Study of Wear Characteristics of Different Structural Materials

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***Abstract* - Selections of Abrasion resistant materials are most challenging subject for designers. An effort has been made to provide reference material chart 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. The study also tries to find out the effect of alloying element in abrasion behavior of readily available materials. This paper also concludes that material grade Cladding Surface material grade having wear resistance, good toughness increased the resistance to failure by fatigue resulting from cyclic loading, and resistance to surface indentation by localized loads.**

***Index Terms* - 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 the equipment and selection of material resistant to wear-induced failures are one of the chief economic considerations. 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. Abrasion is one of the main causes that limit the operation and life of machine elements. It manifests itself in several forms: 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. 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 [2]. Two body systems typically experience from 10 to 1000 times as much loss as three-body systems for a given load and path length of 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 [5]. 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 assumed to be result of complex/mixed wear phenomenon [4]. 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 [6,7]. 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 hardening characteristics, corrosion resistance, wear strength [8,9].

II EXPERIMENTAL SETUP

II (a) MATERIAL SELECTION

In this study seven materials are selected in a group 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.While selection of materials, it was considered that these materials are commonly selected materials for fabrication of wear parts in different application, especially ground engaging parts of excavator. The selected seven materials which are by form, rolled condition, but followed by different treatment processes. Wear plate was also selected as one component which is truly in clad form. The comparison is between basic material i.e., IS 2062 E250 BR and rest materials with different treatment process. Materials with TMCP processing, with Micro alloy and without Micro alloy viz HT 60 and Domex-600 were also considered. Other component includes surface hardened material, i.e., quench and tempered followed by induction hardening. F-Steel is hardened and tempered which is provided better core hardness. While selection of materials, alloying materials and process route for material manufacturing were considered. The selected materials include rolled plates which are processed through normalizing, TMCP, Q&T etc., which can support the materials with varying mechanical and wear properties. Consideration also includes alloying elements viz. specially Nickel, Chromium, Molybdenum, Vanadium &Boron. Nickel strengthens the ferrite and increases hardenability. 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 hardenability, reduce temper embrittlement, resist hydrogen attack & sulfide stress cracking, increase elevated temperature strength

Wear clad plate is hardened and tempered state material available in stated form, a rolled and heat

Table 1. Selected Group of Materials

Material Grade	Description	Supplied Condition
IS 2062 E250BR	Plate	Normalised/Rolled
HT-60/IS 2062-E450BR		TMCP
Domex - 600 (4mm)		TMCP
35C8 (Surface Hardened)		Q&T with Induction Hardening
45C8 (Surface Hardened)		Q&T with Induction Hardening
F-steel (hardened and tempered)		Q&T
Wear Cladding Plate		Cladded

Chemical composition of the materials is selected as per specification &observed value stated in Table 2& 3.

An actual observation of chemical composition to assess the effect of alloying and micro alloying elements is stated in Table 3. Observed chemical test results values were well within specified limit as specified in Table 2.

Table 2. Composition as Specified (%)

Material Grade	C(max)	Mn (max)	S (max)	P (Max)	Si (max)	%(Nb + V + Ti)	Ni (max)	Cr {max)	Mo (max)	B(max)
SS400/IS 2062 E250BR	0.22	1.50	0.05	0.05	0.40	0.25	0.40	0.30		
IS 2062 E450BR/HT60	0.22	1.65	0.045	0.045	0.45	0.25	0.40	0.30	0.20	
35C8	0.30-0.40	0.60-0.90	0.15 - 0.35	0.04	0.15-0.35					
45C8	0.40-0.50	0.60-0.90	0.04	0.04	0.15-0.35					
Domex-600 plates (4mm)	0.12	1.90	0.01	0.03	0.10	V- 0.20 Ti- 0.15				
F-steel (Q&T)	0.25-0.35	0.85-1.15s	0.035	0.035	0.50-1.70		0.60	0.50-1.20		0.15-0.35
Wear Plate	0.20	1.50	0.01	0.03	0.70	Nb- 0.05, V- 0.06	0.50	0.90	0.50	0.01

Table 3. Composition % [Actual]

Material Grade	C (max)	Mn (max)	S (max)	P (Max)	Si (max)	%(Nb + V + Ti) max	Ni (max)	Cr (max)	Mo (max)	B(max)
SS400/IS 2062 E250BR	0.12	0.84	0.004	0.018	0.14	-	-	-	-	-
IS 2062 E450BR/HT60	0.13	1.48	0.009	0.023	0.32	Nb- 0.050, V- 0.070 &Ti- 0.017	0.018	0.006	-	-
35C8	0.35	0.82	0.011	0.012	0.19	-	-	-	-	-
45C8	0.45	0.78	0.022	0.009	0.21	-	-	-	-	-
Domex-600 plates (4mm)	0.10	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	0.65	-	0.20	1.00	-	0.26
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

II (b) Mechanical Properties of Material

After conducting chemical analysis of stated group materials, mechanical testing of materials were done as specified in Table 4.

Table 4. Mechanical Properties, specification, and actual observation

Grade	Specification				Actual				Remarks
	UTS (Mpa min)	YS (Mpa min)	%E (min)	Impact (min)	UTS (Mpa)	YS (Mpa)	%E	Impact J (Avg)	
SS400/IS 2062 E250BR	410	250	23	27J @RT	462	338	28	120	OK
WT 60/IS 2062 E450BR	570	450	20	20J @-20°C	662	565	27	100	OK
35C8	600-700	400	16	33J @RT	656	442	18	66	OK
45C8	700-850	480	15	35J @RT	787	598	19	52	OK
Domex-600 plates-4mm	650-820	600	13	40J @-20°C	732	638	17	56	OK
F-steel (Q&T)	1170	-	10	10J @RT	1420	-	14	38	OK
Wear Cladding Plate	Not Required								

Observed mechanical test results values were well within or better than specified.

II (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 DrySandAbrasionTest. The dry sand-rubber wheel abrasion test was carried out using a Toshin Kogaya, Fig.1 (Tokyo, Japan) equipment in accordance with ASTM G 65 standard and test parameter as stated in Table 5[10]. 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).

Table 5, Test Parameters for Dry Sand Rubber Wheel Test

Parameters	Values
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

Figure 1. Dry sand- rubber wheel abrasion test machine, Toshin Kogaya.

III RESULT AND DISCUSSION

Results of dry sandabrasion test and hardness observation is specified in Table 6.

Table 6. Surface Hardness (BHN) and Average Volume Loss-(mm3)

Material Grade	Description	Supplied Condition	Surface Hardness in BHN	Average Volume Loss-mm3
IS 2062 E250BR	Plate	Normalised/Rolled	132	172.89
HT-60	Plate	TMCP	198	148.55
Domex - 600 (4mm)	Plate	TMCP	237	54.25
35C8 (Surface Hardened)	Plate	Q&T with Induction Hardening	605	25.38
45C8 (Surface Hardened)	Plate	Q&T with Induction Hardening	642	16.34
F-steel (hardened and tempered)	Plate	Q&T	456.5	14.58
Wear Cladding Plate	Plate	Q&T	627	1.84

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

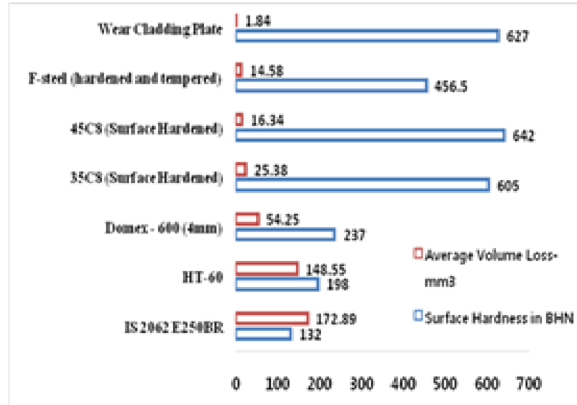

Figure 2. The Wear behavior (Volume loss in mm3 Vs Surface hardness in BHN)

II1 (a) Microstructure of Selected Material Group

The Microstructure of selected materials is given in Figure 3

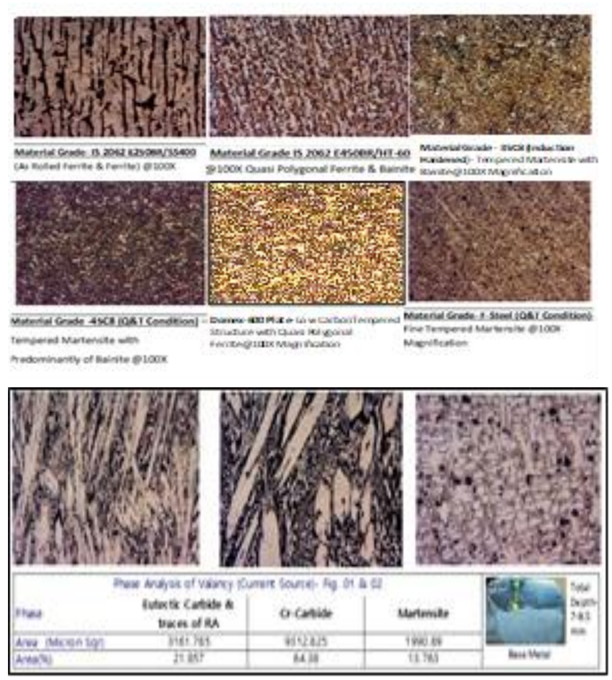

Figure 3. Microstructure Analysis of Selected Material Group

IS 2062 E250BR: Due to Presence of soft Pearlite & ferrite Micro-phase the surface. Its phase goes with early wear & tear. However, no other Micro-alloying elements are present in IS 2062 E250BR or SS-400 grade. HT60: Good Wear & Tear properties due to TMCP [Thermo-mechanical Controlled process] manufacturing route & presence of Micro-alloy elements. This grade is Superior than IS 2062 E250BR/SS-400 grade having Quasi polygon ferrite and bainite in microstructure. Microstructure of

Domex-600 depicts presence of low carbon tempered structure. Whereas the microstructure of 35C8 & 45C8, it shows the presence of tempered martensite with bainite in phase at Core & Fine Tempered Martensite on Case. For F-steel volume hardening [Q&T] provides fine Tempered martensite & better grain size which consequentially helps to improve the toughness & Fatigue life. Eutectic carbide in Wear clad plate microstructure with chromium carbide and martensite gives best wear properties.

III (B) OBSERVATION AND DISCUSSION

SS400/IS 2062 E250BR material in as rolled condition has been found to have higher weal loss volume of 172 mm 3, as compared to other materials in group which are Q&T due to presence of Pearlite& ferrite (Soft Micro-phase) in the matrix hence the surface goes with early wear & tear. However, no other Micro-alloying 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 132 BHN.

WT 60/IS 2062 E450BR being TCMP rolled (THERMO-MECHANICALLY CONTROLLED PROCESSED) steel having higher Hardness value of 192 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 thermo mechanical process has resulted in uniform pearlite and ferritic microstructure.

Domex-600 (4mm) being TCMP rolled (THERMO-MECHANICALLY CONTROLLED PROCESSED) steel having higher Hardness value of 237 BHN as compared WT 60. Higher surface Hardness is due to presence of presence of Micro-alloy elements viz. higher % of Mn, Ti, and V.

35C8 (Surface Hardened) material is having Core Hardness of 210 BHN and surface hardness of 605 BHN. Resulting in lower wear loss is compared to E250 and WT 60/E450BR. Better core and surface hardness is achieved through surface hardening process quench and tempering followed for induction hardening. This gives better wear phenomenon and lower wear loss.

45C8 [Surface Hardened] material having Core hardness of 225 BHN and Surface hardness of 642BHN, 45C8 hardness level is better as compared to 35C8, although both have same processing route of surface hardening process quench and tempering followed for induction hardening, because of higher % of carbon content in 45C8 i.e, 0.45 %, as compared to 35C8 i.e., 0.35 %. The better surface and core hardness of 45C8 has given it better wear resistance property and hence lesser volume loss as compared to Domex& 35C8, i.e 16.34 mm3.

F-steel (hardened and tempered) have better wear & tear properties due to content of Carbon with alloying elements [Cr, Mo & B] with Fine Tempered Martensite all across. And hence lesser wear loss as compared to other components viz. Domex, 35C8, 45C8.

IV CONCLUSION

From the above data sheet, the evidences are clearly shows, 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, Domex-600 (Abrasive plate) grade having better wear properties due to content individual Micro-alloy elements comparison to IS-2062 E250BR/E450BR Hot rolled Structural plates. Similarly, if compared, the Medium Carbon 35C8& 45C8, 45C8 is better than 35C8 grade material due to high %C content& high surface hardness. The Wear pattern comparatively high in-comparison to Domex-600 due to Induction hardened Depth up-to 2mm. The presence of Fine Tempered martensite on Case caused better wear life. However, if compared with F-Steel & 45C8 grade, the F-Steel has better wear life due to presence of alloying elements &Uniform Tempered martensite at Case & Core. Lastly "Cladding Steel "which content high %C, Cr, Mo, B & other alloying elements has increased the Surface hardness with consequential effect. Since the cladding depth is up-to to mark 8.5mm on surface, it helps to avoid wear & tear of material & caused less volume loss in comparison to other grades. Hence it is conclusive, material grade Cladding Surface material grade having wear resistance, good toughness increased the resistance to failure by fatigue resulting from cyclic loading, and resistance to surface indentation by localized loads.

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