Repair and Maintenance Procedures for Heavy Machinery Components

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Introduction

Heavy machinery components are subjected to severe destructive conditions of environmental wear. The hardfacing process is a cost-effective tool that can minimize wear and increase service life of heavy machinery components.

Types of Wear

The OECD (Organisation for Economic Cooperation and Development) defines wear as: "The progressive loss of substance from the operating surface of a body occurring as a result of relative motion at the surface" [1]. Commonly recognized wear categories and their respective estimated shares of heavy machinery wear [2] are shown in Figure 1.

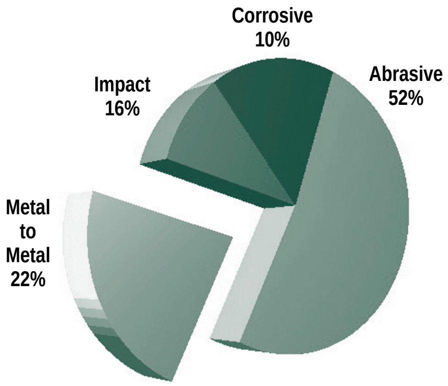


Figure 1. Illustration of the ratio of different wear categories in industry.

Usually, there are several wear mechanisms that act simultaneously on heavy machinery components. The two most common types are abrasive and metal to metal wear.

Metal to Metal Wear

Metal to metal wear occurs when two metallic surfaces slide against each other under the pressure. True metal to metal wear is the most often found under nonlubricated or dry conditions. Archard's Metal to Metal Theory has been widely accepted since the relationship established between the wear volume (V), sliding distance (L), normal load (N) and hardness (H) is consistent with experimentally observed results:

$$V=(K \times L \times N)/H \qquad (1)$$

K is coefficient of wear.

When shear stresses overcome the cohesive strength of the metal matrix, cracks and voids can be nucleated and wear particles can form [4].

Abrasive Wear

Abrasive wear occurs when nonmetallic materials slide or roll, under pressure, across a metallic surface. This type of wear is determined by:

- The properties of the wear material,
- The properties of the abrasive material, and
- The nature and severity of the interaction between the abrasive and wear material.

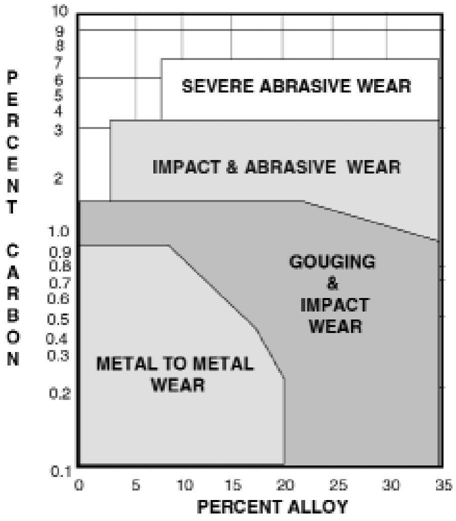
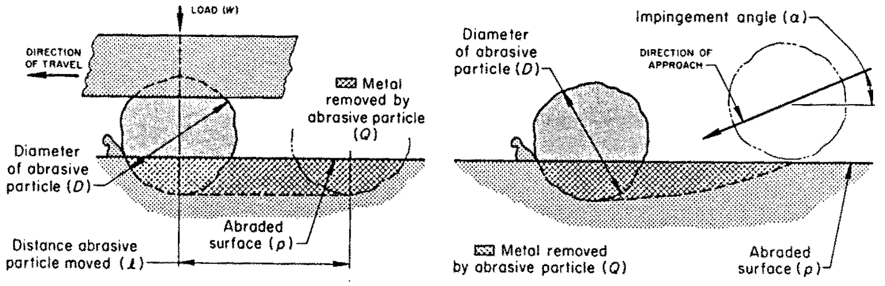


Figure 2. Alloy content as a function of wear. [3]

Abrasive wear can be classified as (a) gouging abrasion, (b) high stress grinding abrasion and (c) low stress scratching abrasion or erosion. In abrasive wear, there are two extreme mechanisms of material removal, one in which plastic deformation plays a dominant role, and the other in which fracture with limited plastic deformation dominates. According to the simplified abrasion wear theory, equation 2, volume loss, Q, is proportional to the applied load (N) and is inversely proportional to the hardness (H) of the abraded surface [5].

$$Q = N/H \qquad (2)$$

Figure 3 illustrates the mechanism of abrasive wear.



(a) (b)

Figure 3. (a) Idealized representation of abrasive wear resulting from mechanical application of force to an abrasive particle. (b) Idealized representation of abrasive wear resulting from kinetic application of force to an abrasive particle.

Impact Wear

During service, heavy equipment components can also be subjected to impact wear. Toughness can be regarded as the capacity of a material to absorb energy by deforming plastically before fracture. Toughness is independent of the strength and ductility of the material and is measured by Charpy and Izod tests. Table 1 gives the impact toughness of selected materials.

Hardfacing

Hardfacing is a surfacing process used to improve the wear resistance of heavy machinery components without affecting the interior of the component. Hardfacing is a process of applying, by welding, a layer, edge or point of wear resistant metal onto a metal component. Table 2 illustrates engineering methods for surface treatment of steel.

Selection of Hardfacing Wires

Selection of hardfacing wires is based on:

- The wear mechanism acting on the component;
- Tribological conditions: load, temperature and impact;
- Comparison with prior experience;
- Compatibility with substrate materials;
- Requirements for heat treatment and machining after welding;
- Availability of materials, equipment and skilled personnel; and
- Cost.

Table 3 gives the hardnesses of the most common materials used in hardfacing wires.

Table 1. Typical properties of selected materials. [6]

Material	Hardness HV	Impact Toughness (J)
Austenitic (11-13%Mn) Steel	200-250	140
Austenitic (6% Mn) Steel	200-250	30
Cast Martensitic Steel	400-600	15-25
Wrought Martensitic Steel	300-550	20-70
Cast Pearlitic Steel	250-420	5-10
Alloy White Cast Irons	600-900	2-5

Table 2. Engineering methods for surface hardening of steel. [7]

LAYER ADDITIONS	SUBSTRATE TREATMENT
HARDSURFACING Fusion hardfacing (welded overlays) Thermal spray (bonded overlay)	DIFFUSION PROCESS Carburising Nitriding Carbonitriding Nitrocarburising Boriding Titanium-carbon diffusion Toyota diffusion process
COATINGS Electrochemical plating Chemical vapour deposition Thin films (physical vapour deposition) Ion mixing	SELECTIVE HARDENING METHODS Flame hardening Induction hardening Laser hardening Electron beam hardening Ion implantation Selective carburising and nitriding

Table 3. Hardnesses of the most common materials used in hardfacing [8]

Material	Formula	Hardness HV
Ferrite	Alpha-Fe	70 – 200
Pearlite (nonalloyed)	Alpha Fe + Fe3C	250 – 320
Pearlite (alloyed)	Alpha Fe + Fe3C	300 – 460
Austenite Cr- alloyed	Gamma- Fe	300 – 600
Austenite low alloyed	Gamma- Fe	250 – 350
Nickel	Ni	560
Bainite	Alpha Fe + Fe3C	250 – 450
Martensite	Alpha Fe + Fe3C	500 – 1010
Cementite	Fe3C	840 – 1100
Chromium Carbide	CrxCy	1330 – 1700
Titanium Nitride	TiN	1800
Tungsten Carbide	WC	1900 – 2000
Vanadium Carbide	VC	2300
Titanium Carbide	TiC	2500
Boron Carbide	B4C	2800

Table 4. Influence of alloying elements on the properties of weld deposits.

CARBON	MANGANESE	CHROMIUM
• Reduces ductility (increases brittleness) • Increases tensile strength • Increases hardness • Increases hardenability	• Increases hardness • Promotes a finer grain size • Acts as deoxidiser • Minimizes sulphur, hot cracking	• 1-2% increases the hardness and toughness without loss of ductility • 4-6% increases resistance to tarnishing • Above 11% becomes corrosion resistant • Promotes carbide formation
NICKEL	**MOLYBDENUM**	**VANADIUM**
• Increases strength & toughness • Prevents grain growth • Lessens distortion • Increases hardenability	• Increases tensile strength and toughness • Increases resistance to creep	• Increases tensile strength • Increases resistance to fatigue • Resistant to high stresses

Design and Selection of Hardfacing Consumables

The design and selection of welding consumables for build-up and wear-resistance applications is based on the following principles:

- Addition of carbon;
- Addition of alloys;
- Providing hard particles in a soft weld metal matrix.

Table 4 shows the influence of alloying elements on the properties of weld deposits.

The influence of carbon and percentage of martensite (cooling rate) on the hardness of steel weld metal deposits [7] is shown in Figure 4. The influence of alloying elements on the microstructures of weld metal deposits is given in Figure 5 [9].

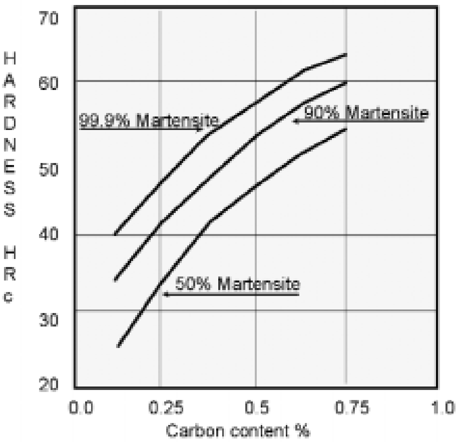


Figure 4. Influence of carbon content and % martensite (cooling rate) on the hardness of steel weld metal deposits.

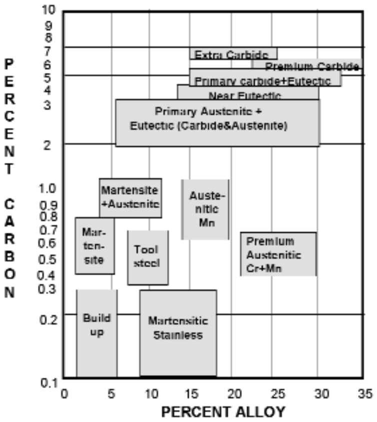


Figure 5. Map of alloying elements and properties of build-up and wear-resistant weld deposits.

Repair Procedures

Preheating

Generally, weld metal and parent metal properties such as chemical composition, hardenability, joint geometry and restraint determine the desired properties for a repaired component. One of the widely adopted approaches for determining weldability is to review the hardenability of the material. The carbon equivalent (CE) formula was developed to indicate how the chemical composition would affect hardenability. The maximum interpass temperature for the repair of austenitic manganese castings is 260°C. Table 5 gives guidelines for preheating temperature as a function of carbon equivalent [10]. The carbon equivalent formula is given in equation 3 [13].

$$CE=C+(Mn+Si)/6+(Cr+Mo+V)/5+(Ni+Cu)/15 \quad (3)$$

Table 5. Guideline preheat temperatures as a function of carbon equivalent (CE).

Carbon Equivalent	Suggested preheat (°C)
Up to 0.45	Optional
0.45 to 0.6	95 to 210
Above 0.6	210 to 370

Special precautions should be taken on applications that are crack sensitive, such as high carbon or alloy steels, previously hardfaced parts and highly stressed parts. The repair (hardfacing) of heavy cylinders, massive parts and parts having complex shapes are all examples of applications producing high internal stresses that may result in delayed cracking (Figure 7). These applications may require one or more of the following:

- Higher preheating temperatures 150 to 260°C (Figure 6).
- Higher interpass temperatures up to 480°C. In general this high interpass temperature will not cause a drop in the hardness of weld deposit. Establishing interpass temperatures should also take into consideration the previous heat treatment history of the component.
- Controlled, slow cooling between passes.

Figure 6. Preheat of massive part.

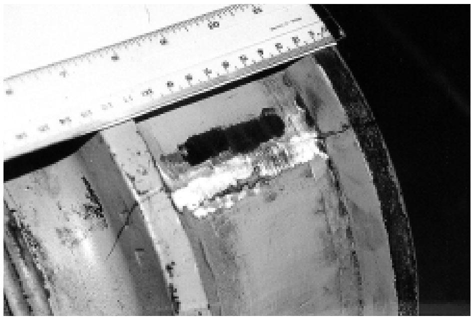


Figure 7. Transverse crack of the repaired idler.

A soaking time of 1 hour per 25 mm of cross section at the recommended temperature is required in order to obtain maximum benefit from preheating. The maximum interpass temperature for the repair of austenitic manganese castings is limited to 260°C.

Postweld Heat Treatment

The iron based hardfacing alloys are among the few engineering alloys that can be heat treated in order to vary their mechanical properties. Heat treatment can be applied to a steel not only to harden it but also to improve its strength, toughness, ductility, decrease the stresses caused by welding and to avoid undesirable microstructures in the heat affected zone. The various heat treatment processes can be classified as : a) annealing; b) normalising hardening; c) tempering; d) stress relieving.

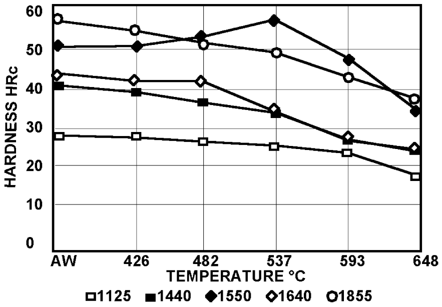


Figure 8. Summary of influence of stress relieving temperature on hardness of weld deposits resistant to metal-to-metal wear (see Table 3).

A summary of the influence of stress relieving temperature on the hardness of weld deposits resistant to metal-to-metal wear is illustrated in Figure 8 [11], while a summary of the influence of annealing on the hardness of weld deposits resistant to metal to metal wear is illustrated in Figure 9 [12].

Figures 10 and 11 [12] summarize the relationship between the percentage of carbon and alloying elements and as quenched hardness of hardfacing weld metal deposits.

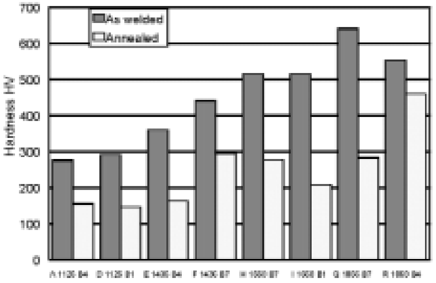


Figure 9. Influence of annealing on the hardness of iron based weld deposits [12].

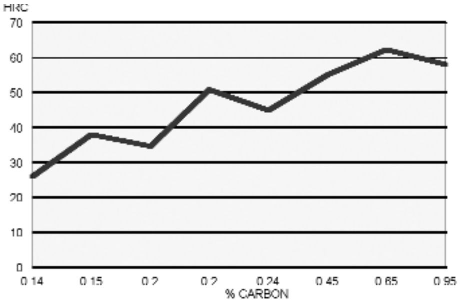


Figure 10. Relationship between carbon content and as quenched hardness of iron based weld deposits [12].

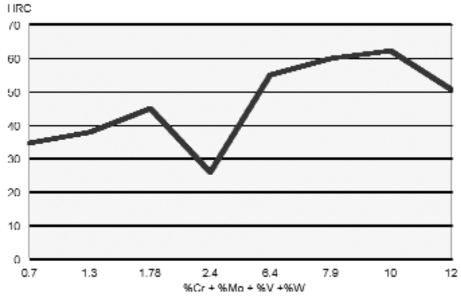


Figure 11. Relationship between total content of alloying elements (Cr, Mo, V and W) and as hardfacing quenched hardness of iron based hardfacing deposits [12].

Examples

Typical Application of a Build-up Product

WIRE CHARACTERISTICS

- Typically less than 0.3%C, less than 6% alloy (Cr, Mn, Mo, Ni);
- Pearlitic/Ferritic weld deposit
- Hardness up to 35 HRc;
- Two distinct applications;
- Provide high compressive strength to support a harder top layer – Build-up layer;
- Final surface for metal to metal wear.

WELDING PROCEDURE

- Preheat 50-210°C;
- Maximum interpass can run as high as 370-430°C;
- Stringers or weave are acceptable;
- Unlimited number of layers;
- Slow cool to avoid cracking;
- Hardness will depend on the cooling rate.

(a) (b) (c)

Figure 12. (a) Idler rebuild; (b) Worn internal surface of dragline chain; (c) chain repaired.

Typical Metal to Metal Wear Application

WIRE CHARACTERISTICS

- Typically less than 0.4%C and 6% total alloy;
- Hardness typically 35-45 HRc;
- Low alloy martensitic weld deposit;
- Austenite transforms to martensite below 371°C;
- Hardness doesn't depend upon cooling rate unless extremely slow;
- Main application is metal to metal wear, especially sliding; also abrasion from softer materials (dirt, limestone).

WELDING PROCEDURE

- Preheat 150-315°C is recommended;
- Max. interpass can go as high as 370-430°C;
- Stringers or weaves are acceptable;
- Usually limited to 3-4 layers maximum;
- Slow cool to prevent cracking;
- Post weld heat treatment required to toughen and soften weld/component after welding.

Figure 13. Shaft repaired using spread arc technique.

Typical Manganese Repair

WIRE CHARACTERISTICS

- Suitable for severe impact applications;
- Typically 0.4 to 0.6 %C, 13 to 20% alloy, mainly manganese;
- Typically 20 to 25 Rockwell C as-welded, work hardens rapidly to 45 to 55 HRC;
- High dilution on mild steel will be martensitic.
- Non-magnetic alloys.

WELDING PROCEDURE

- No preheat required on austenitic base metal;
- Preheat 148-204°C on carbon and low alloy to steel to prevent pullout;
- Limited heat build up to 260°C maximum to avoid embitterment due to Mn-carbide precipitation;
- Unlimited layers;
- No post weld heat treatment required.

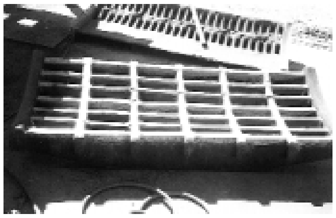


Figure 14. Repaired austenitic manganese steel casting; no preheating applied; maximum interpass temperature was kept below 260°C by immersing component in water bath.

Typical Abrasion and Impact Application

WIRE CHARACTERISTICS

- 2 to 6%C, 14 to 35% total alloy content, mainly chromium;
- Typically 58 to 63 HRC;
- Used primarily to resist abrasion, abrasion & impact – shovel and bucket lips, conveyor screws, blast furnace bells, coal crushers, asphalt mixers etc.

WELDING PROCEDURE

- No preheat on austenitic substrate;
- Preheat at 204°C on carbon steel, low alloy steel, or cast iron;
- First run several beads fast enough to establish tight check crack spacing (6.0 to 19.0 mm) may require ≥1000 mm/min travel speed;
- For a single layer, use heavy overlap (about 70%) to get primary carbides – dilution can lead to primary austenitic or near eutectic structure which has inferior abrasion resistance.

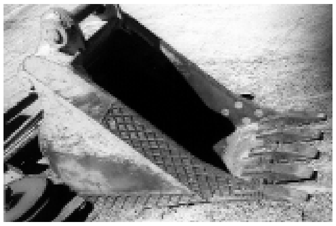


Figure 15. Bucket sides protected with hardfacing.

Summary

Although wear of machinery parts represents a significant economic cost to the owners and operators of heavy equipment, the option of using hardfacing products to restore worn material is a very cost effective alternative to parts replacement. In many cases, the hardfaced deposit will wear better than the original part. The hardfacing solution is successful when the type of wear is properly identified, and the optimal material is selected for the application. Care should be taken to ensure that adequate ventilation and/or local exhaust is used to control operator exposure to welding fumes and its constituents per the material safety data sheet for the consumables being used. Finally, regardless of the hardfacing material selected, the material must be properly deposited to ensure that it performs as intended.

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