Wear Characteristics of Surface Treated Structural Materials

Thesis Submitted by

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PROFORMA – 1

"Statement of Originality"

I, Shri Arup Mukherjee, registered on Aug 19, 2015 do hereby declare that this thesis entitled"**Wear Characteristics of Surface Treated Structural Materials**"contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

All information in this thesis have been obtained and presented in accordance with existing academic rules and ethical conduct. I declare that, as required by these rules and conduct, I have fully cited and referred all materials and results that are not original to this work.

I also declare that I have checked this thesis as per the "Policy on Anti Plagiarism, Jadavpur University, 2019", and the level of similarity as checked by iThenticate software is 8 %.

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PROFORMA - 2

CERTIFICATE FROM THE SUPERVISORS

This is to certify that the thesis entitled "**Wear Characteristics of Surface Treated Structural Materials**" *submitted by Shri. Arup Mukherjee, who got his name registration on 19th August, 2015 for the award of Ph.D. (Engg.) degree of Jadavpur University is absolutely based on his own work under the supervision of **Dr. Sathi Banerjee and Dr. Arghya Majumder** and that neither his thesis nor any part of the thesis has been submitted for any degree/diploma or any other academic award anywhere before.*

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Dedicated to My Family,

Friends,

Guides

&

Dr. Rajib Dey

Prof. Manoj Mitra

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Undertaking this Ph.D. work has been a truly life changing experience for me and it would not have been possible to do without the support and guidance that I received from many people. At this auspicious platform, I am privileged to express my small token of appreciation for them.

While I was pursuing my career in Industry (Tata Hitachi Construction Machinery co. Ltd.), I was always aspiring to take up suitable Industrial project and pursue doctorate program. An opportunity came to me in 2015, when I was asked to take up the charge of Process Engineering, Prod. Engg., PPC and Facility Planning department. This is a thorough technical position, responsible for all Process and Product improvement activities in the organization, along with New technology introduction. This gave me an opportunity to pick up this critical Industrial requirement as my research work. As this was long underlying in my mind, I thought why not give it a try and the journey began. This thesis is almost like reaching a long-cherished destination of my life.

During this difficult but enjoyable journey, I found myself experiencing encouragement, hardship, trust, and frustration coupled with feeling of fulfilment. Today when I am writing this, I hereby come to realize that though only my name appears on the cover of this dissertation, a great many people including my family members, well-wishers, my friends, colleagues, my company THCM and my University have contributed hugely to accomplish this uphill task. At this moment of accomplishment, I am greatly indebted to my research guides, Dr. Sathi Banerjee and Dr. Arghya Majumder for their guidance, support, and encouragement.

"A friend in need is a Friend Indeed". When I decided to go for the PhD, and registered myself, I came across Dr. Rajib Dey. We developed immediate friendship and only because of his timely support and encouragement, I could complete my thesis. I will be truly indebted to him for all his help.
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Words can never be enough in expressing how grateful I am to those incredible people in my life who made this thesis possible.

Above all, I thank God for the blessings, for forgiving my mistakes, for leading me in the right path and for being there whenever I need.

Arup Mukherjee

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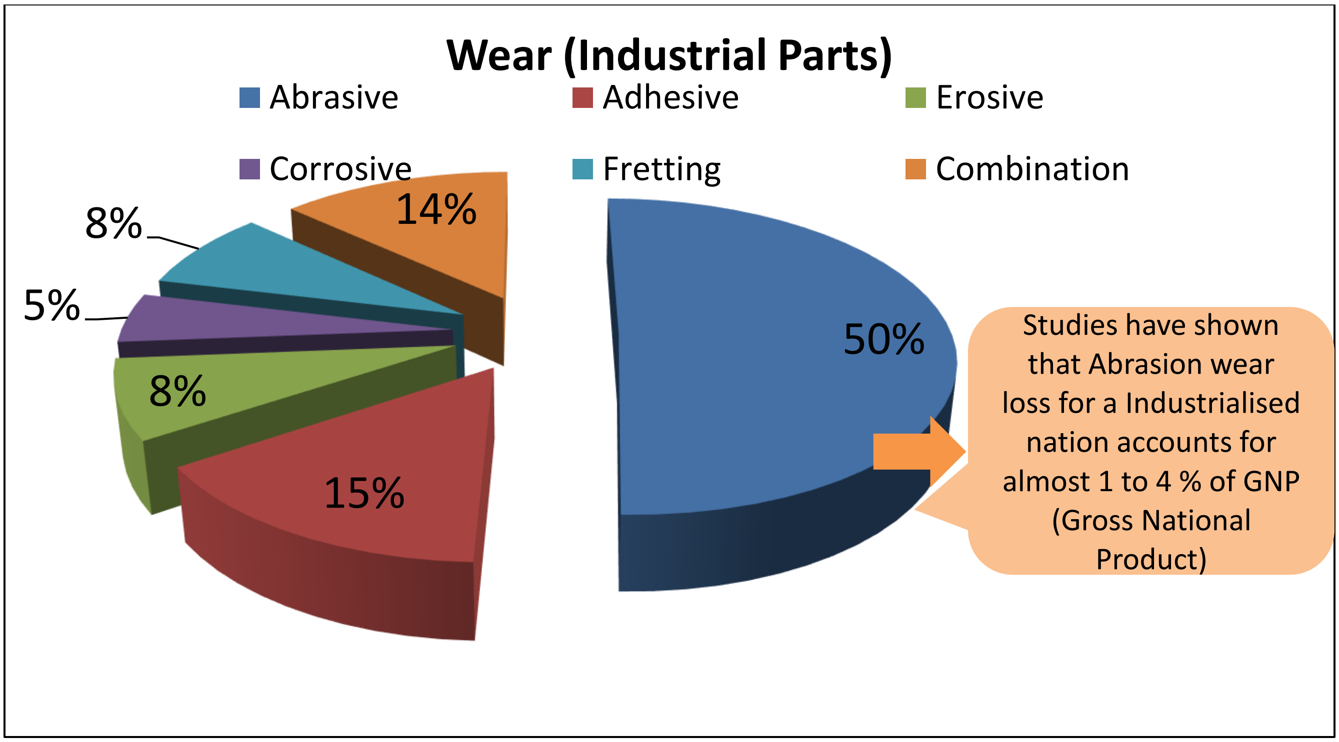
Chapter 1:

Introduction

1.1 Background

Every Mechanical part of a machine or Tool , that is undergoing some rolling or sliding contact, is subject to wear. Mechanical moving parts is having a common failure in terms of wear. The life , performace and the replacement cost for a machine with moving parts , like the excavators , is greatly affected by wear[1] .



[2]

Fig 1.1

In selection and design of automotive components and structural material for tribological applications, least surface deterioration is the prime concern. Wear characteristics of automotive and construction equipment components vary based on their applications and the surface treatment carried out to enhance the mechanical properties. Surface fatigue or pitting, fretting, spalling and scuffing are few of the common wear types encountered in heat treated automotive components.

As evident in fig. 1.1, Abrasive wear is the most serious problem for moving parts and machinery. It alone stands for almost 50% of the total wear loss of developed countries. The process starts when hard, mostly mineral parts gets in contact with the working surface part of the machinery. We can increase the life of service parts by using abrasion resistant materials or treating surface layers to create a abrasion resistant surface on the specific part of the machine or tool. Different types of thermo-chemical treatment is used in case of low abrasion.

1.2 Manifestations of Wear

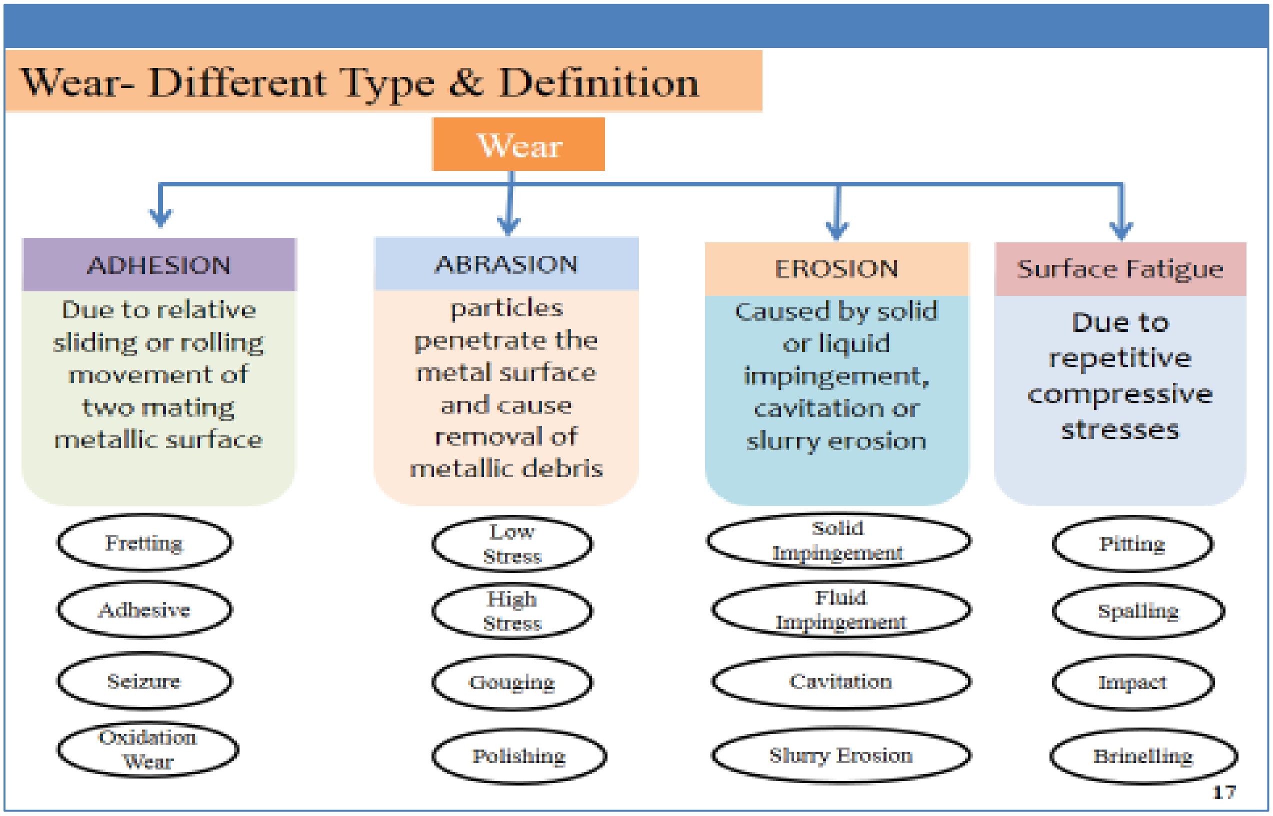
Wear manifests itself by displacement or removal of surface material, thereby damaging it , mostly by mechanical action of contacting abrasive medium **[3]**

Fig 1.2 - Typical Examples of Wear

Wear does not give rise to catastrophic failure – it mainly occurs as a progressive loss of material by the mechanical interaction of two sliding surfaces under load.

This is the most common state of affair in case of sliding bodies. Some amount of wear is always there whenever components undergo rolling or sliding contact

1.3 Wear Types & classification



[3]

Fig 1.3

One of the main cause for failure of moving parts and reducing efficiency of machines is Abrasion. It happens in two ways : i) when the moving parts encounter abrasive particles which rubs against the surface and this is termed as two-body abrasive wear ii) when the abrasive can become trapped between two sliding surfaces , it is called three-body abrasive wear [4]. Compared to three-body systems, two body wear results in from 10 to 1000 times more loss under the same conditions.

Abrasion can be of various types like low-stress, high stress, gouging and polishing.

In low abrasion wear, we find light rubbing contact of abrasive particles with the metal and there is no crushing of the abrasive material. In case of low abrasion wear, the moving machine surface develops scratches, and deformation of the subsurface does not happen. Low abrasion happens for Parts such as screens, chute liners, blades which work in low stress areas like sand slurries.

On the other hand, in case of High-stress abrasion, the abrasive medium is mostly crushed since the stress level is high. So, we encounter strain hardening of the moving surface in high stress abrasion. An example of high stress abrasion is ore crushing with grinding balls in mining industry.

In case of Gouging abrasion, big gouges or grooves are formed on worn surfaces with high-stress abrasion.

A very mild form of wear is Polishing wear, which involves extremely fine scale abrasion and/or chemical corrosion. Usually, smooth Surfaces are created with polishing wear [1, 5-8].

Normally, abrasive wear does not cause catastrophic failure, but it makes the operation inefficient with frequent change of parts, affects economic output and leads altogether to loss of efficiency and high repetitive cost of replacement of worn components .

1.4 Abrasive Wear and its Influencing Factors

Wear is having a very complex phenomenon and the conditions under which the parts undergo abrasive wear also plays a factor in their wear behaviour [4]. The various factors which influence wear are as follows:

1. Various mechanical and physical / chemical properties like composition, hardness, microstructure, work hardening rate etc.

For example, **the amount, size & distribution of carbides** in microstructure have a direct influence on wear resistance, specially at elevated temperature application, as compared to martensitic hardness

2. The conditions under which the Abrasive wear is happening, like the temperature, contact areas, presence of lubricants, speed of operation, time etc.

3. The abrasive characteristics like shape and size and hardness

4. Design parameters like type of motion, contact pattern etc.

The effect of abrasion is maximum in earth moving, mining, mineral processing etc. wherever the machines need to handle dirt, rock & minerals.

Examples are the **Excavators**, Loaders, Crushers and Dump trucks which are used for earth moving, mining etc.

Fig 1.4

1.5 Prevention of Abrasive Wear

- One of the most efficient way to tackle abrasive wear is selection of right material for right application, resulting in maximum wear resistance.

- The solutions may vary depending on the application - **Dimensional change in few centimeters may not cause wear failure on excavator**

bucket tooth, but wear of a few micrometers might cause failure in some Transmission Device

- This makes judicious selection of material and as assessment of surface engineering treatments need, suitable for the application, very important for service life.

1.5.1 Effects of Material Properties on Abrasive Wear

Along with hardness as the main property, other properties such as elastic modulus, yield strength, fracture toughness, microstructure, and composition is also important for service life in an abrasive medium.

For example, in steel, the abrasion resistance is depending on microstructure, hardness, and carbon content [1] the abrasion resistance of ferrous metals. The martensitic structure is hard and gives better abrasion resistance compared to softer ferritic and austenitic structures. This is especially important in low-stress abrasion, where subsurface deformation is minimal. When high-stress abrasion is encountered, work hardening property of the material becomes very important and improved wear resistance is found in materials with high work-hardened property.

Prevention of abrasive wear can be done by assessment of wear properties and selection of right material.

1.5.2 Various Surface Treatments for Prevention of Wear

1. **Surface Engineering to change Surface Chemistry:**
   Example – Carburising, Nitriding, Nitrocarburising

2. **Surface Hardening without changing surface chemistry**
   Example –Induction hardening,

3. **Thermal treatments for specific surface property**
   Example – Toughening, Precipitation hardening

4. **Use of Hardfacing Alloys, Wear Plates**

5. **Hard coat Anodizing, Boronizing and Hard Chromium Plating**

6. **Hard Coatings formed by vapour deposition, e.g TiN**

1.6 Relevance to Industry

In selection and design of automotive and construction equipment components and structural material for tribological applications, least surface deterioration is the prime concern. Optimum cost of the material having maximum service life is the prime concern for sustaining the operation. This will lead to minimum production and operating cost.

For this, there is a need for designers and material scientists to understand the behavior and requirement of parts for various applications. Along with this, they need to have an estimate of the wear characteristics for various material with variety of Heat-treatment and case hardening characteristics, which can impede the wear abrasion rate caused by high abrasive particles. Approximately 50% of wear failures are due to abrasive processes [09-10] and this makes the preventive measure so important.

Depending on the alloying elements used and the material specification , combined with heat-treatment used , there is a great opportunity to save Direct

Material Cost of machines, by optimized selection of materials, while achieving good service performance

Cost comparison of commonly used Material [Grade-wise] (per ton cost) : --

Product	Grade	Q2 FY'22-23 Delivered Prices in INR Per Ton
RCS	SUJ-3	73500
RCS	S35C	71000
RCS	45C8	71000
RCS	S20C	71000
RCS	15B25	72000
RCS	SUP11A	73000
RCS	20MnCr5	74500
RCS	42CrMo4	85000
RCS	SCM420	83000
RCS	SCM822H	89000
RCS	SAE4340	118000
HR	IS 2062 E 250 Gr BR	58500
	IS 2062 E 350 C	61500
	St 52.3	62000
	Fe 360/IS10748-GR2	59967
	IS5986 255 Fe 410	58750
	IS10748 Gr 3	59300
HRPO	IS 2062 E 250 Gr BR	60200
	IS 2062 E 350 C	63200
	St 52.3	63700
	Fe 360	61667
	IS5986 255 Fe 410	60450
HRSPO	IS 2062 E 250 Gr BR	60500
	IS 2062 E 350 C	63500
	St 52.3	64000
	Fe 360	61976
	IS5986 255 Fe 410	60750
CR	DQ	66000
	EDD	68134

Table 1.1

Overall, the economic consequences of wear induced failure are of major concern and this makes the selection of proper material and treatment very important.

In selection and design of automotive components and structural material for tribological applications, least surface deterioration is the prime concern. Wear characteristics of automotive components vary based on their applications and the surface treatment carried out to enhance the mechanical properties.

My association is with Tata Hitachi Construction Machinery Co. Ltd, which is predominantly making **EXCAVATORS**.

Fig -1.5

1.6.1 Scenario of Excavators

Excavators are digging and dumping machines with specialized attachments for handling specialized jobs such as digging, levelling, loading, pipe laying, rock breaking etc.

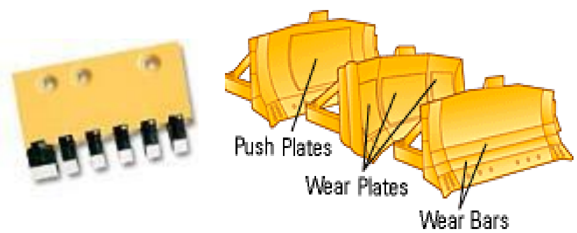
Field applications in Excavators involve wear mechanisms like abrasion, corrosion, impact, frictional wear, erosion, humidity, particle shape etc. all significantly contribute to the deterioration of the component. However, Abrasion has been found to be the most critical wear mechanism

Fig 1.6- Excavator in a sand mine   Fig 1.7- Excavator working in a quarry

The life expectancy of ground engaging tools, in excavators like tooth-points and sprockets and Gears in Transmission significantly determine the working cost of the machine along with Transmission aggregates like Gears, Shafts and Internal Gears. Various examples of ground engaging tools & Transmission components:

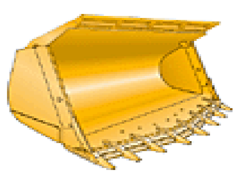
Tooth Point

Sprocket



Adapters and Wear Plate

Track Chain



Bucket

Excessive wear on Swing Device Gears

Fig 1.8

Abnormal Wear Case Study: -

Excavator Introduction & Nomenclature:

Excavators are being used for various industrial, mining, agricultural and material handling applications. Now a day due to demand of low cost & high efficiency production rates in field of building construction, road construction, agricultural application, mineral excavation, ship & ports management, military applications, industrial applications, etc. excavators are treated as first line of machinery.

The bucket of the excavator engages with the ground and its components are subjected to mechanical actions like low stress scratch, high stress cutting/plowing, fatigue, impact, abrasion, etc. As a result, parts of the excavator bucket are subject to extensive wear, driven by complex wear mechanism.

Ferrous based materials are chosen for its affordability and manufacturability. Material composition and structural design should consider actual wear mode, motion of the component subject to wear (rolling or sliding etc.) and how microstructure & mechanical properties are responds to the external wear event. Generally, wear events in earth moving equipment application include low stress scratch, high stress cutting/plowing, indentation fatigue by abrasive particles, impact etc. & assumed to be result of complex/mixed wear phenomenon. Since wear life is determined by the total combined material loss from all relevant wear modes, coating hardness must be balanced with material toughness or abrasion resistance.

Hard facing is a commonly employed method to improve surface properties of agriculture tools, components for mining operation, soil preparation equipment and earth moving equipment. Hard facing can also be employed to improve the life of ground engaging components of the excavator and thus, the cost effectiveness of excavator operation.

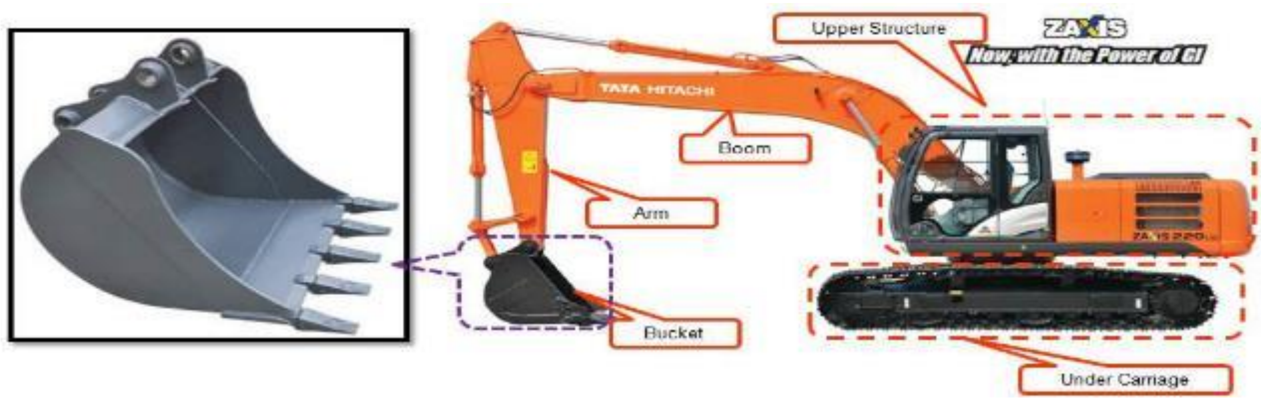


Fig 1.9- Excavator Nomenclature

Challenge : <u>**Low Undercarriage life observed in Excavator**</u>

Bush and track shoes are main ground engaging part Under carriage assembly of excavator.

These are subjected to continual abrasion while in travel operation. The abrasion phenomenon is influenced by wear due to rubbing of parts with ground, viz soil, rock, stone chips, limestone etc. These application has adverse effect on the parts and results in wear and failure.

Fig 1.10 -Bush **worn out** and crack observed leading to low life of

Fig 1.11- Phenomenon of Track shoe

Wear Component from Field:

Fig 1.12 - **Premature wear of the bucket side plate, bottom plate and ground engaging tooth points due to abrasive wear application at site**

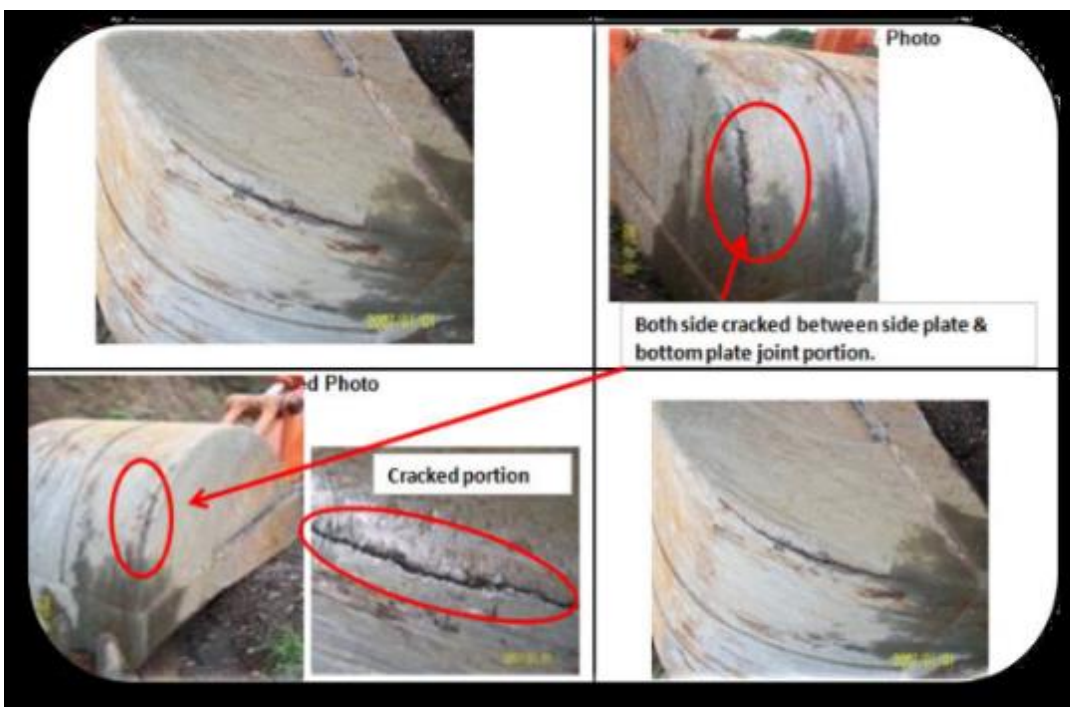


Fig 1.13 - Crack in Bucket observed due to abrasive wear of weld joints and parent material. The crack is due to thinning of material because of wear and reduction in strength of weld join or

Fig 1.14 -Wear in Track link and Sprocket being ground engaging part and subjected to wear phenomenon in application

1.7 Scope of Research

In selection and design of automotive components and structural material for tribological applications, least surface deterioration is the prime concern.

There is a need for designers and Material scientists to have an estimate of the wear characteristics for various materials with variety of Heat-treatment and Surface treatments / case hardening operations. The study is to support that need by Selection of commonly used materials for Earth Moving machines, perform various Heat-treatment & surface treatments, resulting in various combination of hardness, case depth / compound layer Mechanical tests & metallographic verification, Wear test & creating a relative Abrasion Matrix of commonly used structural materials.

The aim will be to establish an empirical relationship between various mechanical properties with wear characteristics of various materials, creating a comparative index of resistance to wear of commonly used structural materials which are treated with various suitable heat-treatments to achieve the desired service life.

1.8 Delimitation of Research

- This Study does not include High Speed Steels and other Tool Steels. Mostly the commonly used Low and medium alloy steels used for Construction Equipment's (for Ground Engaging Tools and Transmission Device Gears and Ring Gears are selected, with various treatments)

- Study of Wear Mechanism is not considered in this study – from existing studies, it is already evident that Abrasive Wear is having the most detrimental effect for such equipment.

- Study of Effect of various parameters like type of strata- for example, stone, limestone, granite flakes, sand etc. Effect of water/humidity , temperature, Effect of loading cycle/pattern, combined effect of impact along with wear etc. on material erosion subjected to wear not considered for this study.

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Chapter 2:

Literature Review

2.Literature Review

Wear is one of the most common failures for mechanical parts. But it is a very complex phenomenon and depends on the many interlinked factors. The effect of these factors also depends on the work type as well as the conditions in which the mechanical parts are being used.

Some proved wear behaviour patterns are shown below (Ref – Metals handbook, ASM, Service Characteristics of carbon and alloy steels P277-279) [1]:

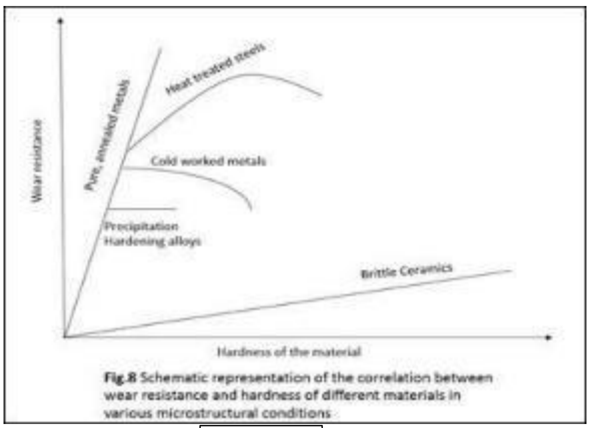

Fig 2.1

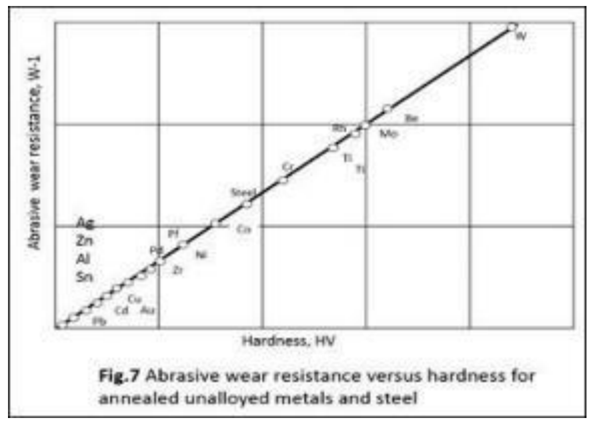

Fig 2.2

Study and comparison of **materials and also improvement through various treatments** for improving wear resistance is the most effective way to improve service life of components and many researchers have reported various works in this area.

2.1 Correlating the Abrasion Resistance of Low Alloy Steels to the Standard Mechanical Properties

There has always been a need to correlate Abrasion resistance with mechanical properties This research work tries to correlate wear resistance some low alloy steels with mechanical properties , like hardness (Hv)[2-6], UTS and YS [7-13], strain hardening exponent (n) [8,14], UE [15-16], or ETF [17].

To meet this need, different low alloy steels (40 nos.) were tested for ASTM G65 abrasion test and standard mechanical testing.

20 samples were taken of the same chemical composition but differently processed for different microstructures and different mechanical properties. Another 20 samples were selected for different compositions but processed in such a way to match the mechanical property of the 1st group.

The results show same composition material show better correlation with abrasion resistance than material of different composition.

But the researchers could not establish any statistically relevant co-relation between abrasion resistance and mechanical properties.

2.2 Correlating Abrasion Resistance of HSLA steel with Microstructure and Mechanical Properties

For wear plate fabrication of buckets in excavator, mostly HSLA steel is used and these encounter 'three-body' or 'low-stress' abrasion in handling abrasive material like sand, stone or soil [19].

A number of steels has been selected for their wear behaviour [19-24]. The effect of composition [22,23], microstructure [20,22-25], and mechanical properties [22,26] has been studied for their wear behaviour. Material with matensitic matrix is found to have less wear loss as compared to material with Ferritic / Pearlitic matrix. [27]. Steels with other heat-treat conditions are also studied and the wear rate vs hardness slope is studies [21,26,28-30]

By this experimentation, it has been found that ~50% improvement in the abrasion resistance can be achieved by selecting suitable heat treatment cycles for the steel. Apart from hardness, Material characterisation and microstructure was found to be playing an important role for determining the Abrasion resistance.

2.3 Study of Abrasive wear for Medium Carbon Low Alloy Steel

In this work, effect of composition [31,32], microstructure [33,34], and other physical and mechanical properties [30,35] has been studied on the wear performance of HSLA steel. The safety performance is evaluated by ductility and toughness [36]. Martensitic microstructure [36] has been found to exhibit the best wear resistance. Advantages of HSLA is we can improve toughness and ductility through controlled rolling (prior austenitic grainsize) and use Heat-treatment for a martensitic microstructure. Hence these HSLA steel finds wide use in Mining and Metallurgical machineries.

Some studies have been done to find the effect of heat-treatment like quenching, annealing and tempering [37-38]. In this case, researchers have studied abrasive resistance of low alloy for various combinations of rolling and heat-treatment [39]. The results show that the optimal hardness and toughness combinations gives the maximum higher wear resistance.

2.4 Study of comparison of abrasion resistance property for selected steels.

A study has been done [40] to compare the abrasion resistance of selected steels, commonly used in Industry.

In their experiment, they have compared Hardox 400 steel and two different, wear resistant, materials cladded by welding technologies as well as Chromium cast iron wear resistant plates .

The tested material specification is as follows:

Chromium Cast Iron: C – 2.8%, Cr – 14-18%, Mo – 2.3 – 3.5, Mn- 0,5-1.5, Si – 1.0, Ni – 5.0%

ABRADUR – Cladded material by MMA technology

WC - Cladded material by MMA technology

HARDOX – HARDOX 400 wear resistant plate

The researchers adopted ASTM G 65 test method and calculated the mass loss, and thereby the volume loss.

Chromium cast iron plate has shown the best wear resistance and is 9 times higher than Hardox 400 and against the cladded steels, it is 2 times better for abrasion resistance.

2.5 Study of effect of Microstructure On wear resistance of micro alloyed steel

Microalloyed steels, which contain small quantities of strong carbide forming elements such as Nb, V or Ti, provide good combination of properties like strength, ductility, formability and weldability. These are determined by the processing methods [41] and are controlled phase distribution in the microstructure.

This investigation is done in two body abrasive wear for samples having ferrite-pearlite, ferrite- Bainite and ferrite-martensite structure and the increasing wear resistance of the samples explained with metallographic analysis.

2.6 Study of Wear Behaviour for Selected Low Alloyed Steels

This work studied the wear behaviour of selected low alloyed steels [43].

Material	Chemical composition (wt.%)							
	C	Si	Mn	P	S	N	Cr	Ni
Sample A	0.061	0.0	0.610	0.00	0.01	0.0039	0.020	0.03
Sample B	0.075	0.2	1.350	0.01	0.00	0.0083	0.040	0.05
Sample C	0.170	0.3	1.770	0.01	0.00	0.0055	0.310	0.05
Sample D	0.200	0.4	1.950	0.00	0.00	0.0040	0.020	0.03
Sample E	0.136	0.3	1.180	0.01	0.00	0.0048	0.400	0.03
Sample F	0.100	0.320	1.830	0.013	0.003	0.0028	0.040	0.290
	Cu	Mo	Al	Nb	V	Ti	B	
Sample A	0.040	0.0	0.050	0.01	0.00	0.000	0.0000	
Sample B	0.140	0.0	0.045	0.04	0.01	0.115	0.0002	
Sample C	0.150	0.0	0.041	0.00	0.01	0.140	0.0002	
Sample D	0.010	0.0	0.060	0.03	0.01	0.000	0.0000	
Sample E	0.012	0.0	0.048	0.00	0.01	0.036	0.0018	
Sample F	0.040	0.010	0.034	0.004	0.010	0.187	0.0007	

Table 2.1

In this research, impeller–tumbler wear test equipment was used for measuring the wear loss of steel samples. LOM, SOM and XRD technique is used for investigating the wear mechanisms.

It is found that with increasing steel hardness, the wear rate of the seel samples decrease. But one observation is that surface hardness needs to be considered instead of bulk hardness while correlating with wear resistance. With increasing carbon percentage and decreasing grain size, the wear loss decreased.

The investigation established the effect of microstructure and chemical composition on wear properties.

2.7 Study of Wear Behaviour of High Strength Steels in high stress abrasion

In this study, which is applicable to mainly High Strength Steels, used in high abrasive environments (crushing, mining etc.), steel samples with hardness of 400-700 HV are selected and the single grit abrasion method was adopted. in the experiments, it is found that, with surface hardening, abrasion resistance increases to a great extent. But, one important thing to note, that abrasion resistance is not completely related with surface hardening.

2.8 Study of effect of thermochemical treatment on abrasion resistance of selected Structural and Tool Steels

The study showed the microstructure is having a high effect and evenly distributed fine carbides across the matrix improves the wear resistance considerably. With increase in hardness and their percentage in microstructure, the abrasion resistance of the material also increases [45-47]. Highly dispersed carbides give the maximum wear resistance [48]. Increase in abrasion resistance in tempered steels is also explained with respect to the dispersion of cementite particles [49].

Another important finding of this research is, it is found that Abrasion resistance low-alloy steels can be increased to the level of high-carbon structural and tool steels by carburizing operation and this helps in a big way for optimized material selection.

Higher Abrasion resistance is found in Steels and Cast Irons with a martensitic matric than a pearlitic matrix. Great improvement in abrasion resistance is found in materials with higher % carbon and alloying elements. [50,51]. Further increase in wear resistance is found by presence of evenly distributed carbides in the martensitic matrix. But with increase in alloying elements, residual austenite also increases and the effect of RA in Abrasion resistance is discussed in various researches [52,53,54], which shows with increase in RA, sliding abrasion improves in certain cases.

2.9 Wear Resistance Tests according to ASTM G 65 Standard

The ASTM wear test methods are grouped by various wear types [56]:

1. Two Body Abrasive wear
2. Three Body Abrasive wear
3. Erosive wear (slurry, solid particles, cavitating fluid, liquid droplets)
4. Sliding wear
5. Surface damage, galling
6. Surface damage, scoring

Dry sand abrasion testing : ASTM G65

Metal – Mineral Wear Resistance Tests according to ASTM G65 Standard methodology.

Dry sand abrasion testing : ASTM G65

ASTM G 65 is the Standard Test Method for measuring 3-body Abrasion, using the Dry Sand/ Rubber wheel Apparatus, for determining the resistance of metallic materials to scratching abrasion by means of the dry sand. The means of wear measurement is by Mass Loss .

TEST PARAMETERS	
LOAD	130 N
REVOLUTION	6000
SAND FLOW RATE	>300GM/MIN
SAND TYPE	Alumina Oxide, 30 grit(Test Sand, AFS 50/70)
RPM	>200
WHEEL TYPE	" Rubber Wheel 58-62 Shore A
WHEEL DIA	223.5 MM
SPECIMEN SIZE	65x20x10 MM

Volume Loss(mm3)=mass loss(g):density(g/cm3)*1000

22

By this test we can rank materials as per their abrasion resistance characteristics, under similar conditions.

Dry sand abrasion test operating mechanism

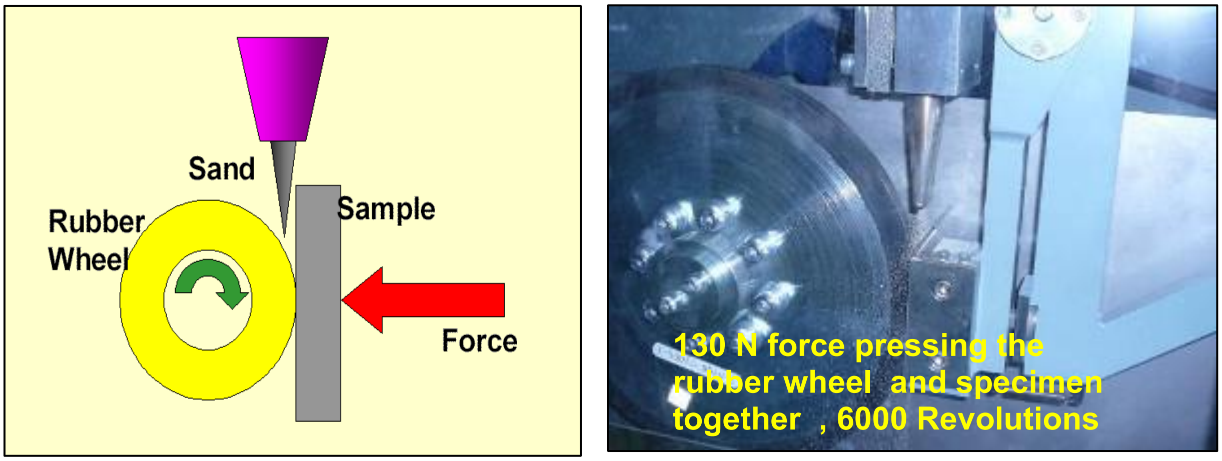

Fig 2.3

This test is very effective for ranking of materials and predicting component wear life. Researchers Adamik and Team [48] has used this process for comparison of selected constructional steel successfully.

2.10 Study of selected low alloy boron steels for Abrasive wear characteristics

In this research [57], results of field tests and laboratory test are compared for selected low-alloy boron steels [58]. The tests indicate that the wheel-rubber wear laboratory test gives a fair estimation for the abrasion resistance capability of the material and can replace costly time consuming field tests.

2.11 Comparison of abrasion resistance between hardened 8620 steel and coated by Ti/TiN

This work by Hilario, Barron and Jimenez [59,60] compared the abrasion resistance of 8620 material, hardened and tempered (oil quenched from 820 deg C) with coated samples of 8620 steel with TiN . Significant improvement in wear Resistance of Coated Steel was observed as compared to thermal treated Steel.

2.12 Wear Resistance behaviour of Carburized Fe-based Powder Metallurgy parts

In this work by Ali Emamian [61] from University of Waterloo, mechanical and tribological properties (specially wear resistance) of powder metallurgy (PM) parts has been studied, after carburizing.

It was found out that surface treatments like carburizing can improve the wear resistance of PM parts.

2.13 Study of Abrasion Resistance of ADI with various heat-treatments

In this research [62], the researchers have processed ADI with one step and two step austempering heat treatment process, and studied on mechanical properties and wear resistance.

It is found that in two-step austempering process, UTS, YS and impact toughness has improved. This also improves the wear resistance in lab condition for two step ADI, as compared to conventional ADI. This is explained in two step heat-treatment for ADI, % of retained austenite increases which in turn improves the properties.

However, in field condition, the components exposed to a more severe environment, showed an opposite tendency also. The effect of Austempering on Ductile Iron seems to be inconclusive.

2.14 Study of abrasion resistance of steels with addition of Effect of titanium and tungsten

In this test [63], the researchers have selected austenitic heat-abrasion resistant steel and tried to find the effect on abrasion resistance for addition of Ti and W. Various studies were conducted for microstructure, hardness tests and wear resistance. The results show, because of the evenly distributed carbides, that the samples having Ti and W increased the hardness and wear resistance considerably.

2.15 Improving the Wear Properties of AISI 4130 Steel Using Laser Surface Hardening Treatment

This study [64], (2022) aimed to investigate the hardness of laser transformations on AISI4130 steel using high-power Nd:YAG pulsed laser technology. Beam scanning speed, focal distance, and peak power were used as available variables for the experiments. An optical microscope, scanning electron microscope, microhardness, and wear tests were performed to assess microstructural changes. The wear surface of the hardened sample exhibited a combination of abrasive and adhesive wear. Therefore, optimal conditions are achieved by beam velocity and focal length. Laser paths with 20% lateral overlap were tested to expand the hardened areas and simulate the actual conditions of primary workpiece. Thermal cycles cause preheating in previously hardened areas and reduce the hardness of these areas in the range of 300 to 400 µm from the surface to 100 HV.

2.16 Resistance of cladding layers made by FCAW method to erosive wear

Janette et al. , [65], (2017) dealt with the tribological properties of investigated types of hard-faced materials under erosive wear conditions. Influence of inclination angle of elements on friction resistance and microhardness changes of hard-faced layer were investigated too. Within quantitative aspects were hard-faced layers evaluated based on weight loses. From achieved results concluded that inclination angle is one from determining factors on to material's wear measure.

2.17 Tribological behaviour of the hardfacing alloys utilised to fabricate the wear parts of an excavator bucket

Sawrav et al., [66] (2021) studied the tribological performance of a number of hardfacing iron-based alloys deposited on steel. In this investigation, the overlays were deposited using manual metal arc welding. The deposits were characterized by their microstructures, phase structures, hardness and residual stress using optical microscopy, Xray diffractometer and hardness tester, respectively. The tribological performance of the hard-facing alloys was assessed using a ball-on-disc test, dry sand abrasive wheel test, and proprietary impact wear test. It was observed that the material loss in wear with an iron-based alloy containing 16 wt. % chromium is significantly lower than those used conventionally for excavator buckets.

2.18 Laser cladding of tungsten carbides hardfacing alloys for the mining and mineral industry.

In this work (2008) [67], Hardfacing NiCr–WC coatings made up of Spherotene tungsten carbides were deposited by laser cladding. Microstructure of the deposited material was investigated in terms of the processing laser parameters. It was found that processing conditions suitable for these types of powders are moderate laser energy densities and large scanning speeds, resulting in a uniform distribution of hard spherotene particles in the coating. For large input laser energy densities and low scanning speeds, spherotene particles are dissolved in the matrix, giving rise to nucleation and growth of WC crystals replacing the spherotene particles in the cladding core. Average hardness of about 1000–1500 HV was obtained, indicating its superiority due to the larger amount of WC spheres in the alloy powder.

2.19 Dry rolling/sliding wear behaviour of pearlitic rail and newly developed carbide-free bainitic rail steels

Sk Md Hasan et al., [68] (2018) studied Rolling/sliding wear behaviour of two newly designed low-carbon, continuously cooled, carbide-free bainitic rail steels and compared with pearlitic rail steel. Bainitic rail steels showed higher wear resistance than pearlitic rail steel and wear resistance increases with increasing starting hardness. Wear resistance of carbide-free bainitic rail steels has been found to increase with increasing retained austenite content and decreasing bainitic ferrite lath thickness.

2.20 The microstructure, mechanical and tribological properties of TiN coatings after Nb and C ion implantation

Bin et al. , [69] (2013) studied Nb and C ions are co-implanted into the TiN coatings, deposited by magnetic filter arc ion plating (MFAIP), using a metal vacuum vapor arc (MEVVA) ion source implantor with doses of 1×1017 and 5× 1017 ions/cm2. The results show that the hardness and plastic deformation resistance of TiN coatings increased remarkably after ion implantation due to the energetic Nb and C ions bombardment and the formation of NbN and TiC phase. Nb ion implantation can effectively improve the wear resistance of the TiN coatings and the Nb + C dual ion implantation shows a better wear behavior due to a carbonaceous layer formed in the implanted zone of the TiN coatings after C ion implantation.

2.21 Manufacturing Component Parts of Mining Equipment With Application of Hardening Technologies

D V Valuev et al. , [70] (2016) develop an aggregate technology of manufacturing mining equipment component parts. The aggregate technology of manufacturing faced component parts includes the following operations: plasma-jet hardfacing with high-speed steels; high-temperature tempering after the facing, ultrasonic surface strengthening treatment, additional tempering, reconstructive facing.

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65. Resistance of cladding layers made by FCAW method to erosive wear Assoc. prof. Ing. Ján Viňáš, PhD., IWE.1, a *, Prof. Ing. Janette Brezinová, PhD.1,b and Ing. Miroslav Greš 1,c 1 Technical University of Košice, Department of Engineering Technology and Materials, Faculty of Mechanical

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68.Dry rolling/sliding wear behaviour of pearlitic rail and newly developed carbide-free bainitic rail steels
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Chapter 3:

Research Objectives

3. Research Objectives

Understanding the mechanisms of sand abrasion wear and hence predicting the wear life is essential for judicious selection of material. This will save a lot of time and energy for COSTLY extensive field trials.

Analyzing the extensive information of research results of the other authors, mostly working on studying wear resistance of pure metals , various coatings, wear resistance plates, hard-facing alloys – there is still a lot of work left for studying the wear characteristics of various materials with variety of Heat-treatment and case hardening operations.

The study is to support that need by experimentation & creating a **relative abrasion index** of commonly used structural materials for Earth Moving Machinery is selected, combined with suitable Heat Treatment and case hardening operations and subjected to abrasion Resistance and hardness test along with material characterization.

This will serve as a **ready reckoner** for Designers and Material Scientists in selection of material and facilitate them to optimize material selection and treatment for specific abrasion resistance need.

The aim of this work is to define and compare abrasion resistance of commonly used materials used in Construction Equipments, mainly Excavators, along with studying and analyzing the correlation between abrasion resistance and hardness (for various materials with surface treatment).

This work is intended to provide a guideline in the form of a **Relative Abrasive Index**, for material selection for Designers and Material Engineers with respect to wear characteristics.

Chapter 4:

Methodology

4. Methodology

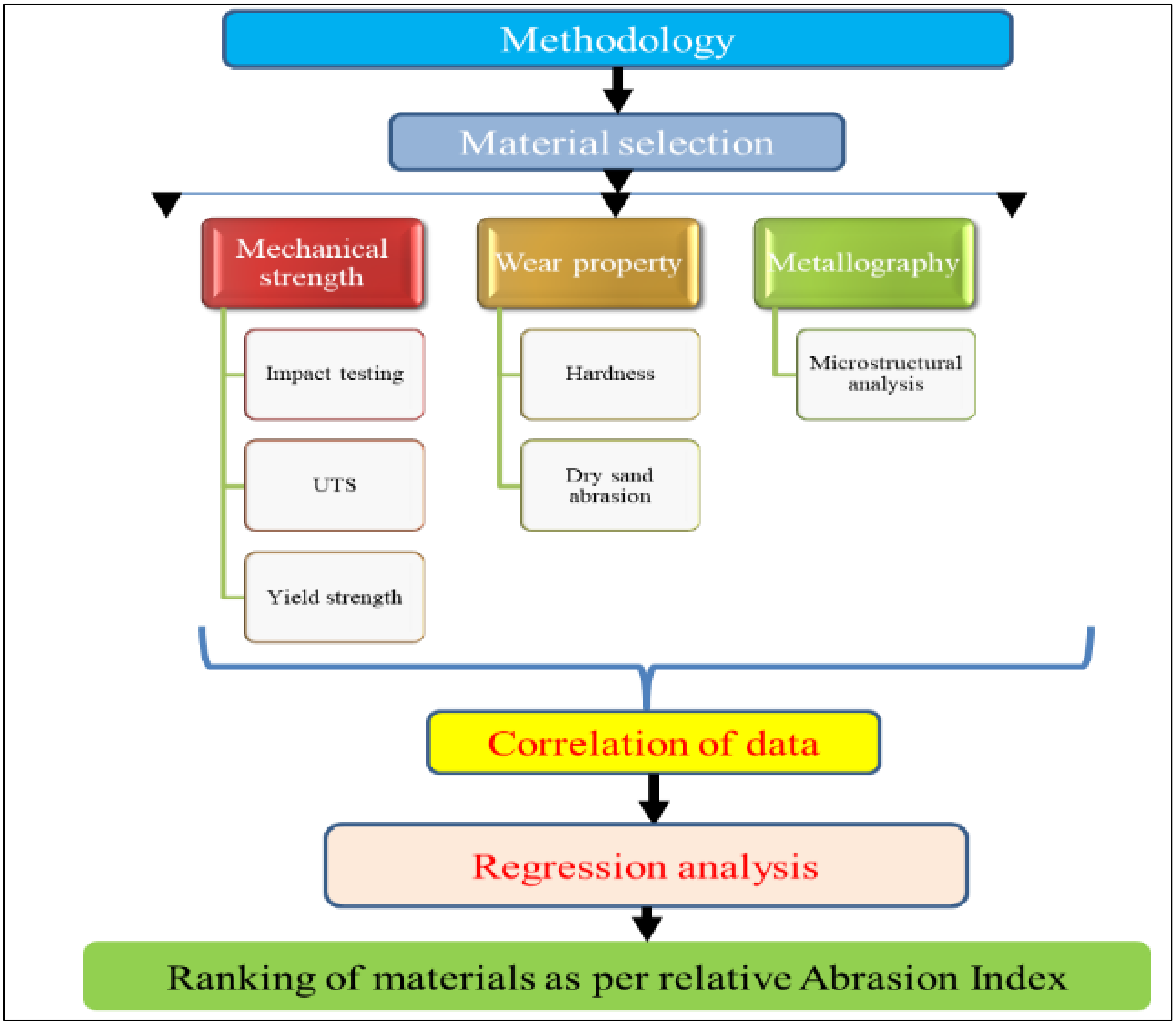


Fig 4.1

Abrasion resistance is decided based on Dry Sand Abrasion test result, along with co-relation with Surface hardness and UTS. The Aim of this work is to establish a correlation between various materials with different combinations of case hardening/surface treatment and their wear characteristics , thereby ranking the materials as per their resistance to abrasive wear, along with material Characterization and study of effect of alloying element in abrasion behaviour of readily available materials.

4.1 Selection of Materials

For our study, we have selected common materials which are widely used in earth moving machinery as transmission parts of ground engaging tools. The material horizon starts from mild steel and combines various TMCP, low and medium alloy steel with various combinations of heat-treatment and surface hardening operations.

We have selected 22 various combinations of materials, which include plate and bar, which are processed through normalizing, TMCP, Q&T, Carburising, Nitrocarburising, surface cladding to study the wear characteristics of materials with varying mechanical and wear properties.

We have also taken consideration for alloying materials viz. specially Nickel, Chromium, Molybdenum, Vanadium & Boron with material characterization and tried to correlate the wear behaviour with microstructure study.

Various Uses & effect of common Alloying Elements given below:

- **Carbon,** the main alloying element of steel; Increases mechanical properties such as strength, hardness, and mechanical resistance. But besides this increase, malleability, ductility, and toughness decrease. In addition, the tensile strength can increase up to a point. The increase in the carbon content in the steel composition reduces the ductility of the material, that is, it causes it to show brittle properties. There is a risk of cracking in high carbon steels due to residual austenite that will occur after the heat treatment is applied. It negatively affects the forging and weldability properties of steel. Martensitic hardness is directly proportional to carbon content and hence the wear resistance property.

- **Silicon :** It gets dissolved in ferrite and hardens the same. Hardenability is increased a little. Acts as a graphitiser. During tempering , sustains hardness and thereby resistance to wear. It increases magnetic permeability and shows increase in resilience in leaf and coil springs. It also provides fluidity in castings. While it increases the hardenability and wears resistance of the material, it adversely affects the surface quality.

- **Manganese :** improves the mechanical properties of steels. It increases the strength and decreases ductility. It increases the malleability by reacting with the sulfur contained in the composition. When viewed from a thermal point of view, it increases the quenching depth. Manganese's ability to increase hardness and strength also depends on the carbon composition of the material. It may also cause an increase in the weldability of the material. In low and medium alloy steels, used only up to 2%. The amount between 2-10% Mn is never used in steel as in this range it makes the steel brittle. Manganese is a cheaper substitute for costly Nickel and Chromium. Austenitizing temperature is decreased. Hardenability is increased considerabley. Manganese goes into Ferrite and may also form carbides. It forms non-metallic inclusions as MnS, MnFeO SiO_2 .

  Higher Manganese , i.e. 12-14 % with high carbon makes the steel austenitic after water quenching. This alloyed austenite toughens the steel and this steel, names as Hadfield Steel, with subsequent servicing is continuously work-hardened on the surface. If this slowly cooled austenitic manganese steel is reheated to about 370 deg c , it will be embrittled.

- **Chromium** content varies up to 5 % in low and medium alloy steels to more than 12% in higher alloy steels. It forms hard carbides and dissolves in austenite with time and temperature and increases hardenability considerably. It improves elastic limit, tensile strength and wear resistance. Compressive strength of chromium steels is extremely high. With increase of carbon, the effect of chromium is more marked. While it increases the tensile strength and heat resistance like carbon, it also decreases the ductility. Higher amount of chromium i.e. more than 12% with higher carbon, forms carbides which makes steel air hardening and wear resistant , to be used in tools. With low carbon, high chromium gives stainless property to the steel.

- **Nickel** : in most of the low and medium alloy steels, Nickel ranges from 0.5-5%. It strengthens the ferrite and increases hardenability. It refines the grains and increases the hardness, elastic limit and tensile strength with practically no loss in ductility. Resistance to fatigue and impact is also improved.

  With higher amount of nickel and in combination with chromium, austenite is retained at room temperature imparting to the steel, scale and corrosion resistant properties. Still higher percentage of nickel along with other alloying elements, Heat resistance properties to the steel.

- **Sulfur** is an undesirable alloying element other than free-cutting steel. Because it makes the steel brittle. For this reason, the effect is minimized by reacting with manganese. It is desired to be in composition as it facilitates machining in free-cutting steels.

- **Molybdenum:** It is used to prevent temper brittleness in steels containing molybdenum, low chromium, and nickel. It increases the heat resistance of steel. Molybdenum has the effect of increasing the effects of other alloying elements. For this reason, it is popular to be used not alone, but with other alloying elements. It inhibits grain growth and raises austenizing temperature and also increases hardenability, toughness and creep resistance. Small amount of molybdenum reduces the tendency of temper brittleness. Molybdenum combines with carbon (goes into ferrite) to form carbide. Since carbides increase the hardness, it is common to use tool steels and other specific applications.

- **Vanadium**; increases the strength, hardness, and wear resistance of steels. Small amounts of added vanadium can prevent grain coarsening. Eat makes a cleaner steel because of its the oxidation properties. It refines the grains, increases wear resistance and hardenability. Along with chromium, it improves strength, toughness and resistance to fatigue failure. Even a small amount all vanadium has a marked effect on steel properties.

- **Tungsten;** increases the wear resistance, hardness, and toughness of steels. It provides hot working and cutting efficiency to the material at high temperatures, by conferring the “red hardness” property. For this reason, it is popular in tool steels and high-speed steels and other specific applications. It is preferred to use in the structure of heat-resistant steels.
- **Cobalt** slows the grain coarsening at high temperatures. Increases the heat resistance of the material and strength at high temperatures. For this reason, it is preferred in tool steels.
- **Aluminum** is used as a deoxidizer. It has a grain refinement feature, therefore it prevents the growth of austenite grains. Increases aging resistance. For this reason, deep-drawn sheets contain aluminum in their structure.
- **Phosphorus**, like sulfur, turns steel into brittle. For this reason, phosphorus is also undesirable. It increases the hardenability of the steel. But it causes a huge drop in ductility. This decrease is observed more in high carbon steels.
- **Copper** imparts corrosion resistance and hardness properties to steel. But at the same time, it decreases ductility very much. For this reason, it is kept at a maximum of 0.5% in the composition.
- **Nitrogen** increases its strength and hardness properties. It increases the hardness by forming nitride in the structure of the steel. It facilitates the machining process. It increases fragility.

Of common alloying elements, Silicon gets dissolved in ferrite and hardens the same. Hardenability is increased a little. Manganese, in low and medium alloy steels, used only up to 2% & increases both strength and ductility.

In most of the low and medium alloy steels, nickel ranges from 0.5 to 5%. It strengthens the ferrite and increases hardenability, refines the grains and increases the hardness, elastic limit and tensile strength with practically no loss in ductility.

Chromium content varies upto 5% in low and medium alloy steels to more than 12% in high alloy steels. It forms carbides and increases hardenability considerably. It improves elastic limit, tensile strength and wear resistance. Tungsten is used generally in combination Chromium and Molybdenum, forms hard carbides and markedly increases the hardenability.

Molybdenum is generally used in combination with nickel and chromium, enters ferrite and forms carbides. Small amount of Molybdenum reduces the tendency of temper brittleness. Vanadium, even in a small amount, has a marked effect on the properties. It refines the grains, increases wear resistance and hardenability. Along with Chromium, it improves strength, toughness and resistance to fatigue failure.

4.2 Specimen preparation

Standard specimens for metallographic observations and mechanical testing will be prepared from the plates and rounds of the steels.

4.2.a Micro sample preparation

Micro sample preparation is as per specified sequence in Table No. 4.1

Sr. No	Facilities	Procedure	Control parameters	Checking Tool	Visualisation
1	Sample Cutting	1. Cut the Micro-samples by ***Abrasive Cut-off m/c*** 2. Use Alumina Oxide or SiO2 wheel for cutting	RPM should be 2000	 **Manually**	 **Abrasive Cut-off**
2	Sample Mounting	1. Mounitng through ***Hot Mounting M/c*** . 2. Use Bakelite Powder for sample mounting like... i. Durofast Coarse grain(Powder) →Epoxy Hot mounting resin with mineral and glass filler & ii. Multifast Fine grain→ phenolic hot mounting set 3.. Cycle time- 10 mins (5 min hot & 5 for Cooling)	1. Quality of Powder to be monitored 2. Heating & Cooling time to be followed	 **Manually**	  **Mounting Powder** 
3	Buffing & Polishing	1. Use ***Grinding cum Polishing m/c*** 2. Accessories & Process followed i. Emery paper sequence– grit size- 180→400→1000→Diamond ii. Polishing cloth & all R.P.M varied from 180-240 (based on expertise & Skill) iii. Use 3-4 Micron diamond paste (M/s Struers- Oil free type) + Alcohol (Methanol) 2-3 mins. iv. All the above are done at 220rpm±10rpm . v. Average time taken 15-20 mins	rpm should be controlled within 250	 Manually	
4	Etching	Accessories & Process followed i. Use ***3% Nital (etchant)*** for etching of Micro-Sample ii. Use Porcelain cup for etching by down-warding sample into porcelain under observation in resulting Nital solution is preserved iii. Use Auto sensor Hot Dryer for Micro-sample iv. In additional use 10-20% Nital Solution for Welding & Induction Hardening Case Depth	Nital preparation should be appropriate	 **Manually**	 **3% Nital Solution with porcelain cup**  **Hot Dryer**

Table No. 4.1: Micro sample preparation specified sequence

4.2.b Brinell Hardness testing:

As per sequence specified in Table No. 4.2

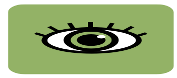
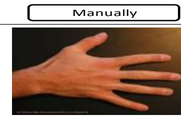
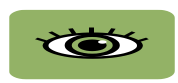
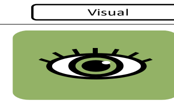
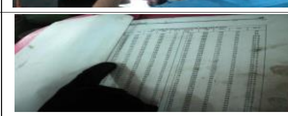
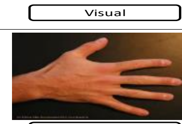
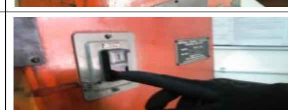
Sequence No.	Procedure	Control Item and Control Value	Checking Method and Tool	Visualisation
1	Wear the Specified PPE before starting the machine to avoid an accident.	Operator Safety	 Visual	
2	Grind the job to make it flat so that hardness of the job can be checked.	Grind the job properly	 Manually	
3	Switch on the machine by using green button	Safely switch on the machine	 Manually	
4	Switch on the light to read the diameter impression of the indent.	Safely switch on the light	 Manually	
5	Clamp the sample on the machine in clockwise directino to apply load.	Clamp the job properly so that readings can be made accurate	 Manually	
6	Push the loading handle to apply load on the machine till 20 sec.	Push the handle slowly as per mark given on the machine	 Manually	
8	Unload the machine	Unloading must be done as per mark given on the machine	 Visual	
9	Read diameter impression of the indent.	Dimension must be read carefully	 Visual	
10	Refer the standard according to the dimension of the indentor.	Standard chart should be checked correctly	 Visual	
11	Put out the job by moving the anvil in anticlockwise direction	Put out the job carefully	 Manually	
12	Switch off the light after the hardness of the job is being checked	Safely switch off the light	 Manually	
13	Switch off the machine to stop machine	Safely switch off the machine	 Manually	

Table No. 4.2: Sequence of test for Brinell hardness

4.2.c Vickers Hardness testing:

As per sequence specified in Table No. 4.3

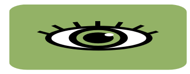
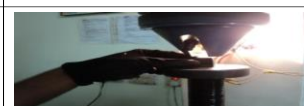
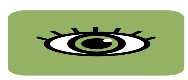
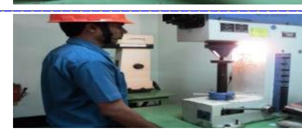
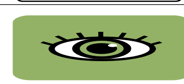
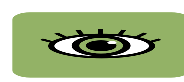
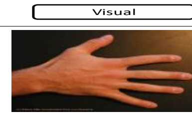
Sequence No.	Procedure	Control Item and Control Value	Checking Method and Tool	Visualisation
1	Wear the Specified PPE before starting the machine	Operator safety	 Visual	
2	Grind the job to make it flat	Grinding operation is to be done properly	 Manually	
3	Switch on the main machine	Safely switch on the main switch	 Manually	
4	Switch on the light to start machine	Safety light switch on	 Manually	
5	Clamp the job on the machine by moving the hand wheel in clockwise direction	Safely clamp the job	 Manually	
6	Push the loading button to give load on the machine	Load is being applied on the test piece	 Manually	
7	Wait during the loading period till 20 sec	Watch proper loading is done	 Visual	
8	Unload the machine by moving the lever download direction	Safely unload	 Manually	
9	Read dimension of the indentor carefully	Proper dimension must be taken	 Visual	
10	Refer the standard according to the dimension of the indent	Standard is being kept	 Visual	
11	Put out the job from anvil by moving anticlockwise direction	Safely put out the job	 Manually	
12	Switch off the light to stop the machine	Safely light switch off	 Manually	
13	Switch off the control panel	Safely switch off properly	 Manually	

Table No. 4.3: Sequence of test for Vickers Hardness

4.2.d Tensile Testing:

As per sequence mentioned in Table No. 4.4

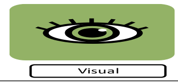
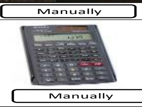
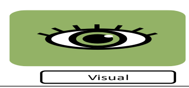
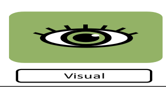
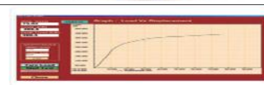
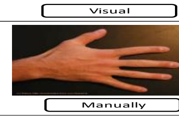
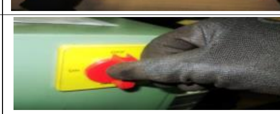
Sequence No.	Procedure For Tensile Test (60 Ton)	Control Item and Control Value	Checking Method and Tool	Visualisation
1	Wear the Specified PPE before starting the machine	Operator Safety		
2	Measure the dimension of the test piece (mm)	Design Specifications		
3	Calculate the gauge length using the formula where 'a' is the cross sectional area of the test piece(mm)	Cross sectional area		5.65va
4	Mark the gauge length on the test piece taking two reference points	Gauge length		
5	Switch On the UTM machine	Safe switch on		
7	Clamp the test piece on the UTM machine within the 2 jaws(Upper & lower jaws)	Safe Clamping		
8	Apply load gently on the machine by turning the Knob in clockwise direction	Control loading		
9	Calculate the yield strength using the formula	Yield calculation		(Initial load/area)*9.8
10	Wait until the test piece break off	Watch proper necking is done or not		
12	Note down the reading from its terminal	Proper reading must be taken.		
11	Switch off the load button of the machine	Switch Off the Load Button		
14	Unclamp the test piece from the jaw of the UTM machine	Safely unclamp the test piece		
15	Calculate the UTS value using the formula	UTS calculation as per fracture load		(Final load/area)*9.8
16	Measure the final gauge length of the test piece and calculate the percentage of elongation by using the formula (final length - original length) / original length *100	Calculate the % elongation		
17	Switch off the machine	Safely Switch Off		

Table No. 4.4 Tensile testing procedure

4.3 Raw material: As Rolled and Heat-treatment

As Rolled –

The simplest rolling method is hot rolling at high temperatures. Immediately following furnace extraction, the slab is rolled to dimension. Forming occurs in the recrystallization zone. This rolling method primarily serves as a shaping process. The rolling process also homogenizes the microstructure and refines the grain size. After being rolled, the plate is cooled in static air. The term as-rolled condition stems from the fact that the product is not heat-treated. This rolling method is used for materials that are subsequently heat-treated by the customer (heat-treatable steels).

- Final deformation is carried out in the austenitic region
- General grades of steel plates are processed using this technique

Various Heat-treatment techniques to be used

i) Normalising

ii) Hardening – tempering

iii) Carburising

iv) Nitrocarburising

v) Induction Hardening

Normalizing is done to refine the grain structure, improve machinability, relieve internal stresses and to improve mechanical properties of structural carbon and low alloy steels. The hardness and strength obtained after normalizing is higher than those obtained from annealing. Normalizing consists of heating the steel above the critical temperatures Ac3 temperature for hypoeutectoid compositions and between Ac2 and Acm for hypereutectoid steels. followed by cooling in air.

Hardening involves Quenching of a steel from austenitic range to produce martensite, as shown in figure 4.2. The cooling rate at the centre of the cross-section should exceed the critical cooling rate for the steel to get full hardening. Hypoeutectoid steels are heated above Ac3 temperature to ensure complete austenisation and to avoid soft ferrite in the microstructure. For hypereutectoid steels, this is not necessary, as the cementite that remains undissolved on heating above Ac1itself is very hard. Moreover, by heating above Ac_m, the steels become susceptible to grain growth.

Tempering is almost always necessary to remove the residual stresses and to reduce the brittleness of martensite. The actual tempering temperature chosen depends on the final properties desired. The overall improvement in hardness increases the wear resistance of the material, whilst the toughness is influenced by the tempering temperature selected.

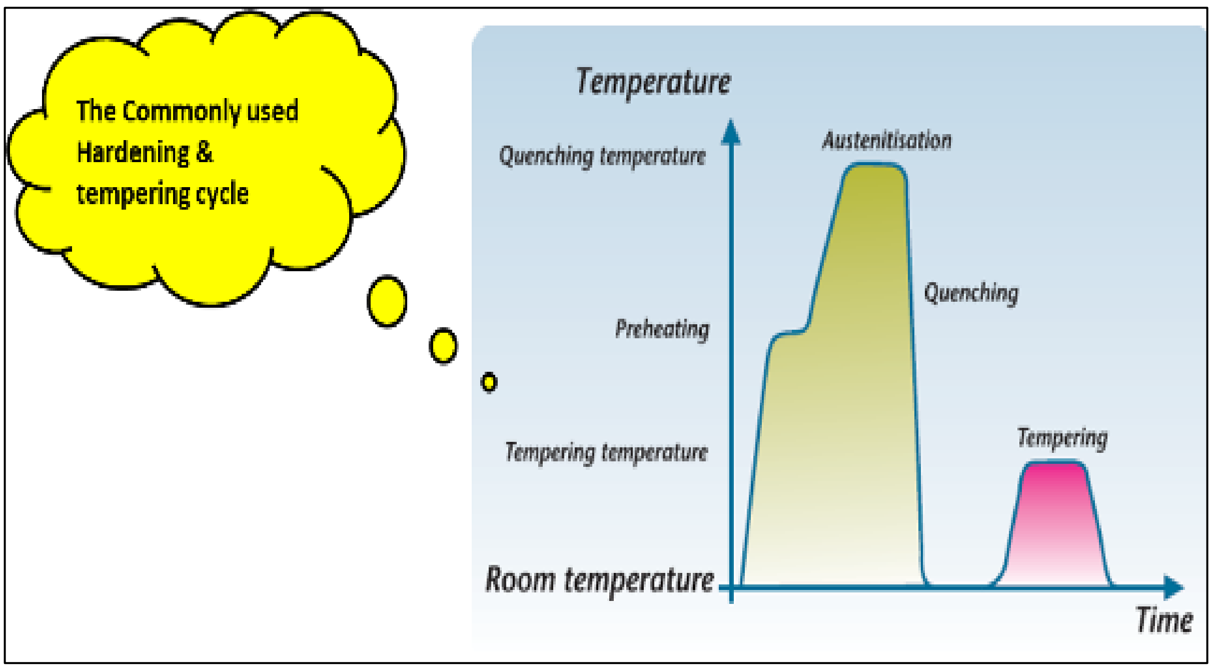


Fig 4.2- Process of hardening

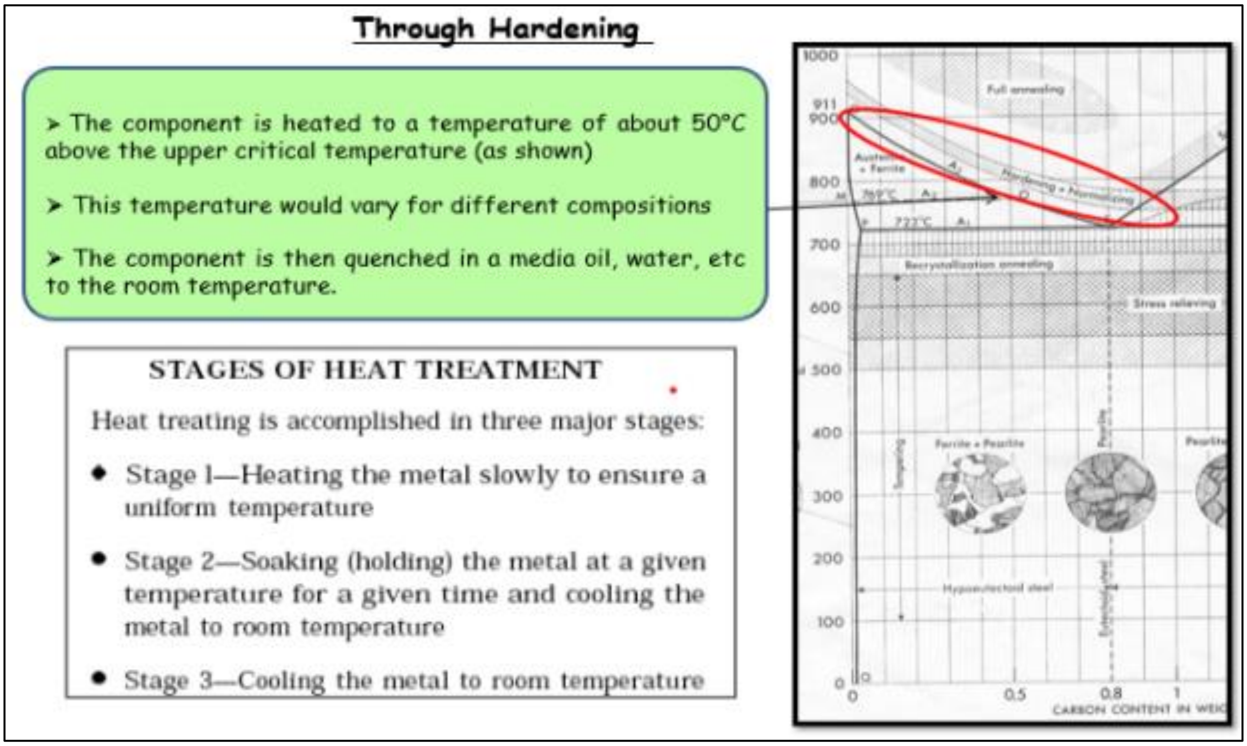


Fig 4.3 - Through hardening

CASE HARDENING PROCESSES:

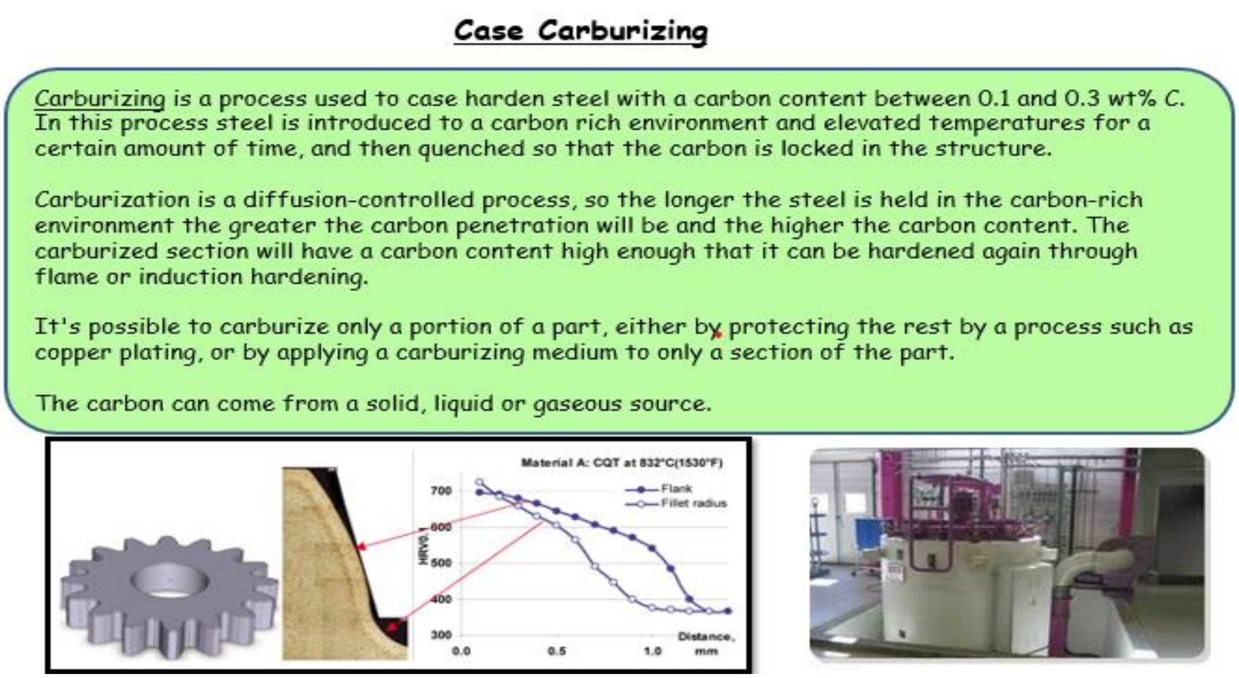


Fig 4.4 – Case Carburizing

Nitro-Carburising

✓ In Nitro-Carburising, the steel part (component) is heated to 480°C-620°C in an atmosphere of ammonia gas and dissociated ammonia.
✓ The time the part spends in this environment dictates the depth of the case (40 - 100 hours)
✓ The hardness is achieved by the formation of nitrides. Nitride forming elements must be present for this method to work; these elements include Cr, Mo & Al.

✓ The advantage of this process is it causes little distortion, so the part can be case hardened after being quenched, tempered and machined.
✓ Good corrosion, wear & fatigue resistance, high temperature hardness resistance (up to 500°C)

✓Disadvantages are high cycle time, brittle case, high cost, only special alloy steels can be treated.

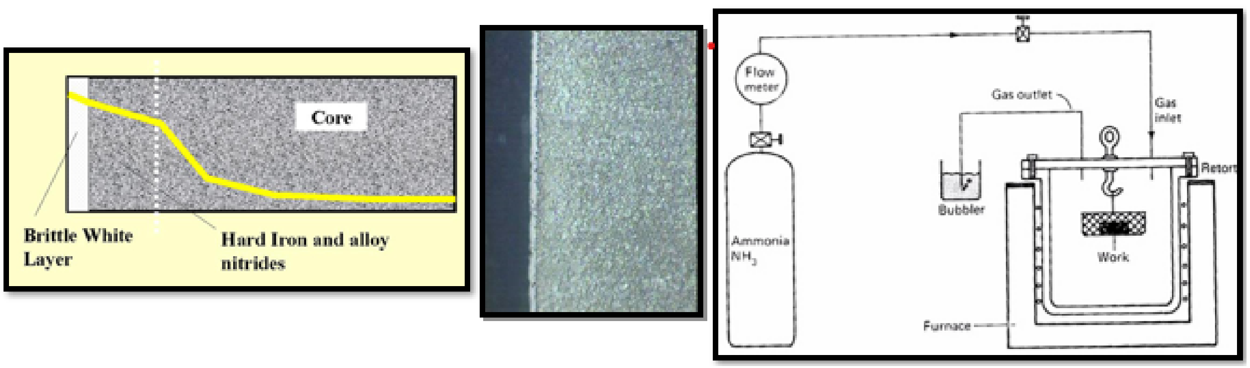


Fig 4.5 – Nitro Carburizing

INDUCTION HARDENING:

Here, an alternating current of high frequency passes through an induction coil enclosing the steel part to be heated treated. The induced emf heats the steel. The depth up to which the penetrates and raise the temperature above AC3 is inversely proportional to square root of the ac frequency. Correspondingly, the hardened depth decreases with increasing frequency. In induction hardening, the heating time is usually a few seconds. Immediately after heating, water jets are activated to quench the surface. Martensite is produced at the surface, making it hard and wear resistant. The microstructure of the core remains unaltered. Induction hardening is suitable for mass production of articles of uniform cross-section.

Thermo-Mechanical Process:

- Thermo mechanical control process (TMCP) is a new generation rolling process
- Producing fine grain steel by rolling the steel plates in recrystallization and non-recrystallization
- The steel slabs are first reheated in furnace for dissolution of micro-alloys
- The rolling is split into two phases
- The thermo-mechanical rolling is followed with accelerated cooling or air cooling depending on the service property requirements.
- TMCP plate helps in achieving high strength, high toughness with lower CE.

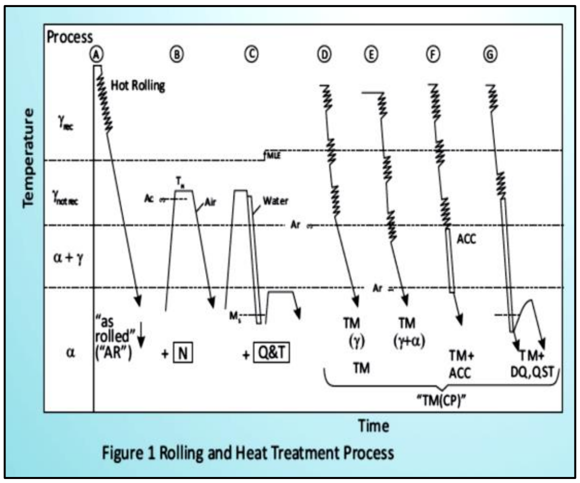


Figure 1 Rolling and Heat Treatment Process

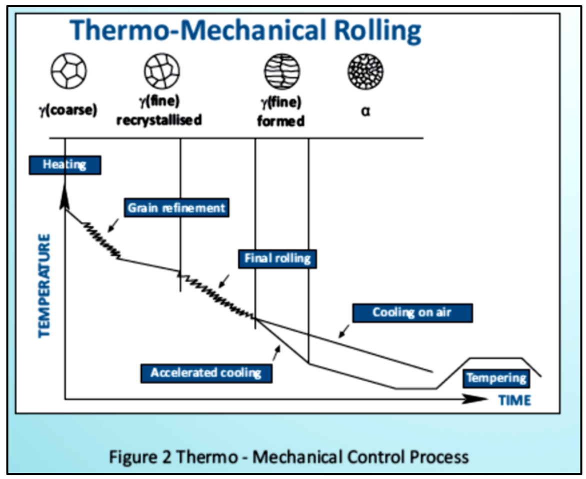


Figure 2 Thermo - Mechanical Control Process

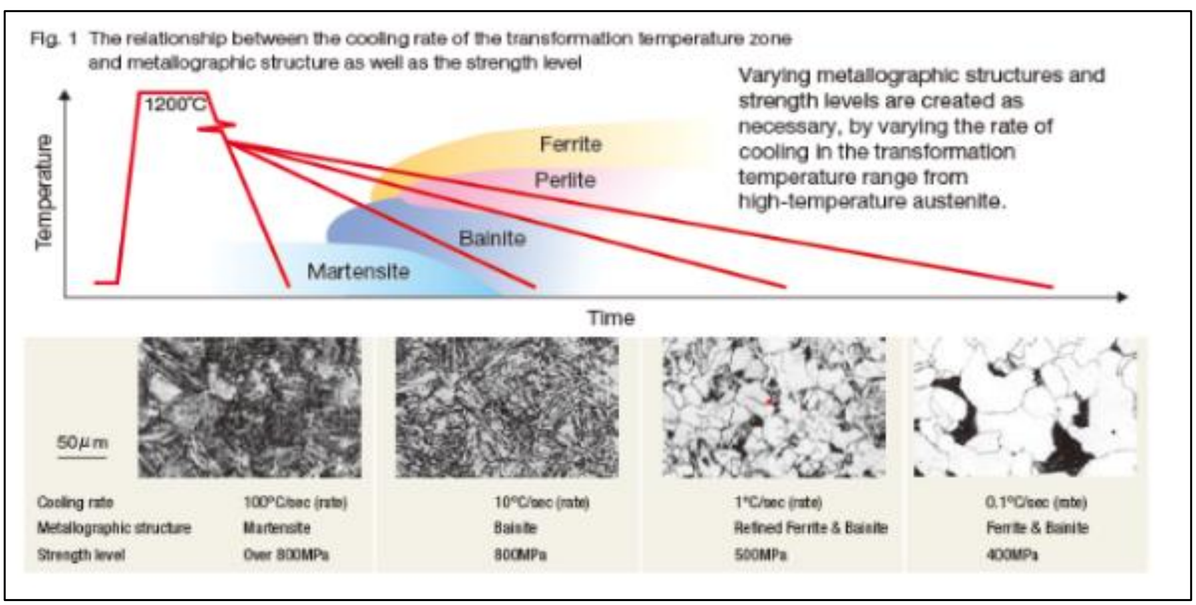
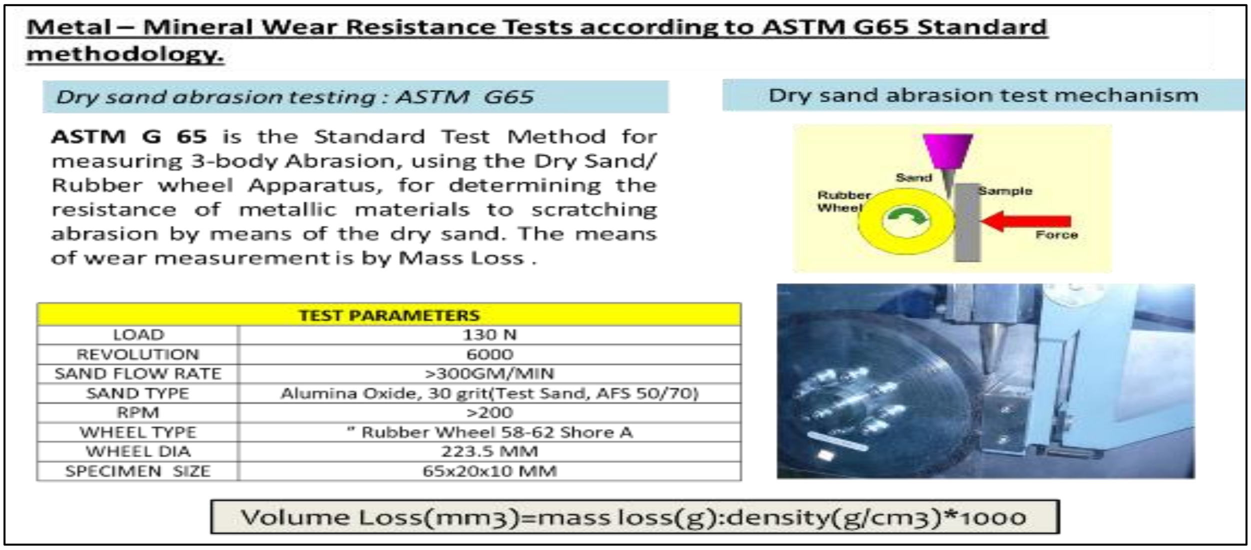


Fig 4.6

4.4 Wear Tests

Low-stress abrasion tests are to be carried out using a Dry Sand/ rubber wheel abrasion test (RWAT) machine as per ASTM G65 specifications. Weight loss to be measured after each test interval to compute the wear rate. Averages of three observations within the variation of ±5% were considered for calculating the wear rate.



TEST PARAMETERS	
LOAD	130 N
REVOLUTION	6000
SAND FLOW RATE	>300GM/MIN
SAND TYPE	Alumina Oxide, 30 grit(Test Sand, AFS 50/70)
RPM	>200
WHEEL TYPE	" Rubber Wheel 58-62 Shore A
WHEEL DIA	223.5 MM
SPECIMEN SIZE	65x20x10 MM

Fig 4.7

This test methodology very well simulates the working condition of soil engaging components (construction work), determining the resistance of metallic materials to scratching abrasion by means of the dry sand / rubber wheel test. It is the intent of the test method to produce data that will reproducibly rank materials in their resistance to scratching abrasion, under a specified set of conditions.

During the tests, a wheel rimmed with chlorobutyl rubber is rotated against the stationary flat rectangular steel specimen. Crushed silica sand particles to be fed between the wheel and the specimen. The specimens to be metallographically polished prior to the tests in the beginning.

4.5 Results and Data Correlation

The relative abrasive wear resistance of the selected materials with various heat-treatments will be obtained through their average volume loss and calculated based on the average mass loss obtained in metal abrasive wear tests conducted in accordance to ASTM G65.

By this, we can prepare an abrasion resistance index for the critical material under study, with their various treatments.

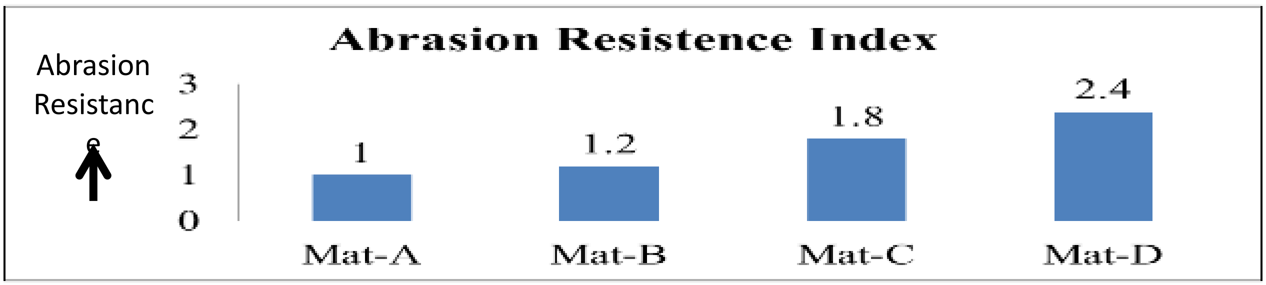


Fig 4.8

This will help to provide a guideline to the designers for proper material selection and cost saving on value engineering, without taking resort to costly Field trials.

The samples will also be analyzed for their characterization through microstructure analysis, studying volume fraction of different phases, Surface hardness and Hardness traverse. The results will be interpreted in terms of Wear Resistance VS Hardness, with an understanding of material characterization, resulting from chemical composition and heat-treatment.

With the experimental data, study and analysis will be carried out to establish correlation between abrasion Index and hardness with material & Heat-treatment combination. Also, the different materials with various heat-treatments will be ranked in relative wear resistance capability (based on volume loss) , so as to act as an Abrasion resistance INDEX facilitating material selection, for various critical applications .

Chapter 5:

Instruments and test facilities

5. Instruments and Test facilities

5.1 Machine Description – <u>Spectro-Max [For Chemical Composition Analysis]</u>

- **<u>Machine Name</u> –** Spectro Max [Type – Portable]
- <u>Make-</u> Ametek Instruments India Pvt Ltd
- <u>Model</u>- AMETEK /MAX LMM04, Qty. - 02 nos. (Bench & Movable type)

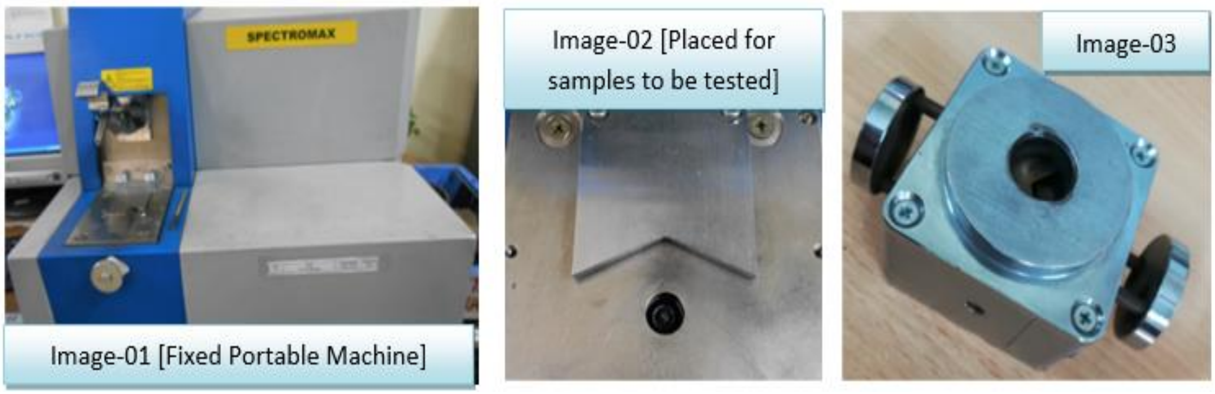


Fig 5.1

- **Application & Features**- A spectrometer is a scientific instrument used to separate and measure spectral components of a physical phenomenon. Spectrometer is a broad term often used. This is Spectro machine being used for chemical composition of Ferrous & Non-Ferrous material grade
- The measurement wavelengths of light over a wide range of the electromagnetic spectrum is widely used for spectroscopic analysis of sample materials. The incident light from the light source can be transmitted, absorbed or reflected through the sample.
- Elements like %C, %Mn, %Cr, %Mo & Micro-alloy elements are being tested [36 elements include Non-Ferrous]
- The fixtures show [Image 03 @Adapter] above being used special application of 3 mm dia samples [wire product]
- The SPECTROMAXx ARC/SPARK OES analyzer delivers fast, accurate, advanced elemental analysis in metal producing and fabricating plants

5.2 Machine Description – Microscope [For Metallography]

- **<u>Machine Name</u> –** SEIWA OPTICAL MICROSCOPE
- Make- Seiwa Correct & Binocular inverted 35,

Fig 5.2

- Application & Uses- The image from this optical microscope can be captured by normal light-sensitive cameras to generate a micrograph
- It is being use for microstructure testing which includes inclusion testing, grain size measurement, layer thickness measurement, nodularity, nodule count, phase segmentation analysis of various Micro-phases
- Used for Ferrous & Non-Ferrous (magnification up-to 1000X)

Details of Optical Microscope: -

The SEIWA Optical Tokyo Model 210 Compound Microscope is a cost-effective microscope, designed for use in schools. The 210's defining feature is the 45° inclined monocular, which sits on a viewing head that rotates 360°. Backing up this monocular would be its widefield 10x eyepiece and objectives which supply 5X, 10X, 20X, 40x, 100x magnification.

In addition to the rotating head the Model 210 also features cool running LED illumination. This light produces virtually no heat and has a life rate at 50,000 hours. A base mounted on/off switch controls the light as well.

Along with these helpful features the 210 also has focusing precautions, designed to protect the microscope from over focusing or other rough treatment. The slip clutch prevents damage from too much turning of the focusing knobs, while the safety rack stop prevents damage to specimen slides and objective lenses. Additionally, the tension adjustment eliminates stage drift.

Optical System

- 45° inclined monocular viewing head rotates 360° for easy sharing
- 3-hole objective turret, reverse position, ball-bearing mounted for smooth, precise changes in magnification

Illumination

- LED illumination delivers greater light and longer life than standard 20-watt tungsten bulb. Virtually no base heat. 50,000 hour rated bulb
- Base mounted on/off switch, heavy-duty 3-wire grounded electrical system and plug
- 0.5A time delay fuse

Focusing

- Separate low position coarse and fine focusing controls
- Slip clutch prevents damage to focusing system
- Tension adjustment eliminates stage drift
- Safety rack stop prevents damage to slides and objective lenses

Stage

- 4.75 x 5" / 120 x 125mm stage, with locked-on spring loaded stage clips, drilled and tapped to accept optional mechanical stage

Special Features

Image-01

Schematic Images of Microscope [Image-

Image-02 – Optical Microscope

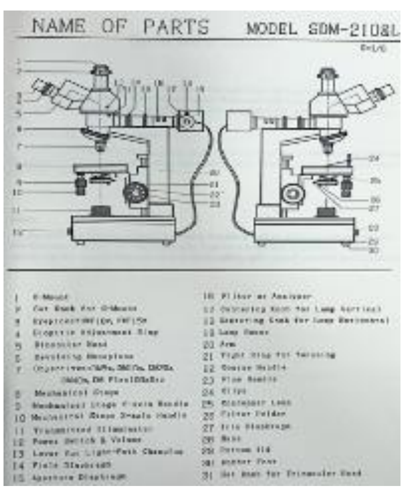


Image -03, Shows Optical Microscope with Image Analyzer Software for Microstructure analysis

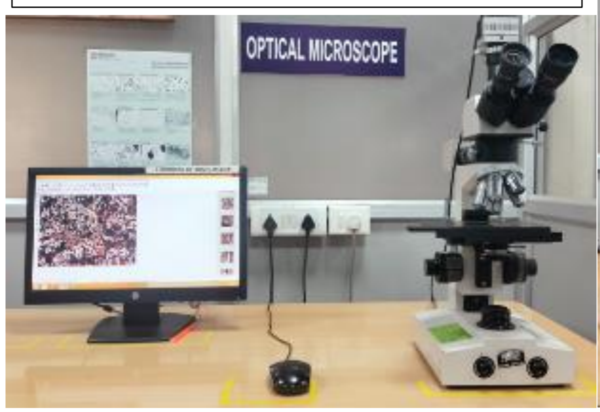


Fig 5.3

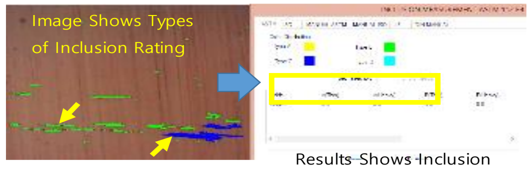
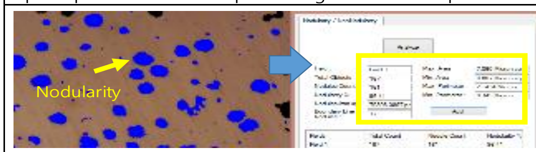
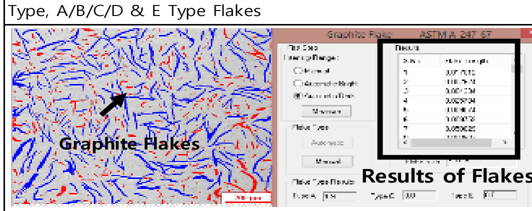
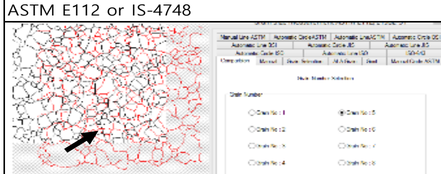
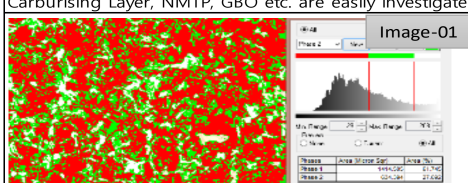
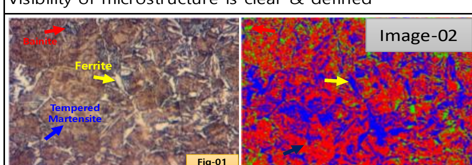
Sr. #	Key Features	SEIWA Optical Microscope with updated software
1	**Software Illustration**	Windows-10 with 4 USB Port which supported & stored images with phase segment view
2	**Inclusion Testing**	Image Clarity is Good & Auto Inclusion ratings are measured
		Able to Capture high Magnification images. For Regular & Irregular sizes of Samples, Images are captured at different angle with all magnifications
		Auto Measurement method as per JIS-G0555 or IS-4163 or ASTM-E45 or Threshold procedures. Advantage of the features are to segregates various types of Inclusion
		 Threshold View of Actual image Results Shows Inclusion Rating Category
3	**Cast Iron Testing**	**Spheroid or Ductile Cast Iron --** Nodularity & other aspects like Nodules Count, Nodularity Sizes, Micro-phases (%Ferrite, %Pearlite & %Primary & Secondary Carbide) are distinguished followed with "Threshold" of actual image
		All "Ductile CI" parts are tested as per JIS G5502 or ASTM 536 with updated software. Specially, all exports parts are tested as per HCM guide line & requirement
		 Threshold View of Actual Image Results Displayed & report generated automatically
		Grey/Flake Type Cast Iron -- Graphite Flakes are being tested followed with Standard JIS G-5501, En-1561, ASTM-A48, SAE J431 & IS-210. It can easily detected Types of Flake like Rosette Type, A/B/C/D & E Type Flakes
		
5	**Grain Size Measurement**	Grain Size measured by Intercept Method, Comparison Method, Threshold method as per JIS G-0551 or ASTM E112 or IS-4748
		 Grain Size Measured by Intercept method
6	**Phase Segmentation**	All Micro-phases like Ferrite, Pearlite, Carbide, Martensite, Bainite, Banding, De-Carburisation, Nitro-Carburising Layer, NMTP, GBO etc. are easily investigated (Example- Image 01 & Image 02) below.
		
7	**Visibility of Image**	Visibility of microstructure is clear & defined
		 Phase Segment view of Fig-01 **Metallography Observations of Fracture Surface** • Phase 1- Free Ferrite (Area- 31.439%) • Phase 2- Tempered Martensite (Area- 56.831%) • Phase 3- Bainite & Retained Austenite (Area- 11.705)

Table 5.1

5.3 Machine Description – Micro-Vicker Hardness Tester [SHIMADZU-JAPAN]

- **Machine Name –** SHIMADZU MV
- Make- JAPAN
- Model- 2T E [344-04154-22]

Fig 5.4

Purpose:

To lay down the procedure for method of Vickers hardness test for metallic material

Scope:

- This document covers the procedure for method of Vickers hardness test for the three different ranges of test force for metallic materials (refer Table 5.2).
- Vickers method is used based on an optical measurement system. The Vickers hardness test is specified for Lengths of indentation diagonals between 0.020 mm and 1.400 mm.
- The force values were calculated from kilogram force values. They were introduced before the SI-system was adopted

TABLE 5.2		
Range of Test Force (F), N	**Hardness symbol**	**Previous Designation**
F ≥ 49.03	**≥ HV 5**	**Vickers hardness test**
1.961 ≤ F < 49.03	HV 0.2 to < HV 5	Low load Vickers hardness test
0.9807 ≤ F< 1.961	HV 0.01 to < HV 0.2	Vickers microhardness test

Table 5.2

Reference: IS 1501: 2002 (3rd revision) (ISO 6507-1: 1997)

5.4 Machine Description – Grinding Cum Polishing machine

- **Make – Chennai Metco**
- **Model-** Semi Automatic Variable Speed Tabletop Double Disc – Bainpol VTD S.A, Disc Size- 10", Sample Size- 25 mm
- Application & Uses- Practical and economic auto polishing machine. Can be the choice for the laboratory looking for reproducible results, can hold up-to 3 moulds- 1, 1 1/2, 2 dia. 1 1/4 Comes with the Machine (standard) Independent powered polish head. Less complicated design keeping Indian context in mind

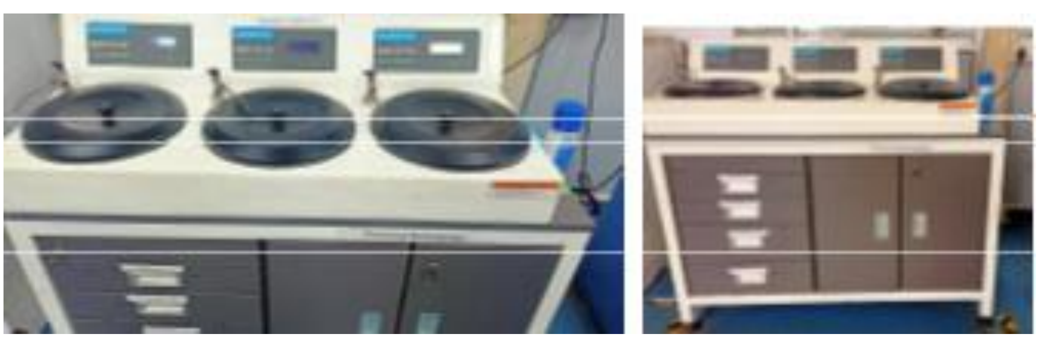


Fig 5.5

5.5 Machine Description – <u>Wear Testing Machine</u>

- Feature: Dry Sand / Rubber Wheel testing machine according to ASTM-G65
- Make: Moritani and Co.Ltd
- Loading system: lever type
- Max capacity load: 425N
- Initial load: 50N
- Load Measurement: load cell with display (rated capacity 1KN)

Rubber wheel type: Chlorobutyl rubber, size: 228.2mm dia, width:12.7mm

Rotation Speed: 20-350 rpm

Nozzle for sand supply: V cut type

Size:ID-12.7mmxOD-17.3mm

Sand feed per rev: 250-350gm/min.

Dry Sand/Rubber Wheel Abrasion Test

Dry sand rubber/wheel abrasion test is one of the most widely used abrasion testing method. Dry sand/rubber wheel abrasion test helps in determining the resistance of metallic materials towards abrasion due to scratching. This test primarily involves a standard test specimen which is abraded with a grit of controlled size and composition introduced between the rotating wheel containing chlorobutyl rubber tyre or rim and the test specimen. To ensure contact of the specimen with the wheel, a specified force is applied to press the specimen to the wheel by means of a lever arm and a controlled uniform flow of grit abrades the specimen surface.

The abrasive, for example dry sand, is fed between the specimen and the rotating rubber wheel(Fig 1). Other abrasives can be used depending on the application such as, industrial equipment for grinding grain, paints, plastics, coatings, slurry abrasion, construction and farm equipment. A wide range of materials can be tested for example; metals, ceramics, plastics, composite materials and coatings. Parametric flexibility (e.g. load, sliding speed and distance, sand size and quality) of this set-up can provide many advantages in simulating various tribological systems.

ASTM G 65 is the Standard Test Method for measuring Abrasive wear, 3 – body. Dry sand abrasion testing Machine and schematic diagram is given in **Fig. 5.5-5.6**

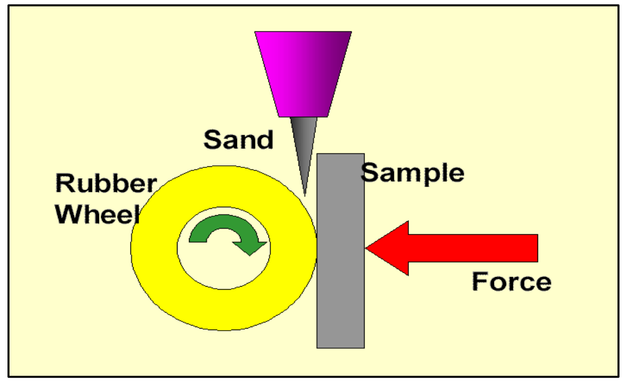


Fig. 5.6: Sand abrasion testing machine ***Fig. 5.7: schematic diagram of Sand***

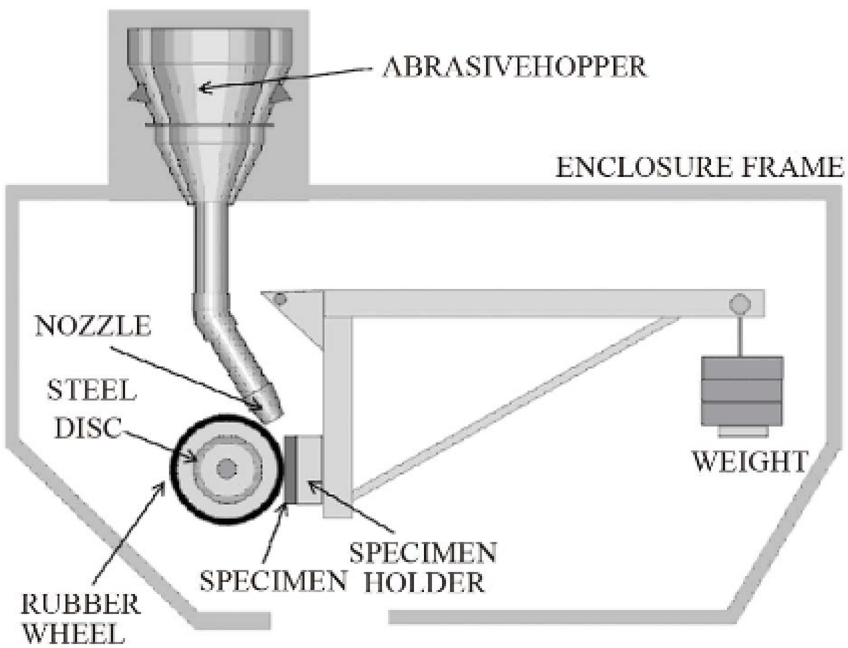


Fig 5.8

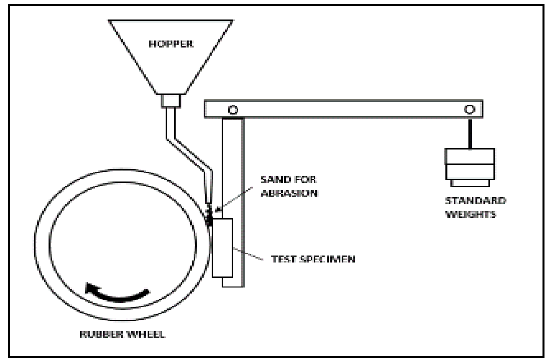


Fig 5.9: Dry Sand abrasion test and its schematic

This test helps us in comparing the resistance to abrasion among different grades of materials. The results obtained is specified in cubic millimeters i.e., volume loss after abrasion. The amount of wear will depend on various factors

> **N.B.:** Let us consider a case where we have standardized an abrasive environment. We have a material whose life in this specified environment is known to us. Now we have a new specimen whose life is unknown subjected to the same environment. In this scenario the volume loss obtained for the unknown specimen can be compared with that of the known specimen. This comparison will help us in deciding which material to choose when abrasion is the predominant factor for causing material deterioration.

of the abrasive particle itself like size, shape and hardness, amount of force applied and frequency of contact of the particle. To obtain a stable and uniform data these conditions are standardized and hence repeatability is assured to great extent.

This test has five recommended procedures which needs to be followed as provided in table below.

Procedure	Application	Force applied to specimen (N)	Wheel revolution (rpm)	Linear abrasion (m)
A	Medium to extreme abrasion	130	6000	4309
B	Medium to low abrasion	130	2000	1436
C	For thin coatings	130	100	71.8
D	Low abrasion (specific generic types)	45	6000	4309
E	Short term variation of procedure B	130	1000	718

Table 5.3

Important components and parameters:

- **Rubber wheel:** It is a steel disk which has the outer layer made of chlorobutyl rubber. The optimum hardness of the rubber should be Durometer A-60. The range of A58 to A62 is acceptable.
- **Abrasive:** It should be rounded quartz grain of type AFS 50/70. The moisture content of the sand should not exceed 0.5 % weight. Moisture content can be determined by measuring the weight loss of the sand after being subjected to 1000C for minimum 1 hour.
- **Sand Nozzle:** The nozzle must produce a steady flow of 300-400 g/min. Nozzle must be positioned close to the junction of test specimen and rubber wheel. Material primarily use for the nozzles are Stainless steels due to ease of welding and corrosion resistance.
- **Motor Drive:** Wheel is driven by normally 1 hp DC motor through gear box (reduction of 10:1) ensuring full torque is produced. RPM must remain constant under the load.
- **Test Specimen:** It is of rectangular shape whose size may range from 25X76 mm to 3.2X12.7mm. The specimen size may vary as per requirements with the restriction that it should show the full-length wear scar after the test and the surface should be flat.
- **Linear abrasion:** Due to abrasion the rubber of the wheel also wears away resulting in reduction in the diameter of the wheel and hence the linear abrasion distance gets affected. In this case the wheel revolution should be adjusted to match the sliding distance, or the reduced abrasion rate shall be taken into consideration by adjusting the volume loss produced by the worn wheel to the volume loss of the new wheel.

Calculating the results:

The abrasion test results is reported as volume loss in cubic millimeters in accordance with the specified procedure used in the test. While mass loss results may be used internally in test laboratories to compare materials of equivalent densities, as the density of the material taken were different result of this procedure reports are reported as volume loss in publications so that there is no confusion caused by variations in density. Mass loss to volume loss as follows:

$$\text{Volume loss (in mm}^3\text{)} = \frac{Mass\ loss\ (g)}{Density\ \left(\frac{g}{cm3}\right)}\ X\ 1000$$

As the rubber wheel decreases in diameter the amount of scratching abrasion developed in a given practice will be reduced accordingly. The actual volume loss produced by these slightly smaller wheels will, therefore, be inaccurate. The “adjusted volume loss” value takes this into account and indicates the actual abrasion rate that would be produced by a 225-mm diameter wheel. Calculate the adjusted volume loss (AVL) as follows:

$$\text{AVL} = \text{Measured volume loss} \times \frac{\text{225 mm .}}{\text{Wheel diameter after use}}$$

Test conditions:

Test sample dimension	**: 10*20*65 (mm.)**
Abrasive Feeding Rate	**: 300-400 gm/min.**
Rubber Wheel RPM	**: 200**
No. Of Revolution	**: 6000**
Load	**: 130N**
Sliding Distance	**: 4191.9m**
Standard	**: ASTM G65**
No of samples / sample size	**: 3**

Table 5.4

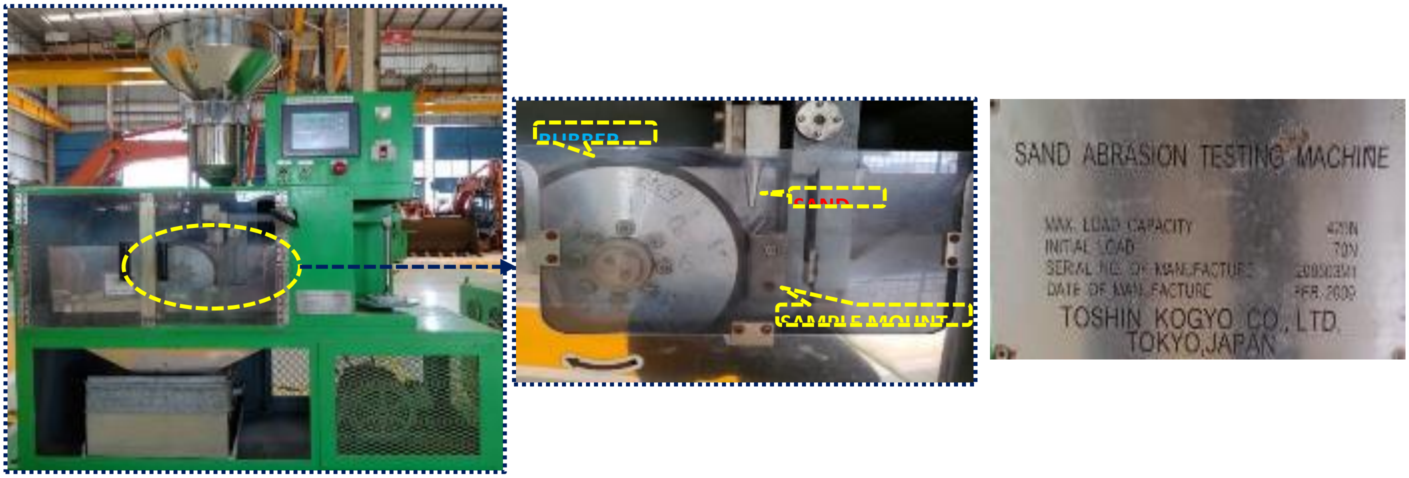


Fig 5.10- Sand Abrasion Testing Machine

Statistical method is employed to ensure uniformity among laboratories using the dry sand/rubber wheel test, the standard deviation and coefficient of variation of results produced from a series of tests but as these test result were obtained in the single laboratory no statistical method was employed .

Dry Sand/Rubber Wheel Test
ASTM G-65 Procedure ____

Qualification of Apparatus (11.4): Date ____
Reference Materials ____ Quantity ____
Adjusted Volume Loss (avg) ____ mm^3 Coefficient of Variation ____ %

Test Data

Material Description: ____ Wheel diameter: ____
Heat Treatment: ____ Wheel width: ____
Hardness: ____ Wheel hardness: ____
Surface Preparation ____

Test No.						
Test load						
Wheel revolutions						
Sand flow, g/min						
Initial mass, g						
Final mass, g						
Mass loss, g						
Density, $g/cm^{3\,A}$						
Volume loss, mm^3 (mass loss/density) × 1000						
Adjusted volume loss, mm^3						

Comments: ____

Company Name ____ Tested by ____ Date ____

Table 5.5

5.6 Machine Description – Abrasive Cutting Unit

- Make- Chennai metco
- Model- Bainpol VDT
- Application & Uses- Abrasive cutter is rugged, sturdy and designed to cut Metallurgical Samples to optimal quality consistently and safely. Cutting Wheel spindle is connected with motor shaft by pulley and belt mechanism.
- The movement of cutting wheel towards the specimen is applied by handle fixed with motor base pivot spindle and the cutter unit is balanced by springs for smooth chop type movement. Corrosion resistant window. Cooling by two high flow water jets to provide optimum cooling. Large (25mm) drain, re-circulation coolant tank with 30LTR. Capacity working on 440 volts, AC main supply with coolant tank of sufficient capacity
- Used for Ferrous & Non-Ferrous Material cutting

5.7 Machine Description – Rockwell Hardness Tester

Purpose:

To lay down the procedure for method of Rockwell hardness test for metallic material (scale A-B-C)

Scope:

This document covers the procedure for method of Rockwell hardness test for metallic materials scale A-B-C.

Reference: IS 1586: 2000 (Re affirmed 2006)

Equipment(s) Used:

Rockwell Hardness Tester having all the three scales (A-B-C) (Make: FIE)

For A & C scale-Sphero-conical Diamond Indenter having an angle of 120°and the radius of curvature of 0.2mm at the tip.

For B scale- Steel ball Indenter having a diameter of 1.5875 mm

Fig 5.11

Environmental Conditions:

In general, the test should be carried out at ambient temperature within the limits of 10°C to 35 °C. Tests carried out under controlled conditions shall be made at a temperature of 23 ± 5°C.

Test Procedure & Requirements:

1. The test shall be carried out on a surface which is smooth and even, free from oxide scale, foreign matter and, in particular, completely free from lubricants.
2. The thickness of the test piece or the layer under test should be such that after the test, no deformation shall be visible on the surface of the test

piece opposite to the indentation and the minimum sheet thickness is linearly related with Rockwell hardness is as follows

0.2 mm (90 HRA) to 1.6 mm (20 HRA)

0.6 mm (100 HRB) to 2.2 mm (20 HRB)

0.6 mm (70 HRC) to 1.6 mm (20 HRC)

3. Special care is taken when testing sheet metal that is curved. The concave side of the curved metal should face towards the indenter. The test piece is placed on a rigid support and is supported in such a manner that the surface to be indented is in a plane normal to the axis of the indenter and the line of the indenting force.
4. Products of cylindrical shape are suitably supported on centering V-blocks of steel with a Rockwell hardness of at least 60 HRC. Special attention is given to correct seating, bearing and alignment of the indenters, the test piece, the centering V-blocks and the specimen holder of the testing machine since any perpendicular misalignment may result in incorrect observations.
5. A flat piece is tested on a flat anvil that has a smooth flat bearing surface whose plane is perpendicular to the axis of the penetrator. For pieces that are not perfectly flat, a flat anvil having an elevated 'spot' about 4 to 6 mm in diameter is used. This spot is polished, smooth, flat and free from pits and heavy scratches. This spot should have at least 60HRC
6. Bring the indenter into contact with the test surface and apply the preliminary test force equal to 10 Kgf without shock or vibration for A, B & C scale by turning the wheel nut in clockwise direction till the small needle on the dial comes to the SET position and bringing the big needle to zero position by rotating the dial with the help of dial adjuster.
7. Apply the secondary force without shock or vibration, neither less than 2 sec nor greater than 8 sec as under by releasing the load lever
   HRA: 50 Kgf (Total Force: 60 Kgf)

HRB: 90 Kgf (Total Force: 100 Kgf)

HRC: 140 Kgf (Total Force: 150 Kgf)

8. While maintaining the preliminary force, remove the additional force, so that:

   a) For materials which under the conditions of test, show some time dependent plasticity, the duration of the total test force shall be up to 5 sec.

   b) For materials which, under the conditions of test, show considerable time - dependent plasticity, the duration of total test force shall be neither less than 10 sec nor greater than 15 sec.

9. Throughout the test, the apparatus shall be protected from shock or vibration.
10. After each change, or removal and replacement, of the indenter or the test piece support, it shall be ascertained that the new indenter or the new support is correctly mounted in its housing, the first two readings after such a change has been made, shall be disregarded.
11. The distance between the centers of 2 adjacent indentations shall be at least 4 times the diameter of the indentation (but at least 2mm) for Rockwell hardness. The distance from the center of any indentation to an edge of the test piece shall be at least 2.5 times the diameter of the indentation.

5.8 Machine Description – Brinell Hardness Tester

- Brinell cum Vickers Hardness Tester (Make: FIE OPFB-3000)
- Indenter, a polished hard metal ball, as specified in ISO 6506-2.

Purpose:

To lay down the procedure for method of Brinell hardness test for metallic materials

Scope:

This document covers the procedure for method of Brinell hardness test for metallic materials and is applicable up-to the limit of 650 HBW.

Reference: IS 1500: 2005 (3rd revision) [ISO 6506-p1: 1998] & ASTME10- 01

Receipt and handling: Refer to procedure of METALLURGY LAB

Test Procedure & Requirements:

- The test is carried out on a surface which is smooth and even, free from oxide scale, foreign matter and, in particular, free from lubricants. The test piece is having a surface finish that allows an accurate measurement of the diameter of the indentation.

Fig 5.12

- Test sample preparation is carried out by grinding on a belt grinder of 320 grit size belt and use of water to minimize the heat effect.
- The thickness of the test piece shall be at least eight times the depth of indentation. Values for the minimum thickness of the test piece in relation to the mean diameter of indentation are given as under. No deformation at the back of the test piece should be visible, which clearly indicates that the test piece is too thin.

- Minimum sheet thickness — Mean diameter of Indentation

Minimum sheet thickness	Mean diameter of Indentation
0.29 mm	0.6 mm
0.40 mm	0.7 mm
0.53 mm	0.8 mm
0.67 mm	0.9 mm
0.83 mm	1.0 mm
1.02 mm	1.1 mm
1.23 mm	1.2 mm
1.46 mm	1.3 mm
1.72 mm	1.4 mm
2.00 mm	1.5 mm

- For Ferrous use 187.5 Kgf load and for Non-Ferrous use 62.5 Kgf load on a 2.5 mm ball dia indenter having a Force / Diameter ratio ($0.102 \times F/D^2$) as 30 & 10 respectively.
- After cleaning the test platform, the test piece is placed. The contact surface is cleaned free from foreign matter (scale, oil, dust, etc).
- Switch on the power of the tester, bring the indenter into contact with the test surface and apply the test force in a direction perpendicular to the surface, without shock, vibration or overrun, until the applied force attains the specified value.
- The time from the initial application of force to the time the full test force is reached shall not be less than 2 secs nor greater than 8 secs. Maintain the test force for 10 secs to 15 secs. For certain materials, where a longer dwell time is required; this time shall be applied with a tolerance of about 2 secs.
- Throughout the test, the testing machine shall be protected from significant shock or vibration which can influence the test results.
- The distance from the edge of the test piece to the center of each indentation is to be a minimum of 2.5 times the mean indentation diameter.

- The distance between the centers of two adjacent indentations is to be kept at least 3 times the mean indentation diameter.
- Measure the diameter of each indentation in two directions perpendicular to each other. The arithmetic mean of the two readings is taken for the calculation of the Brinell hardness.
- Table C.1 (see annex C) contains calculation tables which shall be used to determine the Brinell hardness for tests on flat surfaces, or table below (at the end) can be used to determine the HBW values.
- At least one periodic check of the testing machine each day is done. Take at least two preliminary indentations to ensure that the test piece, indenter and anvil are seated correctly. The results of these preliminary indentations are to be ignored.
- Take at least one hardness indentation on a reference block with approximately the same hardness as the material being tested. If the difference between mean value of the hardness readings of the test material and the hardness of the reference block are within the limit of given in Table 5.2 of ISO 6506-2:1999, the tester may be regarded as satisfactory. If not, the tester is to be taken out of service and indirect verification is to be performed at the earliest

5.9 Machine Description – Brinell Cum Vicker Hardness Tester

Brinell cum Vickers Hardness tester (Make: ZWICK, Model: HP250, Serial No: 2400/60/110)

Environmental Conditions:

In general, the test should be carried out at ambient temperature within the limits of 10°C to 35 °C. Tests carried out under controlled conditions shall be made at a temperature of 23 ± 5°C.

Principle:

A diamond indenter in the form of a right pyramid with a square base and with a specified angle (136°) between opposite faces at the vertex is forced into the surface of a test piece followed by measurement of the diagonal length of the indentation left in the surface after removal of the test force, , F (refer the figure 5.10 below).

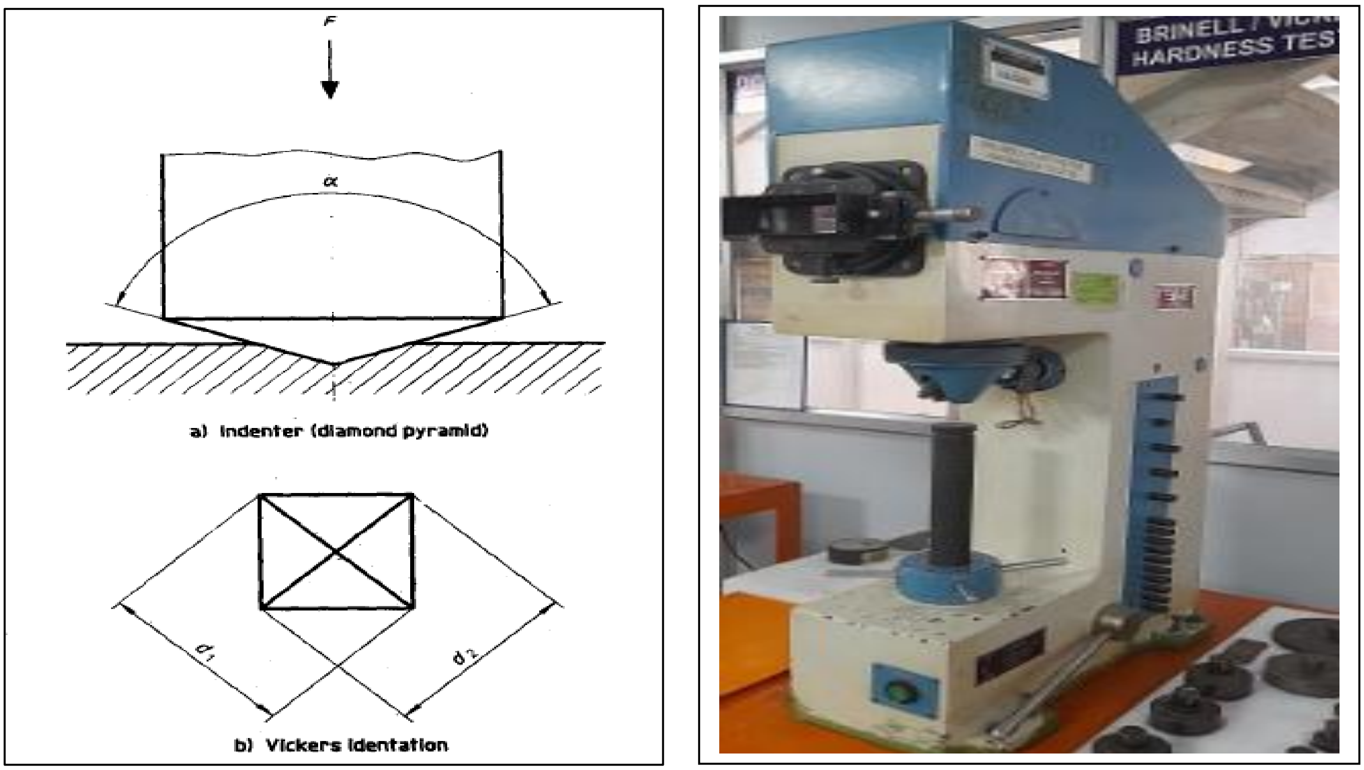


Figure 5.13: Principle of the test

The Vickers hardness is proportional to the quotient obtained by dividing the test force by the sloping area of the indentation which is assumed to be a right pyramid with a square base, and having at the vertex the same angle as the indenter.

TABLE 5.6	
Symbol	**Designation**
A	Angle between the opposite faces at the vertex of the pyramidal indenter (136°)
F	Test force, in Newtons
D	Arithmetic mean, in millimeters, of the two diagonals length d_1 and d_2 (refer Figure 1)
HV	Vickers hardness = Constant x (Test force / Surface area of indentation) = (1 / 9.80665) x (2 F sin 136°/2) / d^2 = 0.102 x (2 F sin 136°/2) / d^2 = 0.1891 x F / d^2

Symbols & Designations used:

For symbols & designations refer Table 5.6 .

The Vickers hardness is denoted by the symbol HV preceded by the hardness value followed by:

a) a number representing the test force
b) The duration of loading, in seconds, if different from the specified time (10secs to 15secs)

Test piece:

1.The test is to be carried out on a surface which is smooth and even, free from oxide scale, foreign matter and completely free from lubricants, unless otherwise specified in product standards. The finish of the surface shall permit accurate determination of the diagonal length of the indentation.

2.Preparation is to be carried out in such a way that any alteration of the surface hardness, due to heat or cold working for example, is minimized. Due to the small depth of Vickers microhardness indentations, it is essential that special precautions are taken during preparation. It is recommended to use a polishing / electro-polishing process which is suitable for the material parameters.

1. The thickness of the test piece or of the layer under test shall be at least 1.5 times the diagonal length of the indentation. No deformation should be visible at the back of the test piece after the test.

Test Procedure & Requirements:

TABLE 5.7					
Hardness test		**Low force hardness test**		**Microhardness test**	
Hardness symbol	Nominal Value of the test force F (N)	Hardness symbol	Nominal Value of the test force F (N)	Hardness symbol	Nominal Value of the test force F (N)
HV 5	49.03	HV 0.2	1.961	HV 0.010	0.09807
HV 10	98.07	HV 0.3	2.942	HV 0.015	0.1471
HV 20	196.1	HV 0.5	4.903	HV 0.020	0.1961
HV 30	294.2	HV 1	9.807	HV 0.025	0.2452
HV 50	490.3	HV 2	19.61	HV 0.05	0.4903
HV 100	980.7	HV 3	29.42	HV 0.1	0.9807

1. The sample on which the Vickers hardness test is to be done on the surface it is ensured that the surface is smooth and even, free from oxide scale, foreign matter and, in particular, completely free from lubricants.
2. If the surface is note as per point no 1 above, then surface need to be prepared as per point no 4 & 5.
3. If the Vickers hardness test is to be done on an area away from the surface (core) of any sample then the test specimen is to be cut perpendicular to the axis with help of abrasive cutoff machine taking proper care during cutting for avoiding any heating of the specimen by using appropriate cutting fluid
4. The cut faces is to be then smoothened by using grinding belt of 320 grit size and for avoid any heating of the specimen by using water.
5. The surface is then polished by using grinding / polishing paper of grit size 400, 600 and then alumina using polishing cloth.
6. The following test forces (refer table 5.3) can be used.
7. The test piece is placed on a rigid support. The support surface is to be cleaned and free from foreign matter (scale, oil, dirt; etc.). It is ensured that the test piece lies firmly on the support so that displacement cannot occur during the test.
8. Bring the indenter into contact with the test surface and apply the test force in a direction perpendicular to the surface, without shock or vibration, until the applied force attains the specified value. The time from the initial application of the force until the full test force is reached is 2secs – 8secs.
9. The total time of the test force is to be kept from 10secs to 15secs.
10. If for particular materials, a longer time for maintaining the force is applied then this time is be applied with a tolerance of ±2secs.
11. Special care is taken when testing sheet metal that is curved. The concave / convex side of the curved metal is faced towards the indenter. Products of cylindrical / spherical shape are suitably supported on centering V-

blocks of steel. Special attention is given to correct seating and alignment of the indenters.

12. The test piece is placed on a rigid support and is supported in such a manner that the surface to be indented is in a plane normal to the axis of the indenter and in the line of the indenting force.
13. Measure the lengths of the two diagonals with the help of the scale attached to the Brinell cum Vickers hardness tester.
14. The arithmetical mean of the two readings is taken for the estimation of the Vickers hardness. For flat surfaces, the difference between the lengths of two indentation diagonals should not be greater than 5%. If the difference is greater, then this is to be stated in the test report.
15. The distance between the center of any indentation and the edge of the test piece is to maintained at least 2.5 times the mean diagonal length of the indentation in the case of steel, copper and copper alloys and at least three times the mean diagonal length of the indentation in the case of light metals, lead and tin and their alloys.
16. The distance between the centers of two adjacent indentations is to be maintained at least 3.0 times the mean diagonal length of the indentation in the case of steel, copper and copper alloys; and at least 6.0 times the mean diagonal length in the case of light metals & lead, tin and their alloys. If two adjacent indentations differ in size, the spacing shall be based on the mean diagonal length of the larger indentation.

5.10 Machine Description – <u>Universal Testing Machine</u>

Purpose:

To lay down the procedure for method of tensile testing at ambient temperature (metallic materials).

Scope:

This document covers the procedure that specifies the method for tensile testing of metallic materials and defines the mechanical properties which can be determined at ambient temperature.

Reference: IS 1608: 2005 (3^{rd} Revision)

Equipment(s) Used:

Universal tensile machine (60 ton) (Model: UTN/E-10, Make: FIE)

Principle:

The test involves straining a test piece by tensile force, generally to fracture, for the purpose of determining one or more of the mechanical properties such as:

- Ultimate tensile strength.
- Yield strength.
- Percentage Elongation.
- Percentage reduction in Area.

Environmental Conditions:

In general, the test is carried out at ambient temperature between 10°C and 35°C, unless otherwise specified. Tests carried out under controlled conditions shall be made at a temperature of 23° C ± 5° C.

Shape & Dimensions:

General:

The shape and dimensions of the test pieces depend on the shape and dimensions of the metallic product from which the test pieces are taken.

The test piece is usually obtained by machining a sample from the product or a pressed blank or casting. However, products of constant cross-section (sections, bars, wires, etc.) and as-cast test pieces (i.e. cast irons and non-ferrous alloys) may be tested without being machined.

The cross-section of the test pieces may be circular, square, rectangular, annular or, in special cases, of some other shape.

Test pieces, the original gauge length of which is related to the original cross-sectional area by the equation $L_O = k \sqrt{S_O}$ & are called proportional test pieces. The internationally adopted value for k is 5.65.

The original gauge length shall be not less than 20 mm. When the cross-sectional area of the test piece is to 6 small for this requirement to be met with the coefficient value of 5.65, a higher value (preferably 11.3) or a non-proportional test piece may be used.

In the case of non-proportional test pieces, the original gauge length (L_O) is taken independently of the original cross-sectional area (S_O).

Machined test pieces:

Machined test pieces shall incorporate a transition curve between the gripped ends and the parallel length if these have different dimensions.

The gripped ends may be of any shape to suit the grips of the testing machine. The axis of the test piece shall coincide with or be parallel to the axis of application of the force.

The parallel length (L_c) or, in the case where the test piece has no transition curve, the free length between the grips, shall always be greater than the original gauge length (L_o).

5.11 Machine Description – <u>Sealed Quenched Carburizing Furnace</u>

Sealed Quench Furnace

In a Sealed Quench Furnace, The Components are heated in an atmospherically closed chamber. The Totally enclosed treatment ensures that the treated components are Scale Free.

Design Features

The Sealed Quench Furnace consists of two main parts. A heating chamber and a quenching chamber which are separated from each other by intermediate and heavily insulated door. The door can be raised or lowered by means of a pneumatic cylinder. The heating chamber houses radiant tube heating elements for heating the components to the required process temperature of up to 1000° C . The heating chamber is atmospherically sealed and thermally insulated by refractories and specially designed ceramic fibre blocks which ensure high thermal efficiency. A roof mounted fan allows proper circulation of gas inside the furnace. The heating chamber has thermocouples and oxygen probe assembly to sense the process temperature and carbon potential respectively. The oxygen probe controls the carbon potential inside the furnace by monitoring the actual value with respect to the set value and by actuating various solenoid valves in the gas lines.

There are basically two designs of Sealed Quench Furnace. In the 'straight-through 'design the components charged from the front, get into the heating chamber and quench tank in succession and emerge at the other end. In the other type called the 'in-out' design, both charging and discharging of the components are done through the front door itself. The schematic arrangement of both types of shown in Fig 1. As can be seen, the second type offers savings in the space required for the furnace installation and eliminates the need for a second charge car. In this design, the quench tank in housed in the front part of the furnace and the heating chamber at the rear.

The quench tank assembly has an elevator mechanism which has two tires. The elevator can move up and down with the heated components with the help of two pneumatic cylinders. The tip tire is used for loading the charge into the furnace and the bottom one to take out the hated job from heating chamber and quench in oil. An agitator is provided to break the oil vapor and thereby ensure effective quenching. Baffles inside the quench tank direct the quenching oil in a conducted path of up flow from the bottom to top of charges so the maximum severity of quenching is achieved. A heat exchanger and oil pump are provided to cool the quench oil with the help of cooling tower and raw water pump. The quenching tank can be closed and opened by the front door assembly operated by pneumatic cylinder.

The job movement into/outside the heating chamber is done by robust rear handler mechanism made of high temperature alloy material and a brake motor.

The equipment is installed with flow control panel to control and monitor the flow rates of nitrogen, methanol, LPG, acetone, ammonia, air, etc.

The control panel houses PLC logics, power controller and other logic controls to control the operation of the furnace. Both manual and auto cycles are possible in these furnaces.

Main Advantages

Heat Treatment in Sealed Quenched Furnaces offers the following main advantages:

1. Scale -free Components. Because of this, machining after heat treatment can be minimized. For the same reason, machining stock allowance can be reduced with potential material savings.
2. Quick changeover to different heat treatment processes can be offered with minimum loss of time in these furnaces.
3. Since quenching is also done in the chamber filled with process atmosphere, the uniformity of the end results is superior to what is achievable in the other conventional furnace like pit type

gas carburizing furnace.

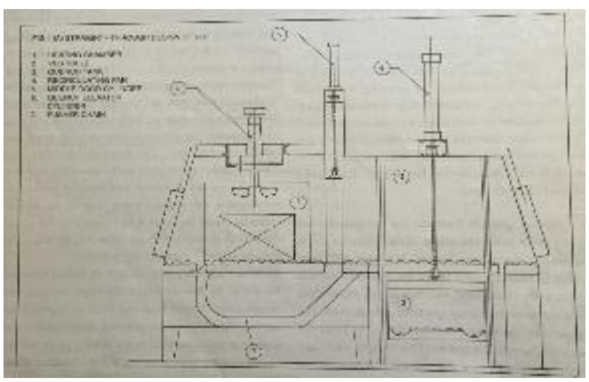


Fig 5.14 (a) STRAIGHT- THROUGH DESIGN OF

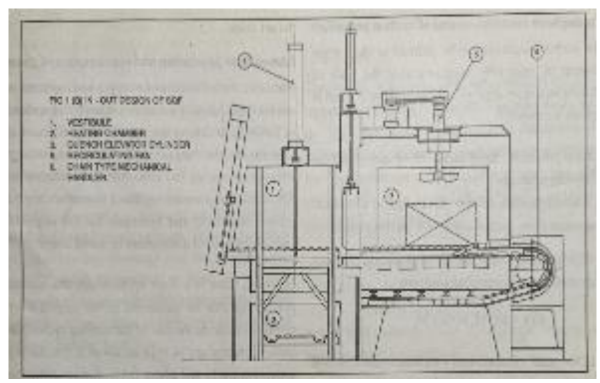


Fig 5.14 (b) IN-OUT- DESIGN OF SQF

Fig 5.15

- Make: Unitherm Engineers Ltd.
- Electrically Heated, 600 Kg & 1000 Kg capacity
- Process used: Methanol – Nitrogen – LPG system
- Temp. control within +/- 1 deg.C
- Cp control within +/- 0.01%

5.12 Machine Description – Nitro Carburizing Furnace

- Make: Ipsen Technologies Pvt. Ltd.
- Front Loading Furnace with gas tight casing
- Electrically Heated, 1200 Kg
- Gas Composition used: 50% Ammonia, 45% Nitrogen, 5% LPG

Fig 5.16

5.13 Machine Description – <u>Sursulf Bath</u>

- Make: Tribology India Ltd.
- Patented from HEF, Germany
- Salts used: CR4 (Base Salt) , CR2 (Regenerator salt) with Potassium
- Sulfide (to control CN)

Fig 5.17

5.14 Machine Description – <u>GHI Induction Hardening Machine</u>

- Make: GHI
- Patented from Germany
- Working Method – Thermo Mechanical Process
- Coolant used – Polymer Quench

Fig 5.18

Chapter 6:

Selection of Materials

6. Selection of materials

6.1 Application based material matrix

For our study, we have selected common materials which are widely used in earth moving machinery as transmission parts of ground engaging tools. The material horizon starts from mild steel and combines various TMCP, low and medium alloy steel with various combinations of heat-treatment and surface hardening operations.

We have selected 22 various combinations of materials, which include plate and bar, which are processed through normalizing, TMCP, Q&T, Carburising, Nitrocarburising, surface cladding to study the wear characteristics of materials with varying mechanical and wear properties.

The selected group of materials were chosen considering it should cater most of the relevant application of wear component applicable for excavator (including Ground engaging tools and bucket) .

Based on this consideration application-based matrix was made.

Material	Wear plate on bucket	Boom & Arm Structure	Tooth Point	Bucket fabrication plate		Transmission part	Under Carriage Parts	Bushings
SS400/IS 2062 E250BR		√		√				
WT 80	√			√				
45C8 (Normalised)						√		√
Sailma 450 HI/IS 2062 E450BR		√		√				
Domex plates (4mm)	√							

WT 60	√			√				
P & H 11 (Adapter)				√				
Hardox 400	√			√				
EN19						√	√	√
Berco Track Shoe [27MCB5]							√	
EN24						√	√	
Berco Track Link [KM-3573]							√	
P & H 11 (Sprocket)							√	
Esco Tooth Point [ESCO Steel-Import]			√					
F-steel			√					
35C8						√	√	
20MnCr5-Carburised								√
45C8 – Q&T and I/Hardened						√	√	√
EN 19 -Nitriding						√		
45C8- Q&T and Nitrided						√		
EN 24 -Nitriding						√		
Wear Plates (cladded)	√							

Table 6.1

6.2 Supply condition

The selected materials, in the form of plate or bar and processed through normalizing, TMCP, Q&T, Carburising, Nitrocarburising, surface cladding are used to study the wear characteristics of materials.

We have taken consideration for alloying materials viz. specially Nickel, Chromium, Molybdenum, Vanadium & Boron with material characterization and tried to correlate the wear behaviour with microstructure study.

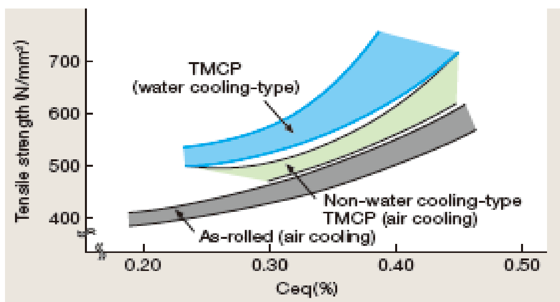
Material	**Form**	**Supply condition**
SS400/IS 2062 E250BR	Plate	As rolled, Source – JSPL
Sailma 450 HI/IS 2062 E450BR	Plate	TMCP, Source – JSPL
Domex plates (4mm)	Plate	TMCP – Source Tata Steel
35C8	Square	Supplied in Q&T condition & Induction Hardened done at Tata Hitachi
45C8	Square	Supplied in Q&T condition & Induction Hardened done at Tata Hitachi
F-steel	Tooth Point	Supplied in Q&T condition, Actual Sample Cut & prepared into Square Size for inspection
Wear plates	Plate	Supplied with Surface Cladding
WT 80	Plate	Q&T, Source – JSPL
WT 60	Plate	TMCP, Source – JSPL
Hardox 400	Plate	Q&T, Source – JSPL
EN24	Square	Supplied as Q&T
EN19	Square	Supplied as Q&T

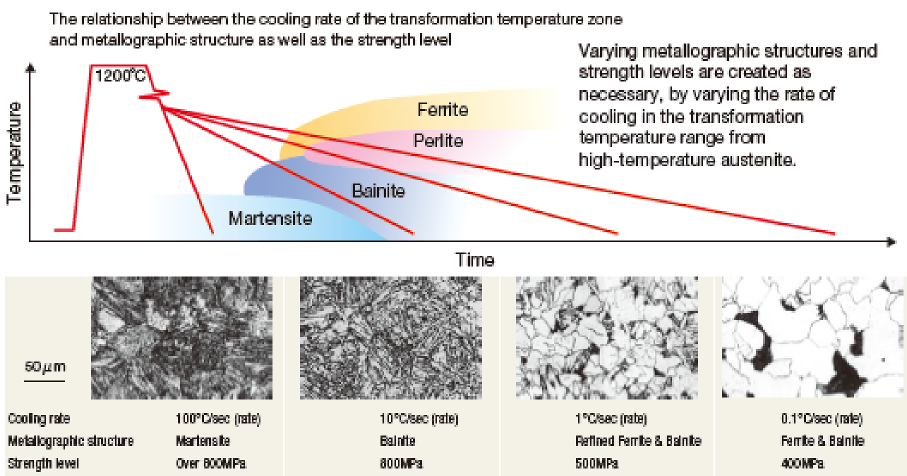
P & H 11 (Sprocket)	Plate	Supplied as Normalised, Induction Hardening done in-house
Berco Track Shoe [27MCB5]	Plate	Q&T, Supplier – Berco Italy & tested with actual part
Berco Track Link [KM-3573]	Plate	Q&T with Induction Hardening, Supplier – Berco Italy & tested with actual part
Esco Tooth Point [ESCO Steel- Import]	Square	Q&T, Source – ESCO Steel India, Actual Sample tested with Square Size
20MnCr5-Carburised	Square	Supplied in Normalised condition, Case Carburised In-house [THCM]
P & H 11 (Adapter)	Plate	Q&T, Supplier – Big casting
45C8	Square	Normalised, Source- Supplier MCPL
EN 19 -Nitriding	Square	Supplied in Q&A condition (RKFL), Machining & Nitriding done In-house [Tata Hitachi]
45C8-Nitiding	Square	Supplied in Q&T condition (MCPL), Nitriding done inhouse [THCM]
EN 24 -Nitriding	Square	Supplied in Q&A condition (RKFL), Machining & Nitriding done In-house [THCM]

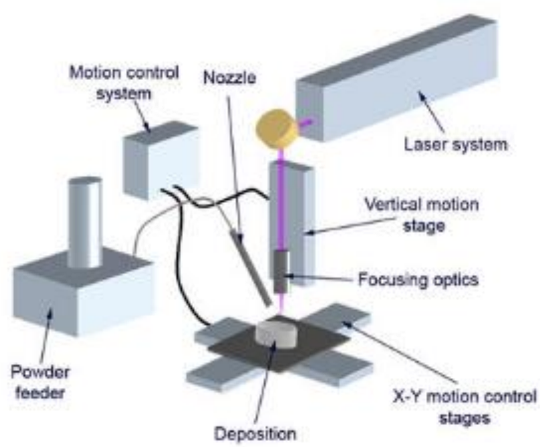
Table 6.2

6.3 Heat-treatment & Case Hardening details

<table>
<tr><th>Material Grade</th><th>Form</th><th>Supply condition</th><th>HT Cycle Time</th></tr>
<tr><td>SS400/IS 2062 E250BR</td><td>Plate</td><td>As rolled</td><td>The simplest rolling method is hot rolling at high temperatures. Immediately following furnace extraction, the slab is rolled to dimension. Forming occurs in the recrystallization zone. This rolling method primarily serves as a shaping process. The rolling process also homogenizes the microstructure and refines the grain size

As Rolled at 870 Deg. C</td></tr>
<tr><td>SAILMA-450 HI/ IS 2062 E450BR/ WT-60 & DOMEX [4mm thick plate]</td><td>Plate</td><td>TMCP</td><td>TMCP is a manufacturing process of Steel plates based on a combination of Control Cooling & Rolling. This HT process is being applied when required High Strength Thick plates such as low Temperature toughness & Weld ability.



</td></tr>
<tr><td>35C8</td><td>Square</td><td>Q&T + Induction Hardened</td><td>Induction Hardening Parameters
<table>
<tr><td colspan="6">(A) <u>Setting parameters:</u></td></tr>
<tr><td>Transformer Ratio:</td><td>10:01</td><td>Feed:</td><td>400 mm / min</td><td>Quenching Media:</td><td>water</td></tr>
<tr><td>Capacitor:</td><td>600 KVAR</td><td>Dwell Time:</td><td>2 sec</td><td>Inductor no:</td><td>150</td></tr>
<tr><td>Heat:</td><td>23.00%</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">(B) <u>Output parameters:</u></td></tr>
<tr><td>Current:</td><td>200 AMP</td><td>Power :</td><td>60 KW</td><td colspan="2"></td></tr>
<tr><td>Voltage:</td><td>600 V</td><td>Frequency:</td><td>6.2KHz</td><td colspan="2"></td></tr>
</table></td></tr>
</table>

<table>
<tr>
<td>45C8</td>
<td>Square</td>
<td>Q&T + Induction Hardened</td>
<td>
Induction Hardening Parameters
<table>
<tr><td colspan="5">(A) Setting parameters:</td></tr>
<tr><td>Transformer Ratio:</td><td>18:01</td><td>Feed:</td><td>700 mm / min</td><td>Quenching Media: water</td></tr>
<tr><td>Capacitor:</td><td>637.5 KVAR</td><td>Dwell Time:</td><td>2 sec</td><td>Inductor no: 73</td></tr>
<tr><td>Heat:</td><td>11.00%</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">(B) Output parameters:</td></tr>
<tr><td>Current:</td><td>200 AMP</td><td>Power :</td><td>50 KW</td><td></td></tr>
<tr><td>Voltage:</td><td>600 V</td><td>Frequency:</td><td>6 KHz</td><td></td></tr>
</table>
</td>
</tr>
<tr>
<td>F-steel</td>
<td>Tooth Point</td>
<td>Q&T</td>
<td>
Furnace Type – Batch Type
<table>
<tr><td>Temperature on Entry</td><td rowspan="3">Hardening</td><td>Entry Temperature 650⁰</td></tr>
<tr><td>Soaking Time & temp</td><td>Soaking Time – 5 hours
900⁰C ± 20⁰C</td></tr>
<tr><td>Temperature on Exist</td><td>Exist Temperature – 900
20⁰C</td></tr>
<tr><td>Casting Temperature</td><td rowspan="5">Quenching</td><td>880 – 900⁰C</td></tr>
<tr><td>Water Temperature</td><td>35-50⁰C</td></tr>
<tr><td>Total Travelling Time (From f/c door to quenched water)</td><td>8 – 17 sec</td></tr>
<tr><td>Agitator – 2 nos.</td><td>300 rpm & 10 HP Each</td></tr>
<tr><td>Hold Time in Quenching Water</td><td>3-5 mints</td></tr>
<tr><td>Furnace Temperature on Entry</td><td rowspan="3">Tempering</td><td>Entry Temp 460 - 470</td></tr>
<tr><td>Soaking Time & Temp</td><td>5 hours at 460 – 470⁰C</td></tr>
<tr><td>Casting cooling</td><td>Normal Air Cooling</td></tr>
</table>
</td>
</tr>
<tr>
<td>Wear plates</td>
<td>Plate</td>
<td>Surface Cladding</td>
<td>
Process of Cladding
Cladding is a covering or layer applied to the external surfaces of a structure to protect it or give it a new look & help to avoid Wear & tear of Metal
Schematic Image of Cladding Process


Advantages -

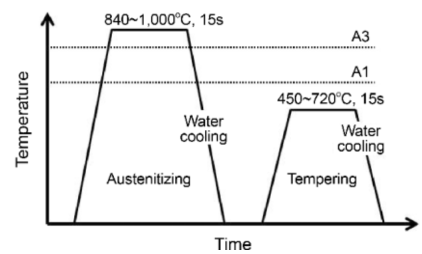
Best technique for coating any shape => increase lifetime of wearing parts.
Most suited technique for graded material application.
Well adapted for near-net-shape manufacturing.
Low dilution between track and substrate (unlike other welding processes and strong metallurgical bond.

</td>
</tr>
</table>

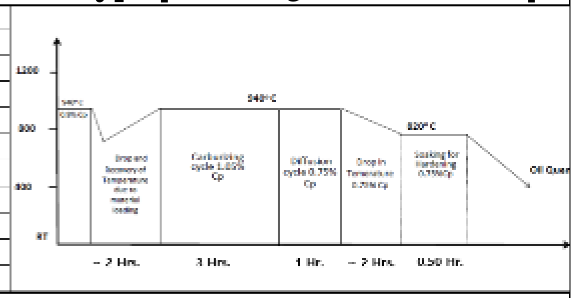
<table>
<tr>
<td>WT 80</td>
<td>Plat
e</td>
<td>Q&T</td>
<td>

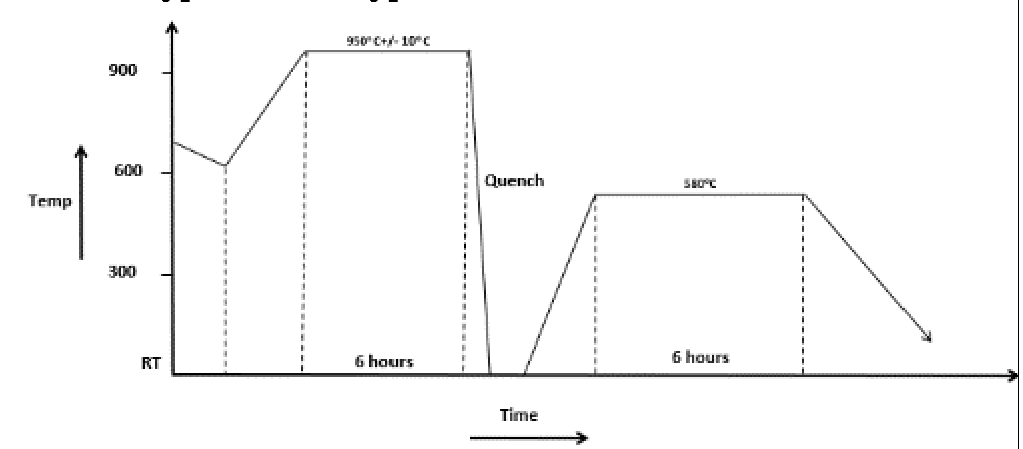
- **Quenched and Tempered Steel Plate** are heated between a range of 815 to 900 degrees C. Extra care needs to be taken to keep the temperature stable. The resultant metal can be distorted with the slightest variation in temperature.
- Quenched and tempered plates also require the temperature of the cooling element to remain constant. A fluctuation in the temperature of the cooling element can make the edges of these plates brittle.
- Hence there are different cooling elements used to cool these Quenched and Tempered Alloy Steel Plates namely, minerals, water, oils, and inert gases like nitrogen and helium. Tempering post quenching improves the hardness of these plates and makes them more ductile.

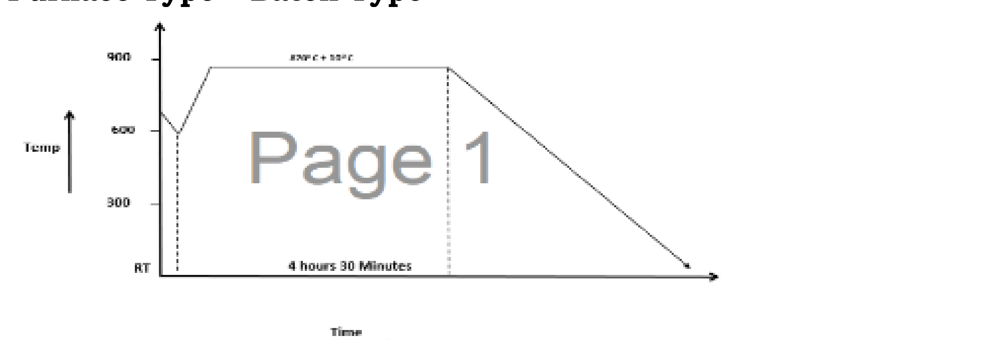
</td>
</tr>
<tr>
<td>Hardox
400</td>
<td>Plat
e</td>
<td>Q&T</td>
<td>

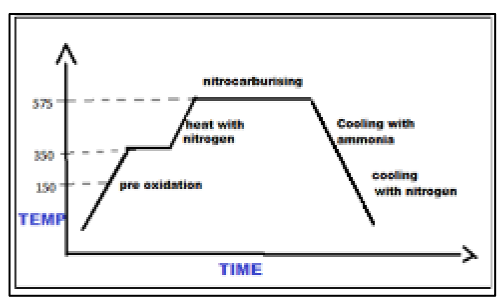



</td>
</tr>
<tr>
<td>En-24</td>
<td>Squ
are</td>
<td>Q&T</td>
<td>
Furnace Type – Batch Type
<table>
<tr><th colspan="2">Hardening Parameters</th><th colspan="2">Quench Details</th><th colspan="2">Tempering Parameters</th></tr>
<tr><th>Temp. ± 5°C</th><th>Time (Mints)</th><th>Medium</th><th>Temp. °C(max.)</th><th>Temp. ± 5°C</th><th>Time (Mint)</th></tr>
<tr><td>850</td><td>60</td><td>Oil</td><td>45°C</td><td>650</td><td>90</td></tr>
</table>
</td>
</tr>
<tr>
<td>En-19</td>
<td>Squ
are</td>
<td>Q&T</td>
<td>
Furnace Type – Batch Type
<table>
<tr><th colspan="2">Hardening Parameters</th><th colspan="2">Quench Details</th><th colspan="2">Tempering Parameters</th></tr>
<tr><th>Temp. ± 5°C</th><th>Time (Mints)</th><th>Medium</th><th>Temp. °C(max.)</th><th>Temp. ± 5°C</th><th>Time (Mint)</th></tr>
<tr><td>870</td><td>80</td><td>Oil</td><td>45°C</td><td>650</td><td>90</td></tr>
</table>
</td>
</tr>
<tr>
<td>P & H 11
(Sprocket)</td>
<td>Plat
e</td>
<td>Q&T with
Induction</td>
<td>
Induction Hardening
<table>
<tr><th colspan="6">Setting parameters</th></tr>
<tr><td>Power</td><td>73% ± 3%</td><td>Heat Time(Sec)</td><td>100 ± 10</td><td>Frequency (KH)</td><td>2.6 ± 0.3</td></tr>
<tr><td>Quench Time (s)</td><td>120 ± 5</td><td>Quenchant Conc(%)</td><td>6.5 (Range- 4 to 8)</td><td></td><td></td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td>20MnCr5 [High Case]</td>
<td>Square</td>
<td>Case Carburising</td>
<td>
High Case Carburising – Furnace Type [Sealed Quench Furnace]
<table>
<tr><td colspan="2">1. Operating parameters:</td></tr>
<tr><td>Temperature (Carburizing)</td><td>940°C</td></tr>
<tr><td>Carbon potential (Carburizing)</td><td>1.05%</td></tr>
<tr><td>Time (Carburizing)</td><td>3Hrs</td></tr>
<tr><td>Temperature (Diffusion)</td><td>940°C</td></tr>
<tr><td>Carbon potential (Diffusion)</td><td>0.75%</td></tr>
<tr><td>Time (Diffusion)</td><td>1 Hrs</td></tr>
<tr><td>Temperature (Hardening)</td><td>820°C</td></tr>
<tr><td>Carbon potential (Hardening)</td><td>0.75%</td></tr>
<tr><td>Hardening Time</td><td>30 min</td></tr>
<tr><td>Oil Temperature</td><td>120°C</td></tr>
</table>


</td>
</tr>
<tr>
<td>P & H 11 (Adapter)</td>
<td>Plate</td>
<td>Q&T</td>
<td>
Furnace Type – Batch Type


</td>
</tr>
<tr>
<td>45C8</td>
<td>Square</td>
<td>Normalised</td>
<td>
Furnace Type – Batch Type


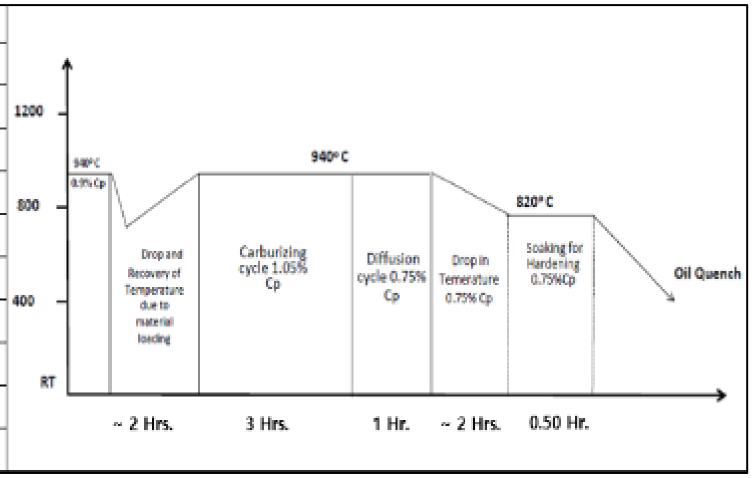
</td>
</tr>
<tr>
<td>En-19, 45C8, En-24</td>
<td>Square</td>
<td>Nitro-Carburising</td>
<td>
<table>
<tr><td colspan="2">Operating parameters:</td></tr>
<tr><td>Preoxidation Temperature</td><td>350°C</td></tr>
<tr><td>Pre-oxidation duration in hours</td><td>45 min</td></tr>
<tr><td>Nitrocarburising Temp</td><td>575°C</td></tr>
<tr><td>Nitrocarburising duration in hours</td><td>6 hrs</td></tr>
<tr><td>Heating with nitrogen(temperature)</td><td>350°C-510°C</td></tr>
<tr><td>Temp. for entry of ammonia + CO2</td><td>510°C</td></tr>
<tr><td>Cooling with ammonia(Temperature)</td><td>300°C</td></tr>
<tr><td>Cooling with nitrogen(Temperature)</td><td>300°C-150°C</td></tr>
</table>


</td>
</tr>
</table>

6.3.1: In-house Heat treatment parameters

1. Carburising – Sealed Quench Furnace

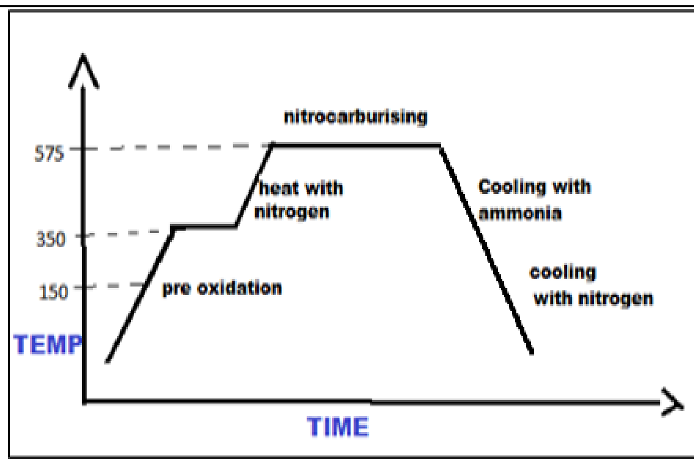
1. Operating parameters:	
Temperature (Carburizing)	940°C
Carbon potential (Carburizing)	1.05%
Time (Carburizing)	3Hrs
Temperature (Diffusion)	940°C
Carbon potential (Diffusion)	0.75%
Time (Diffusion)	1 Hrs
Temperature (Hardening)	820°C
Carbon potential (Hardening)	0.75%
Hardening Time	30 min
Oil Temperature	120°C



Case Carburised of 20MnCr5 Grade Bush

2. Nitro-carburising

Operating parameters:	
Preoxidation Temperature	350°C
Pre-oxidation duration in hours	45 min
Nitrocarburising Temp	575°C
Nitrocarburising duration in hours	6 hrs
Heating with nitrogen(temperature)	350°C-510°C
Temp. for entry of ammonia + CO2	510°C
Cooling with ammonia(Temperature)	300°C
Cooling with nitrogen(Temperature)	300°C-150°C



Nitro-Carburising of En-19, En-24 & 45C8 Grade

3. Induction Hardening of Sprockets (P&H-11)

Setting parameters					
Power	73% ± 3%	Heat Time(Sec)	100 ± 10	Frequency (KH)	2.6 ± 0.3
Quench Time (s)	120 ± 5	Quenchant Conc(%)	6.5 (Range- 4 to 8)		

Cycle time for Sprocket [Induction Hardening]

4. Induction Hardening of 45C8

(A) Setting parameters:					
Transformer Ratio:	10:01	**Feed:**	400 mm / min	**Quenching Media:**	water
Capacitor:	600 KVAR	**Dwell Time:**	2 sec	**Inductor no:**	150
Heat:	23.00%				
(B) Output parameters:					
Current:	200 AMP	**Power :**	60 KW		
Voltage:	600 V	**Frequency:**	6.2KHz		

Material Grade - 35C8 / 45C8

Case Depth Specification - 2mm min. at 450HV

6.3.2: Supplier Heat-treatment parameters

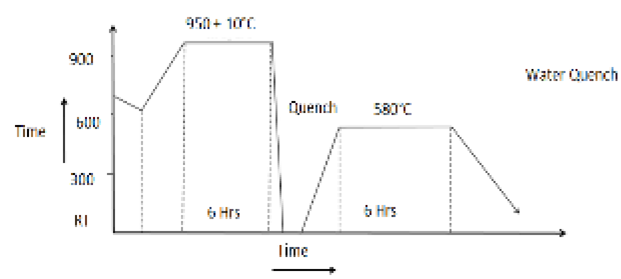
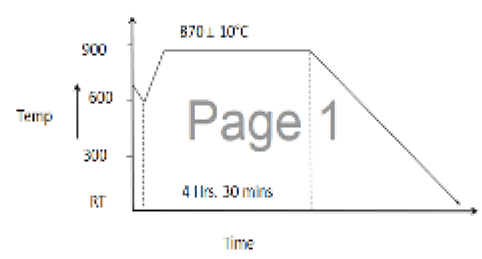
<table>
<tr><th rowspan="2">Material</th><th rowspan="2">Form</th><th rowspan="2">Supply condition</th><th colspan="4">HT Cycle Time</th></tr>
<tr><th>Pre-heating Temp & Time</th><th>Soaking Temp. & Time</th><th>Hardening Temp & Time</th><th>Quenching Media</th></tr>
<tr><td>SS400/IS 2062</td><td>Plate</td><td>As rolled, Source – JSPL</td><td colspan="4">As Rolled at 870 Deg.C</td></tr>
<tr><td>Sailma-450 HI/IS-2062 E450BR</td><td>Plate</td><td>TMCP, Source – JSPL</td><td colspan="4">TMCP at 500±20 Deg.C</td></tr>
<tr><td>Domex plates (4mm)</td><td>Plate</td><td>TMCP – Source Tata Steel</td><td colspan="4">-</td></tr>
<tr><td>WT 80</td><td>Plate</td><td>Q&T, Source – JSPL</td><td>-</td><td>870 Deg.C</td><td>870 Deg.C</td><td>Water Quench & Tempering at 620 Deg.C @3 Hrs</td></tr>
<tr><td>WT 60</td><td>Plate</td><td>TMCP, Source – JSPL</td><td colspan="4">TMCP at 500±20 Deg.C</td></tr>
<tr><td>Hardox 400</td><td>Plate</td><td>Q&T, Source – JSPL</td><td>-</td><td>870 Deg.C</td><td>870 Deg.C</td><td>Water Quench & Not Tempered</td></tr>
<tr><td>EN24</td><td>Square</td><td>Q&T, Source – Heat Treatment done In-house</td><td colspan="4"><table><tr><th colspan="2">Hardening Parameters</th><th colspan="2">Quench Details</th><th colspan="2">Tempering Parameters</th></tr><tr><th>Temp. ± 5°C</th><th>Time (Mints)</th><th>Medium</th><th>Temp. °C(max.)</th><th>Temp. ± 5°C</th><th>Time (Mint)</th></tr><tr><td>850</td><td>60</td><td>Oil</td><td>45°C</td><td>650</td><td>90</td></tr></table></td></tr>
<tr><td>EN19</td><td>Square</td><td>Q&T, Source – Heat Treatment done In-house</td><td colspan="4"><table><tr><th colspan="2">Hardening Parameters</th><th colspan="2">Quench Details</th><th colspan="2">Tempering Parameters</th></tr><tr><th>Temp. ± 5°C</th><th>Time (Mints)</th><th>Medium</th><th>Temp. °C(max.)</th><th>Temp. ± 5°C</th><th>Time (Mint)</th></tr><tr><td>870</td><td>80</td><td>Oil</td><td>45°C</td><td>650</td><td>90</td></tr></table></td></tr>
<tr><td>P & H 11 (Adapter)</td><td>Plate</td><td>Q&T, Supplier – Big casting</td><td colspan="4">
</td></tr>
<tr><td>45C8</td><td>Square</td><td>Normalised, Source- In-house</td><td colspan="4">
</td></tr>
</table>

Table 6.3

Chapter 7:

Observations

7. Observations

7.1 Chemical Compositions

Following table states the Chemical composition analysis for selected materials. The chemical composition were taken using Spectomax make spectrometer.

Material Grade	Composition % [Actual]									
	C	Mn	S	P	Si	%(Nb + V + Ti)	Ni	Cr	Mo	B
SS400/IS 2062 E250BR	0.12	0.84	0.004	0.018	0.14	-	-	-	-	-
IS 2062 E450BR (20 mm Thick Plate)	0.13	1.48	0.009	0.023	0.32	Nb- 0.050, V- 0.070 & Ti- 0.017	0.018	0.006	-	-
35C8 with Induction Hardening	0.35	0.82	0.011	0.012	0.19	-	-	-	-	-
45C8 with Induction Hardening	0.45	0.78	0.022	0.009	0.21	-	-	-	-	-
Domex-600 plates (4mm)	0.14	1.41	0.015	0.010	0.27	V- 0.080 & Nb- 0.040	-	-	-	-
F-steel (Q&T)	0.27	1.02	0.009	0.023	1.38	-	0.45	1.00	0.19	-
Wear Cladding Plate	2.52	0.83	0.005	0.003	0.57	Ti- 0.042, Nb- 0.012 & V- 0.002	0.05	10.16	-	0.24
WT 60 (16 mm Thick)	0.17	1.52	0.010	0.033	0.32	Nb- 0.060, V- 0.070 & Ti- 0.017	0.018	0.016	-	-
WT 80/S690QL	0.15	1.26	0.004	0.009	0.31	V- 0.007 & Ti- 0.025	0.15	0.52	0.16	0.018
Hardod-400	0.10	1.47	0.005	0.014	0.45	Nb- 0.015	0.12	0.48	0.22	0.005
EN19/42CrMo4 with Q&T	0.42	0.79	0.015	0.22	0.22	-	-	1.00	0.21	-
EN24 with Q&T	0.41	0.68	0.014	0.009	0.19	-	1.56	1.20	0.25	-
P & H 11 (Sprocket) - Induction Hardening	0.37	1.24	0.010	0.013	0.51	-	0.038	0.11	0.16	-
Berco Track Shoe [27MCB5]	0.25	1.18	0.004	0.002	0.30	-	-	0.31	-	0.002
Berco Track Link [KM-3573]	0.38	1.24	0.012	0.006	0.25			0.19		0.004
Esco Tooth Point [ESCO Steel-Import]	0.19	0.90	0.03	0.024	1.25			1.09	0.24	
20MnCr5 [High Carburised Case Depth]	0.21	1.26	0.012	0.011	0.210	-	-	1.20	-	-

P&H - 11 (Adapter) - Q&T	0.38	0.48	1.20	0.017	0.110	-	0.040	0.12	0.18	-
45C8 [Normalised]	0.44	0.81	0.021	0.023	0.21	-	-	-	-	-
45C8 - Nitriding	0.43	0.82	0.160	0.020	0.02	-	0.009	0.016	0.010	
EN 19 - Nitriding	0.42	0.810	0.18	0.010	0.01	-	0.020	0.980	0.190	
EN 24 - Nitriding	0.41	0.820	0.17	0.010	0.02	-	1.400	1.090	0.200	

Table 7.1

7.2 Mechanical Tests

7.2.1 Hardness Test

Microhardness of sample across was measured as per guidelines of ASTM E92 – 17, Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials. For measuring microhardness, a diamond indenter was used and a load of 500 grams with 10 seconds of dwell time was applied.

Observed values of microhardness are described in below table.

Material	Actual Hardness in BHN/VPN
SS400/IS 2062 E250BR	132
IS 2062 E450BR (20mm Thick Plate)	198
Domex plates (4mm)	237
35C8 with Induction Hardening	640 VPN
45C8 with Induction Hardened	672 VPN
F-steel with Q&T	480 VPN
Wear plates	627 VPN
WT 80	278
WT 60 (16mm Thick Plate)	174

Hardox 400	363
EN24 with Q&T	409
EN19 with Q&T	383
P & H 11 (Sprocket) – Induction Hardening	645 VPN
Berco Track Shoe [27MCB5]	407.3
Berco Track Link [KM-3573]	419.5
Esco Tooth Point [ESCO Steel- Import]	432.5
20MnCr5 - High Case Carburised	654 VPN
P & H 11 (Adapter) – Q&T	328.0
45C8 (Normalised)	198
EN 19 -Nitrided	750 VPN
45C8-Nitrided	732 VPN
EN 24 -Nitrided	762 VPN

Note - Hardness >444 BHN taken with VPN Scale

Table 7.2

7.2.2 Tensile Test

Tensile testing samples were cut from all metal to make a test specimen. The test was conducted as per ASTM - E8/E8M – 16a, Standard Test Methods for Tension Testing of Metallic Materials. A unidirectional gradual tensile load applied on 60 Ton universal testing machine on a round bar sample.

Observed values of individual samples are expressed in below table.

Material Grade Nomenclature	Actual UTS [Mpa min]	Inspection Condition
SS400/IS 2062 E250BR	462.0	As Rolled
IS 2062 E450BR (20mm Thick Plate)	662.0	TMCP
Domex plates (4mm)	732.0	TMCP
35C8 with Induction Hardening	656.0	Q&T
45C8 with Induction Hardened	787.0	Q&T
F-steel with Q&T	1420.0	Q&T
Wear plates	NA	NA
WT 80	878.0	Q&T
WT 60	682.0	TMCP
Hardox 400	1320.0	Q&T
EN24 with Q&T	1462.0	Q&T
EN19 with Q&T	1380.0	Q&T
P & H 11 (Sprocket) with Induction Hardening	733.0	Q&T
Berco Track Shoe [27MCB5]	1672.0	Q&T
Berco Track Link [KM-3573]	1132.0	Q&T
Esco Tooth Point [ESCO Steel- Import]	1428.0	Q&T
20MnCr5-High Case Carburised	624.0	Normalised
P & H 11 (Adapter) with Q&T	756.0	Q&T
45C8-Normalised	675.0	Normalised
EN 19 -Nitriding	NA	NA
45C8-Nitiding	NA	NA
EN 24 -Nitriding	NA	NA

Table 7.3

7.3 Metallographic confirmation

Instruments Used for Metallography – Optical Microscope [SEIWA OPTICAL, JAPAN]

Material Grade – **IS 2062 E250BR/SS-400 [20 mm Thick – Original]**

Microstructure Description @ 100X Magnification – Uniform Distribution of Ferrite & Pearlite

Fig -7.1

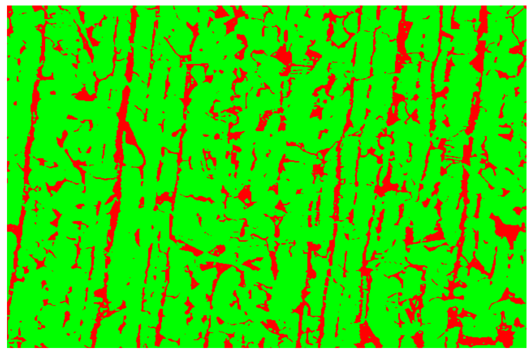


Fig-7.2 → Phase Analysis of Fig-7.1

Phase Name [Image-2]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite [Red]	41375.054	17.874	Normalising Rolling
Ferrite [Green]	190106.427	82.126	

Material Grade – **IS 2062 E350C [Original Thickness – 40 mm]**

Microstructure Description @ 100X Magnification – Uniform Distribution of Ferrite & Pearlite

Fig -7.3

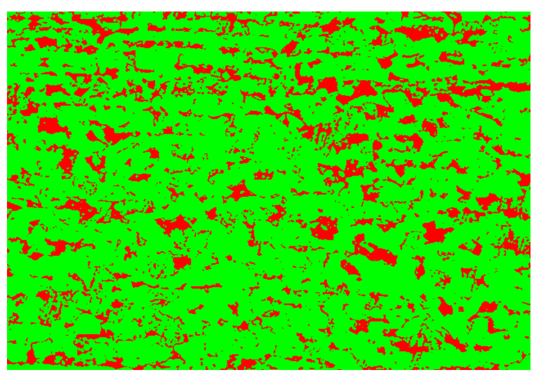


Fig -7.4 → Phase Analysis of Fig-7.3

Phase Name [Image-04]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite [Red]	44715.41	19.317	Normalising Rolling
Ferrite [Green]	186766.071	80.683	

Material Grade – **IS 2062 E450BR/SAILMA – 450/HT-60 [20 mm Thick – Original]**

Microstructure Description @ 100X Magnification – Quasi Polygonal Ferrite & Pearlite & traces of Bainite

Fig -7.5

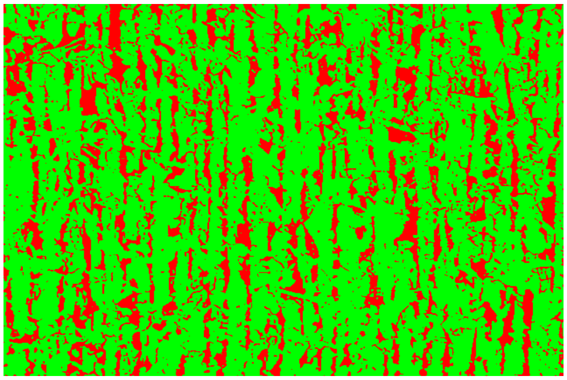


Fig -7.6 → Phase Analysis of Fig-7.5

Phase Name [Image-06]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite & Bainite [Red]	57305.23	24.756	TMCP [Thermo-Mechanical Control]
Quasi Ferrite [Green]	174176.251	75.244	

Material Grade – **Hardox-400 [Original Thick – 10mm]**

Microstructure Description @ 100X Magnification – Low Carbon Tempered Structure & Predominantly Bainite with traces of Transformed Structure

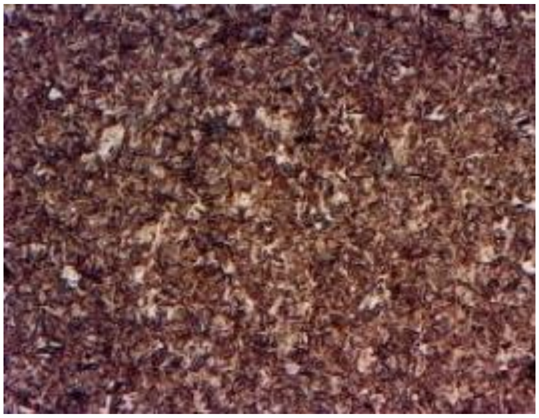


Fig -7.7

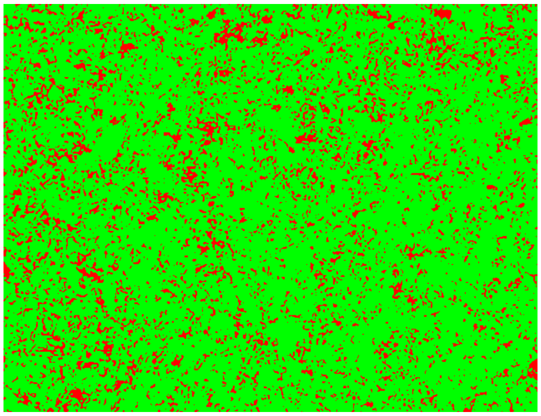


Fig -7.8 → Phase Analysis of Fig-7.7

Phase Name [Image-08]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Transformed Structure [Red]	33181.273	14.334	Quenched & Tempered
Low Carbon Structure & Bainite [Green]	198300.209	85.666	

Material Grade – **EN-19 [Square]**

Microstructure Description @ 400X Magnification – Tempered Martensite with Bainite & Traces of Transformed Structure

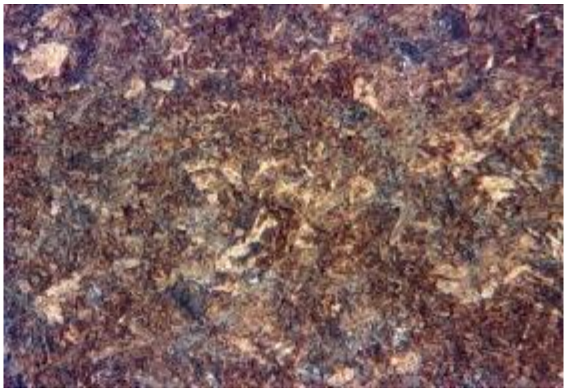


Fig -7.9

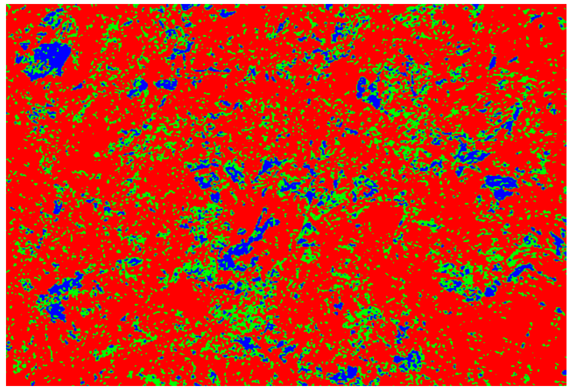


Fig -7.10→ Phase Analysis of Fig-7.9

Phase [Image-10]	Tempered Martensite [Red]	Bainite [Green]	Transformed Structure [Blue]	Heat Treatment
Area (Micron Sqr)	43003.019	10524.145	3745.067	Q&T
Area (%)	75.085	18.376	6.539	

Material Grade – **EN-24 [Square]**

Microstructure Description @ 200X Magnification – Tempered Martensite with Bainite & Traces of Transformed Structure

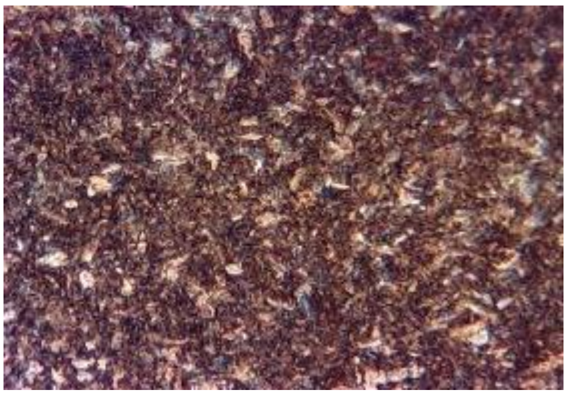


Fig -7.11

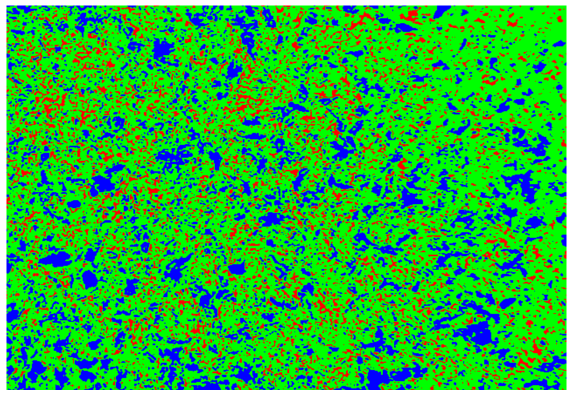


Fig -7.12 → Phase Analysis of Fig-7.11

Phase [Image-12]	Tempered Martensite [Red]	Bainite [Green]	Transformed Structure [Blue]	Heat Treatment
Area (Micron Sqr)	160695.017	27567.546	43218.919	Q&T
Area (%)	69.42	11.909	18.671	

Material Grade – **IS 2062 E250BR/SS-400 [50 mm Thick- Original]**

Microstructure Description @ 100X Magnification – Uniform Distribution of Ferrite & Pearlite

Fig -7.13

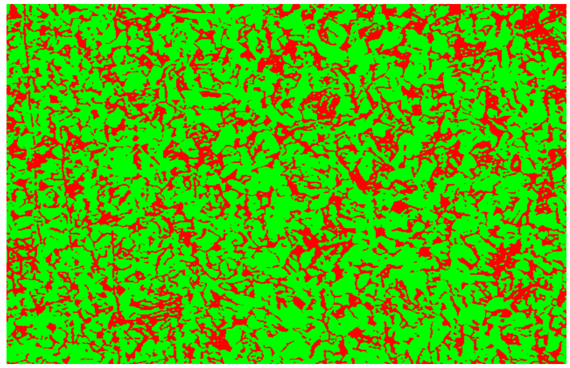


Fig -7.14 → Phase Analysis of Fig-7.13

Phase Name [Image-14]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite [Red]	71295.844	30.8	Furnace Normalised
Ferrite [Green]	160185.637	69.2	

Material Grade – **IS 2062 E450BR/SAILMA – 450/HT-60 [Original Thickness – 32 mm]**

Microstructure Description @ 100X Magnification – Quasi Polygonal Ferrite & Pearlite & traces of Bainite

Fig -7.15

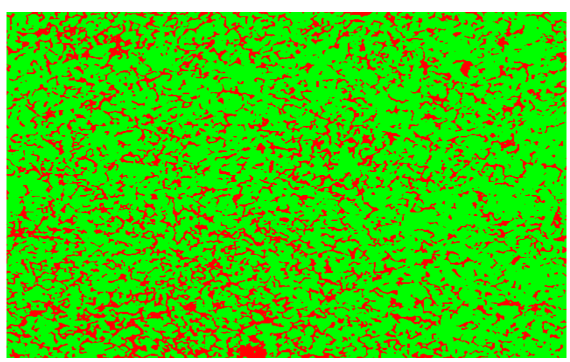


Fig -7.16 → Phase Analysis of Fig-7.15

Phase Name [Image-16]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite & Bainite [Red]	50552.933	21.839	TMCP [Thermo-Mechanical Control]
Quasi Ferrite [Green]	180928.548	78.161	

Material Grade – **35C8 [Induction Hardened – Original Pin]**

Microstructure Description @ 100X Magnification – Tempered Martensite with Transformed Structure

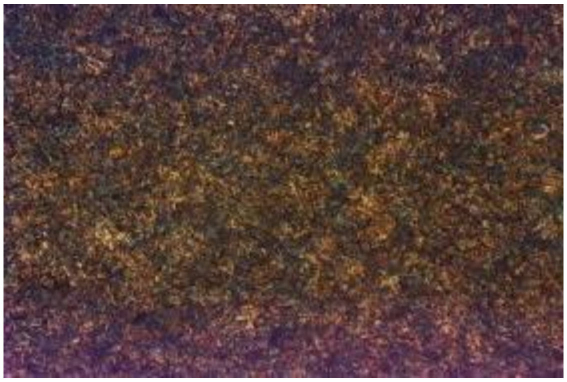


Fig -7.17

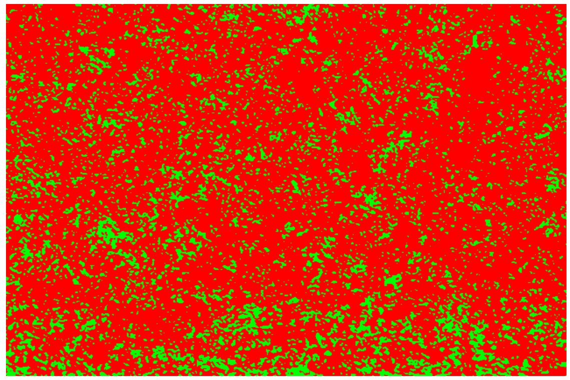


Fig -7.18 → Phase Analysis of Fig-7.17

Phase Name [Image-18]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Red]	180928.548	78.161	Surface – Induction Hardened
Transformed Structure [Green]	50552.933	21.839	

Material Grade – **45C8 [Square]**

Microstructure Description @ 100X Magnification – Tempered Martensite with Bainite & Transformed Ferrite

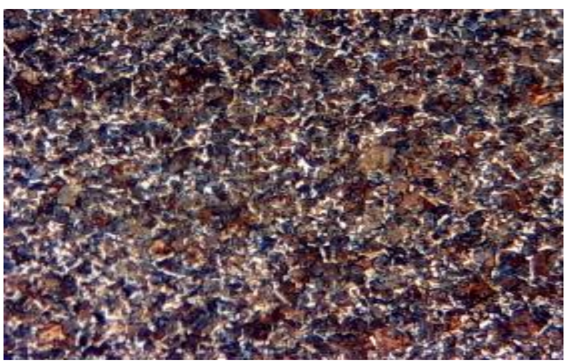


Fig -7.19

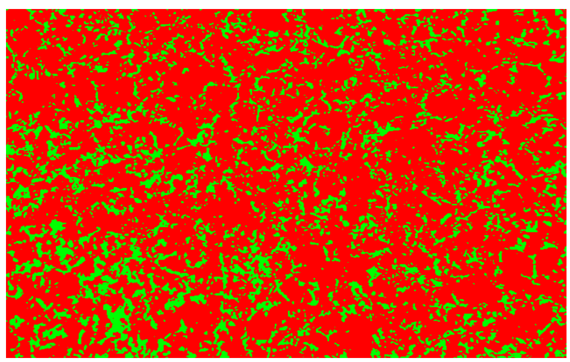


Fig -7.20 → Phase Analysis of Fig-7.19

Phase Name [Image-20]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite with Bainite [Red]	183556.827	79.297	Quenched & Tempered
Transformed Structure [Green]	47924.654	20.703	

Material Grade – **Domex-600 [4 mm Thickness Original]**

Microstructure Description @ 100X Magnification – Quasi Polygonal Ferrite & Pearlite & traces of Bainite

Fig -7.21

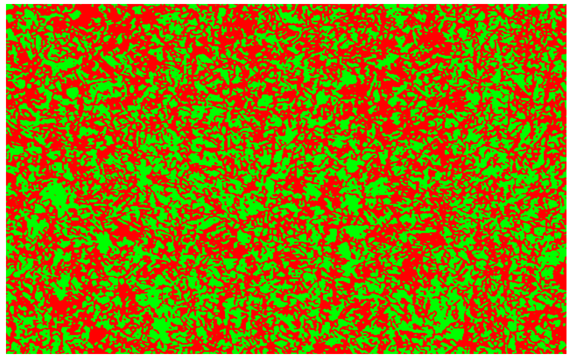


Fig -7.22 → Phase Analysis of Fig-7.21

Phase Name [Image-22]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite & Bainite [Red]	106513.883	46.014	TMCP [Thermo-Mechanical Control]
Quasi Ferrite [Green]	124967.599	53.986	

Material Grade – **F-Steel [Tooth Point]**

Microstructure Description @ 200X Magnification – Tempered Martensite with Bainite & Transformed Structure

Fig -7.23

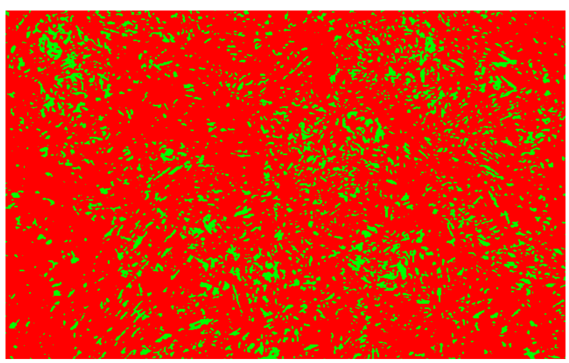


Fig -7.24 → Phase Analysis of Fig-7.23

Phase Name [Image-24]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite with Bainite [Red]	199171.278	86.042	Quenched & Tempered
Transformed Structure [Green]	32310.203	13.958	

Material Grade – **P&H-11 [Induction Hardened – Sprocket Actual Sample]**

Microstructure Description @ 200X Magnification – Tempered Martensite with Transformed Structure

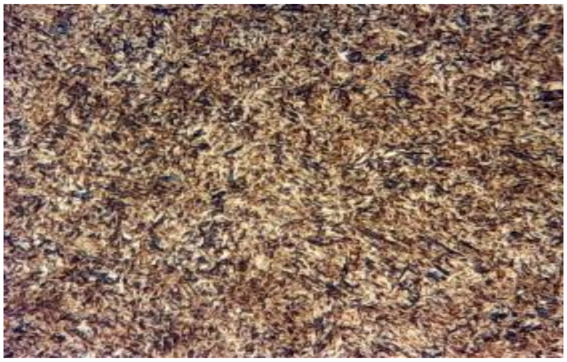


Fig -7.25

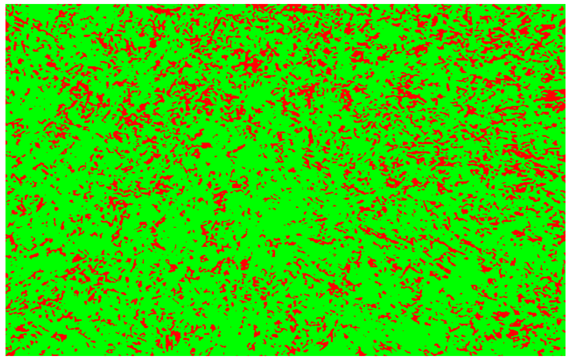


Fig -7.26 → Phase Analysis of Fig-7.25

Phase Name [Image-26]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Green]	1829.691	79.868	Surface – Induction Hardened
Transformed Structure [Red]	461.198	20.132	

Material Grade – **27MCB5 [Track Shoe – Actual Sample]**

Microstructure Description @ 200X Magnification – Tempered Martensite with Transformed Structure

Fig -7.27

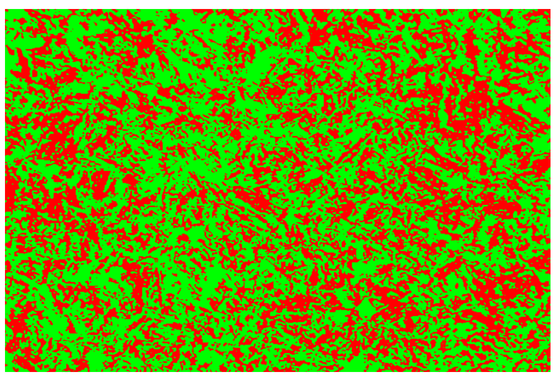


Fig -7.28 → Phase Analysis of Fig-7.27

Phase Name [Image-28]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Green]	1326.605	57.908	Quenched & Tempered
Transformed Structure [Red]	964.284	42.092	

Material Grade – **KM3573 [Track Link - Induction Hardened – Actual Sample]**

Microstructure Description @ 200X Magnification – Tempered Martensite with Transformed Structure

Fig -7.29

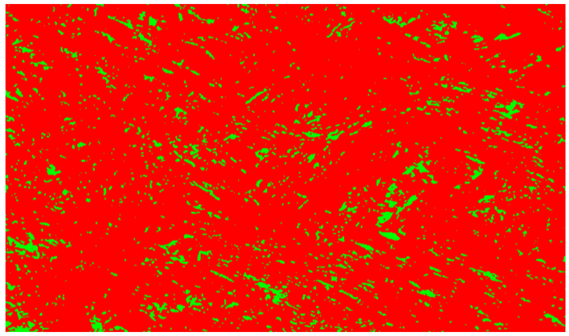


Fig -7.30 → Phase Analysis of Fig-7.29

Phase Name [Image-30]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Red]	52564.424	91.78	Surface – Induction Hardened
Transformed Structure [Green]	4707.807	8.22	

Material Grade – **ESCO-Steel [Tooth Point – Actual Sample Tested]**

Microstructure Description @ 100X Magnification – Tempered Martensite with Bainite & Transformed Structure

Fig -7.31

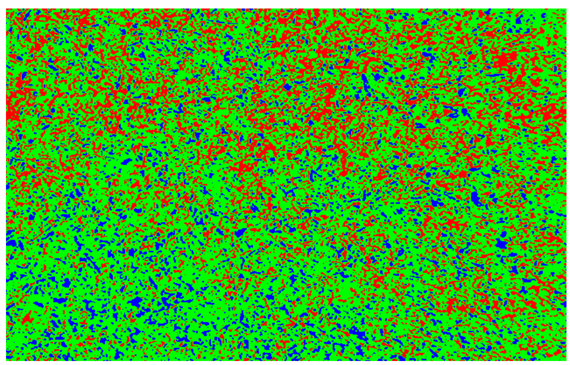


Fig -7.32 → Phase Analysis of Fig-7.31

Phase Name [Image-32]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Green]	37351.301	65.217	Quenched & Tempered
Bainite [Red]	13403.417	23.403	
Transformed Structure [Blue]	6517.513	11.38	

Material Grade – **20MnCr5 [Case Carburised Bush]**

Microstructure Description @ 100X Magnification at Case – Tempered Martensite with Retained Austenite

Fig -7.33

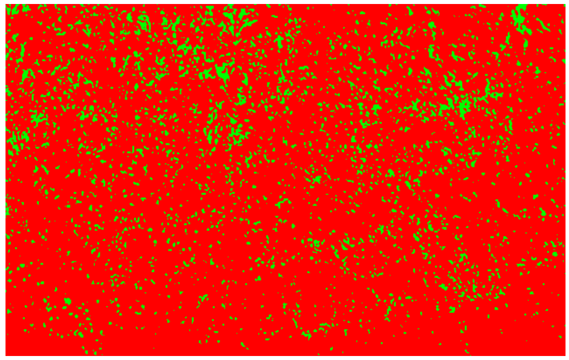


Fig -7.34 → Phase Analysis of Fig-7.33

Phase Name [Image-34]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Red]	41090.402	90.152	Case Carburised
Retained Austenite [Green]	4488.748	9.848	

Material Grade – **20MnCr5 [Core Carburised Bush]**

Microstructure Description @ 100X Magnification at Core – Low Carbon Bainite Structure

Fig -7.35

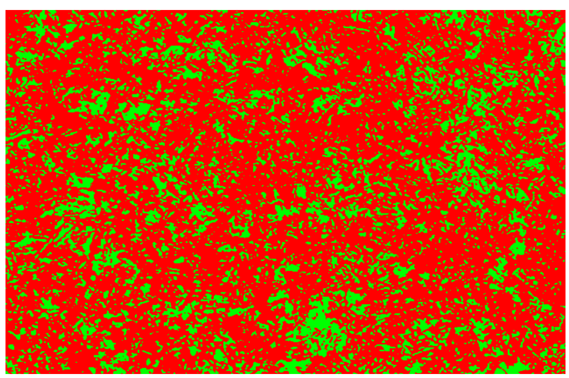


Fig -7.36 → Phase Analysis of Fig-7.35

Phase Name [Image-36]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Low Carbon Bainite [Red]	43433.493	75.837	Case Carburised
Transformed Structure [Green]	13838.738	24.163	

Material Grade – **P&H-11 [Tooth Adapter]**

Microstructure Description @ 100X Magnification – Tempered Martensite with Bainite & Traces of Transformed Ferrite

Fig -7.37

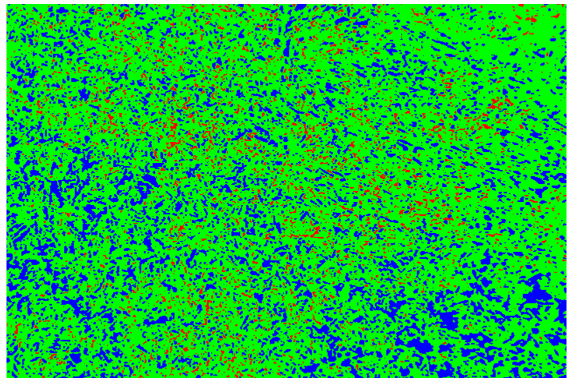


Fig -7.38 → Phase Analysis of Fig-7.37

Phase Name [As per Image-38]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Tempered Martensite [Green]	42132.563	73.565	Quenched & Tempered
Bainite [Blue]	12142.943	21.202	
Traces of Transformed Ferrite [Red]	2996.725	5.232	

Material Grade – **45C8**

Microstructure Description @ 100X Magnification – Pearlite & Ferrite

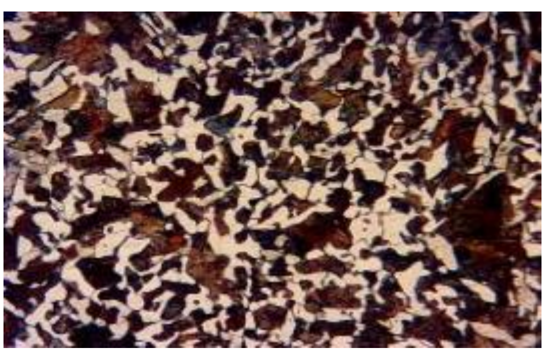


Fig -7.39

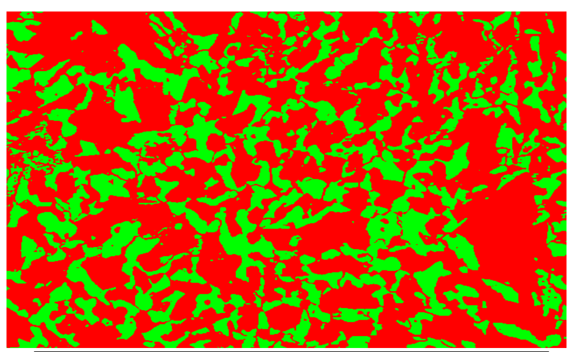


Fig -7.40 → Phase Analysis of Fig-7.39

Phase Name [Image-40]	Area (Micron Sqr.)	Area (%)	Heat Treatment
Pearlite [Red]	152727.292	65.978	Normalised
Ferrite [Green]	78754.19	34.022	

Material Grade – **En-19 [Nitro-Carburised]**

Microstructure Description @ 200X Magnification at Case – White Compound Layer

Fig -7.41

Phase Name [Image-41]	Length (Micron)	Heat Treatment
White Compound Layer	16.183µ	Nitro-Carburised

Material Grade – **En-24 [Nitro-Carburised]**

Microstructure Description @ 200X Magnification at Case – White Compound Layer

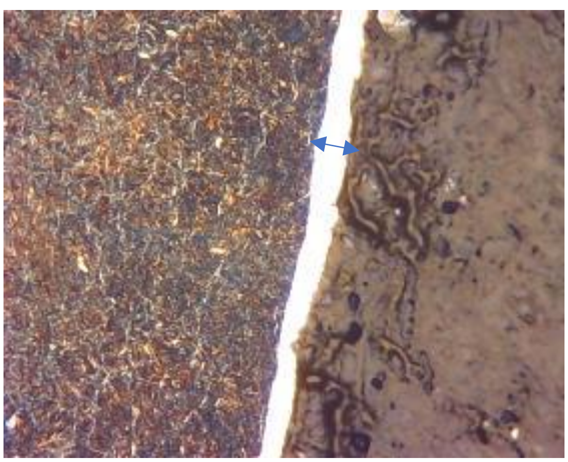


Fig -7.42

Phase Name [Image-42]	Length (Micron)	Heat Treatment
White Compound Layer	18.155µ [Avg.]	Nitro-Carburised

Material Grade – **45C8 [Nitro-Carburised]**

Microstructure Description @ 200X Magnification at Case – White Compound Layer

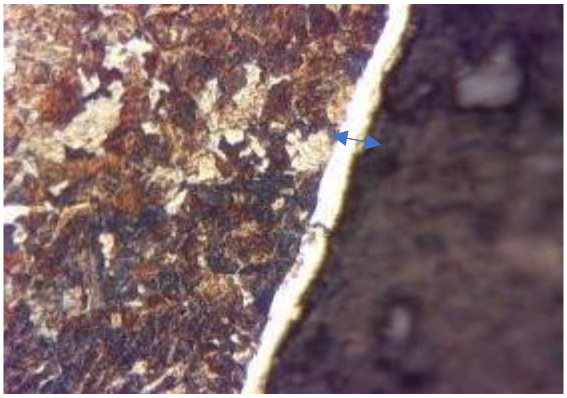


Fig -7.43

Phase Name [Image-43]	**Length (Micron)**	**Heat Treatment**
White Compound Layer	12.574µ [Avg.]	Nitro-Carburised

7.4 Wear Test Result

Low-stress abrasion tests were carried out using a Dry Sand/ rubber wheel abrasion test (RWAT) machine as per ASTM G65 specifications. Weight loss measured after each test interval to compute the wear rate. Averages of three observations within the variation of ±5% were considered for calculating the wear rate.

Material	Average Volume Loss-mm3 observed
SS400/IS 2062 E250BR	172.9
IS 2062 E450BR (20mm Thick Plate)	148.6
Domex plates (4mm)	54.3
35C8 with Induction Hardening	25.4
45C8 with Induction Hardened	16.3
F-steel with Q&T	14.6
Wear plates	1.8
WT 80	135.8
WT 60	134.5
Hardox 400	120.8
EN24 with Q&T	57.2
EN19 with Q&T	61.1
P & H 11 (Sprocket) with Induction Hardening	22.8
Berco Track Shoe [27MCB5]	27.5
Berco Track Link [KM-3573]	28.3

Esco Tooth Point [ESCO Steel- Import]	35.0
20MnCr5- High Case Carburised	35.9
P & H 11 (Adapter) with Q&T	42.3
45C8-Normalised	165.9
EN 19 -Nitrided	44.5
45C8-Nitided	76.2
EN 24 -Nitrided	36

Table-7.4

Chapter 8:

Results and Discussions

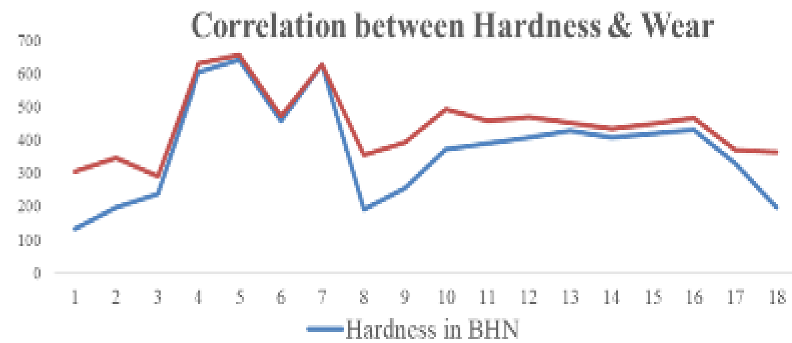
8. Results and Discussion

We have analyzed the wear loss data, for correlation with material composition, Hardness , UTS with Wear behaviour analysis also did mathematical modelling with best fit curve equation, for materials where wear loss data is not readily available.

8.1 Wear Behavior analysis : correlation with hardness

Material Grade	Hardness in BHN	Average Volume Loss mm3
IS 2062 E250BR	132	172.89
IS 2062 E450BR/HT-60	198	148.55
Domex 600 (4mm)	237	54.25
35C8 (Surface Hardened)	605	25.38
45C8 (Surface Hardened)	642	16.34
F-steel (hardened and tempered)	456.5	14.58
Wear Cladding Plate	627	1.84
WT 60/IS 2062 E450BR	190	165.75
WT 80/S690QL	256	135.75
Hardox 400	373	120.81
EN19	390	67.40
EN24	409	61.07
P & H 11 (Sprocket)	428.75	22.78
Berco Track Shoe [27MCB5]	407.3	27.46
Berco Track Link [KM 3573]	419.5	28.30
Esco Tooth Point [ESCO Steel-Import]	432.5	35.01
P & H 11 (Adapter)	328	42.25
45C8 [Normalised]	198	165.87
EN 19 Nitriding	670	44.5
45C8 Nitiding	680	76.1
EN 24 -Nitriding	690	36

Mathematical modeling for generation of correlation factor 0.84 <-- Strong correlation between Hardness & Wear



Very suitable

Note - Hardness >444 BHN taken with VPN Scale

Fig -8.1

Strong correlation has been found between Hardness and Wear resistance for the selected materials.

By assessing the correlation between volume loss and hardness, we have derived best fit curve for the materials matrix. This will enable to assess the wear resistance of a material, for a known hardness and assist in material selection.

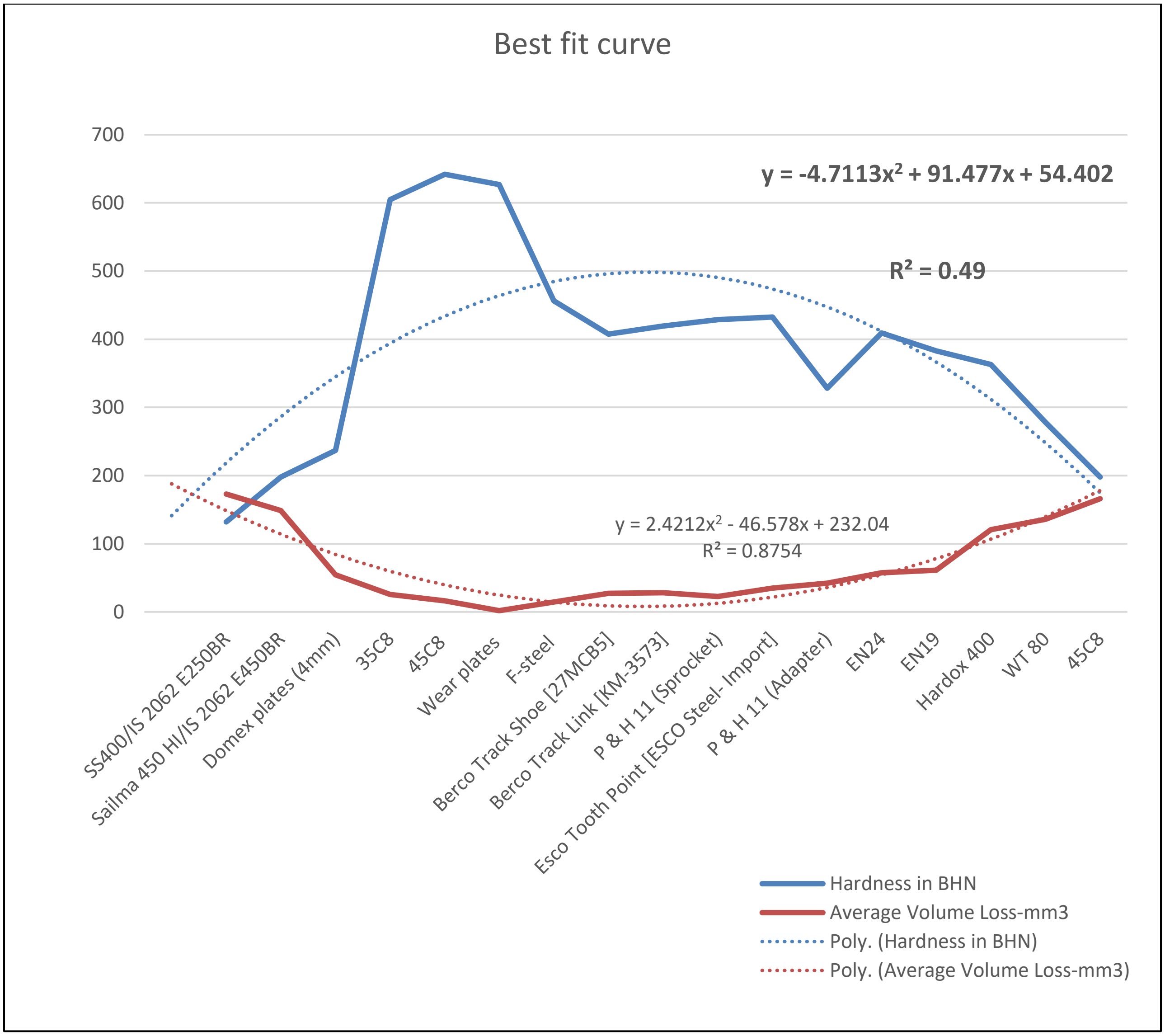


Fig -8.2

8.2 Correlation of Data: Trend graph for hardness vs volume loss

Material hardness and volume loss was considered most important factor for generation of wear matrix in our case. For same the trend graphs were made shown below.

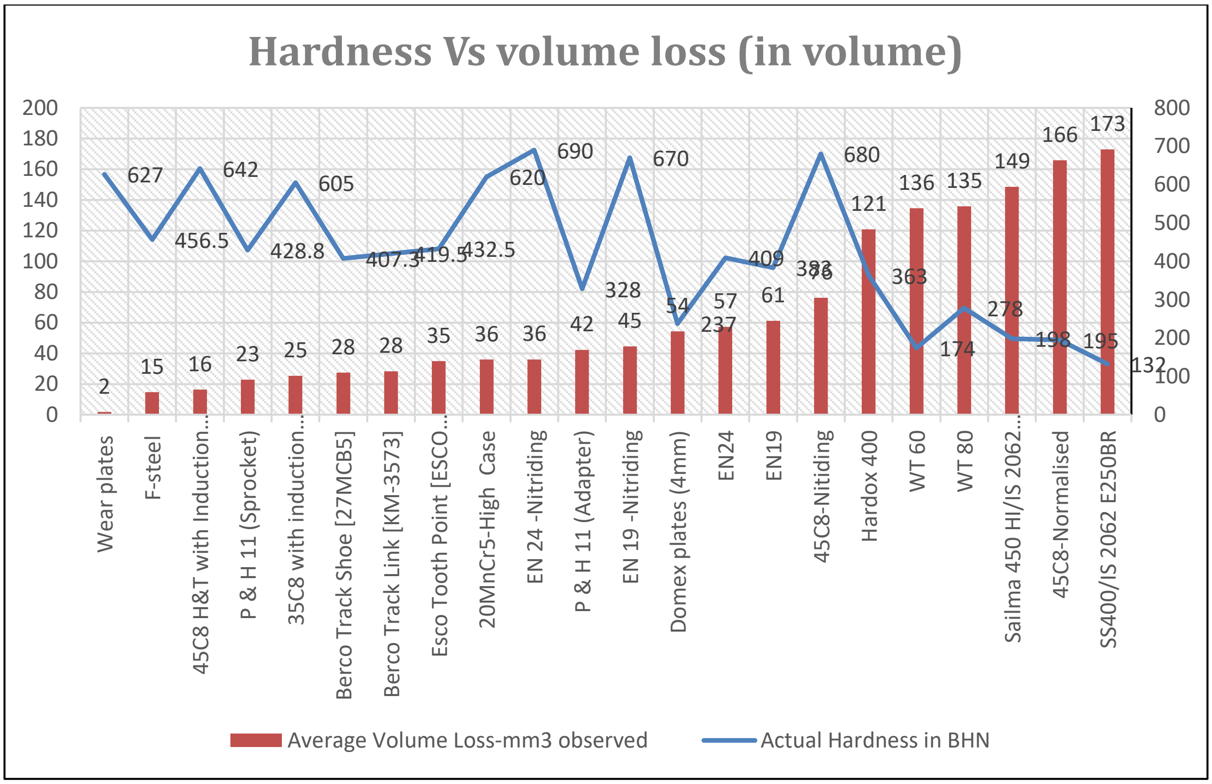


Fig -8.3

Note - Hardness >444 BHN taken with VPN Scale

Comparison analysis for abrasion resistance

Further to trend graph we have also generated comparative matrix for the observed values of wear loss and material hardness. Same has been shown in below figure.

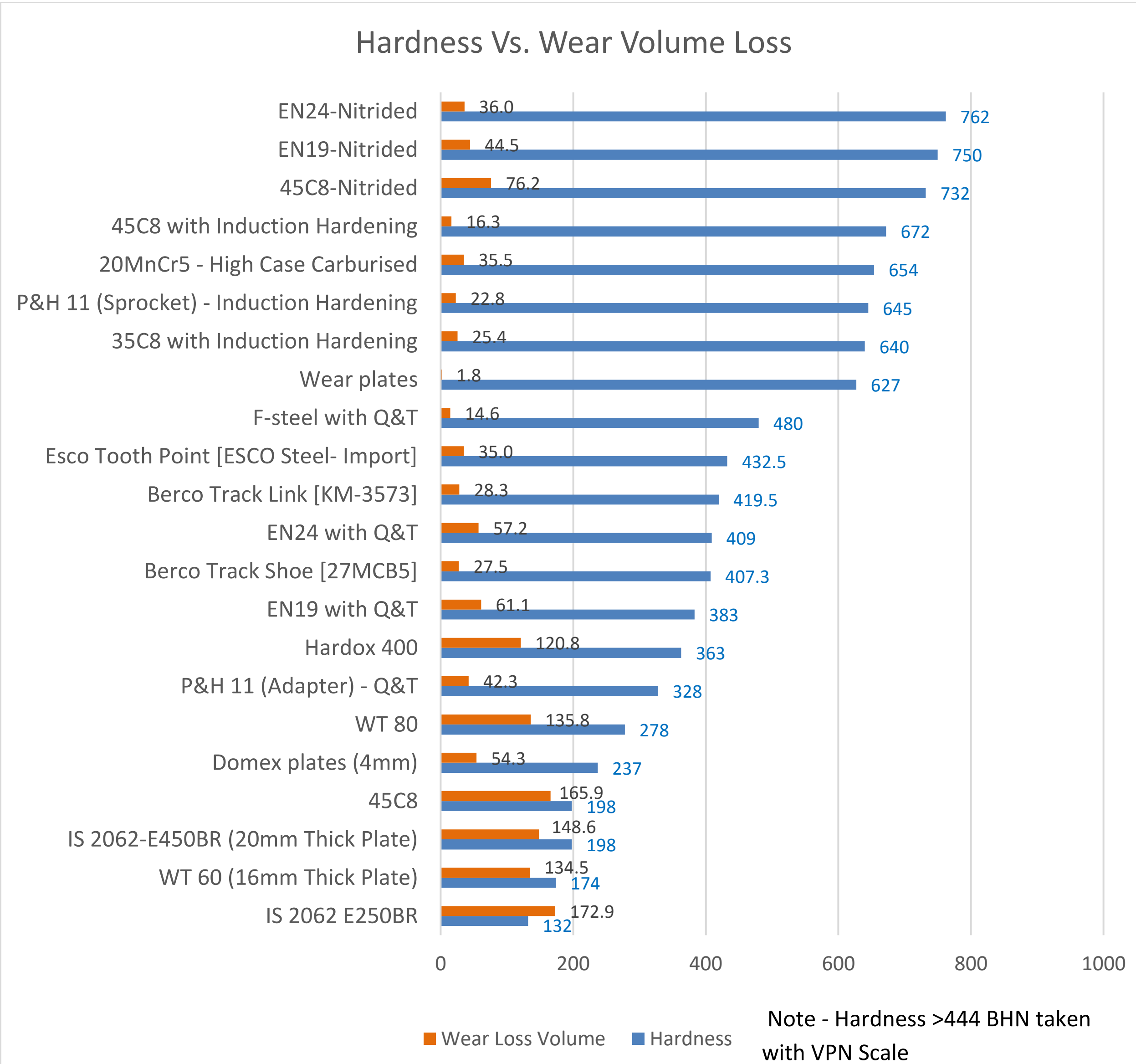


Fig -8.4

Explanation of the observation:

From the above data sheet and microstructure , we can correlate the wear test result with metallurgical parameters as below:

- ✓ Material grade like SS440 / IS 2062 E250BR , having Ferrite – Pearlite Structure (82% Ferrite, 18% Pearlite), is having high volume wear losses due to absence of Micro-alloying elements & low Carbon content

- ✓ WT 60/IS 2062 E450BR and Domex-600 (Abrasive plate) grade (Hot rolled TMCP processed high strength plates), having better wear properties due to presence of Micro-alloy elements (as compared to IS-2062 E250BR).

- ✓ Higher Hardness in Domex 600 is due to presence of higher quantity Micro-alloy elements viz. higher % of Mn, Ti, Nb & V. The micro-elements helps to form Quasi Polygonal Ferrite & Pearlite with traces of lower Bainite.

- ✓ WT 80/S690QL is having Q&T process with presence of other alloy elements (Cr, Mo & B). The Microstructure consists of Low Carbon Tempered martensite with Transformed Structure. Hence it is found to give has comparatively less weight loss and comparatively high wear resistance & better Mechanical Strength compared to IS 2062 E450BR/HT-60 TMCP Plate

- ✓ Hardox-400 (Abrasive plate) grade, having higher content of alloying elements like Cr, Mo & B in comparison to IS-2062 E250BR/E450BR Hot rolled Structural plates and undergoing Q&T operation, results in Low Carbon Tempered Martensite structure and. showing better wear properties

- ✓ For Medium Carbon Alloy Steels, if we compare EN-19 (Cr-Mo alloy Steel) with EN-24 (Ni-Cr-Mo) material grade, En-24 has better wear resistance properties due to presence of Ni & high content of Mo with Cr. The Uniform Fine Tempered Martensite & higher Hardness increased the wear life as well.

- ✓ 35C8 (Surface Hardened) material undergoing Induction hardening process, achieves Core Hardness of 210 BHN and Surface hardness of 640 VPN - Better surface hardness through fine tempered martensite . This results in lower wear loss as compared to E250BR and WT 60/E450BR, which in turn gives better abrasion resistance.

- ✓ Comparing Medium Carbon 35C8 & 45C8 steels, 45C8 is better than 35C8 grade material due to higher %C content & higher surface hardness (Matensitic Hardness is directly proportional to the carbon content). The Wear resistance is comparatively high in comparison to Domex-600 due to Induction hardened Depth up-to more than 2mm.

- ✓ F-Steel shows better wear life than Domex 600, 35C8, 45C8 due to higher alloying elements [Cr, Si, Mo], achieving better hardenability & Uniform Tempered martensite at Case & Core.

- ✓ EN-19 due to presence of higher %Carbon (comparison to other rolled & TMCP plates) and alloying elements like Cr & Mo has better Mechanical properties and Wear resistance properties. EN-24, due to existence of Cr, Ni & Mo shows better wear resistance than EN 19.

- ✓ Grades like 45C8 with Nitrocarburisng <u>(Compound Layer up-to 12.57μ)</u> having higher wear loss as compared to En-19/En-24 grade Nitrided, due to absence of hard nitride forming alloying elements like Cr, Mo.

- ✓ However, due to higher case depth achieved in Carburising (1.2~2.0 mm) and Induction hardening (2~4 mm), as compared to the minor Compound white layer formed in Nitro-Carburising, 45C8 with Induction Hardening or 20MnCr5 with Carburising exhibits much less wear loss as compared to the Nitrocarburised Steels- EN 19/EN-24 (even though the surface hardness achieved in Nitriding/ Nitrocarburising is much higher).

- ✓ For P&H 11 material, presence of Mn & Mo increases the Mechanical & Hardenability properties of material which is increases the Wear resistance properties after Post Q&T Process, as compared WT80 . This is being used in Bucket tooth Adopter for digging purpose. With Induction Hardening, it achieves high hardness and shows better wear resistance as compared to EN 24 (Q&T).

- ✓ Finally, in "**Cladding Steel**" , microstructure in the clad layer in Cladding Steel consists of **tempered martensite, retained austenite, and fine carbides**. Because of the high %C, Cr, Mo, B & other alloying elements, increased Surface hardness is achieved with the cladding depth is up-to to 8.5mm on surface. This helps to achieve less volume loss in comparison to other grades and experimental result shows that amongst the materials tested, Cladding Surface is having maximum wear resistance and resistance to surface indentation by localized loads.

Further to our analysis we have also generated and tried to understand the nature of variation of wear loss with the % carbon content of the material. Same has been shown in below figure.

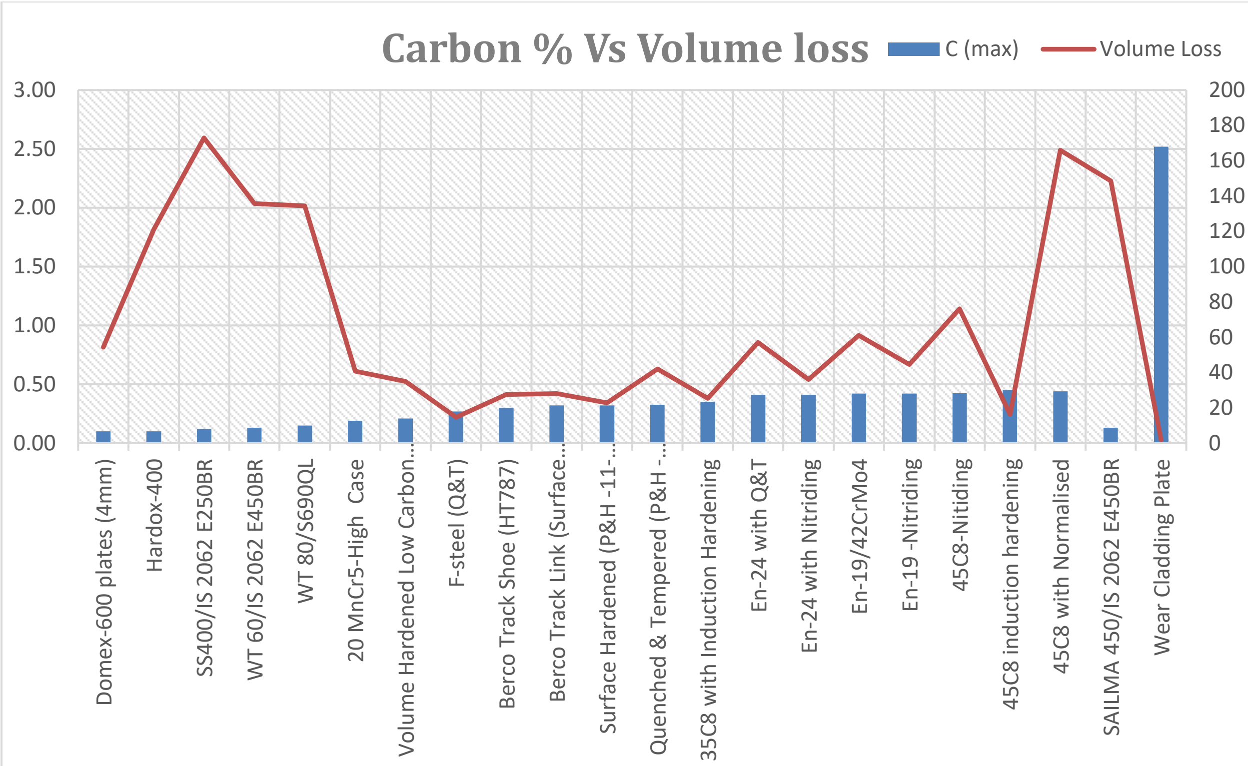


Fig -8.5

Explanation – From the above fig. 8.5, it shows that

- ✓ The Wear Cladding plate having high Hardness due to high Surface Carbon, high alloying elements which resulted better surface abrasion comparison to other grades
- ✓ 45C8 grade with Induction Hardened Surface resulted better wear life comparison to others. Although the grade content with Medium Carbon Steel, the Hardened Depth & the consequential resultant of Tempered Microstructure on Case helps to provide high wear & tear life as well.
- ✓ In F-Steel, the material grade content with Medium carbon & high alloy steel which consequentially helps to provide better life due to high % of Tempered Martensite with traces of lower Bainitic Structure

- ✓ Material Grade like Berco Track Shoe, Track Link, having lower volume loss due to presence of Boron comparison to other grades like En-19 & En-24 Q&T
- ✓ Medium Carbon Steel with Nitriding processed grade like En-19, En-24 & 45C8 having high volume loss comparative to Surface hardened medium carbon steel grade material like 45C8, P&H-11 [Sprocket], 35C8 with Induction Hardened, due to high acquired Case Depth, compared to shallow compound layer (~12-13 μ)

In addition, we have also generated and tried to understand the nature of variation of hardness with the % carbon content of the material. Same has been shown in below figure.

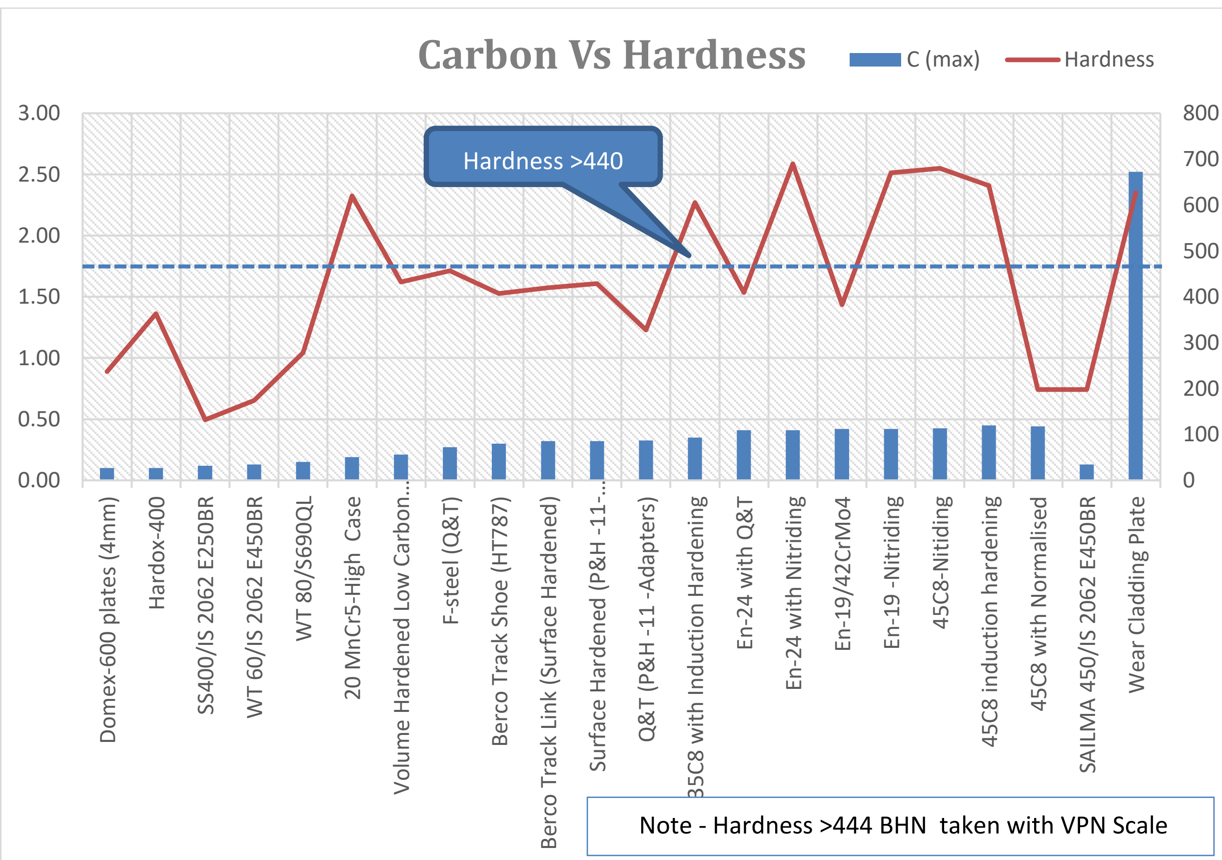


Fig -8.6

Explanation – From the above fig. 8.6 shows that

- ✓ 20Mncr5 Grade – Although the material grade having low Carbon% [0.18-0.23%], processed through Case Carburising which increases the % Surface Carbon [varies from 0.65-1.00%] by diffusion & consequentially increases the Surface Hardness to 58-63 HRC

- ✓ Similarly, material grade like P&H-11, En-19 & En-24 undergone with Q&T heat treatment process which exhibits lower surface Hardness in-comparison to Surface hardened [Nitriding, Induction Hardening & Case Carburising Steel

- ✓ 35C8 and 45C8 grade (Medium Carbon) with Induction hardening showing high surface hardness compared to Q&T P&H 11

- ✓ Other grades like Berco Track Shoe, Berco Link, F-Steel, ESCO Steel having high hardness due to higher alloying element like B, Cr, Mo along with high Speed water spray Quenching resulting in better wear & tear life as well

- ✓ Low Carbon grades like IS 2062 E250BR, IS 2062 E450BR/WT-60/WT-80 having low hardness due to content low alloy & the condition of supply [As rolled, TMCP]

8.3 Wear Behavior analysis: check correlation UTS

For correlation of mechanical properties with wear loss we have tried to understand the trend of wear loss with Ultimate tensile strength of individual materials. We could not find any direct correlation of the UTS with wear loss, as shown in below figure.

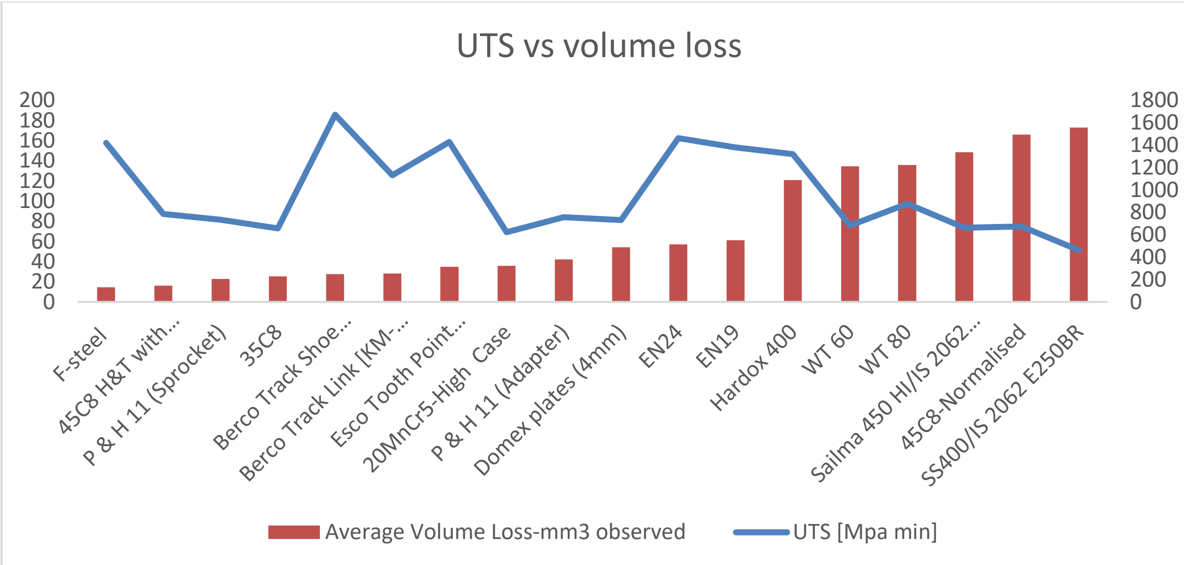
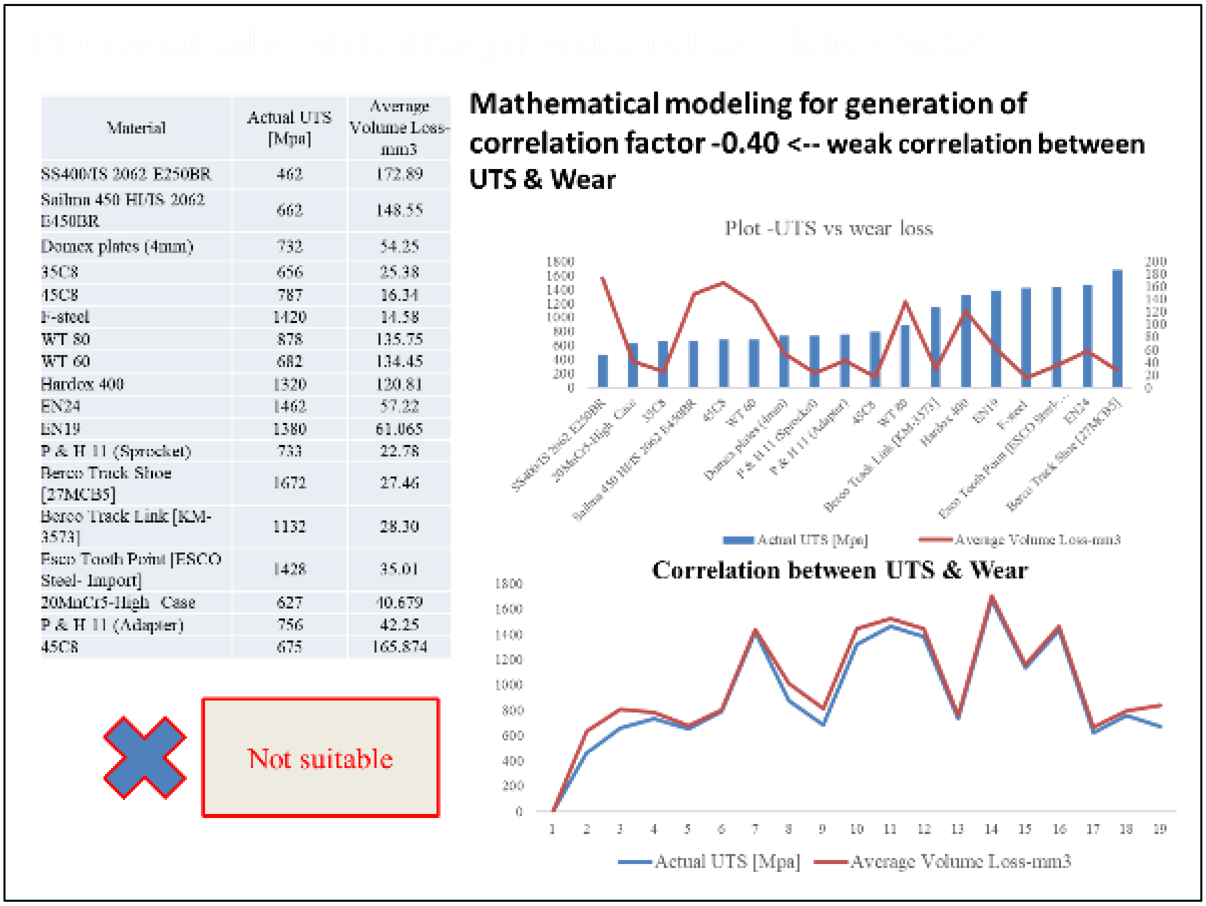


Fig -8.7

To understand the correlation of UTS with wear loss we have loss plotted the co-relation tend and observed to have negative co-relationship and it cannot be considered as true representation. Details as shown in below figure. In UTS, the bulk hardness of the material comes into picture, for the yield point and the necking. But, wear properties, being more of a surface property is related more directly with hardness than UTS.



Material	Actual UTS [Mpa]	Average Volume Loss-mm3
SS400/IS 2062 E250BR	462	172.89
Sailma 450 HI/IS 2062 E450BR	662	148.55
Domex plates (4mm)	732	54.25
35C8	656	25.38
45C8	787	16.34
F-steel	1420	14.58
WT 80	878	135.75
WT 60	682	134.45
Hardox 400	1320	120.81
EN24	1462	57.22
EN19	1380	61.065
P & H 11 (Sprocket)	733	22.78
Berco Track Shoe [27MCB5]	1672	27.46
Berco Track Link [KM-3573]	1132	28.30
Esco Tooth Point [ESCO Steel- Import]	1428	35.01
20MnCr5-High Case	627	40.679
P & H 11 (Adapter)	756	42.25
45C8	675	165.874

Fig – 8.8

8.4 Generation of Abrasion Wear Index

The relative abrasive wear resistance index of the selected materials with various heat-treatments / Surface treatments is obtained through their average volume loss and calculated based on the average mass loss obtained in metal abrasive wear tests conducted in accordance to ASTM G65.

We have generated the Table 8.1, for calculating the relative wear factor, from the average volume loss (converted from average mass loss of the specimens).

Material	Average mass loss (gms)	Average Volume Loss(mm3)	Comparative wear factor
Wear plates	0.13	2	96.11
F-steel	0.11	15	11.85
45C8 H&T with Induction Hardened	0.13	16	10.61
P & H 11 (Sprocket)	0.18	23	7.59
35C8 with induction hardening	0.20	25	6.81
Berco Track Shoe [27MCB5]	0.22	28	6.29
Berco Track Link [KM-3573]	0.22	28	6.11
EN 19 Nitriding	0.35	44.5	3.89
45C8 Nitriding	0.59	76	2.27
Esco Tooth Point	0.27	35	4.94
20MnCr5-High Case	0.32	35.5	4.87
P & H 11 (Adapter)	0.33	42	4.09
Domex plates (4mm)	0.43	54	3.19

EN24	0.45	57	3.02
EN19	0.48	61	2.83
Hardox 400	0.93	121	1.43
EN 24 Nitriding	0.28	36	4.81
WT 60	1.06	135	1.29
WT 80	1.05	136	1.27
Sailma 450 HI/IS 2062 E450BR	1.17	149	1.16
45C8-Normalised	1.30	166	1.04
SS400/IS 2062 E250BR	1.36	173	1.00

Table -8.1

On this basis, we can prepare an **abrasion resistance index** for the critical material under study, with their various treatments.

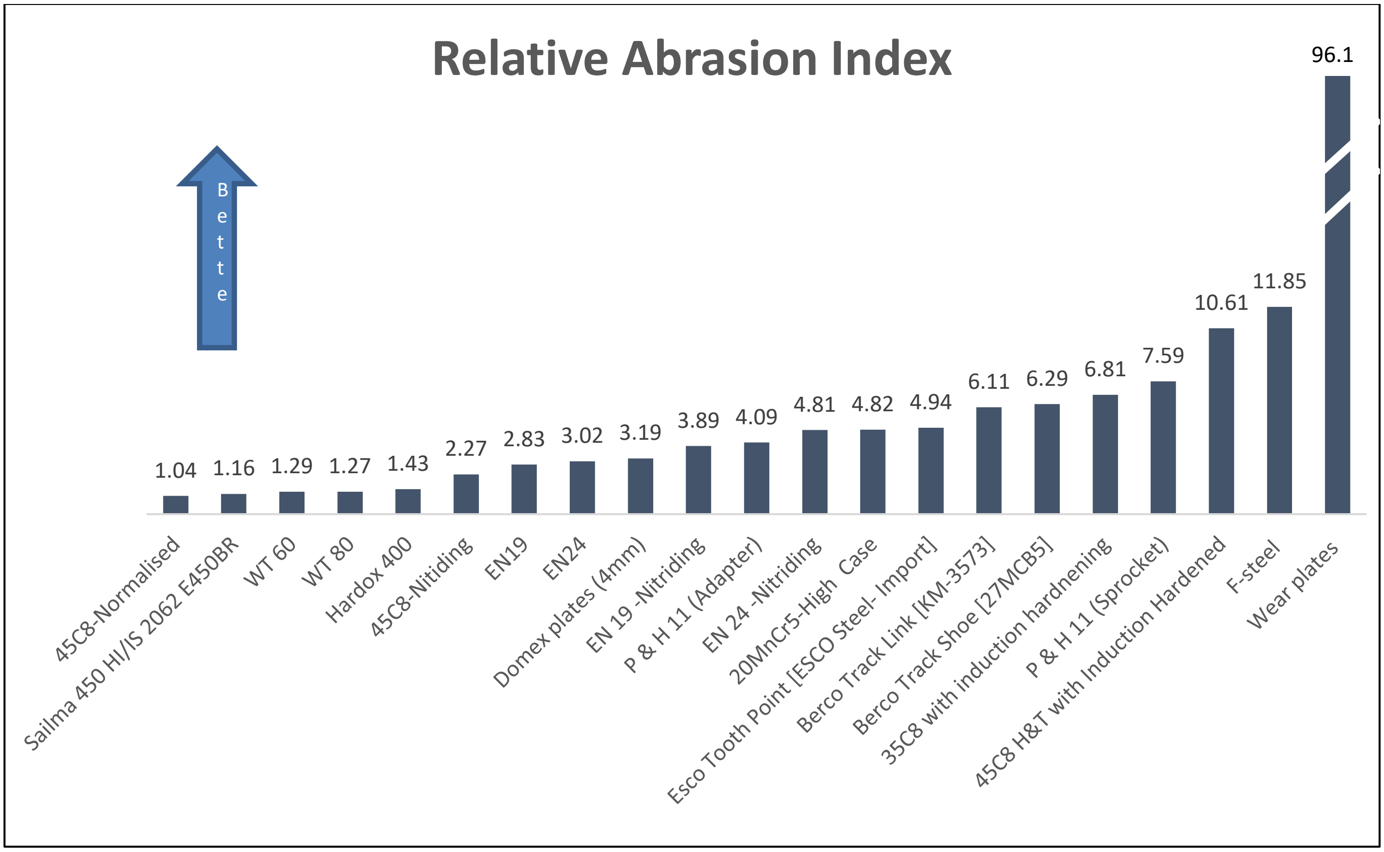


Fig -8.9

This **Relative Abrasive Index** provides a basic guideline and can be used as a **ready reckoner** for Designers and Material Scientists in selection of material and facilitate them to optimize material selection and treatment for specific abrasion resistance need. Cost reduction activities for material cost, with cheaper material substitution can be taken up, without resorting to costly field trials.

Chapter 9:

Overall conclusion and future scope

9.1 Overall Conclusion

1. The objective of this study is to establish a correlation between various materials with different combinations of case hardening / surface treatment and their wear characteristics.

2. By experimentation, a comparative index of resistance to wear of commonly used structural materials is prepared.

3. This is a Ready reference guide for designers for material selection with relative ranking of material.

4. Wear behavior of various materials studied with material characterization and effect of alloying elements. Although hardness is the most important factor in the resistance to abrasion, other properties such as alloying elements, Heat-treatment and microstructure also play an important role.

5. Mathematical modeling for generation of correlation factor - best fit curve for wear resistance established with hardness for selecting suitable material in absence of wear loss value.

9.2 Future Scope of work

1. We can further extend this study with HSS and other Tool Steels for tool life estimation.

2. Study can be carried out for some more advanced material like Dual Phase steel, Hadfield Steel and various other coated materials like weld hardfacing coatings, Ceramic or cermet thermal spray materials deposited by plasma spraying, hard coatings by vapour deposition, for example TiN.

3. We can further study the effect of impact toughness along with abrasion on different material grades, with various surface treatments.

4. Application based study can be done (Quarry application, Earthwork or Stone application) for getting wear pattern and further optimise material selection based on application.

(ARUP MUKHERJEE)

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10. Abbreviations

ASM, ASM, International, formerly known as the American society for metals

ASTM – American Society for testing of Material

BHN – Brinell Hardness Number

CE – Carbon Equivalent

**GETs - ** Ground engaging tools

GMA – Gas Metal Arc Welding

HSS – High Speed Steel

HSLA – High Strength Low Alloy Steel

HV – Vickers Hardness

HT – Heat-treated

HRC – Hardness in Rockwell C

IS – Indian Standard

I/H – Induction Hardening

JSPL – Jindal steel and power Limited

MCPL – Multitech Components Pvt. Ltd

PM – Power Metallurgy

Q&T - Quenching and tempering

RA – Retained austenite

RKFL – Rama Krishna Forgings Limited

RWAT – Rubber Wheel Abrasion Testing

SOP – Standard Operating Procedure

TMCP - THERMO-MECHANICALLY CONTROLLED PROCESSED:

THCM- Tata Hitachi Construction Machinery

UTS – Ultimate Tensile Strength

UTM – Universal testing machines