 Blade 1 before and after operation

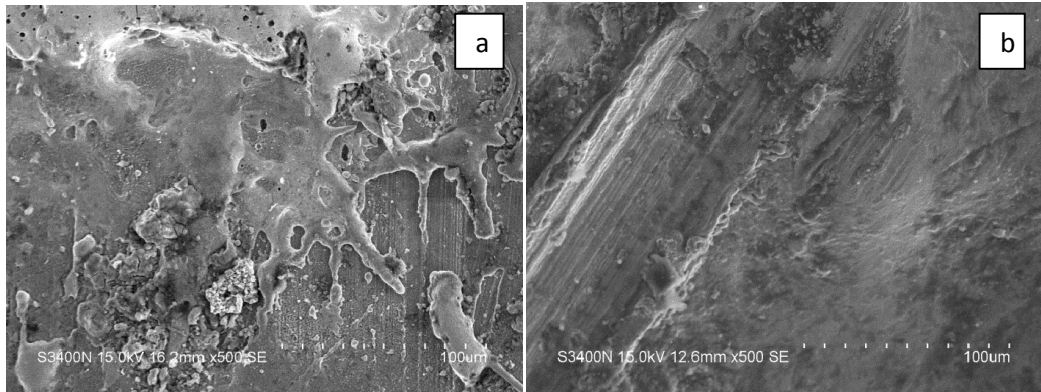


Fig 4.13: Micro structure of treatment T1 Blade 1 before and after operation

4.6.2 Microstructure study of Blade 2

The Fig 4.16a shows that the various sizes of coating particles, then Fig 4.16b showed that the small smoothed wear tracks with small indentations and pulled out of carbide particles. The Fig 4.17a showed that the pore spaces of various size, in the Fig 4.17b showed that the little coating appeared after the operation also and small indentation.

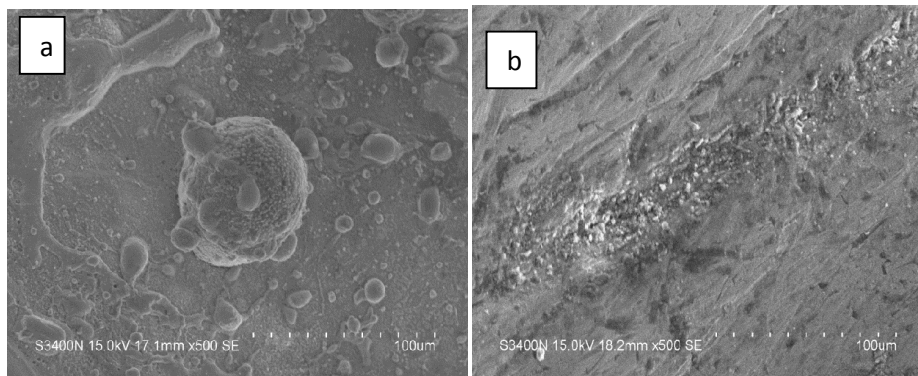


Fig 4.14: Micro structure of treatment C2 Blade 2 before and after operation

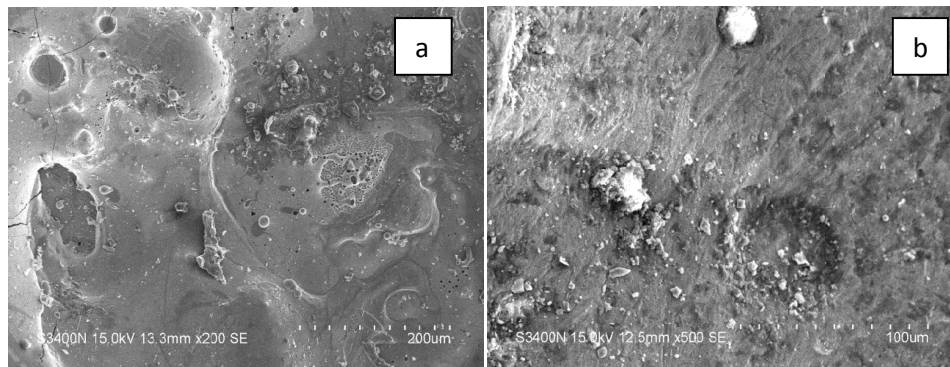


Fig 4.15: Micro structure of treatment T2 Blade 2 before and after operation

4.7 Comparison of Phase Analysis of Coating Treatments on Selected Rotavator Blades

The Fig 4.18 illustrated that treatment C3 Blade 2an has the dominant phases are Fe,Ni and Carbon, after this Cr_7C_3 ,cr and Fe_2C . It was observed that from above Fig 4.18 iron carbide and chromium carbides are formed in the form of Fe_2C and Cr_7C_3 after the coating.

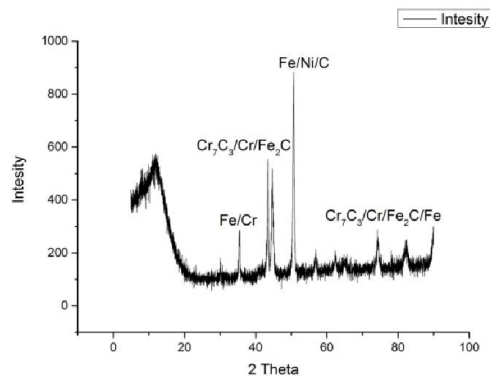


Fig 4.16: XRD patterns of C3 Blade 2

The Fig 4.19 showed that treatment S3 Blade 1 has the dominant phases was C, after this Cr,W and Co. It was observed that from above Fig 4.19 iron carbides are formed in the form of Fe_2C and Fe_5C_2 after the coating.

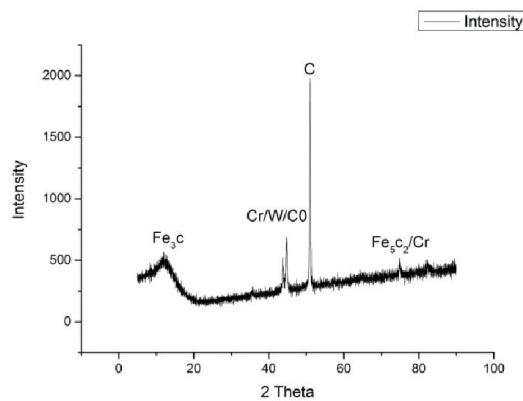


Fig 4.17: XRD patterns of S3 Blade 1

The Fig 4.20 showed that treatment C2 Blade 1 blade has the dominant phases was Fe_3C , Cr and Ni after this C and Fe_3C . It was observed that from above Fig 4.20 iron carbide are formed in the form of Fe_3C after the coating.

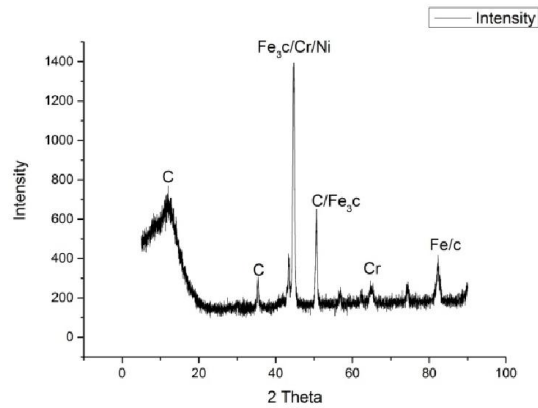


Fig 4.18: XRD patterns of C2 Blade 1

The Fig 4.21 showed that treatment T2 Blade 2 has the dominant phases was Fe_3C , C and Ni, after this Cr_3C_2 , W and Fe_3C . It was observed that from above Fig 4.20 iron carbide are formed in the form of Fe_3C after the coating.

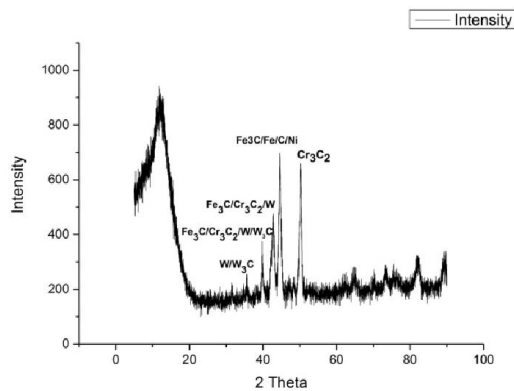


Fig 4.19: XRD patterns of T2 Blade 2

The Fig 4.22 showed that Control Blade 2 blade has the dominant phases was Fe_2C , Fe, Cr and Co after this Cr and Fe . It was observed that from above Fig 4.22 iron carbide are formed in the form of Fe_2C after the coating.

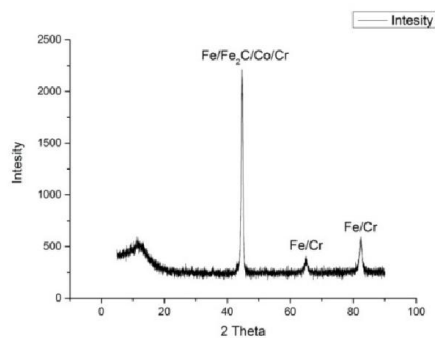


Fig 4.20: XRD patterns of Control Blade 2

The Fig 4.23 showed that Control Blade 1 blade has the dominant phases was Fe_5C_2 and Ni after this C. It was observed that iron carbide are formed in the form of Fe_5C_2 .

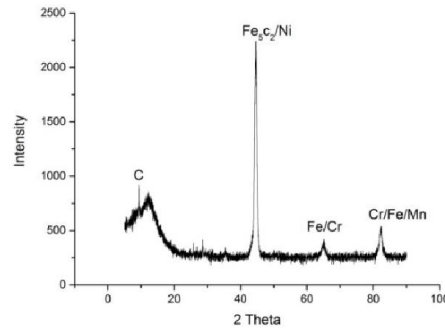


Fig 4.21: XRD patterns of Control Blade 1

The Fig 4.24 showed that treatment S1 Blade 2 has the dominant phases was Fe_5C_2 , after this C, Co, Fe and Fe_2C . It was observed that from above Fig 4.24 iron carbide are formed in the form of Fe_2C and Fe_5C_2 after the coating.

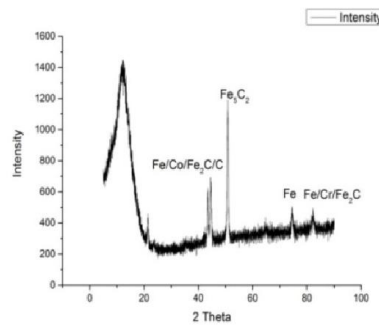


Fig 4.22: XRD patterns of S1 Blade 2

The Fig 4.25 showed that treatment T2 Blade 1 has the dominant phases was C, after this Fe_2C and W. It was observed that from above Fig 4.25 iron carbide are formed in the form of Fe_2C and Fe_5C_2 after the coating.

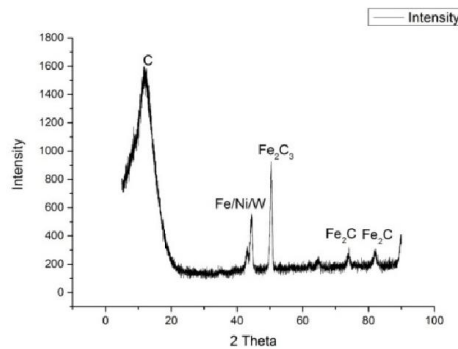


Fig 4.23: XRD patterns of T2 Blade 1

4.8 Cost Economics of Coating Treatments on Selected Rotavator Blades

A cost economic of different coating treatments for rotavator blades were worked out. The cost of different coating materials has been taken as per the prevailing market rates at the industry and it has same for all types of modes. On the basis of the area prone for wearing were identified for coating purpose. The blades were coated at 2nd, 4th and 6th mode. The cost of coating with different materials and modes are shown in table.

4.8.1 Cost of electro spark coating of rotavator blades with different materials Blade 1 Rotavator blade

Horizontal length of blade (cm)	11.12
Width of blade (cm)	7.620
Effective Vertical length of blade (cm)	10.66
Thickness of blade (cm)	0.762
Cutting edge thickness (cm)	0.203
Total area of the coating (cm ²)	175.5
Additional coating area for lab test is for one mode on one type blade (cm ²)	35.48
So the total area including coating area for lab test is (cm ²)	207.8

Blade 2 Rotavator blade

Horizontal length of blade (cm)	11.53
Effective Vertical length of blade (cm)	11.17
Width of blade (cm)	7.82
Thickness of blade (cm)	0.711
Cutting edge thickness (cm)	0.203
Total area of the coating (cm ²)	173.1
Additional coating area for lab test is for one mode on one type blade (cm ²)	35.48
So the total area including coating area for lab test is (cm ²)	208.58

Cost of Coating of Different materials per square centimeter for Electro Spark coating

Tungsten Carbide	- 4.65 Rs
Stellite-21	- 12.4 Rs
Chromium Carbide	- 15.5 Rs

Table 4.8 Electro spark coating cost for 1 set of coating treatments of Blade 2 rotavator blades

Modes	Total surface area to be coated for 1 blade (cm ²)	Cost of Tungsten Carbide coating		Total Cost of Stellite-21 coating		Total Cost of Chromium carbide coating	
		Cost of coating for 1 blade (4.65Rs@cm ²)	Cost of coating for 1 set (36 No) Rs	Cost of coating for 1 blade (12.4Rs@cm ²)	Cost of coating for 1 set (36 No) Rs	Cost of coating for 1 blade (15.5Rs@cm ²)	Cost of coating for 1 set (36 No) Rs
2 nd	207.8	966	34776	2576	92736	3221	115956
4 th	207.8	966	34776	2576	92736	3221	115956
6 th	207.8	966	34776	2576	92736	3221	115956

Table 4.9 Electro spark coating cost for 1 set of coating treatments of Blade 2 rotavator blades

Mod es	Total surface area to be coated for 1 blade (cm ²)	Cost of Tungsten Carbide coating		Cost of Stellite-21 coating		Cost of Chromium carbide coating	
		Cost of coating for 1 blade (4.65Rs@cm ²)	Cost of coating for 1 set (36No) Rs	Cost of coating for 1 blade (12.4Rs @cm ²)	Cost of coating for 1 set (36 No) Rs	Cost of coating for 1 blade (15.5Rs @cm ²)	Cost of coating for 1 set (36 No) Rs
2 nd	208.58	969	34884	2586	93096	3223	116028
4 th	208.58	969	34884	2586	93096	3223	116028
6 th	208.58	969	34884	2586	93096	3223	116028

4.8.2 Cost economics

Out of the study, it has been found that the Tungsten carbide coating was better compound and also less cost compared to other used coating treatments. Hence the cost economics of Tungsten carbide coating has been worked out and it is given in table: 4.10

Table 4.10 Cost economics of the Tungsten carbide coating rotavator blades

Particular	Normal blade	Coated blade
Numbers blades for 1 set of blades	36	36
200Rs@1 blade		
Cost of coating	0 Rs	35000 Rs
Cost for 1 set of blades	200 X 36= 7200	42000 Rs
Cost of rotavator	95000 Rs	95000 Rs
Cost of the system	1,02,200 Rs	1,37,000 Rs
Hiring charges of rotavator per hour	300 Rs	300 Rs
Life for blade	200 hours	450 hours
The total amount received for the system if it given on hiring per 1 year	300 X 200=60,000 Rs	300 X 450 = 135000 Rs
Comparison	The time required for recovering the cost of system was 340 hours or 1 year 8 months	The time required for recovering the cost of system was 460 hours or 1 year

We can recover the cost of whole system within one year of rotavator operation with ESC tungsten coated blades.

CHAPTER- V

SUMMARY AND CONCLUSIONS

In recent years rotavator is becoming popular among the farmers for land preparation where two or more crops taken in a year. Result shows that rotavator saved 30-35% of time and 20-25% in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30%) than as cultivator. Rotavator produces a perfect seedbed in fewer passes.

The primary cause that limits the persistence of rotavator is wear of blade. The rotavator is under dynamic loading, rotavator blades are subjected to fatigue and abrasive wear. Surface modification techniques have emerged as an alternative processes to curb wear resulted from abrasive action of soil particles.

The surface of the tiller blade, which is normally heat treated by the manufacturer, can be further improved to achieve higher wear resistance and strength by surface engineering techniques, HVOF thermal spray coating, Gas Tungsten Arc Welding, and Electro Spark Coating. Electro Spark Coating is a deposition process replaced the detonation-gun or HVOF processes and provided orders of magnitude increase in wear and damage resistance, a five-fold improvement in corrosion performance, lower friction, and more than a 50% saving in cost, with the same material.

Considering all these points, conducted the study on two blades i.e. blade1 and blade2, coated on their surface where wear takes place by ESC using three hardened material electrodes i.e. Tungsten carbide, Stellite-21 and Chromium Carbide with 3 modes for each material. This study has been taken with following objectives.

1. To study the wear characteristics of commercially available rotavator blades.
2. To find out suitable materials for electro spark coatings to increase the wear life of the rotavator blades with a special reference to soil type.
3. To work out the cost economics for the system.

To determine the effect of different coating materials on wear loss of two rotavator blades manufactured by two different companies i.e. blade 1 and blade 2, coated by ESC machine using three types of electrodes i.e. Tungsten carbide,

Stellite-21 and Chromium Carbide, with three different modes experiment was carried out in hard and dry clay loam soils at CRIDA, Hyderabad research farm during the season 2016-17. The effect of wear loss of different coated treatments of blade 1 and blade 2 was observed in the weight basis and volume basis. The hardness of different coated treatments of blade 1 and blade 2 was also observed. Thus on the basis of information secured throughout the study the following conclusion could be inferred.

1. The wear loss on weight and volume basis was on higher in case of blade 1 comparison to blade 2. The hardness was also on lower side in case of blade 1. It concludes that blade 2 having lower wear loss and higher hardness value.
2. Weight basis, in case of blade 1, the performance of treatment T1 (0.829% per hour) was better compared to all other tested treatments on the basis of less wear loss. It has 2.04 times better performance than of blade 1 control treatment. The wear loss was found maximum as 1.810% per hour in blade 1 control treatment.

In case of blade 2, the performance of treatment T2 (0.8067% per hour) was better compared to all other tested treatments on the basis of less wear loss. It has 2.23 times better performance than of blade 2 control treatment.

The rotavator blades were under field operation for 2, 7.5 and 10 hours and it was observed that more wear loss (% per 1hour) was recorded during initial duration i.e. 2 hour operation. It means that the increase in hours of use reduces the wear loss (% per hour) in the tested treatments.

3. Volume basis, in case of blade 1, the performance of treatment C1 (3.8634% per hour) was better compared to all other tested treatments on the basis of less wear loss. It has 1.46 times better performance than of blade 1 control treatment. The wear loss of treatment T1 was very close to treatment C1. The wear loss was found maximum as 5.6608% per hour in blade 1 control treatment.

Volume basis, in case of blade 2, the performance of treatment T2 (2.3296% per hour) was better compared to all other tested treatments

on the basis of less wear loss. It has 1.60 times better performance than of blade 2 control treatment.

4. In case of blade 1, the hardness of treatment T1 (55.33 HRA) was higher than rest of all treatments. The hardness of this treatment T1 was about 1.23 times more than hardness of the control treatment. The treatments S2, C2, T3, T2, S1, S3 and C3 were having higher hardness after the hardness of treatment T1.

In case of blade 2, hardness of treatment C2 (58.33) was showed significantly higher than hardness of rest of all the treatments. The hardness of this treatment C2 was about 1.49 times more than hardness of the control treatment. The treatments S1, S3, T2 and C1 were having higher hardness after the hardness of treatment C2.

5. The wear loss was calculated on the basis of weight and volume basis, it was found that the blade 2 coated with Tungsten was better compared to blade 1. The hardness was higher side in chromium treated blades in blade 2.
6. On the basis of outcome of blade 2, it was found that coating of Tungsten carbide is better compared to all the coatings. Hence economic analysis was done for Tungsten carbide coating. On the basis of economic analysis it can be said that cost of coating can be recover within one year, if these blades are put under hiring.

Suggestions for future work:

1. Similar type of study can also be done on the blades available in Chhattishgarh region for land preparation during rabi season.
2. The study can also be done on rotavator blades manufacturer as per BIS for knowing this effect of coating

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Appendix-A

Statistical Analysis

Table A1 ANOVA for wear loss of Italian blades (Weight based)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	2.771	9	.308	4.558	.002
Error	1.351	20	.068		
Total	55.070	30			
Corrected Total	4.122	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 0.453

The SEM value =0.1526

Table A2 ANOVA for wear loss of Shaktiman blades (Weight based)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	3.661	9	.407	10.793	.000
Error	.754	20	.038		
Total	88.849	30			
Corrected Total	4.414	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 0.307

The SEM value =0.103

Table A3 ANOVA for wear loss of Italian blades (Volume based)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	10.563	9	1.174	.909	.536
Error	25.823	20	1.291		
Corrected Total	36.387	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 1.847

The SEM value =0.621

Table A4 ANOVA for wear loss of Shaktiman blades (Volume based)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	19.503	9	2.167	4.829	.002
Error	8.975	20	.449		
Total	405.742	30			
Corrected Total	28.478	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 1.031

The SEM value =0.347

Table A5 ANOVA for hardness of Italian blades

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	2116.533	9	235.170	24.412	.000
Error	192.667	20	9.633		
Total	64144.000	30			
Corrected Total	2309.200	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 3.971

The SEM value =1.336

Table A6 ANOVA for hardness of Shaktiman blades

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Trt	284.700	9	31.633	3.595	.008
Error	176.000	20	8.800		
Total	69293.000	30			
Corrected Total	460.700	29			

If the value of significant on above table is less than 0.05 then the data is significant

The LSD value = 4.03

The SEM value =1.359

Appendix – B

Technical Specification of Rockwell hardness tester

Table B1 Technical specifications of Rockwell hardness tester.

Model	Unit	Values
Loads	kgf	60, 100, 150, 187.5, 250
Initial Load	kgf	10
Max. Test Height	mm	330
Depth of Throat	mm	150
Max. depth of elevating screw below base	mm	355
Size of base	mm	210x474
Machine Height	mm	850
Net Weight	kg	100

Table B2 Loads and Indentors for Rockwell Hardness Testers

Total load in kgf. (Initial load 10 kgf.)	60	100	150	187.5	250
Indentor	Diamond 120°	Ball 1/16" 0	Diamond 120°	Ball 2.5mm 0	Ball 5mm 0
Test Scales	Rockwell A	Rockwell 1 B	Rockwell C	Brinell, F/D2=30	Brinell, F/D2=10
Suitable for	Tests on case hardness steel	Annealed, d, Ferrous & non ferrous metals	Annealed, hardened & tempered deep case hardened steel	Annealed steel & cast irons	Copper, Copper alloys & Al. alloys

Appendix-C

Specifications of Scanning Electron Microscope

Secondary electron image resolution	1.0 nm (at 15 kV) 2.0 nm (at 1 kV)
Backscattered electron image resolution	3.0 nm guaranteed (at 15 kV YAG detector)
Electron optics	Electron gun
Cold field emission electron source	0.5 30 kV (variable at 0.1 kV/step)
Acc. Voltage	
Magnification	x 30 x 800,000
Detectors	Secondary electron detector (upper/lower/upper + lower), YAG BSE detector Transmitted electron detector Energy dispersive X-ray detector
Specimen stage	PC-controlled 5 axis motor drive Traverse X: 0-110 mm Y: 0-110 mm Z: 1.5-40 mm R: 0-360 ° T: -5~+70 degrees (depends on Z)
Frame memory	640 x 480 pixels, 1,280 x 960 pixels, 2,560 x 1,920 pixels, 5,120 x 3,840 pixels
Image file format	BMP, TIFF, JPEG selectable
Liquid Nitrogen Cooled X-ray Detector	Crystal area 30mm ² Mn resolution 134 eV F resolution 65 eV Light element detection down to Beryllium

RESUME

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