HARDFACING FOR MINING AND MINERAL PROCESSING INDUSTRIES

R. S. Chandel
Division of Materials Engineering, School of Applied Science
Nanyang Technological University, Singapore 639798

Introduction

Wear is the most important cause of component material loss and degradation in mining and mineral processing operations. Such degradation necessitates substantial maintenance effort along with scheduled and unscheduled interruptions in production. According to one Canadian survey, the estimated cost of wear and friction losses in 1982 to its economy was in excess of $5 billion annually (1). Out of this, losses in mining and mineral processing industry were estimated to be $940m. These estimates included the replacement cost of worn components, labour and other charges incurred in replacement operations and any consequential losses due to shortfall in production and additional costs of procedures substituted temporarily for failed systems. Although it is accepted that it may not be feasible to eliminate the wear attack totally, nonetheless, through the proper understanding of the prevailing wear mechanism and selection of appropriate materials, the total losses to mining and mineral processing industry can be reduced significantly.

To address part of this problem, the author, while working in Canada, carried out a survey to assess: (i) the causes of component failure in the mining and mineral processing industry in Canada, and (ii) the awareness and availability of hardfacing technology and the need for further information regarding such protections (2). The results of this survey showed that in 90% cases components that required replacement/repair or hardfacing were subjected to some kind of abrasive wear. Of the mines that responded, 12% did not have any knowledge of hardfacing while, 50% had limited knowledge and were generally influenced by consumable suppliers.

Amongst the methods available to combat wear, hardfacing stands out for its versatility, economic and technical attractiveness. Despite its proven advantages, hardfacing is still not being used to its fullest potential. This in part is due to the lack of appreciation and understanding of welding processes and procedures among maintenance personnel. Therefore this paper is written to inform the readers about the potential and versatility of welding processes for hardfacings, especially for mining and mineral processing industries.

This series of articles is written to address the hardfacing related problems of mining and mineral processing industries. It should be pointed out that only metallic materials are being discussed. The three articles are in the following order:

1. Analysis of Wear in Mining and Mineral Processing Industries

2. Welding as a Hardfacing Process

3. Hardfacing consumables and their characteristics

This article discusses various wear mechanism(s) operative in mining and mineral processing industries.

ANALYSIS OF WEAR IN MINING AND MINERAL PROCESSING INDUSTRIES

Wear Mechanism

Wear is damage to a solid surface involving progressive loss of material, due to relative motion between that surface and a contacting substance or substances.

The removal of material from the surface is either through the physical action of the abrasives or through corrosion. Both mechanisms may operate individually or may complement each other.

There are a large number of wear modes, the main mechanisms are given in Table 1.

Table 1 – Main categories of wear (3)

Wear Modes			
Abrasion	**Erosion**	**Adhesion**	**Surface Fatigue**
Low Stress	Solid	Fretting	Pitting
High Stress	Impingement	Adhesive	Spalling
Gouging	Fluid	Seizure	Impact
Polishing	Impingement Cavitation Slurry Erosion	Galling Oxidative	Brinelling

The following four modes are predominant in the mining and mineral processing industries:

- Gouging abrasion
- High stress abrasion
- Low stress abrasion
- Erosion and corrosion

Gouging Abrasion : This occurs when abrasive lumps or rocks impact or contact a surface with sufficient force to gouge out material (Fig. 1). For example when a heavy hard rock is impacted by a moving jaw. In this situation the stresses at the contact points are high, but the overall loading on the surface is low. Other examples of this type of wear occur in hammer mills , crushers, earth movers in rocky strata, etc.

High-Stress Abrasion : This occurs when abrasives are trapped between two heavily loaded surfaces such as in jaw crushers, ball and rod mills, rock drills, etc, (Fig. 2). The wear surface is subjected to very high stresses which may result in penetration, deformation of the matrix and fracture of hard phases such as metallic carbides. Damage is always severe. To resist this form of wear, it is desirable for surfaces to have a compressive strength greater than that of the abrasive.

Other examples of this type of wear in mining and mineral processing operations are in milling, tractor undercarriages in rocky and sandy operations, dragline buckets wheels, roller running over dirt tracks, earth moving equipment, heavily loaded metal-to-metal sliding systems in dirty environments.

Low-Stress Abrasion : This form of wear results from the sliding action of free moving particles over a softer surface (Fig. 3). Stresses involved are generally low and abrasives are not crushed. The material is generally removed from the surface at low impingement angles by a scratching mechanism hence this is also called scratching abrasion. Examples of this type of wear are particles sliding on hoppers and chutes, plowing in sandy soil, etc.

Erosion-Corrosion Abrasion : This form of wear damage is produced by the impingement of sharp particles

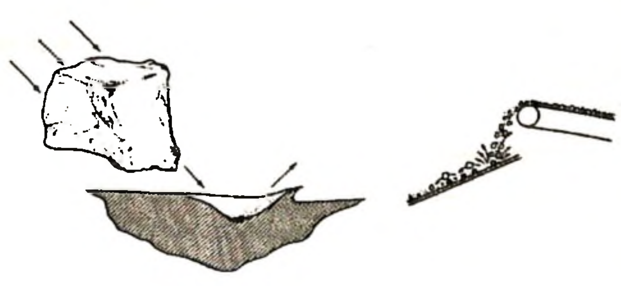

Fig. 1 : Schematic illustration of gouging abrasion

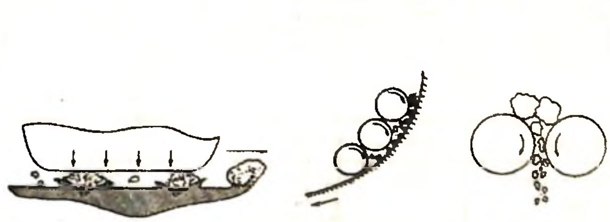

Fig. 2 : Schematic illustration of high-stress abrasion

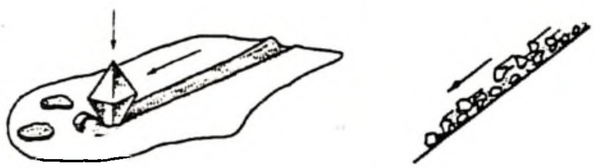

Fig. 3 : Schematic illustration of low-stress abrasion

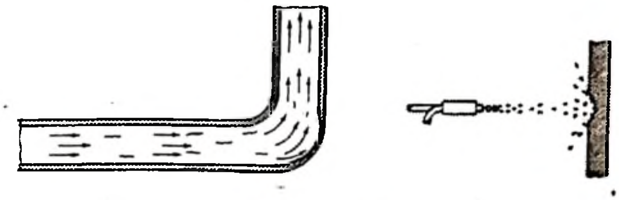

Fig. 4 : Schematic illustration of erosion

transported in a moving liquid or gas on a surface (Fig. 4) such as the transportation of slurries in pipelines, nozzles, valves, separation equipment, movement of pump impellers in slurries, shot-blasting, or exposure to sandstorms, etc. Other examples of this type of abrasion are, fans in dirty environments, cyclone separators, air blast comminution equipment, exhaust systems carrying particles, etc. The presence of moisture in the conveying media also poses additional problems of corrosion, and in many cases this may become the more predominant mechanism of wear.

Table 2 summarizes the above types of wear mechanisms in terms of nature of contact, environment, etc.

Wear of Mining and Mineral Processing Equipment

In a typical operation ore is dug, loaded and transported to processing plants where it is crushed to size, and separated as required. At some mines, both mining and processing activities are carried out at the same site, while in other cases mineral processing is combined with extraction activities which may be remote from the mine site.

Fig. 5 is representation of mining and mineral processing operations. Wear conditions within these operations can range from severe (high impact, large abrasive sizes) in digging and crushing operations, to relatively mild (low forces and velocities, small abrasive particles) in some classification and separation processes. In operations where there is aqueous or liquid environment such as in grinding, significant corrosion can also take place. It is very common to find two or more types of wear systems are operational in each stage of operation.

The extent and rate of wear of a component depends to a large extent on the nature (size and abrasivity) of the ore or mineral to be handled and the production rate. The abrasivity of a mineral and the energy required for comminution in crushing and grinding operations is dependent on its hardness, size and shape, and compressive strength and fracture properties, respectively. The characteristics for a range of

Table 2 – Characteristics of main wear modes in mining and mineral processing (4)

Conditions/ Wear Type	Gouging Abrasion	High Stress Abrasion	Low Stress Abrasion	Erosion/ Corrosion
Abrasive Size	Large	Medium	Small	Fine
Impact	High	Low	Low	Low
Force	High	High	Low	Moderate (depending upon velocity)
Velocity	Low	Low	Variable	High
Impingement Angle	Low	Low	Medium-Low	Variable
Environment	Dry	Slurry, Variable pH	Variable	Slurry, Variable pH
Mechanism of Material Removal	Ploughing Cutting	Cutting, Corrosion and some Fragmentation	Cutting and Some Corrosion	Cutting, Corrosion and some Fragmentation

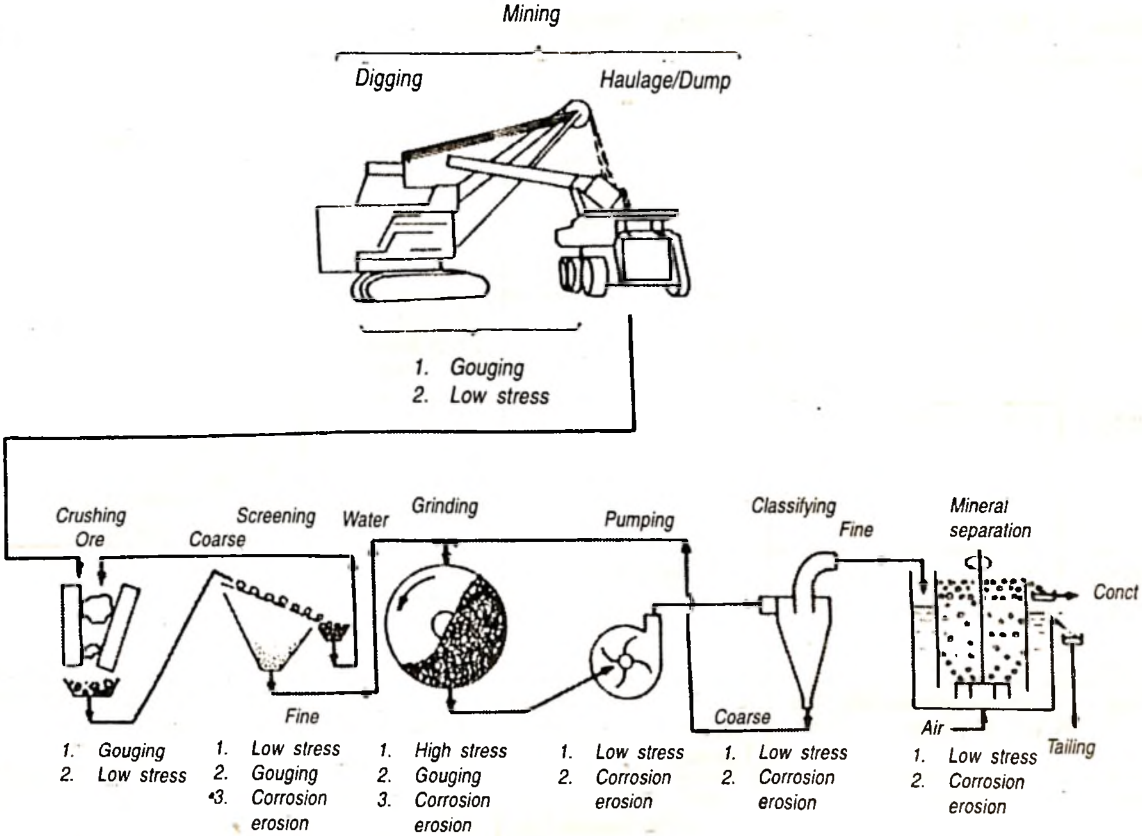

Fig. 5 : Major stages in mining and mineral processing (5)
(The numbers 1,2,3 indicate the order of the type of wear machanism operate in that particular operation)

Table 3 – Properties of some minerals and ores (4)

Ore/Mineral Type	Relative Density	Hardness (Hv)	Compressive Strength (MPa)	Abrasion Index	Bond Work Index
Bauxite	4.9-5.2	150-420	–	–	–
Coal	1.2-2.0	150-250	5-40	–	12
Limestone	2.3	150-250	130-200	0.03	12
Heavy Sulphides (Lead/Zinc)	7.4-7.6	–	60-100	0.13	11
Copper Ore Chalcopyrite	4.1-4.3	350-400	–	0.15	12
Hematite	5.3	470-650	180-250	0.17	9
Granite	–	500-800	100-300	0.39	17
Quartz	2.7	800	140-650	0.78	17

Table 4 – Mining and Mineral Processing Stages, Components and Materials of Fabrication (4,5)

Operation	Equipment	Wear Components	Abrasive Wear Classification	Metallic Material of Construction/Protection
Mining	Shovel, Draglines, Front End Loaders, Trucks, Bucket wheel excavators, Scrapers	Bucket, Teeth, Adapters, Trays, Blades, Digging, Chains, undercarriages	1-Gouging 2-Low Stress	-Austenitic Mn steels -Cast martensitic steels -Alloy white irons -CrC hardfaced plates -Wrought martensitic steels
Crushing	Jaw, Cone and Gyratory Crushers, Impact Crushers	Jaws, Mantles, Concaves, Bowls, Liners, Hammers, Blow Bars	1-Gouging 2-High Stress 3-Low Stress	-Austenitic Mn steels -Alloy white irons -CrC hardfaced plates
Screening	Grizzlies, Screens, Trommels	Screen Decks, Underpans, Discharge Lips	1-Low Stress 2-Gouging 3-Erosion-Corrosion	-Alloy white irons -CrC hardfaced plates -Austenitic Mn steels -Wrought martensitic steels -WC spray coatings
Conveying/ Handling	Conveyors, Chutes, Pipes, Launders, valves, hoppers	Liners, Impact Curtains, Bends	1-Low Stress 2-Erosion-Corrosion	-Wrought martensitic steels -Alloy white irons -CrC Weld overlays -WC spray coatings
Grinding	Semi-autogeneous Mills, Rod Mills, Ball Mills	Balls, Rods, Liners, Grates, Feed Chutes, Discharge Trommels	1-High Stress 2-Gouging 3-Erosion-Corrosion	-Wrought/Forged/Cast martensitic steels -Alloy white irons -Cast pearlitic steels
Pumping	Slurry Pumps	Impellers, Volute and Frame Plate Liners, Sleeves	1-Low Stress 2-Erosion-Corrosion	-Alloy white irons -CrC Weld overlays -WC spray coatings
Classification	Cyclones. Spirals	Hoods, Vortex Finders, Bodies, Spigots	1-Low Stress 2-Erosion-Corrosion	-Alloy white irons -CrC Weld overlays
Separation	Flotation Cells, Magnetic Separators, Centrifuges	Agitators, Drums	1-Low Stress 2-Erosion-Corrosion	-Alloy white irons -Stainless steels -WC spray coatings

typical ores and minerals are listed in Table 3. Abrasion and work indices, based on laboratory wear tests are also included which provide an indication of power requirements for crushing and grinding operations.

A brief overview of metallic wear materials of construction for mining and mineral processing equipment is given in Table 4. Such information is necessary and helpful when considering hardfacing. For example if the equipment/component is made from white iron, it will be very difficult to hardface by weld overlaying. In this case the equipment will either be replaced by a new one, or thermal spraying process might be used.

REFERENCES

1. *"A Strategy for Tribology", National Research Council Canada, Associate Committee on Tribology' NRC No. 26556, 1986*
2. *R.S.Chandel, Unpublished Results of a Survey, MTL/CANMET, Energy, Mines and Resources Canada, 1991.*
3. *Budinski, "Surface Engineering for Wear Resistance", Published by Prantice-Hall, 1988.*
4. *Mutton, "Abrasion Resistant Materials for the Australian Minerals Industry, Vol.I-Materials Selection Handbook", Published by Australian Mineral Industries Research Association Limited, 9th.Floor, 128 Exhibition Street, Melbourne, Australia, 1988.*
5. *Norman, "Wear in Ore Processing Machinery", in Wear Control Handbook, Ed. M.B.Peterson and W.O.Winer, ASME, 1980.*