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Wear characteristics of hardfacing alloys: state-of-the-art

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Abstract

Life factor of machine parts depends on the wear and machine parts intended fracture due to effect caused by wear. Wear has typical modes such as abrasion, erosion, adhesive, impact and corrosion. Hardfacing is a resistance to wear, it is an application of build-up of deposits of special alloys on the surfaces. The wear resistance depends on the factors like hardfacing alloys, matrix materials, matrix hardening agents, temperature, erodent and abrasion particles. The present work report's a review on wear behavior characteristics of hardfacing alloys on some ferrous based alloy and nickel based alloys.

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Keywords: Carbide volume fraction , Thermal fatigue, Harfacing , Wear resistance, Weld consumables.

1. Introduction

Hardfacing are welded as the protective layers, deposited on matrix and commonly used in industries to increase the service factor of the components or on tools that are subjected to abrasive wear of mineral materials. A hardfacing should be a composite, with base material selected for high hardness and coarse micro structural and for strength and economy. Hardfacing is applicant for surfacing of base material having imparting properties as resistance between metal sliding with high contact stress, abrasion, erosion or pitting and corrosion. Hardfacing materials selected for wear resistance for some critical conditions as temperature effected areas and for critical wear conditions to specific areas which subjected in service.

Wear is the most predominant factor that effect service of machine parts. All machine part have different stages of failures they don't fail in a single stage of wear like sudden impact, but they fail by combination of stages such as

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adhesion, erosion, abrasion, corrosion, oxidation etc. To reduce the wear effect various hardfacing alloys are used for better resistance [Coronado et al (2009)], reported that the increase in volume of carbide improved the abrasion resistance. Wear resistance of materials can be improved by heat treatment and applying a hard surfacing material on a parent (substrate) material. Micro structure plays a major role on wear resistance in addition to the effect of hardness in hardfacing.

Coarse hard phases have more withstand to abrasive wear. The hardness of phases should be more than hardness of abrasive. The erosive wear behavior depends on the carbide volume fraction of hardfacing alloys. At extreme service conditions at cyclic thermal fatigue treatments cracks are formed on surface and propagated throughout the boundaries of materials. Cracking can also occur as the result of welding contraction strain and reduce the service life factor and sometimes reduces the residual stress.

Fe-Cr-C alloys are used commonly in industries due to superior abrasion resistance. Both the carbide fraction volume and toughness of the matrix are responsible for excellent for abrasive resistance. Increase in the carbon content in deposited layers can improves the abrasive wear resistance of hardfacing alloys. Abrasion resistance depends on the type of hardfacing alloy, morphology, distribution pattern of the carbides and matrix structure. Fe based alloys with high chromium amounts are used vastly industries due to higher hardness and excellent abrasive resistance having high formation of chromium carbides.

Wear behavior can be determined and reduced on the basis of carbide distribution in nucleation structure affected by hardness. Formations of borides with transition elements have extreme applications due to their higher hardness and resistance to wear and corrosion. Ceramic materials exhibits excellent wear resistance as compared with metals, when the abrasive material is softer then the target. The dispersion of the ceramic region in ductile matrix improved toughness in abrasion resistance but less in erosion.

2. Hardfacing technology

Hardfacing can be performed various welding process. Selection of Welding process depends on the type of job, hardfacing alloys, base metal composition, size and shape of component, accessibility of welding equipment etc.

- Hardfacing by - Metal Arc Welding [Chatterjee and Pal, (2003)], [Svensson et al, (1986)], Open Arc Welding [Yuksel and Sahin, (2014)], [Berns and Fischer, (1998)], Shielded Metal Arc Welding [Y.L. Su and Chen, (1997)], Flux Cored Arc Welding [Sapate and rao, (2003)].

- Hardfacing by - Gas Tungsten Arc Welding by [Chia-Ming Chang et al, (2010)], [Chieh Fan et al, (2006)], [Arabi Jeshvangani et al, (2010)], [Jun and Seon, (1999)], [Berns and Fischer, (1998)].

- Hardfacing by – Plasma Transferred Arc Welding [Jong- Ning Aoh et al, (1999)].

3. Hard surfacing material and substrate materials in hardfacing technology

3.1. Hard Surfacing Materials

Different types of hardfacing alloys are used. These are categorized as below:

- High carbon- high chromium and Fe based hardfacing deposits of various compositions (4.26% of C, 21.85% of Cr) [Chatterjee and Pal, (2003)].

- Various compositions of Chromium and Graphite mixtures (3.61% of C, 33.86% of Cr) are used to get high carbon hypereutectic Fe-Cr-C hardfacing alloy [Chia-Ming Chang et al, (2010)]. Fe-Cr-C alloy of M_7C_3 and $M_{23}C_6$ composition [Chieh Fan et al, (2006)].

- Iron-based alloys with niobium (Nb), Titanium (Ti), molybdenum (Mo), boron (B) and carbon (C) hardfacing alloy (3.45% of C, 30.39% of Cr, 0.12% Nb, 2.90% of B) [Yuksel and Sahin, (2014)]. Fe-Cr-C and Fe-Cr-C-Nb/Ti hardfacing alloy [Berns and Fischer, (1998)].

- Stellite-6 hardfacing alloy is (1.2% of C, 29% of Cr, 4% of W, 2% Ni, <2.0% of Si, <3.0% of Fe, <1.0% of Mo and remaining is Co) used to get high carbon hypereutectic Fe-Cr-C hardfacing alloy [Arabi Jeshvangani et al, (2010)].

- Nickel-based hardfacing alloys with Fe-Nb, Fe-Cr, Fe-Mo, and Fe-C of various compositions [Y.L. Su and Chen, (1997)].

- Cobalt based Stellite alloys used for hardfacing due high wear resistance and plastic deformation at temperature 750^0 C [Jong- Ning Aoh et al, (1999)].

- Fe-34Cr-4.5C wt% hardfacing alloy contains large volume fraction of hard, primary and eutectic chromium-rich carbides in soft matrix [Svensson et al, (1986)]. Iron based NOREM02 hardfacing alloy [Jun and Seon, (1999)].

- Varying compositions of Fe-Cr-C-Mn with addition of Si and Mo powders [Vishal I. lad et al, (2013)].

3.2. Base Materials

Most of the base materials used for hardfacing is steel based materials of various grades. The principal material of steel is iron due to some various bonding and alloying parameters steel is mostly preferred but in some cases ductile iron also preferred.

- Grey cast iron plate (ASTM grade 2500) [Chatterjee and Pal, (2003)], Ductile iron used a base plate [Arabi Jeshvangani et al, (2010)].

- ASTM A36 steel plates [Chia-Ming Chang et al, (2010)], [Chieh Fan et al, (2006)],

- Stainless steel plates of grade SUS 304 [Jun and Seon, (1999)], Steel plates of AISI 1020 grade [Yuksel and Sahin, (2014)],

- Mild steel plate substrate [Berns and Fischer, (1998)], [Sapate and rao, (2003)], [Vishal I. lad et al, (2013)].

- AISI 1045carbon steel plates [Y.L. Su and Chen, (1997)],

- S45C Medium carbon steel [Jong- Ning Aoh et al, (1999)].

3.3. Test Equipments

Various types of test are performed for investigation of properties like micro-structural carbide formation, harness and wear behaviour at various conditions as stated below:

- Dry Sand Rubber Wheel Test Rig: [Chatterjee and Pal, (2003)], [Chia-Ming Chang et al, (2010)].
- Scaninng Electon Microscope: [Chatterjee and Pal, (2003)], [Chia-Ming Chang et al, (2010)], [Chieh Fan et al, (2006)], [Jun and Seon, (1999)], [Yuksel and Sahin, (2014)], [Berns and Fischer, (1998)], [Sapate and rao, (2003)].
- Scaninng Electon Microscope: [Chatterjee and Pal, (2003)], [Chia-Ming Chang et al, (2010)], [Yuksel and Sahin, (2014)].
- Hardness Test: Vickers- [Chatterjee and Pal, (2003)], Rockwell-[Chia-Ming Chang et al, (2010)].
- X-Ray Diffraction: [Arabi Jeshvangani et al, (2010)], [Vishal I. lad et al, (2013)].

4. Summary.

The research is going away on various fields on parameters of hardfacing alloys and various weld consumables as well as on base materials. Most of research is carried out on the wear character at critical conditions and to improve the life service factor of various industrial components. Low cost, high wear resistance hardfacing alloys are used in industries to pretend the wear, corrosion of components and strong binding agents are added to matrix for coarse matrix nucleation.

Different hardfacing electrodes are used to get different combinations of alloys. Composition of (0.69% of Ni, 17.5% of Cr and 4.25% of C) can improve wear resistance. Nickel posses a little effect on abrasive resistance with stable behavior of austenite matrix. Abrasion resistance may not improve further with high carbide volume fraction beyond a certain limit. Hardfacing electrode with niobium as carbides and molybdenum as matrix can reduce wear rate about half of the commercial electrodes [Chatterjee and Pal, (2003)].

$(Cr, Fe)_7C_3$ carbides are found in Fe-Cr-c alloys with higher contents of carbon (2-5 wt %) and chromium (18-30 wt %). These microstructures indicate good wear resistance property. Increase in the carbon content in Fe-Cr-C, the $(Cr, Fe)_{23}C_6$ Carbides disappeared. And the eutectic colonies of Cr-Fe+ $(Cr, Fe)_7C_3$ decreased. The wear behavior is classified based on the morphology of scratches caused. The hardness of primary carbide $(Cr, Fe)_7C_3$ is high and the formation of carbides increased which could prevent the eutectic matrix from damage from abrasive particles and the scratches followed discontinue path [Chia-Ming Chang et al, (2010)].

The control over the distribution of primary carbides and the carbide sizes became challenge for Fe-Cr-C hardfacing alloys due the brittleness of large block primary carbides. The observation on morphology showed that increase in the hardness due increase in the contents of carbon, chromium and boron and they dispersed in dendrite structure. [Eroglu,M. , (2009)] reported the high hardness value can be obtained (1450-1700) by increase in boron content. [Jacuinde et al, (2010)] reported on the wear behavior enhanced with microstructure development of carbide phases and increase in volume of boron carbides [Yuksel and Sahin, (2014)].

High chromium content (Fe-Cr-C) hardfacing alloys are in hypereutectic structure can reduce the formation of cracks on surfaces. To get Cr-Fe solid solution, hypereutectic, eutectic, hypoeutectic high chromium Fe-Cr-C structures, different amount of chromium and graphite powders are added. In general the two constituents of wear resistance materials play different functions: Hard particles are to impede wear by grooving and while matrix material is meant to provide sufficient toughness. These properties depend on the amount, size and distribution of hard particles. In hypoeutectic structure $(Cr, Fe)_{23}C_6$ is fine lamellar structure. In eutectic structure $(Cr, Fe)_{23}C_6$ is equal-axed dendrite. In hypereutectic has found in three phases α, $(Cr, Fe)_{23}C_6$ and with some amounts of $(Cr, Fe)_7C_3$ [Chieh Fan et al, (2006)].

A group of typical cobalt hard facing alloys are known as “Stellite”. In this alloy Cr provides oxidation, corrosion resistance and corrosion resistance at higher temperatures. Stellite 6 alloy has α-Co dendrites with a face centered cubic crystal structure and carbide phase resulting from the eutectic reaction during solidifications. The resistance not only depends on the hardness but also on modulus of elasticity of material. Morphology study stated that surface layer consists of Co-rich dendrites with eutectic carbides such as M_7C_3 and $M_{23}C_6$ the inter-dendrite regions [Arabi Jeshvangani et al, (2010)].

Better improvement in abrasive wear resistance can be obtained by using alloyed boron instead of using niobium and titanium which are expensive. Micro structure of Fe-Cr-C-Ni/Ti showed that all of these alloys have coarse hard phase and eutectic phase. Volume of fractions of coarse hard phases of 6 to 41% of MC-type carbides, together with 0 to 28% chromium carbides of M_7C_3 type was found. Hardness values varied between 1090-1650 HV for chromium carbides. The volume fractions varied from 17-85% for chromium free hardfacing alloys and the hardness values for M_2B-, M_3C-, or $M_{23}B_6$ –type have 1090-1740 HV and M_7C_3-, M_3B-, have hardness values between 1190- 2300 HV and the volume fractions range from 27 to 59%. Titanium carbide of the MC-type and titanium boride of the MB_2 have hardness value between 2300-4000 HV and the volume fractions is 2 to 24% [Berns and Fischer, (1998)].

Nickel hardfacing alloys are divided into five categories: carbide-type, boron-type, silicide-type, intermetallic-type, and solid solution–type and major types used are silicide and boron type is used. Addition of niobium, chromium and molybdenum to the flux effects the microstructure of deposited layer and its hardness initially increases then decreased with increase in amount of alloy element and carbon content. Under dry wear against the Si_3N_4 ball, the micro structure of hardfacing alloys plays a key role in providing good wear resistance with coarse hard particles. Under oil lubrication, the wear loss can be reduced by accumulated layer formed by wear debris in the interface between the wear surfaces. Niobium can combine with carbon to form spherical niobium carbide, reduces the coefficient of friction and adding of carbon and molybdenum can also improves the wear resistance of deposited layer [Y.L. Su and Chen, (1997)].

The abrasion resistance of high chromium irons have more than twenty five times greater than low carbon steels, when abrasive particles are softer than carbides. This priority changes when alumina and silica particles are added. The erosion rate of wear decreases with increase carbide volume fraction of alumina and silica based under mild erosion condition but erosion rate increase in severe erosion conditions. Alumina particles are plastically indent and cause lateral fracture of carbide particles [Sapate and rao, (2003)].

Hardness of the tungsten carbide at elevated temperatures together with the cobalt-cobalt based alloy matrix has extremely resistant to wear [Stott et al (1997)] have reported that maximum wear rates occurred around 250^0C under different sliding conditions. The wear resistance of Co-base alloys has revealed that superior abrasive wear resistance was obtained with microstructures having coarse carbide morphologies. Stellite 6 alloys with Cr_3C_2 showed best resistance towards wear at elevated temperatures and wear resistance can be improved by adding of chromium carbide particles in the matrix of stellite 6. The wear behavior of cobalt based alloys after oxidation was affected by oxidation film and surface hardness [Jong- Ning Aoh et al, (1999)].

NOREM alloy is cobalt free hard facing alloy possess high resistance to galling, cavitation erosion and corrosion effects. The wear loss of NOREM 02 nearly equivalent to that of stellite 6 below 180^0C and the wear loss began to increase above 180^0C and galling occurred above 200^0C. The wear resistance of NOREM 02 under contact stress of 103 MPa was equivalent to that of stellite 6 below 180^0C, on further increase of temperature the wear mode of NOREM 02 changed to adhesive wear [Jun and Seon, (1999)].

Comparison of different compositions of Fe-C-Mn-Cr with addition of silicon and molybdenum is surfaced on mild steel showed that addition silicon varied the hardness of the material by varying the volume fraction of ferrous carbides and resulted in formation of silicon ferrous carbides. Molybdenum acted as strong binding agent, dominated the formation of carbide precipitations during welding even austenite was elevated to high temperatures but it does not showed effective result of increasing in hardness when added to high Mn alloy as compared with high Cr alloy [Vishal I. lad et al, (2013)].

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