International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 2 Feb 2022, pp: 1004-1010 www.ijaem.net ISSN: 2395-5252

Comparison of Abrasion Resistance of Selected Structural Steels: A Study

Arup Mukherjee[1], Chanchal Biswas[2],Srinath Ghosh[1], Arghya Majumder[1],Kumar Sawrav[3], Sathi Banerjee[1†]

[1]Department ofMetallurgical and Material Engineering, Jadavpur University, Kolkata-700032, India
[2]School of Mining and Metallurgical Engineering, KaziNazrul University, Asansol-713340, India
[3]TATA Hitachi Construction Machinery Co. Pvt. Ltd, Kharagpur, West Bengal 721301, India

Submitted: 05-02-2022 Revised: 18-02-2022 Accepted: 20-02-2022

ABSTRACT: Selections of Abrasion resistant materials are most challenging subject for designers. Understanding the effect of abrasive wear and hence predicting the wear life is essential for judicious selection of material. The study is to support this need by experimentation and creating a relative abrasion index of some commonly used structural material. This will support Designers for easy selection of material based on abrasive behavior of materials. Abrasion resistant is decided based on Dry Sand Abrasion test result, compared with Surface hardness. In this paper, we have tried to find effect of alloying element in abrasion behavior of readily available materials.

KEYWORDS: Dry Sand Abrasion Test, Abrasion, Wear

I. INTRODUCTION:

One of the most common failures for mechanical parts is by Wear. As per ASM definition, “Wear may be defined as damage to a solid surface caused by the removal or displacement of material by the mechanical action of a contacting solid, liquid or gas” [1]. For deterioration of machinery with moving parts, like the excavators, wear limits both the life and the performance of theequipment and selection of material resistant to wear-induced failures is one of the chief economic consideration. It is such a universal phenomenon that rarely no two solid bodies slide over each other or even touch each other without measurable material transfer or material loss. Wear determines the operation and life of machine elements and it manifests itself in several forms i.e. in the wear of equipment which engages an abrasive medium, in the wear of seals or machine parts between which abrasive particles can penetrate and wear by abrasives entrained in fluids [2]. Abrasion is one of the main causes that limit. The first case in which abrasive particles simply rub against a surface is referred to as two-body abrasive wear. In the second case, in which the abrasive can become trapped between two sliding surfaces are referred to as three-body abrasive wear. All mechanical components that undergo sliding or rolling contact are subject to some degree of wear and abrasion [3]. Wear is probably the most important factor in the deterioration of machinery with moving components, often limiting both the life and performance of such equipment. In Earthmoving machines like Excavators, Wear resistance plays a very important role in determining the service life of major parts, specially the GETs (Ground Engaging Tools) like, Buckets, Bucket Teeth, Rollers, Sprockets and Idlers. A good selection of material helps to improve the performance and production efficiency in a big way [4].

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 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. Also it 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, surface hardness has to balance with material toughness or abrasion resistance [5-8]. The wear mechanisms are very complex, because of interlinked factors, whose intensity of interaction depends on the conditions – type of environment, in which the mechanical parts are used but also on the type and parameters of work: Physical, chemical properties of materials, such as composition, microstructure, hardness, work

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 2 Feb 2022, pp: 1004-1010 www.ijaem.net ISSN: 2395-5252

hardening characteristics, corrosion resistance, wear strength [9-10].

II. EXPERIMENTATION

(a) Material selection:

In this study, six materials were selected in groups which are widely used as a raw material for wear parts or assembly and fabrication of parts in mining machinery. These selected materials are given in Table 1.

Table 1: Material Composition % [Specification]

Grade	C (max)	Mn (max)	S (max)	P (max)	Si (max)	Nb + V + Ti	Ni (max)	Cr (max)	Mo (max)	B
SS400/IS 2062 E250BR	0.220	1.500	0.045	0.045	0.400	0.250	0.400	0.300	0.200	-
WT 60/IS 2062 E450BR	0.220	1.650	0.045	0.045	0.450	0.250	0.400	0.300	0.200	-
WT 80/S690 QL	0.200	1.700	0.010	0.020	0.800	Nb- 0.060, Ti- 0.050 & V- 0.12	1.500	0.800	0.700	-
Hardod-400	0.200	1.500	0.010	0.030	0.700	Nb- 0.05, V- 0.06	0.500	0.900	0.500	0.005
EN19/42 CrMo4	0.35-0.45	0.50-0.80	0.035	0.350	0.10-0.35	-	-	0.90-1.20	0.20-0.35	-
EN24	0.36-0.44	0.45-0.70	0.035	0.350	0.10-0.35	-	1.30-1.70	1.00-1.40	0.20-0.35	-

Material specification as checked is mentioned in Table 2. While selection of materials, alloying materials and process route for material manufacturing were considered. Selected materials include plate and bar which are processed through normalizing, TMCP, Q&T etc., which can support the materials with varying mechanical and wear properties. Alloying materials viz. specially nickel, chromium, molybdenum, vanadium and boron were considered. Nickel strengthens the ferrite and increases harden ability. It refines the grain sand increases the hardness, elastic limit and tensile strength with practically no loss in ductility. This improves the toughness and correspondingly the shock and impact resistance of the steel. Chromium will increase the steel's strength, hardness, and ability to be heat treated. Molybdenum is used efficiently and economically in alloy steel & iron to improve harden ability, reduce temper embrittlement, resist hydrogen attack and sulfide stress cracking, increase elevated temperature strength. Vanadium, even in small amount, refines grains, increases wear-resistance (through the precipitation of vanadium carbonitrides) and is a commonly used alloying element in high strength low alloy (HSLA) steels. In low carbon alloy steels, Niobium lowers the transition temperature and aids in a fine grain structure. Niobium forms very stable carbides and is used in HSLA steels. After conducting chemical analysis of stated group materials, mechanical testing of materials were done as specified in Table 2.Observed chemical test results values were well within specified limit.

Table 2: MaterialComposition % [Observed]

Grade	C (max)	Mn (max)	S (max)	P (max)	Si (max)	Nb + V + Ti	Ni (max)	Cr (max)	Mo (max)	B
SS400/IS 2062 E250BR	0.12	0.84	0.004	0.018	0.14	-	-	-	-	-

WT 60/IS 2062 E450BR	0.13	1.48	0.009	0.023	0.32	Nb- 0.050, V- 0.070 & Ti- 0.017	0.018	0.006	-	-
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	0.420	0.79	0.015	0.22	0.22	-	-	1.00	0.21	-
EN24	0.410	0.680	0.014	0.009	0.19	-	1.56	1.20	0.25	-

(b) Mechanical Properties of Material:

After conducting chemical analysis of stated group materials, mechanical testing of materials were done as specified in Table 3.Observed mechanical test results values were well within or better than specified.

Table 3 : Mechanical Properties

Grade	Specification				Actual			
	UTS (min) (Mpa)	YS (min) (Mpa)	%Elongation (min)	Impact (min)	UTS (Mpa)	YS (Mpa)	%E	Impact J (Avg.)
SS400/IS 2062 E250BR	410	250	23	27	453	324	29	110
WT 60/IS 2062 E450BR	570	450	20	20	682	563	26	92
WT 80/S690QL	770	690	14	47	878	738	18	128
Hardod-400	1300	1100	12	20	1320	118	15	66
EN19/42CrMo4	1100	-	10	10	1380	-	14	56
EN24	1240	1160	-	-	1462	1310	12	52

(c) Understanding Wear Phenomena:

Most prominent mode of wear observed in industrial mining equipment's are Sliding friction, Rolling friction, Impact erosion, Heavy plastic deformation, Low stress multiple gouging, Micro-ploughing and micro-cutting etc. Most suitable test to determine nature of materials against above stated wear phenomenon is Dry Sand Abrasion Test. The dry sand- rubber wheel abrasion test was carried out using a ToshinKogaya, Fig 1 (Tokyo, Japan) equipment in accordance with ASTM G 65 standard and test parameter as stated in Table 4 [11]. Samples of size 65 x 20 x 10 (thickness) mm were used for this purpose. Prior to the test, the surfaces of the overlays were ground using a surface grinder to make them flat. Alumina Oxide of grit size 30 was used as abrasive. The sand was cleaned & dried in an oven for 6 hr at 400C immediately before each trial. The sand flow rate was set at 300 g/min. The rubber wheel used for this test had a hardness of 58-62 (Shore A).

The other test parameters were as follows: load 130 N, no of rotations of the wheel 6000, time 30 mins. These parameters correspond to a sliding velocity and distance of 2.4 m/sec and 4000m, respectively. Wear was measured from the loss of mass using a precision electronic balance. Each test is repeated 3 times and the average wear is reported. The worn surfaces were examined under an SEM (Zeiss, EVO 15, Jena, Germany).

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 2 Feb 2022, pp: 1004-1010 www.ijaem.net ISSN: 2395-5252

Table 4: Test Parameters for Dry Sand Rubber Wheel Test

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 1- Dry sand- rubber wheel abrasion test machine, ToshinKogaya

III. RESULTS AND DISCUSSIONS

3.1: Compare the Dry Sand Abrasion Test with Hardness:

Results of dry sand abrasion test and hardness observation is specified in Table 5.

Table 5: Dry sand abrasion test and hardness observation

Material Grade	Description	Supplied Condition	Hardness observed in BHN	Average Volume observed Loss-mm3
SS400/IS 2062 E250BR	Plate	Normalised/Rolled	152	243.00
WT 60/IS 2062 E450BR	Plate	TMCP	190	165.75
WT 80/S690QL	Plate	Q&T	256	135.75
Hardox 400	Plate	Q&T	373	120.81
EN19	Bar	Q&T	390	67.402
EN24	Bar	Q&T	409	57.22

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 2 Feb 2022, pp: 1004-1010 www.ijaem.net ISSN: 2395-5252

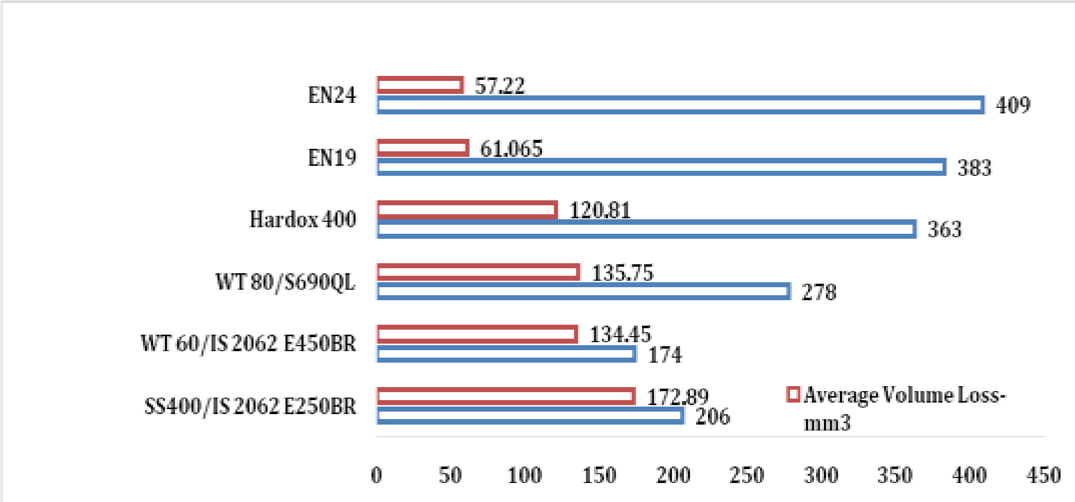


Fig. 2: Wear behavior (Volume loss in mm^3 Vs Surface hardness in BHN)

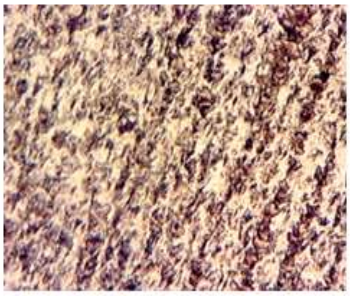
Comparison analysis for observed harness value and material loss observed in dry sand abrasion test is mentioned in Fig. 2.

From the Fig. 2 below depicts nature of Volume loss in mm3 as compared to surface hardness of selected materials in BHN.

3.2: Microstructure Analysis of Selected Material Group:

The following microscope was used to analyze the microstructure of the selected material group. Make-Seiwa, Japan &Carlzeiss with Image Analyser Software (Metalyser Software)Model-SeiwaCorrect and Binocular inverted 35 (Fig 3).

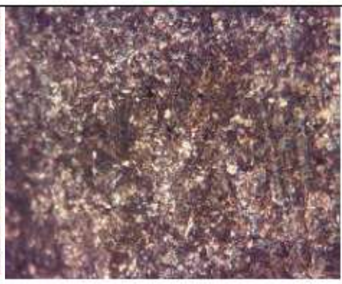
Material Grade- IS 2062 E250BR/SS400
(As Rolled Ferrite & Ferrite) @100X



Material Grade- IS 2062 E350C/HT-50
(As Rolled Ferrite & Ferrite) @100X

Material Grade- IS 2062 E450/HT-60
(Uniform Pearlite & Ferrite) @100X

Material Grade- Hardox-400 (Q&T Condition)- Tempered Martensite @100X magnification



Material Grade -En-19 (Q&T Condition)
Tempered Martensite with Bainite
@100X Magnfication

Material Grade- En-24 (Q&T Condition)
Fine Tempered Martensite @

Fig 3: Microstructure of materials selected

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 2 Feb 2022, pp: 1004-1010 www.ijaem.net ISSN: 2395-5252

IV. OBSERVATION:

- SS400/IS 2062 E250BR material in as rolled condition has been found to have higher wear loss volume of 243 mm 3as compared to other materials in group which are Q&T due to presenceof Pearlite& ferrite (Soft Micro-phase) in the matrix hence the surface goes with early wear & tear. However,no other Micro-alloying (Nb+V+Ti) elements are present in IS 2062 E250BR or SS-400 grade which also do not support in hardening of the mass and have lower hardness value 152 BHN.
- WT 60/IS 2062 E450BR being TMCP rolled (THERMO-MECHANICALLY CONTROLLED PROCESSED) steel having higher harness value of 190 BHN as compared to SS400/IS 2062 E250BR material in as rolled condition because the mechanical properties introduced to the steel through this processing route are virtually equivalent to those obtained by heat treating conventionally rolled or forged steel. TMCP involves controlled hot working and micro alloyed steel compositions. Thermo-mechanical controlled process is normally used to obtain excellent properties for steel plates such as high strength, excellent toughness along with excellent weldability through maximizing of grain refinement. This grain refinement obtained during thermomechanical process has resulted in uniform Quasi Polygonal Ferrite &Bainite microstructure.
- WT 80/S690QL has comparatively less weight loss due to Q&T process with presence of other alloy elements (%Cr, Mo & B). The Microstructure are consisting of Low Carbon Tempered martensite with Transformed Structure. It has comparatively high wear resistance & better Mechanical Strength to IS 2062 E450BR/HT-60 TMCP Plate
- Hardox-400 has better wear resistance due to Q&T process (achieving a hardness level of 360-440 BHN) with presence of alloy elements (%Mn, %Nb, %Cr, %Mo& B). The Microstructure is consisting of Low Carbon Tempered martensite with predominantly of Bainite. It increases payload & service life while maintaining good process ability and toughness.
- EN-19 due to occurrence of higher %Carbon (comparison to other rolled & TMCP plates) and alloying elements like Cr & Mo increased the Mechanical properties & increased the Wear resistance properties. The Microstructure is consisting with Tempered Martensite & predominantly of Bainite.
- EN-24 due to existence of Cr, Ni & Mo increased the Mechanical properties & Hardenability properties of material which is consequentially increased the Wear resistance properties also. The Microstructure is consisting with Fine Tempered Martensite & Traces of Bainite

V. CONCLUSIONS:

From the above data sheet, the evidences clearly show, material grade like IS 2062 E250BR, IS 2062 E450BR are having high volume wear losses due to absence of Micro-alloying elements & low Carbon content. However, Hardox-400 (Abrasive plate) grade having better wear properties due to content of alloying elements like Cr, Mo & B comparison to IS-2062 E250BR/E450BR Hot rolled Structural plates. Similarly, if the Medium Carbon was compared with Cr-Mo alloy steel and En-19 with En-24 (Ni-Cr-Mo) material grade, the En-24 has better wear resistance properties due to presence of %Ni and high content of Mo with Cr. In addition, the Uniform Fine Tempered Martensite and high Hardness increased the wear life as well. Hence it is conclusive, material grade En-24 having high wear resistance, good toughness increased the resistance to failure by fatigue resulting from cyclic loading, and resistance to surface indentation by localized loads.

REFERENCES

[1]. Budinski, K.G; 1988, Wear Modes, Surface Engineering for Wear Resistance, Prentice Hall, 1988. P15-43
[2]. Moore, M.A; 1994, A review of two Body Abrasive wear – Wear , 27: Page 1-17
[3]. Rendon, J; Olsson, M; 2009. Abrasive wear resistance of some commercial abrasionresistant steels evaluated by laboratory test methods, Wear 267,2055–2061.
[4]. Mutton, P.; Watson, J.D; 1978,Some effects of microstructure on the abrasion resistance of metals, Wear 48, 385–398.
[5]. Gahr, K.H.Z; Microstructure and Wear ofMaterials, Elsevier Science Ltd.,Amsterdam, 1987.
[6]. Jha, A.K; Prasad, B.K;Modi,O.P; Das, S;Yegneswaran,A.H; 2003, Correlating micro-structural features and mechanical properties with abrasion resistance of ahigh strength low alloy steel, Wear 254, 120–128.
[7]. Modi, O.P;Mondal, D.P; Prasad, M. Singh,B.K;Khaira, H.K; 2003, Abrasive wearbehaviour of a high carbon steel:

effects of microstructure and experimentalparameters and correlation with mechanical properties, Mater. Sci. Eng. A 343, 235–242.

[8]. Moore, M.A; 1974, The relationship between the abrasive wear resistance, hardness and microstructure of ferritic materials, Wear 28, 59–68.

[9]. Balamurugan, S; Murugan, N; 2014, A wear study on plasma transferred arc hardfaced structural steel with titanium carbide , World Journal of Modelling and Simulation 10 (2), pp. 108-115

[10]. Buchely, M.F; Gutierrez, J.C; Le´on, L.M; 2005, The effect of microstructure on abrasive wear of hardfacing alloys, A. ToroTribology and Surfaces Group, National University of Colombia, Colombia.

[11]. ASTM G 65, Standard Test Method for Wear Testing with Dry Sand Rubber Wheel Abrasion TestTechnical Ref.: Surface Engineering for Corrosion and Wear Resistance – ASM International – Chapter 3 – Wear, P 54-61.