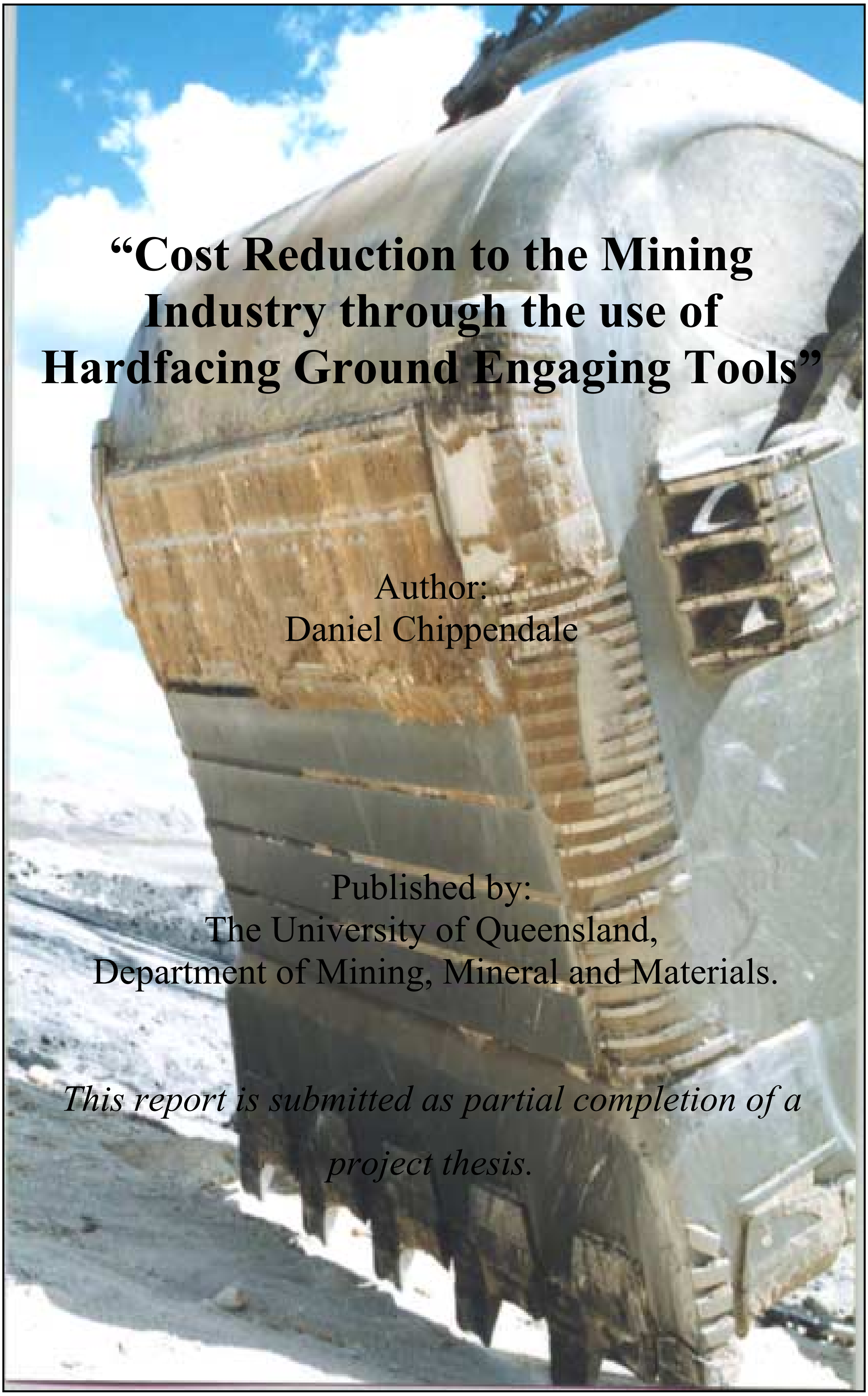

“Cost Reduction to the Mining Industry through the use of Hardfacing Ground Engaging Tools”

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Published by:
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This report is submitted as partial completion of a project thesis.

ABSTRACT

Wear must be minimised as it reduces the efficient performance of equipment. BHP Gregory and Abrasion Resistant Materials (A.R.M) commissioned this report to investigate the use of hardfacing to prevent wear in dragline buckets and dozer blades. This was achieved by analysing results from field trials that were conducted at BHP Gregory Mine, in which A.R.M's hardfacing was applied to various components of a Marion 8050 dragline bucket and on the cutting edges of four Caterpillar D11 dozers.

ACKNOWLEDGMENTS

I would like to thank the following people for their contributions to this report:

- Phillip Nixon, Production Supervisor, BHP Gregory Mine.
- Mr Tim Falkenagen, Managing Director, Abrasion Resistant Materials.
- Dr Martin Smith, lecture and supervisor, University of Queensland, Department of Mining, Minerals and Materials Engineering.

EXECUTIVE SUMMARY

Wear reduces the efficient performance of the equipment used in an open cut mining operation, and therefore must be minimised. For this reason, BHP Gregory and Abrasion Resistant Materials (A.R.M) commissioned this report to investigate the use of hardfacing to prevent wear in dragline buckets and dozer blades.

Abrasion Resistant Materials is one of the leading manufacturers of Mig Carbide hardfacing, a welding process that deposits tungsten carbide chips onto the wear surface. Field trials were conducted at BHP Gregory Mine in which A.R.M's hardfacing was used on various components of a Marion 8050 dragline bucket and on the cutting edges of four Caterpillar D11 dozers.

The following significant results were obtained when using hardfaced parts on the dragline bucket:

- The annual saving, on wear parts alone, is approximately **$163 147** (per dragline).
- When using hardfaced quick tips, there is a saving of **$225 000** (per dragline per year).
- The bucket fill characteristics were not noticeably changed, and the digging ability was increased due to the quicktips maintaining their original shape for a longer period of time.

When using hardfaced cutting edges on the dozer blades, the following results were obtained, based on an operating period of 6 000 hours:

- There was a saving in the cost of blades of **$13 120** per dozer.
- The saving in downtime was **$12 000** per dozer.
- When using hardfaced dozer blades on four dozers, there was a total fleet saving of **$100 480** (per year).
- Although the cutting ability of the blade decreased in unbroken ground, it was quite satisfactory for use in broken or soft ground. Eg. Rehabilitation

The two major risks with the implementation of hardfacing at an open cut mine are the changing in geology and using hardfacing in unsuitable conditions. However, with proper management practices, these risks are controllable.

It is the conclusion of this report that by using A.R.M's hardfacing on dragline components and dozer cutting edges, savings can be achieved by the ensuing reduction in the cost of wear parts and the resultant decrease in downtime.

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1.0 Introduction

As the mining industry tends towards the use of large equipment with greater production capacity there is a growing importance in ensuring machine efficiency, as any losses can dramatically reduce production. Wear has a major influence on the efficient running of the equipment used in an open cut mining operation and therefore needs to be reduced. It is for this reason that BHP Gregory and Abrasion Resistant Materials (A.R.M) commissioned this report to examine wear prevention of dragline buckets and dozer blades. Field trials commenced at BHP-Gregory in December 1999 in which A.R.M's Mig carbide hardfacing was applied to dragline quick tips. The results from this trial showed great potential and were later expanded to incorporate other high wear areas of the dragline bucket and dozer blade.

This report investigates the results of these ongoing field trials not only by calculating the cost savings when using hardfaced wear parts, but by also examining other issues such as changes in dragline bucket flow characteristics, digging ability, safety and dozer blade cutting ability, personnel safety and project risk.

The following is the scope of this report and allows hardfacing on ground engaging tools, specifically dragline buckets and dozer blades, to be effectively evaluated.

1. Identify the cost/influence of wear in the mining industry.
2. Examine the different types of wear and their prevention.
3. Identify the major pieces of equipment subject to wear in open cut mining operations.
4. Examine the dragline bucket for wear and evaluate the implementation of hardfacing.
5. Examine the dozer blade for wear and evaluate the implementation of hardfacing and design modifications.

2.0 Literature Review

Abrasion Resistant Materials Pty Ltd, [Online]. Available at: http://www.arm.com.au [Accessed July 4 2000]

Abrasion Resistant Materials is a Brisbane-based company that provides hardfacing products/services to the mining industry. Their web-site contains information based on specific hardfacing applications which have been trialed, including dragline buckets, dozer and grader edges, wheel loaders and excavators. A.R.M has also conducted a costing analysis which was essential when determining the viability of the process. This web-site covers the varied types of mining hardfacing applications, provides case studies and evaluates the extra cost of the process compared with the benefits gained.

Budinski, K G, 1988. Surface Engineering for Wear Resistance. 420 p (Prentice-Hall: New Jersey)

A metallurgical consultant, Kenneth Budinski, who examined the different aspects of surface engineering, compiled this book. The book initially examines the different types of wear and then describes the processes that can be employed to reduce this wear. It proved an invaluable asset in identifying the specific type of wear which was being examined, and in suggesting alternative methods for wear reduction. It examines the different coatings that can be applied to a material when using hardfacing techniques, to increase its wear resistance. Also identified are the consumables used in the hardfacing process, their effect on their environment and the history of surface engineering. Aside from the topics listed above, only a limited amount of additional information was garnered from this book, as the remainder details the processes of the different hardfacing techniques, which is outside the scope of the report.

Cladded wear plates find mining applications, [online].
Available at: http://www.cladtechnologies.com/Articles/Minetec/mintec.htm
[Accessed July 4 2000]

This website provides information on the use of hardfaced, cladded wear plates on dragline buckets to counteract the effects of wear. It outlines the use of hardfacing in every day life and its history. Also, the comparison of Hardness V's Wear is discussed in an article which was essential in establishing the specific type of hardfacing needed to counteract wear. Most of the available information on hardfacing focuses on hardfacing the actual item, rather than placing a hardfaced plate over the area of wear. Although it is not possible to use cladded wear plates in all applications, its examination will be useful in evaluating other alternatives or extensions of hardfacing. The website does not provide any evidence of the actual benefits of using cladded wear plates, and therefore was only used to provide a possible alternative to hardfacing.

Dasgupta, R, et al, 1997. Surface engineering for improving performance of mining and agricultural implements. *Surface Engineering*, 13(2):123-127
The paper examines the wear and erosion of ground engaging tools in both mining and agricultural sectors. It is an overview of a surface engineering technique's ability to improve the tribological performance of different types of equipment. Several case studies evaluating different hardfacing processes have been examined and evaluated. The paper was useful in determining the necessary type of hardfacing technique to be adopted, given the operating conditions and monetary constraints.

Garrett, G G, et al, 1986. Experimental trends in the assessment of composition and wear process variables for weld deposited hardfacings for abrasive wear resistance. *Weld Surfacing,* 2:157-174.
This paper has categorised the different types of wear and also investigates the strength of the different materials used in hardfacing processes. The article bases its evaluation of the hardfacing materials on the microstructure of the elements or alloys used. Hence, the information contained within the paper delves into far greater depth of the chemical composition and microstructure than that which was required for this report. However, it provided essential information for establishing the impact of wear on surface materials.

Kingsbury, G R, 1988. Wear Resistance of Metal and Alloys, in *proceedings of a conference held in conjunction with the 1988 World Materials Congress,* p 113 (ASM International: USA).

This book investigates the basic wear properties of different materials. This was useful in determining the initial wear properties of the components before they are hardfaced. It was also useful in determining the most suitable type of hardfacing for an application, by comparing the abrasive material with that selected for the hardfacing. Also examined are the components of the different types of wear and methods used to minimise material wear. This was useful in isolating the type of wear on the various parts of the dragline bucket. The book identifies other wear reduction techniques, which were useful in understanding and evaluating the types of wear reduction currently used on a piece of mining equipment. These methods, when compared to hardfacing techniques, allow the benefits of hardfacing to be identified and quantified.

Although this book does not specifically focus on the use of hardfacing techniques, it discusses the basic premises for the need of such wear reduction methods.

Llewellyn, R and Tuite, C, 1995. Hardfacing fights wear in oil sands operation, *Welding Journal (Miami),* 74(3):55-60.

The above article specifically investigates the significant role surface engineering has on increasing both surface wear resistance and productivity. Also discussed is the substantial reduction in repair and replacement costs. Although the article does not directly relate to coal mines, the welding processes used on the equipment and its exposure to abrasive materials means that the disadvantages and advantages of the system will be relevant.

Mega, A H and Fabshield F, 1993. Weld surfacing keeps coal on line. *Welding Riview International*, 12(1):18-21.

This paper looks at a subsidiary of BHP that is currently using welding processes on its heavy mining equipment, such as dragline buckets and hammermills. The improvement of service life and financial savings are discussed. This paper also investigates the increase in productivity gained as a result of hardfacing weld techniques. Maintenance labour costs are identified as the greatest saving when the hardfacing process is used. The paper was not heavily used as it only briefly discusses the key aspects, relating to the thesis, before delving into the welding composition side of hardfacing.

Milled tooth hardfacing, [Online].
Available at: http://www.geodiamond.com/tool/cs_feats.htm [Accessed on July 4 2000]
Another area in the mining industry where hardfacing has been trialed is on drill bits and related items. This website details the different types of hardfacing and its placement on the bit to give the drill specific properties. The technologies outlined in this website include self-sharpening drill bits and increased wear resistance. This data was be useful in establishing the types of hardfacing used on metal and the benefits that could be gained. Although this website provided another example of hardfacing, it was of minor relevance to hardfacing applications in the mining industry.

Welding Technology Institute of Australia, 1996. Industry Guide to Hardfacing for The Control of Wear, Ben Gross (ed), 28 p (Welding Technology Institute of Australia: Lidcombe, NSW)
This technical note was developed by the Welding Technology Institute of Australia. It initially examines the health and safety aspects of hardfacing operations, then progresses to identify the different types of wear. The selection of the most suitable hardfacing process is discussed and is an aid in determining whether the technique currently being used is the most suitable. Typical hardfacing patterns are examined and the economics of hardfacing are discussed. The book outlines many major issues covered in the thesis and was be used extensively.

3.0 Company Review

3.1 About A.R.M

Abrasion Resistant Materials Pty Ltd is one of Australia's largest manufactures of Tungsten Carbide Hardfacing. They achieve this by utilising proprietary welding techniques to apply tungsten carbide to various wear parts.

A.R.M is a Brisbane-based company currently employing six permanent staff and numerous casual staff members and has Mr Tim Falkenhagen as Managing Director.

Mr Falkenhagen spent 17 years managing and maintaining earthmoving equipment throughout Australia. He has held a range of positions, including: on-site maintenance fitter, maintenance manager and a technical consultant for a major equipment supplier.

During this period he recognised a need for an increase in the life of wear parts which led him to investigate the Tungsten Carbide Hardfacing process. After an extensive analysis of the current process, and by applying his knowledge gained from years of industry exposure, Mr Falkenhagen designed a method of applying tungsten carbide hardfacing which was far superior to any existing welding process.

This Hardfacing process utilises Mig Carbide welding to apply tungsten carbide chips onto the parent metal. The depth of penetration and the amount of tungsten carbide deposited before solidification, are some of the major differences between the hardfacing applied by A.R.M and that of its competitors. Another advantage of A.R.M's hardfacing is that the parent metal is not dramatically weakened by its application. This is supported by independent tests which examined various hardfaced parts and noted that the Heat Affected Zone extended only 1.0mm below the hardfacing matrix, and was same hardness as the parent metal.

Since the development of this process, A.R.M has grown to become a premium manufacturer of tungsten carbide hardfacing by continual innovation and the setting of higher standards in terms of both wear rates and overall cost effectiveness.

A.R.M identified that this new hardfacing process had numerous applications in the mining industry, including increasing the surface wear life of the following pieces of earth moving equipment:

1) Dragline buckets
2) Dozer Blades

3) Grader Blades
4) Excavator Buckets

When using A.R.M’s hardfacing process on wear parts, their life is greatly increased and the mine’s maintenance program is reduced. A.R.M has catered for this transition by developing an alternative maintenance strategy to correspond with an individual mine’s needs.

3.2 About BHP

“In Australia, BHP Coal operates seven open-cut mines and one underground mine in the Bowen Basin, Queensland, and five underground mines in the Illawarra, NSW. Annual shipments typically represent approximately one third of Australia's total coal exports and twenty per cent of the world's seaborne trade in coking coal.” (BHP net)

BHP manages the coal mining operations in Central Queensland on behalf of their owners - the Central Queensland Coal Associates (CQCA) Joint Venture, the Gregory Joint Venture and BHP Mitsui Coal Pty Ltd. BHP currently owns 52.1 per cent in five CQCA mines, 64.14 per cent in Gregory and Crinum mines and 80 per cent in two BHP Mitsui Coal Mines. (BHP Net)

Detailed exploration in 1957 led to the establishment of BHP’s open-cut mining operations at Mitsui Coal at Moura in 1961. The development of the Central Queensland Coal deposits in the 1960s was aimed at supplying growing world markets. The exploration continued to discover significant coking coal reserves, and the Blackwater open-cut mine in Queensland's Bowen Basin was established in 1967. Subsequently, the CQCA joint ventures developed the Goonyella, Peak Downs, Saraji and Norwich Park open-cut coalmines. BHP purchased the operations of Utah International Inc from General Electric of the United States in 1984, hence, acquiring the Utah Development Company. (BHP net)

In response to an increasing demand for high-grade coking and thermal coals around the world, BHP commissioned Gregory mine in 1979, Riverside mine in 1983 and Crinum, an underground mine, in October 1994. (BHP net)

Gregory open cut coal mine is situated approximately 60 kilometres north-east of Emerald and 270 kilometres west of Rockhampton. Gregory’s coal reserves lie within the Lilydale seam which forms part of the Permian German Creek Coal

Measures. The seam averages 3.5 metres in thickness and dips at approximately 3-4 degrees. A total of 46 workers are employed, with 29 of these working in the open cut. The core production equipment is comprised of a Marion 8050 dragline and a fleet of 8 dozers, including 5 CAT D11's. Annual coal production from the open cut is approximately 1.4 million tonnes which is sold for coking, thermal and PCI applications.

4.0 Mining & Hardfacing

4.1 Wear & its Effects on the Mining Industry

"Wear is defined as damage to a solid surface, most of the time in the form of a gradual material removal from a surface, by the action of relative motion with a contacting substance or substances." (Budinski 1988)

As a by-product of nearly all mining operations, wear is costing the mining industry a large amount of money in the following areas:

1. Reduced life of components
2. An increase in parts inventories
3. An increase in operating costs
4. An increase in maintenance costs and maintenance staff levels
5. An increase in machine downtime

To quantify the effects of wear in the mining industry with a monetary figure is a very difficult task, however, the Welding Technology Institute of Australia (1996) estimated this to be in excess of 1 Billion dollars per annum. With wear directly adding to production costs it is necessary to identify a method of reducing its influence. This can only be achieved by firstly identifying the type/s of wear that is/are present and then implement a suitable surface engineering process.

5.0 Identification of Wear, Wear Modes and Solutions

The type and mode of wear affecting equipment in mining operations are specified below.

5.1 Wear Types

There are literally hundreds of terms used to describe various wear effects. Budinski (1988) states that the loose use of these terms tends to confuse the understanding of wear modes and the solution to wear problems. Therefore to rectify any misconceptions the four major categories of wear types are identified below:

5.1.1 Abrasion

Abrasion wear is produced by hard particles forced against and moving along a softer solid surface. An additional qualifier for the abrasion process is that the abradant usually has sharp angular edges that produce a cutting/sheering action on the softer solid (Budinski 1988*)*.

5.1.2 Erosion

Erosion involves the progressive loss of original material from a solid surface due to the mechanical interaction between that surface and a fluid, or fluid stream, which may, or may not, contain solids (Budinski 1988).

5.1.3 Adhesive Wear

Adhesive wear involves the progressive loss of material from a solid surface in relative motion that is, at least, initiated by localised bonding between these surfaces. In adhesive wear, bonding between the contacting surfaces eventually results in the fracturing of material from one or both of the interacting surfaces. In many instances a problem exists with using the term *adhesive wear* because, after this initial step, the wear debris particles usually separate the sliding surfaces and the wear then becomes abrasive. It is for this reason that adhesive wear is commonly referred to as Metal-to-Metal wear (Budinski 1988).

5.1.4 Surface Fatigue

Surface fatigue results in the fracture of a material from a solid surface caused by the cyclic stress produced by repeated rolling or sliding on a surface. Surface fatigue can be accelerated by the combination of cyclic high temperatures and mechanical wear properties (Budinski 1988).

5.2 Wear Modes and Prevention

To accurately identify the wear process, in a given situation, the four major wear types above can be broken down into specific modes of wear. Discussed below are the wear modes that a typical machine, operating in open cut mine, would be exposed to. Once this is achieved the selection of the correct wear prevention technique can be made.

Before examining the different modes of wear, Figure 5.1 gives a clearer understanding of how they relate to each other and to the four wear types.

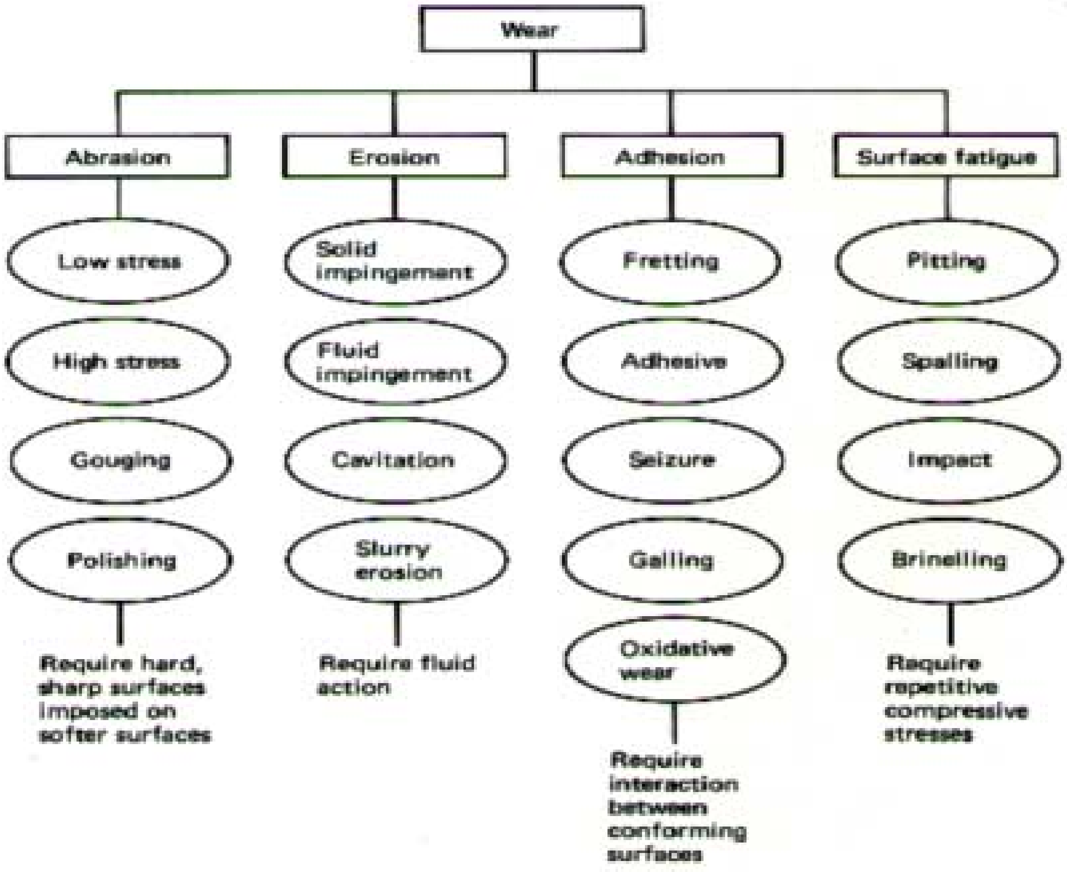

Figure 5.1 (Budinski 1988)

5.2.1 Abrasion

a) Low Stress

Low stress abrasion or scratching abrasion is essentially a primary mechanism for damage. Equipment subject to low-stress abrasion displays evidence of structural wear caused by hard, sharp particles/surfaces plowing the surface of the equipment out in furrows. The low-stress qualifier means that the abradant interacts with the other surface with a relatively low normal force (Budinski 1988). See Figure 5.2

Examples:

Plowing sandy soil, cutting materials containing abrasive substances, sliding heel of dragline bucket on dirty environments, ash-handling equipment and mineral handling equipment.

Surface engineering solutions include:

Hardfacing, hard plating, case hardening and selective hardening,

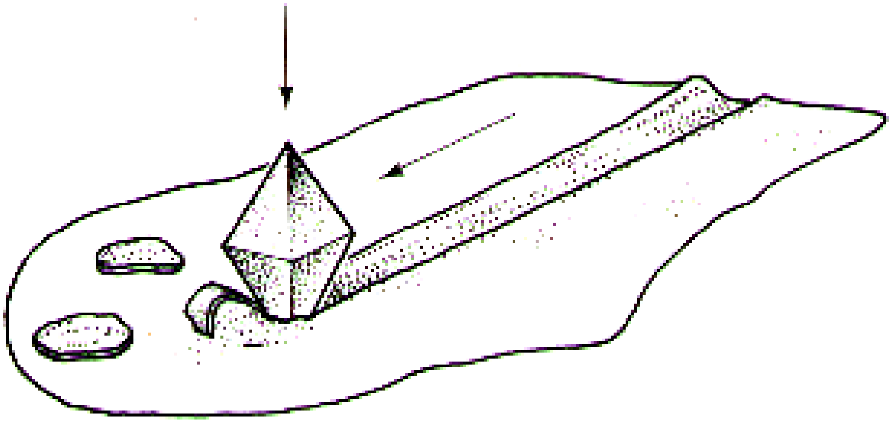

Figure 5.2 Low Stress Abrasion (Budinski 1988**)**

b) High Stress

This form of abrasion is characterised by scratching, plastic deformation of surfaces and pitting from impressed particles. The wear process is similar to low-stress abrasion, however, high-stress abrasion results in more severe damage (Budinski 1988).

See Figure 5.3

Examples:

Milling of materials, rollers running over dirty tracks, earth-moving equipment, farm implements in hard soil, heavily loaded metal-to-metal sliding systems (dragline chains and shackles) in dirty conditions.

Surface engineering solutions include:

Hardfacings, cemented wear tiles, flame hardening, cast white iron wear plates.

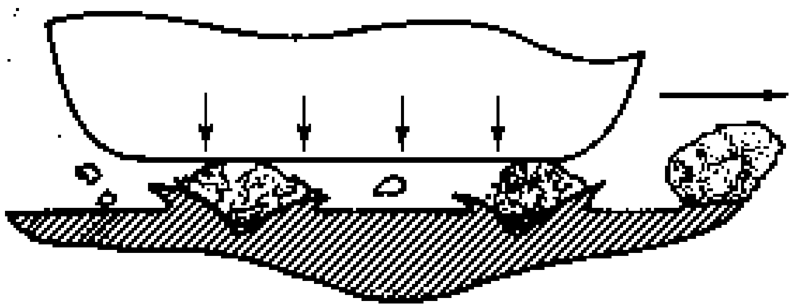

Figure 5.3 High Stress Abrasion (Budinski 1988)

c) Gouging

Gouging abrasion is the removal of material by repetitive compressive loading of hard materials, such as rocks, against a softer surface. The mechanism of gouging abrasion is plastic deformation coupled with chip removal, both normally macroscopic. The impact of a single rock on a metal surface is unlikely to result in chip removal, however, fatigue can result in material removal where two gouges overlap (Budinski 1988*)*. See Figure 5.4

Examples:

Hammermill hammers, ball mill parts, jaw crushers, earthmovers and agricultural implements operating in rocky strata.

Surface engineering solutions include:

Hardfacing and steel wear plates

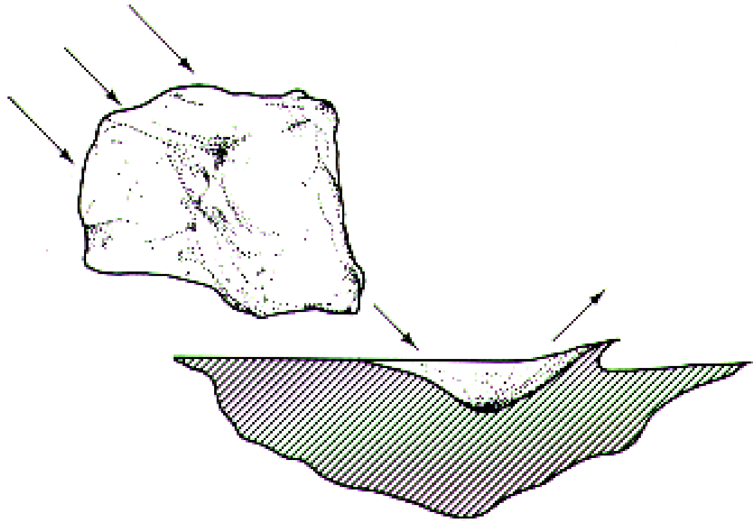

Figure 5.4 Gouging Abrasion (Budinski 1988)

d) Polishing

Polishing wear is the progressive unintentional removal of material from a surface by the action of rubbing from other solids, under such conditions that material is removed without visible scratching, fracture or plastic deformation of the surface. Materials that have been subjected to polishing wear usually have a smoothed or brightened appearance. An illustration of polishing wear can be seen in Figure 5.5 (Budinski 1988).

Examples:

Lens-grinding equipment, fans moving fine particles and mixing devices for fine particles.

Surface engineering solutions include:

Hardfacing, hardplating, selective hardening, wear tiles, thin-film hard compounds.

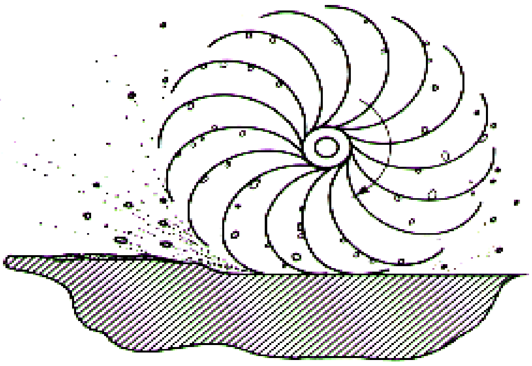

Figure 5.5 Polishing Wear (Budinski 1988)

5.2.2 Erosion

a) **Solid impingement**

Impingement means the act of hitting or striking Solid particle impingement is erosion produced by a continuous succession of impacts from solid particles onto a surface. The mechanism of surface damage can be plastic deformation, with each impinging particle forming a small crater, or it can be by microchip removal (Budinski 1988). See Figure 5.6

Examples:

Fans exhausting dirty air, conveyance of solid particles and exhaust systems.

Surface engineering solutions include:

Carbide or ceramic wear tiles.

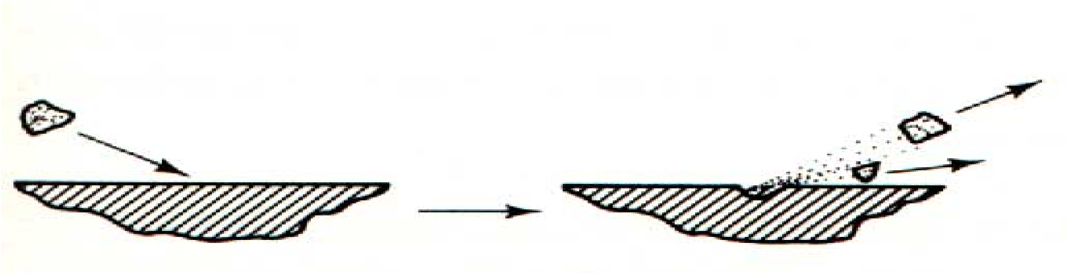

Figure 5.6 Solid particle impingement (Budinski 1988)

5.2.3 Adhesion

a) Fretting

Fretting wear is defined as the oscillatory movement, of small amplitude, between two solid surfaces. If often occurs between surfaces that are not supposed to experience relative motion. Fretting wear is usually microscopic in nature and is initiated by local adhesion of the mating surfaces. This form of wear produces low rates of material removal and is often ignored until it results in surface fatigue (Budinski 1988). See Figure 5.7

Examples:

Gears

Surface engineering solutions include:

Hardfacings, soft platings and lubrication

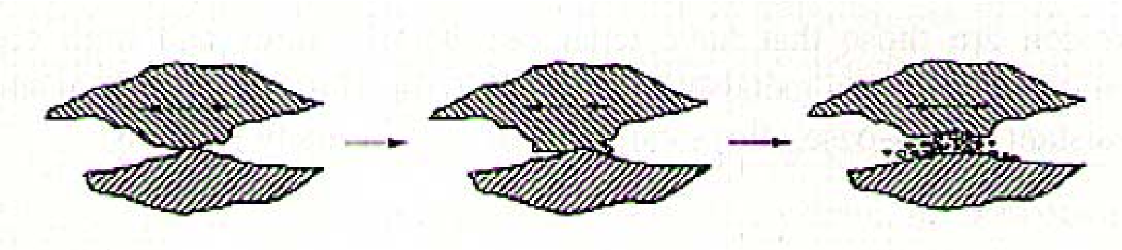

Figure 5.7 Fretting (Budinski 1988)

b) Adhesive

Adhesive wear is caused by localised bonding between two contacting surfaces. This leads to material transfer between the two surfaces, or losses from either. Wear results when the forces that bond the two items together become greater than the molecular forces that keep the structural material intact. See Figure 5.8. The four types of adhesive wear are:

1. Metal to Metal
2. Ceramic to Ceramic
3. Ceramic to Metal
4. Plastic to Metal (Budinski 1988)

Examples:

O-ring seals, gears, cams and pistons.

Surface engineering solutions include:

Hardfacing, hard metal platings, case hardening and thin film coatings.

Figure 5.8 Adhesive Wear (Budinski 1988)

c) Seizure

Seizure is the stopping of relative motion as a result of friction between two surfaces. Although there is not necessarily a loss of material from either, localised solid welding is the usual mechanism of seizure (Budinski 1988). See Figure 5.9

Examples:

Thermal expansion of pistons, valves and seldom used, unlubricated sliding systems.

Surface engineering solutions include:

Hardfacing, case hardening and thin film coatings.

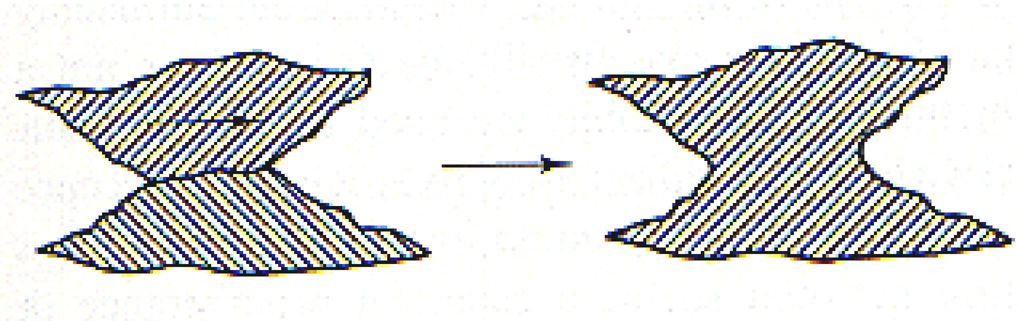

Figure 5.9 Seizure (Budinski 1988)

d) Galling

Galling is the damage to one or both surfaces in a solid to solid sliding system, caused by macroscopic plastic deformation of the apparent area of contact, leading to the formation of surface areas that interfere with sliding (Budinski 1988). See Figure 5.10

Examples

Gate valves, slides and heavily loaded unlubricated sliding members.

Surface engineering solutions include:

Hardfacing, soft metal plating, hardcoating, case hardening, selective hardening, lubrication and wear plates

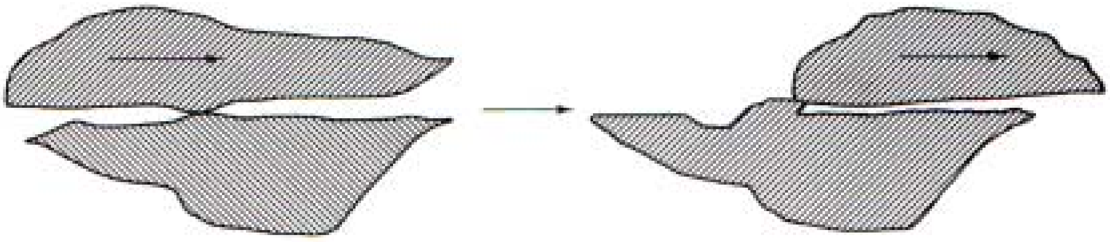

Figure 5.10 Galling (Budinski 1988)

5.2.4 Surface Fatigue

a) Pitting

Pitting is the removal or displacement of material by a fatigue action which forms cavities in a surface. In surface fatigue, pitting is usually caused by repeated stresses from sliding or rolling, causing sub-surface cracks that grow to produce a localised fracture (Budinski 1988). See Figure 5.11.

Examples:

Gear teeth, cam paths and rails or metal tyres

Surface engineering solutions include:

Hardfacing and selective hardening.

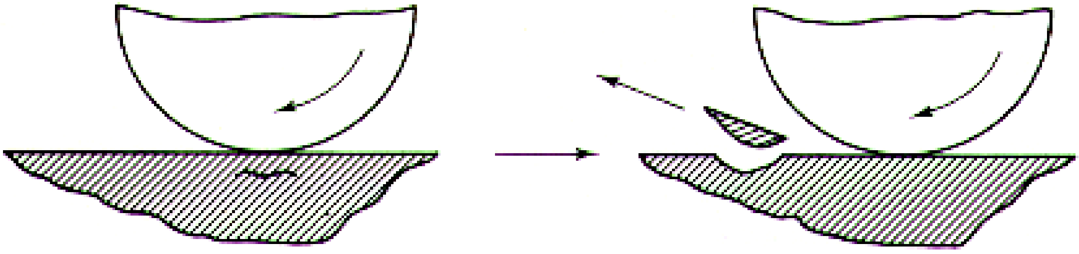

Figure 5.11 Pitting (Budinski 1988*)*

b) Spalling

Spalling is where particles fracture from a surface in the form of flakes. Spalling arises from the same mechanisms as pitting and normally occurs in rolling systems that have thin hard coatings (Budinski 1988*)*. See Figure 5.12.

Examples:

Coated cams and gears, rails and thin platings

Surface engineering solutions include:

Hardfacing and selective hardening

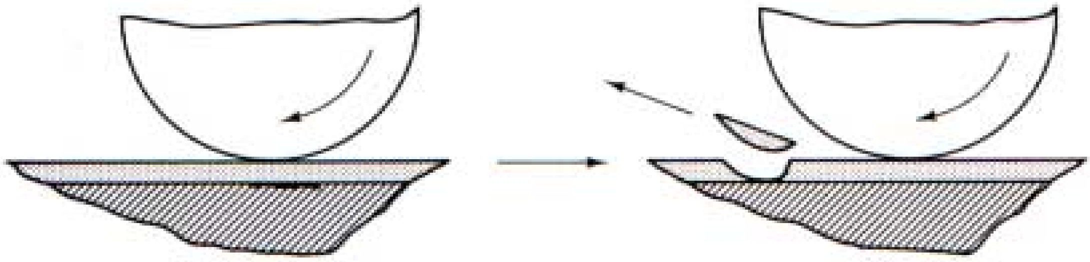

Figure 5.12 Spalling (Budinski 1988**)**

c) Impact

Impact wear encompasses material damage and removal by the repetitive impacting of two solid surfaces (Budinski 1988). See Figure 5.13.

Examples:

Hammer heads, pneumatic drills and striking anvils.

Surface engineering solutions include:

Hardfacings, selective hardenings and carbide wear tiles.

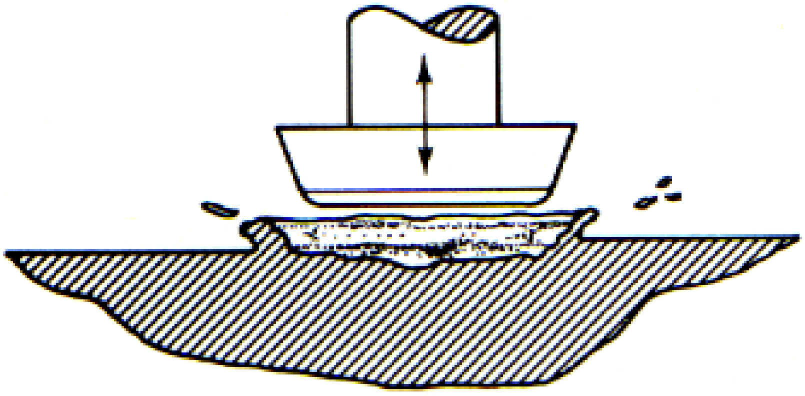

Figure 5.13 Impact (Budinski 1988*)*

d) Brinelling

Brinelling is the wear term used to describe surface damage of solids by repeated local impact or by static overload. It is a form of surface damage characterised by local plastic denting or deformation of the surface. Material is not necessarily removed, it may only be displaced (Budinski 1988). See Figure 5.14

Examples:

Static overloads on wheels, rails and rolling element bearings.

Surface engineering solutions include:

Hardfacings, selective hardening and carbide wear tiles.

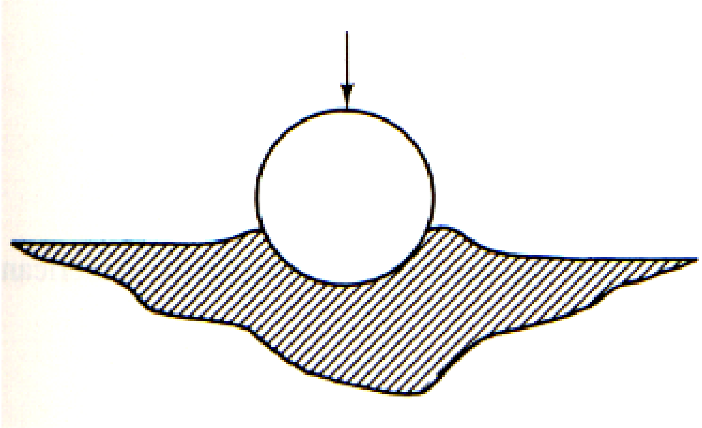

Figure 5.14 Brinelling (Budinski 1988*)*

For a brief summary of the fore-mentioned wear types, wear and solutions, refer to Appendix 1.

5.3 Major Sources of Equipment Wear in Open Cut Mining Operations

To examine the major sources of wear in an open cut mining operation, it is first necessary to identify the types of equipment used. The following are major equipment items that are commonly utilised:

- Draglines
- Dozers
- Excavators
- Drills
- Rear dump trucks
- Graders

As this report was undertaken in conjunction with BHP Gregory, an open cut mining operation employing a Marion 8050 dragline and a fleet of eight Caterpillar D11 dozers, wear examination and prevention has been limited to these two types of equipment.

5.4 Processes Used to Counteract Wear

The solutions to the wear types and wear modes, as outlined above, can be categorised into the six traditional techniques listed below.

1. Separate conforming surfaces with lubricant.
2. Make the wearing surface hard.
3. Make the wearing surface resistant to fracture.
4. Make the eroding surface resistant to corrosion.
5. Choose material that are resistant to interaction in sliding.
6. Make the wearing surface fatigue resistant (Budinski 1988).

These methods of wear prevention are employed according to the wear mode and wear type experienced by the exposed material.

5.5 Hardfacing

This report will investigate the second wear prevention technique listed above, namely, making the wearing surface hard. This is achieved by utilising a surface engineering technique called hardfacing.

5.5.1 What is Hardfacing?

The hardfacing that is being examined in this report is a Mig Carbide welding process that applies Tungsten Carbide to the wear surface.

Tungsten was first discovered in Sweden in the 1780’s by Carl Scheele. One of its main uses in its first 100 years was as the light filament in Carbide Lights.

The first person to use Tungsten Carbide to hardface wear parts was Mr. Marion Woods, in the 1920’s. Mr Woods was a welding engineer with the US Company, Stoody, which either directly or indirectly was involved with the development of most of the traditional hardfacing options still available today, including Mig Carbide Hardfacing. Other hardfacing weld applications include:

- Manual Metal Arc Welding
- Submerged Arc Welding
- Flux Cored Welding
- Gas Metal Arc Welding
- Gas Welding
- Gas Tungsten Arc Welding
- Plasma Transferred Arc Surfacing
- *Laser surfacing (Welding Technology Institute of Australia 1996)*

5.5.2 A.R.M’s Hardfacing Process

Since its invention, the Mig Carbide hardfacing process has been improved and refined by numerous hardfacing applicators. Abrasion Resistant Materials (A.R.M) developed and are currently applying the latest Mig Carbide techniques to hardface wear parts for the mining industry.

The item which is to be hardfaced is initially cleaned of all dirt, paint and any other inhibitor of the hardfacing process. See Appendix 2.

Although A.R.M's hardfacing process is a heavily guarded trade secret an examination of Figure 5.15 will provide a better insight into the type of process used by A.R.M*.

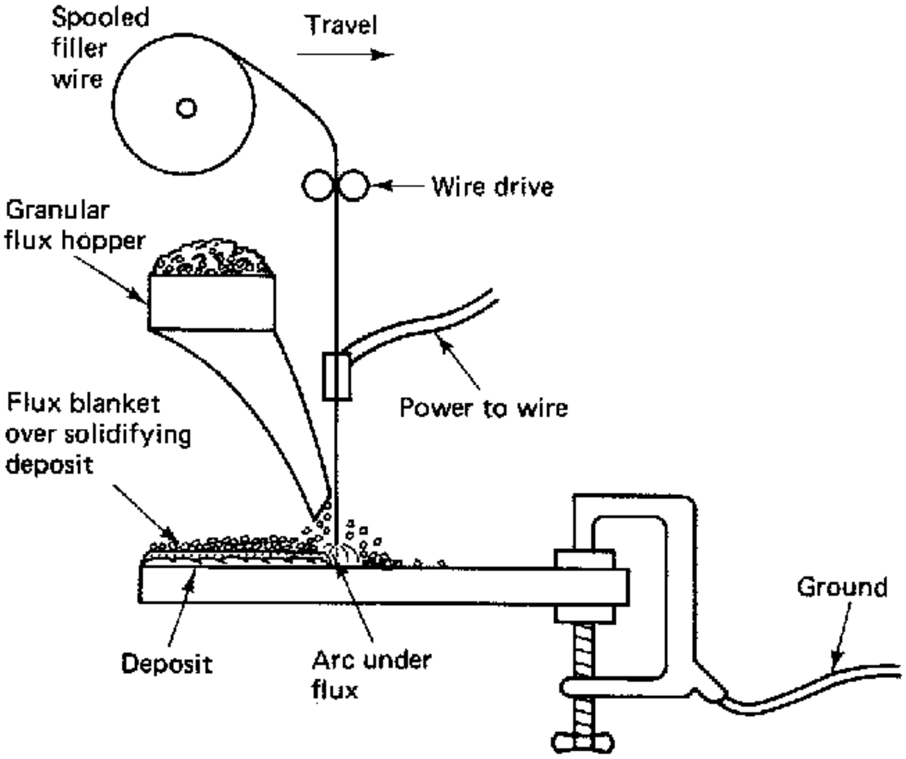

Figure 5.15 Hardfacing Process

A.R.M 's hardfacing method is similar to that depicted in the diagram above except that tungsten carbide chips, not granular flux, are being deposited onto the surface of the parent metal. Wire is fed through the Mig welder; the welding process is initiated on contact and forms a molten puddle on the surface of the host metal, into which the Tungsten Carbide chips are fed. This puddle then solidifies, leaving the Tungsten Carbide chips being held firmly within the weld matrix.

The hardfaced part is finished, cleaned, painted and shipped to the desired location. For a picture of a hardfaced adaptor ready to be shipped, refer to Appendix 3.

A.R.M 's hardfacing process is relatively quick, with a very short turn around period.

5.5.3 Selection Material Type to be used for Hardfacing Application

The selection of the consumables used in the hardfacing process is beyond the scope of this report and will not be discussed in great detail. However, when selecting a hardfacing alloy, the basic objective is to provide the optimum solution to the wear

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A.R.M* is an abbreviation of the company name Abrasion Resistant Materials Pty Ltd problem. A typical approach to the selection of candidate alloys involves the following steps:

1. Determine the wear mode or modes.
2. Determine the load, temperature and impact conditions.
3. Select a candidate alloy from available tables.
4. Assess the suitability of candidate alloys considering
    - Comparison with prior experience
    - Compatibility with substrate materials
    - Suitability for any heat treatment or machining requirements
    - Availability of materials, equipment and personnel
    - Cost
5. Verify selection with practical tests and/or field trials *(Welding Technology Institute of Australia 1996).*

If this process is followed, then the optimal hardfacing alloy/s should be identified.

6.0 Case Study of Dragline Bucket

Draglines are large pieces of equipment used to remove overburden in open-cut mining operations. There are several types and numerous models of draglines, ranging in price from 20-150 million dollars, available. However, each has the following characteristics:

1. They utilise a bucket, which is suspended by ropes, to remove and relocate overburden.
2. They represent a large proportion of the mine's investment in the operation.
3. Any downtime results in a large cost to production.

As the dragline is estimated to be worth $10 000/hr in cost to production, it is imperative that it continually operates efficiently and any loss in production or unnecessary maintenance expense is minimised or eradicated.

The dragline bucket experiences a large amount of wear which causes losses in production and a large expenditure in replacing the worn items.

It is for these reasons that field trials investigating the use of hardfacing to counteract wear have been conducted on a Marion 8050 dragline at BHP Gregory Mine.

6.1 Illustration of Bucket and Identification of Different Types of Wear Present

The components of a dragline bucket are outlined in Figure 6.1, Figure 6.2, Figure 6.3 and Figure 6.4

All the components illustrated above are exposed to wear caused by the continuous interaction with the overburden. The most prominent wear modes that the dragline bucket is exposed to during operation are:

1. Low stress abrasion
2. High stress abrasion, mainly around the heel area
3. Gouging abrasion
4. Polishing wear
5. Impact erosion

All of these wear modes can be addressed using A.R.M's hardfacing procedure found in Figure 5.15. However, there are some areas of the dragline that experience different wear, including the inside of the dragline shackles and chains, and need to managed using processes other than A.R.M's hardfacing.

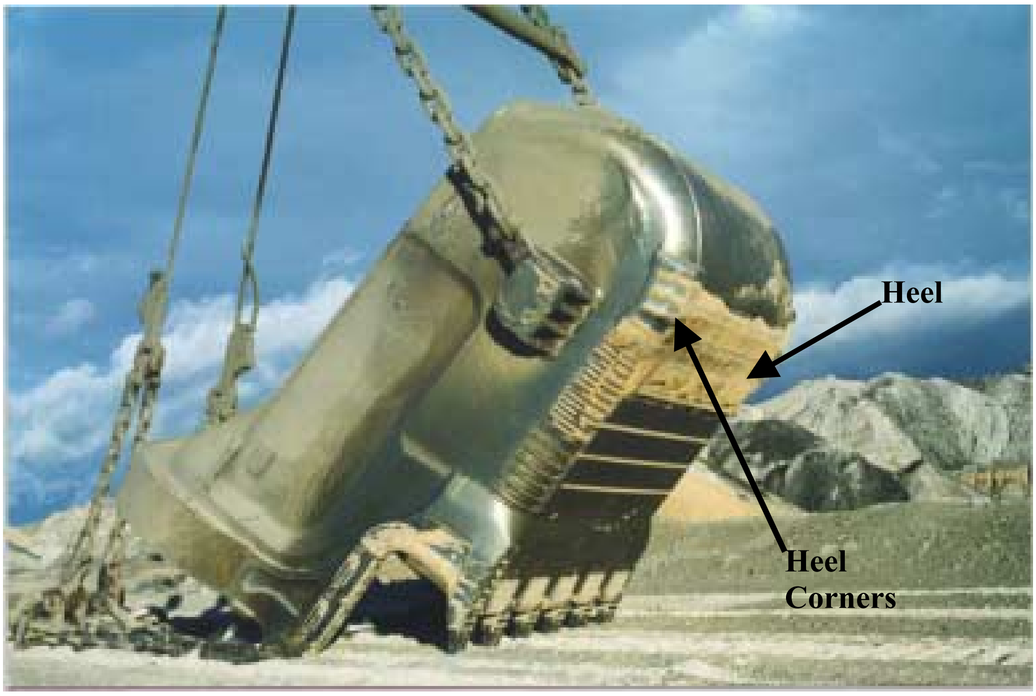

Figure 6.1

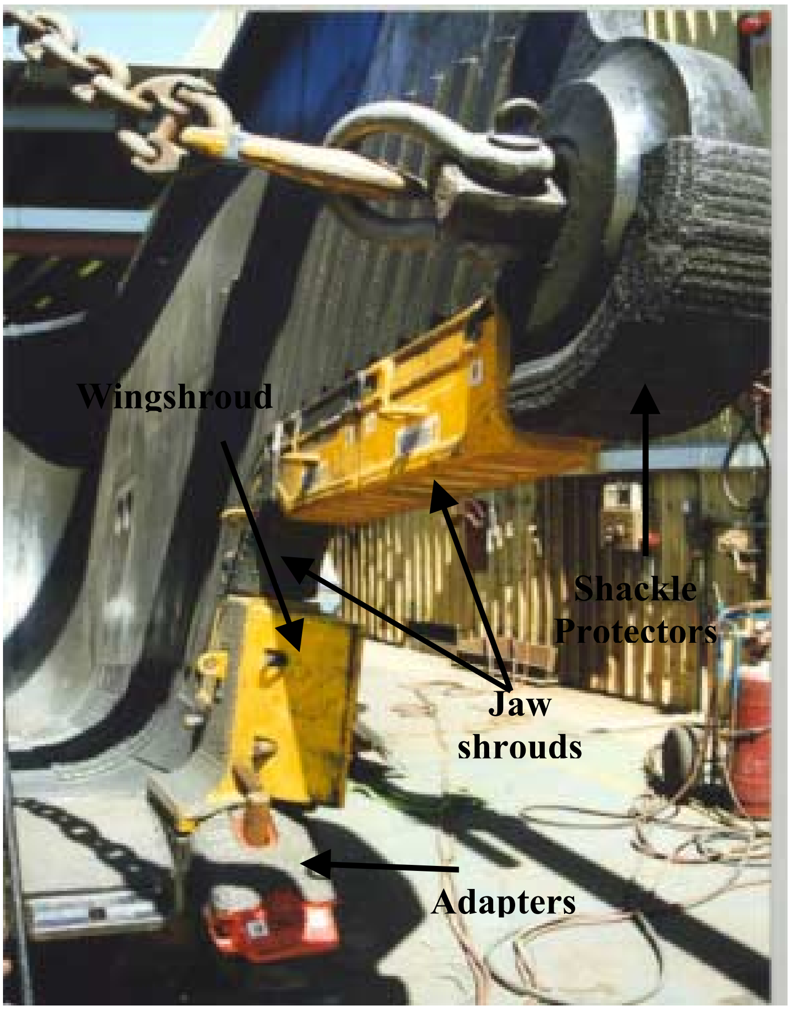

Figure 6.2
NOTE: P&H Bucket – used for illustration purposes only

Figure 6.3 A.R.M's Heel Package at BHP Gregory after 3 million BCMs

Figure 6.4 A.R.M's Heel Package on a P&H Bucket after 14 million BCMs

6.2 Parts of the Bucket Currently which are Currently Hardfaced at BHP Gregory Mine

- .Adaptors are shown in Appendix 2 & 3
- Quick tip trials one, two and three are shown in Appendix 4, 5 & 6
- Wingshroud are shown in Appendix 7
- Heel packages can be seen in Appendix 8
- Shackle protectors are shown in Appendix 9
- Drag shackle can be found in Appendix 10
- Jaw shrouds can be seen in Appendix 11
- Adaptor nose protectors are in Appendix 12

6.3 Costing

The comparison of costs between using a hardfaced or non-hardfaced part is a complex issue. Therefore, costs will be broken down into:

1. The difference in cost between the wear parts themselves, and,
2. Other costs involved with maintaining the bucket.

6.3.1 Cost of Wear Parts

Examining the individual costs of the wear parts alone does not give an accurate understanding of any advantage or disadvantage present. This is because the cost of the hardfaced part includes the extra cost of hardfacing which is not offset by the increase in its life. To accurately compare a hardfaced to a non-hardfaced part, it is necessary to examine both the cost and life of each option.

It was decided that the costs and life spans of the different parts should be reduced to the common denominator of cents/BCM.

The first step is to itemise the costs of both the hardfaced and non-hardfaced parts. These can be seen in Table 1.

Table 1. Costs of Non-Hardfaced Parts Compared to those Hardfaced

	Cost of Non-Hardfaced Part (\$AUS)	Cost of Hardfaced Part (\$AUS)
Quick Tips	\$2025	\$3025
Adaptors	\$9395	\$16 145
Wingshroud	\$3864	\$7864
Heel	\$15 000	\$23 000
Shackle Protectors	\$1400	\$2800
Drag Shackle	Unknown	Unknown
Jaw Shrouds	\$4000	\$8 000
Adaptor Nose Protector	\$5000	\$10 000

The next step is to obtain the actual life span of each part from controlled field trials. BHP Gregory has conducted such tests and has provided the results found in Table 2.

Table 2. Comparison of Production Life for both Non-Hardfaced and Hardfaced Parts.

	Life of Non-Hardfaced Part (BCMs)	Life of Hardfaced Part (BCMs)
Quick Tips	200 000 – 250 000	1 000 000
Adaptors	2 000 000	4 000 000 – 5 000 000
Wingshrouds	2 000 000 – 3 000 000	15,000,000
Heel	4 000 000 – 4 500 000	15 000 000 – 20 000 00
Shackle Protectors	5 000 000	15 000 000
Jaw Shrouds	5 000 000	15 000 000
Drag Shackles	Field Trials Continuing	Field Trials Continuing
Adaptor Nose Protectors	Field Trials Continuing	Field Trials Continuing

Note: The specified life of adaptors can be increased by re-applying hardfacing.

By utilising the equation below, the cost in cents/BCM of the individual wear items can be found.

Wear Cost (cents/BCM) = Cost of Part (cents) / Production Life (BCMs)

Example calculation: Quick tips

Wear cost = ($2025 x 100) / 250 000 BCMs

= 0.81 cents

The wear cost of each item can be found in Table 3.

Table 3. Wear Cost Comparison of Wear Parts

	Cost of Non-Hardfaced Part (cents/BCM)	Cost of Hardfaced Part (cents/BCM)	Difference in Cost (cents/BCM)
Quick Tips	0.810	0.303	**0.508**
Adaptors	0.470	0.182	**0.288**
Wingshrouds	0.129	0.052	**0.076**
Heel	0.333	0.153	**0.180**
Shackle Protectors	0.028	0.019	**0.009**
Jaw Shrouds	0.080	0.053	**0.027**
Drag Shackles	Field trials not completed	Field trials not completed	Field trials not completed
Adaptor Nose Protectors	Field trials not completed	Field trials not completed	Field trials not completed
Total	**1.85**	**0.76**	**1.09**

Note: Adaptor cost per BCM is based on a life of three A.R.M rebuilds.

The annual savings when using hardfaced parts can now be calculated. This is achieved by calculating the total difference, in cents/BCM, between the two options and multiplying it by the annual production of the dragline of 15,000,00 BCMs. This was undertaken and the results can be found in Table 4.

Table 4. The Annual Savings when using Hardfaced Parts.

	Difference in Cost (cents/BCM)	Dragline Production (BCMS/yr)	Amount Saved per Part Type ($AUS)
Quick Tips	0.508	15,000,000	$76,125
Adaptors	0.288	15,000,000	$43,166
Wingshrouds	0.076	15,000,000	$11,456
Heel	0.180	15,000,000	$27,000
Shackle Protectors	0.009	15,000,000	$1,400
Jaw Shrouds	0.027	15,000,000	$4,000
Drag Shackles	Field trials not completed	Field trials not completed	Field trials not completed
Adaptor Nose Protectors	Field trials not completed	Field trials not completed	Field trials not completed
Total	**1.09**	**15 000 000**	**$163 147**

The current **annual saving, on wear parts** alone, is approximately = **$163 147 per dragline**.

6.3.2 Other Costs/Issues

Machine down time

The dragline is crucial to the mine's production as it is the sole remover of overburden. As stated earlier, its dollar value to production was estimated to be approximately $10,000/hr. Therefore, any downtime is costly and needs to be eliminated. The cost to production of replacing bucket wear parts can be estimated by examining the amount of downtime it takes to *change them out*. However, not all hardfaced wear parts need to be replaced during regular shifts, causing interruption to production. Instead, their condition is monitored and replacement is left until a scheduled maintenance period. Although this periodic replacement has minimal effect on production, it still requires labour input which will be discussed later. All dragline components are replaced as part of Scheduled Preventative Maintenance except for the quick tips. Table 5 lists the decrease in downtime and the cost saved when using hardfaced quick tips.

Table 5. Bucket Wear Parts and Downtime for Replacement

	Regular Shift or SPM	Replace. Time (Hours)	Cost to Production ($AUS)	Non-Hardfaced ($AUS/yr)	Hardfaced ($AUS/yr)
Quick Tips (set)	Regular Shift	0.5	$5000	$300 000	$75 000
Total				**$300 000**	**$75 000**

From these calculations it can be seen that there is a downtime saving of **$225 000 (per dragline per year)** when using hardfaced quick tips.

Parts inventory

A large parts inventory is needed to supply the dragline with the wear parts necessary to maintain efficient production. However, at Gregory Mine the bucket wear parts are held at the store on consignment and are not paid for until they are actually used, resulting in no outlay for parts which are not in use.

This is one of the small advantages over using the hardfacing system in which the bucket components need to be purchased up-front, the cost of hardfacing added and the parts then stored until they are required. Although the initial outlay may be substantial, the number of sets of each component that need to be purchased is reduced by correctly timing the hardfacing applications to coincide with expected change out times. Any extra outlay is offset by the savings gained by their increased wear life as previously discussed.

Digging quality

The digging quality of the bucket is an issue that has to be investigated. Two features that have to be considered are the bucket's flow characteristics and its actual digging ability. After conducting field trials and talking to experienced dragline operators, who have used both hardfaced and non-hardfaced bucket configurations, the following information was obtained:

1. The bucket fill characteristics are determined by the shape of the bucket and the type of materials used for its construction/wear prevention. The flow characteristics between the standard bucket and hardfaced bucket were unchanged.
2. The length and quality of the quick tips largely determine the digging ability of the bucket. Standard quick tips wear in a manner that decreases the overall length of the tooth. Appendix 13 shows the wear of a standard quick tip after approximately 50 000BCMs. This wear decreased the digging ability of the tooth and it had to be replaced.

   When using the A.R.M* Hardfaced quick tip, the length and shape of the tooth is retained. This enables a high digging quality to be maintained for a longer period of work. This can be seen in by examining the quick tip in Appendix 14 which has completed 550 000 BCMs and was still digging well.

Safety & Worker Fatigue

There are always safety concerns when working with large heavy parts. When handling hardfaced wear parts there is an extra safety concern in that the wear parts are not only heavier than normal but that the hardfacing itself is a lot sharper. Based on experience at BHP Gregory, this poses a risk of those workers handling the wear parts suffering lacerations. However, this risk was easily managed by ensuring that those workers involved wore gloves when handling the hardfaced parts.

By limiting the number of wear parts that need to be replaced, there is also a reduction in the amount of stress and fatigue experienced by the workers. This is exemplified by the reduction in the number of sledgehammer hits required to replace wear pins. Although this results in obvious savings, they cannot be easily quantified in dollar terms.

Weight Comparison between standard buckets and those using Hardfaced Wear Parts

BHP Gregory has trialed both the ESCO heavy wear package and A.R.M's hardfacing package. During these trials both bucket options were examined for their weight and capacity. It was found that an unloaded bucket with the standard ESCO heavy wear package was considerably heavier than the A.R.M* Hardfaced bucket. Some of this weight reduction is due to the re-configuration of the wear package. Other things like rigging changes have also contributed to the weight reduction programme. We do not have the exact weight reduction figures that can be attributed specifically to the use of A.R.M* Hardfacing , however the overall weight reduction achieved on this Dragline Bucket package so far is around 9.0 tonnes (from 50 tonnes down to 41 tonnes). This reduction in weight does not increase the bucket’s capacity, although it does decrease the suspended load carried by the dragline each swing. The effect that this decrease in weight has on reducing dragline fatigue is not able to be measured quantitatively.

Bucket Life and Rebuild Life

ESCO originally identified areas of the bucket which were subjected to large amounts of wear. They designed packages which consisted mainly of detachable wear parts that could easily be installed without having to take the bucket out of service. However, some of these areas could not be made detachable and are at present welded onto the parent metal of the bucket. These parts still pose a problem because the bucket must be taken out of service for their replacement to be undertaken. Although hardfacing does not alleviate the need for removal of the bucket from service, it does increase the time it takes for the parts to wear, and therefore, the time interval between rebuilds. At BHP Gregory the working life of the bucket before rebuilds are required has increased from 5 months to 7 months. This extension of time also creates the opportunity to decrease the total number of buckets which are needed for the efficient running of a dragline.

Consumables

There are numerous consumables used when replacing the wear components of a dragline bucket. It is hard to quantify these but they include:

- Cost of necessary vehicles and their maintenance, petrol, registration and capital outlay.
- Consumables such as sledgehammers and pin-knocking equipment used when replacing pins securing wear items.

6.4 Summary of Costs Savings when Hardfacing the Dragline Bucket at BHP Gregory

From the results of field trials conducted at BHP Gregory, it can be seen that hardfacing wear-prone areas of the dragline bucket saves a substantial amount of money per annum. These costs can be broken down into two areas:

1. Those that can be quantified into dollar terms, and,
2. Those that are obvious savings but cannot be quantified into a dollar value.

The areas and results that can be reduced to a dollar value are found in Table 6 below:

Table 6. Summary of Cost Savings when using Hardfacing on Dragline Buckets

	Savings (per year/per dragline)
Savings of wear parts	**$ 163 147**
Savings to production losses through downtime	**$ 225 000**
Total	**$ 388 147**

Other cost savings which cannot be expressed in monetary terms include:

- Maintained digging ability.
- Decrease in the need for consumables used when regularly replacing wear parts.
- Decrease in dragline fatigue due to the hardfaced bucket being lighter.
- The increased working life between bucket rebuilds.

6.5 Future Potential for Hardfacing on Draglines at Gregory

A mine's geology not only dictates the degree of wear to which the equipment is exposed, but also the amount, type and placement of hardfacing required. As the wear experienced at BHP Gregory is not extremely high they are not compelled to trial hardfacing on any other part of the dragline bucket. However, if the geology changed and the level of wear increased, then the following areas would be trialed with hardfacing:

1. Lipshrouds
2. Hoist trunnion.

3. High areas of wear on the inside walls of the bucket.
4. Dragline Chains

6.6 Dragline Conclusions

The dragline is an important piece of equipment used to remove overburden and expose coal. It represents a large investment for mine and it is essential that it continually operates efficiently. The influence of wear has to be reduced as it increases both the operating and maintenance costs of the dragline.

Due to the changing geology between mines and the numerous hardfacing processes available, this report does not conclude that the use of **any** hardfaced part will guarantee a cost saving for a mine. However, based on field trials at BHP Gregory, it can be concluded that by applying A.R.M 's hardfacing to the various wear components of a dragline bucket, a decrease in the costs associated with wear can be achieved.

7.0 Case Study of a Dozer

The following case study examines hardfacing applications on four Caterpillar D11R dozers operating at BHP Gregory Mine.

7.1 Importance of Dozers in the Mining Industry

Dozers have a substantial role in maintaining production and are often the only pieces of equipment used to re-shape stockpiles for rehabilitation. They are also used for dragline clean up and assist, coal stockpile management, bench preparation for blasts, topsoil removal and dragline bench preparation after blasts. Each of the dozers represents a large investment for the mine and it is important to maintain their efficient performance. One of the factors which was preventing this is at BHP Gregory was the considerable maintenance cost due to the high wear rate of dozer blades.

7.2 Identification of Wear on Dozer and where Hardfacing can be Used

This report focuses on the wear resulting from the interaction between the ground and equipment. Dozers have three major areas that are exposed to this type of wear. They are as follows:

1. The blade.
2. The ripper located at the rear of the dozer.
3. The tracks used to propel the dozer.

Field tests conducted at BHP Gregory have, to date, focussed solely on the dozer blade and the associated wear problems. Therefore, the scope of this report will be limited to evaluating the hardfacing of this element.

7.3 Illustration of Dozer Edge and Wear Areas.

Figure 7.1 shows a typical dozer blade and illustrates the areas that are exposed to high wear rates. The cutting edge is exposed to the greatest amount of wear and it also determines the dozer's cutting ability. Thus, it is the most important part of the blade. The wear modes experienced by these edges are a combination of all of the wear modes previously discussed including:

1. Low stress abrasion
2. High stress abrasion, mainly around the heel area
3. Gouging abrasion
4. Polishing wear
5. Impact erosion

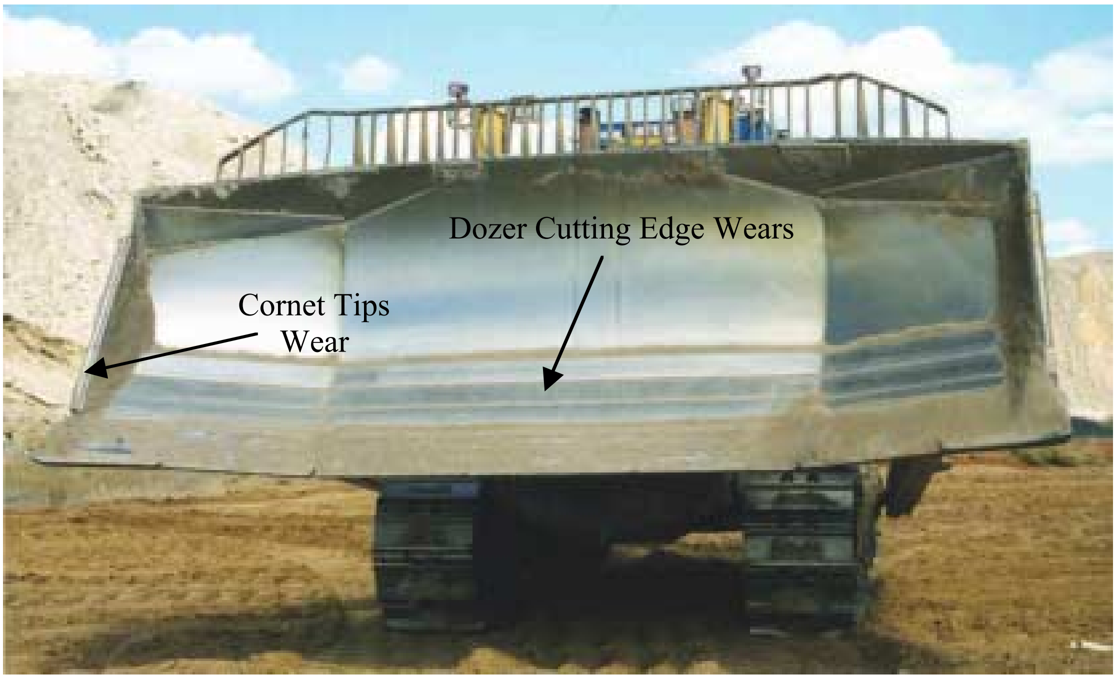

Figure 7.1 A.R.M* Premium cutting edges (Patents Pending)

7.4 Type and Placement of Hardfacing to Counteract Wear

To reduce the effects of wear A.R.M has developed a hardfaced wear package, see Appendix 15. A.R.M's Premium Cutting edge package consists of five hardfaced blades and two hardfaced corner tips.

7.5 Costing

To evaluate A.R.M's premium blade package, numerous field trials were conducted at BHP Gregory. The following results were obtained:

Table 7. Results and Costing of Field Trials at BHP Gregory (per dozer)

	Wear Life (hrs)	**Dozer Usage** (hrs/yr)	**Blades Needed** per yr	**Cost per Blade** ($AUS)	**Cost of Blades** ($/yr)	**Labor** ($)	**Total Cost** ($/yr)	**Cost** ($/hr)
Standard Cutting Edge	2000	6000	3	$8000	$24 000	$4680	$28 680	$4.78
A.R.M's Premium Package	6000	6000	1	$14 000	$14 000	$1560	$15 560	$2.59
Total Difference						**$3120**	**$13 120**	**$2.19**

NOTE: The results above have been based on a dozer usage of 6000 hrs/yr to make the calculations more realistic. The actual utilisation at BHP Gregory is closer to 5000 hrs/yr.

Justification of results

- The wear life includes using both sides of the blade.
- The costs of the blades were those obtained from BHP Gregory.
- The cost of the blades includes consumables such as bolts, nuts, washers, 2 x corner tips & 5 x cutting edges.
- The A.R.M's Premium package cost includes those consumables listed above and the required hardfacing.
- Labour costs were based on 12 hrs (2 x fitters @ 6hrs each) of labour to either fit or turn the blades at a fitter's rate of $65/hr.

7.6 Cost of Machine Down time

It is difficult to accurately calculate the cost of the machine downtime required for the replacement or turning of a set of blades. An estimate of the cost can be achieved by ascertaining the actual time a dozer is removed from production and multiplying this by the cost of hiring a replacement dozer. This procedure was undertaken and the results can be found in Table 7.

Table 8. Machine Downtime Comparison between CAT Standard Blades and A.R.M's Premium Package

	No. of times blades are replaced or turned in 6000 hrs	**Machine downtime to either replace or turn blades**	**Total downtime per 6000 hrs**	**Cost of replacement dozer**	**Total Cost**
CAT Standard Blades	6	12 hrs	72 hrs	$250/hr	$18 000
A.R.M's Premium Package	2	12 hrs	24 hrs	$250/hr	$6 000
Total Difference	**4**		**48 Hrs**		**$12 000**

7.7 Other Costs and Issues

Fleet Savings

Gregory's total savings can now be calculated by applying the cost savings for one dozer to the fleet of four that are currently using hardfacing at Gregory.

Table 9. Total Fleet Savings at BHP Gregory

	Cost Savings per Dozer	**Cost savings For Fleet of 4**
Wear Parts Savings	$13 120	$52 480
Downtime Savings	$12 000	$48 000
Total Savings	**$25 120**	**$100 480**

Cutting Ability and Quality

The cutting ability of the blade is the most important property of the dozer as it determines its efficiency. When hardfaced blades were trialed on undisturbed ground at BHP Gregory, there was a noticeable decrease in the bite of the blade which, in turn, resulted in a decrease in its cutting ability. However, when performing rehabilitation work there was not a noticeable difference in the cutting ability of the blade and it maintained a high level of efficiency.

Hardfacing is not applied to the Gregory's four remaining dozers, as they are allocated to coal handling and dragline assist, areas in which the hardfacing is not suited.

Safety

Safety concerns always arise when working with large, heavy parts. An added safety concern when handling hardfaced wear parts is that, not only are they heavier than normal, but the hardfacing increases their sharpness. Based on experience at BHP

Gregory, this poses a risk of workers cutting themselves whilst handling these items. However, this risk was found to be easily managed by ensuring that those involved wore gloves when working with the hardfaced parts

7.8 Future Potential for Hardfacing on Dozers

As the wear experienced at BHP Gregory is not extremely high, there is not expected to be any advantage in hardfacing dozer rippers. However, if the geology changed and the level of wear increased, hardfacing would be trialed and the results evaluated.

7.9 Dozer Conclusion

The conclusion reached from these trials was that hardfaced dozer blades, when used in previously broken or soft ground, increase the efficiency of the dozer. For the fleet of four dozers there was a calculated total saving of $100 480 per 6000 hrs. However, when trialed on undisturbed ground there was a noticeable loss in the hardfaced blade's cutting ability, and whilst there was a saving in wear parts, the overall efficiency of the dozer decreased. Therefore, the value of using hardfaced blades in a mining operation is determined by the specific task allocated to the dozer.

8.0 Risk Assessment

A risk assessment was undertaken to accurately identify, prioritise and provide controls to the risks associated with the implementation of hardfaced parts into a mine's operation.

A Fault Tree was used to identify the possible reasons why the integration of hardfaced parts may not be successful. This method was chosen because it systematically analysed the logical structure of all causes and contributory factors leading to this possible failure. See Appendix 15.

These risks then_needed to be analysed. This was achieved by using a Work Place Risk Assessment and Control (WRAC) method that ranked each failure using the probability of its occurrence and the severity of the outcome. The probability of the failure was assigned a letter, found in Table 10, and its severity was assigned a number from Table 11. When these two properties were combined they formed the risk ranking found in Table 12.

Table 10. Probability of Event

Allocated Letter	Probability of Occurrence
A	Frequent occurrence
B	In known to occur
C	Could occur
D	Not likely to occur
E	Practically impossible

Table 11. Maximum Reasonable Consequence of Event

Number	Status of Implementation	Economic Consequence
1	**Implemented but experiences a major failure**	**Major economic loss**
2	Implemented but experiences a moderate failure	Moderate economic loss
3	Implemented but experiences a minor failure	Minor economic loss
4	Implemented with but advantage/disadvantage	No economic loss
5	Not implemented	No economic loss

Table 12. Risk Ranking of Event

Event	Ranking
Mine cannot afford initial outlay for hardfacing and therefore it is not used	B5
Geology changes resulting in the hardfacing being placed in conditions which it was not designed for	A1
Hardfacing is not suited for the tasks/conditions in which it is placed and cases a decrease in part’s wear life	B2
Previous negative experiences with traditional hardfacing techniques result in the new process not being trialed	A5
Perceived complications of implementing hardfaced wear parts result in the new process not being trialed	A5
The hesitancy of trialing something new prevents hardfaced parts from being used	A5

These ranked events can be assigned a level of importance by using Table 13.

Table 13. Risk Ranking Table

		Probability				
		A	B	C	D	E
Consequence	1	1	2	5	7	11
	2	3	5	8	12	16
	3	6	9	13	17	20
	4	10	14	18	21	23
	5	15	19	22	24	25

Controls for the two risks of highest rank have been discussed below.

1. Changing geological_conditions

   The geological_conditions can change in a number of different ways including within the current area being mined and between different areas of the mine. Any of these unexpected changes in geology can result in a decrease in component life. However, they can be managed by regularly examining up-to-date geological models for any changes and by creating a monitoring system that allows workers to liase with supervisors, technical services members and maintenance staff. If the awareness of this change is high, then steps can be taken to limit the effect that this change in conditions has on the equipment, for example, by changing the type of wear components so that they are more resistant to the new environment.

2. Hardfacing not suited to geology

   It could be detrimental to the machine’s efficiency if the hardfacing is not resistant to the conditions to which it is exposed. An example of this is when a dozer with hardfaced cutting edges is used for earthworks in unbroken ground. In these conditions, the dozer’s cutting ability is decreased and it becomes difficult for it to perform efficiently. This can be managed by determining the main conditions in which the dozer will be working, and selecting a hardfacing that will increase the surface’s wear resistance. Field trials should then be used to confirm the selection and, if necessary, the process repeated until the optimal solution is reached.

9.0 Conclusions

With the mining industry progressing towards larger machinery with high production outputs, it is becoming increasingly important to improve efficiency. Wear is a major influence. It adds to both equipment operating and maintenance costs by increasing machine downtime and the consumption of costly parts. The numerous wear types and modes have been identified and their wear prevention discussed, including the use of mig-carbide hardfacing. This form of wear prevention was trialed at BHP Gregory Mine on both dragline buckets and dozer blades.

Hardfacing was applied to the following areas of the dragline bucket: quick tips, adaptors, wingshrouds, heel, shackle protectors, drag shackle, jaw shrouds and the adaptor nose protectors. Costs were broken down into wear part consumption and machine downtime. Results of the trials found that when using A.R.M’s hardfaced bucket package, rather than the standard option**, there was a $163 147 saving of wear parts and an estimated $225 000 saving in machine downtime, per dragline**.

Cost savings were also identified in the following areas:

- The digging quality was sustained for a greater period of time because the quick tips maintained their original shape and length longer.
- The weight of the bucket with ESCO’s heavy wear package was approx. 50 tonnes and with the A.R.M’s hardfaced bucket it was around 41 tonnes. Although this decrease in weight did not expand the capacity of the bucket, it did reduce the strain on the dragline.
- The interval of time between bucket rebuilds was increased from 5 to 7 months.

Hardfacing was also trialed on the blades of four Caterpillar D11 dozers at BHP Gregory, and the cost reduction in consumable wear parts and machine downtime was investigated. The saving on blades and machine downtime was calculated to be $13,120 and $12,000 respectively, based on 6000hrs of operation. However, when using hardfacing, there was a noticeable reduction in the blade’s cutting ability. For this reason, Gregory has limited the use of dozers with hardfaced blades to areas where the ground has been previously broken. Dozers with hardfaced blades are being successfully utilized at BHP Gregory to perform tasks such as rehabilitation. Field trials at BHP Gregory have demonstrated that the application of A.R.M’s hardfacing, to ground engaging equipment, can result in significant cost savings.

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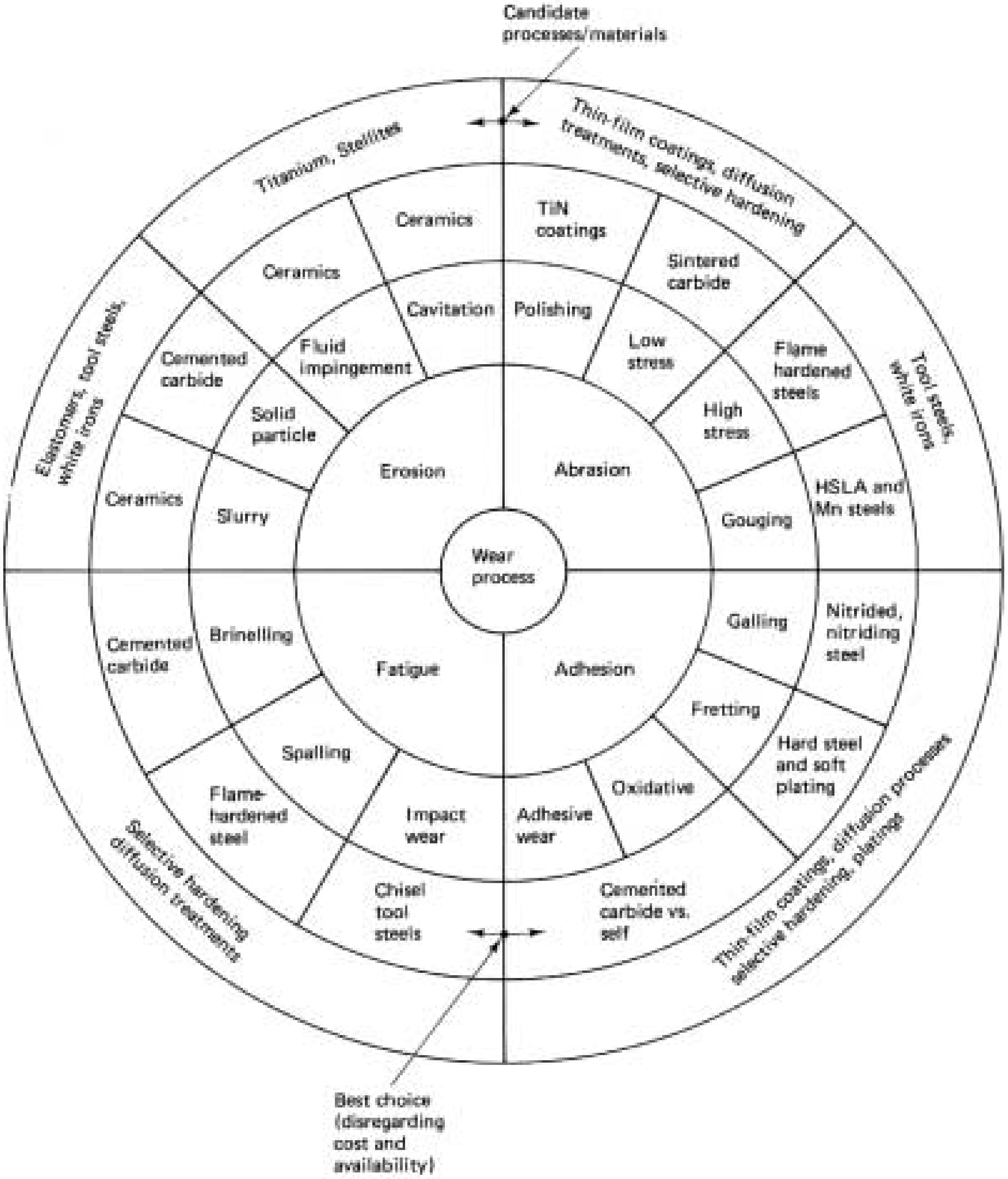
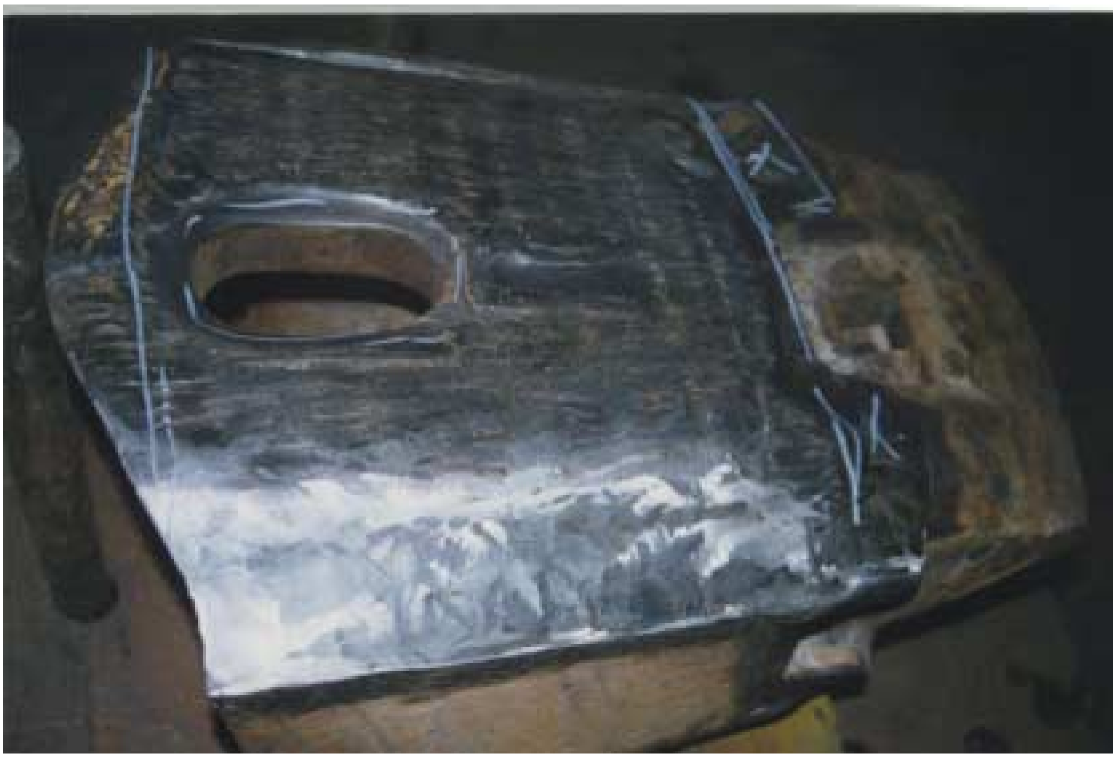
Appendix



Appendix 1(Budinki 1988)



Appendix 2: Adaptor prior mid life Rebuild

Appendix 3: After an A.R.M* Rebuild

Appendix 4: First quick tip trial

Appendix 5: Second quick tip trial

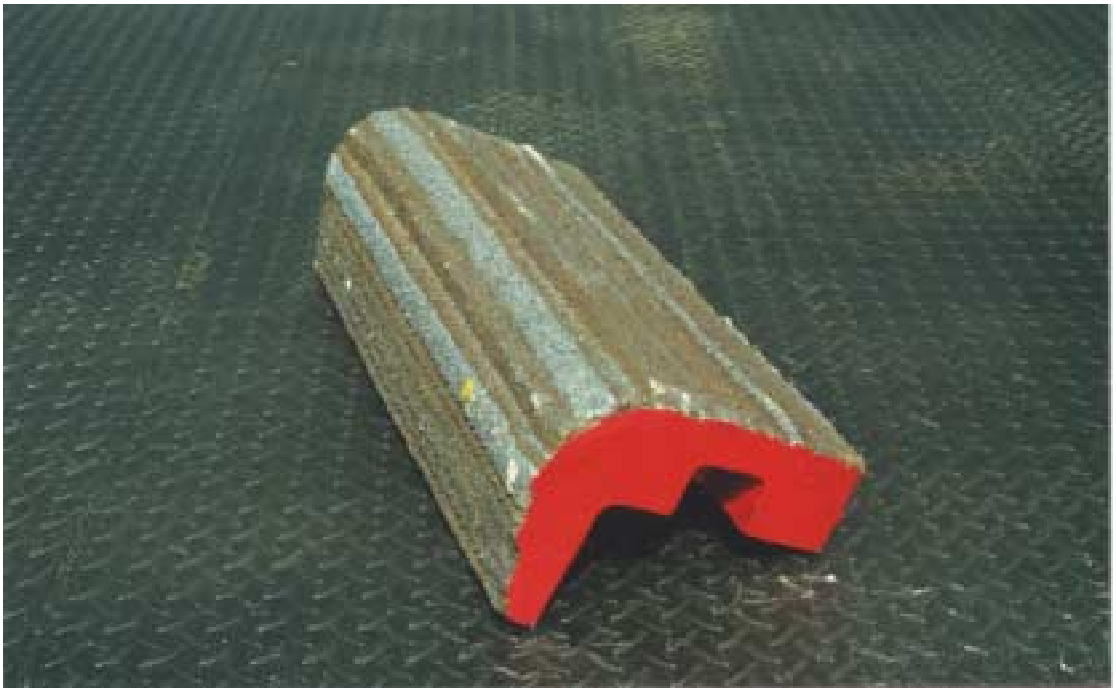
Appendix 6: Third quick tip trial

Appendix 7:A.R.M* Hardfaced wingshrouds

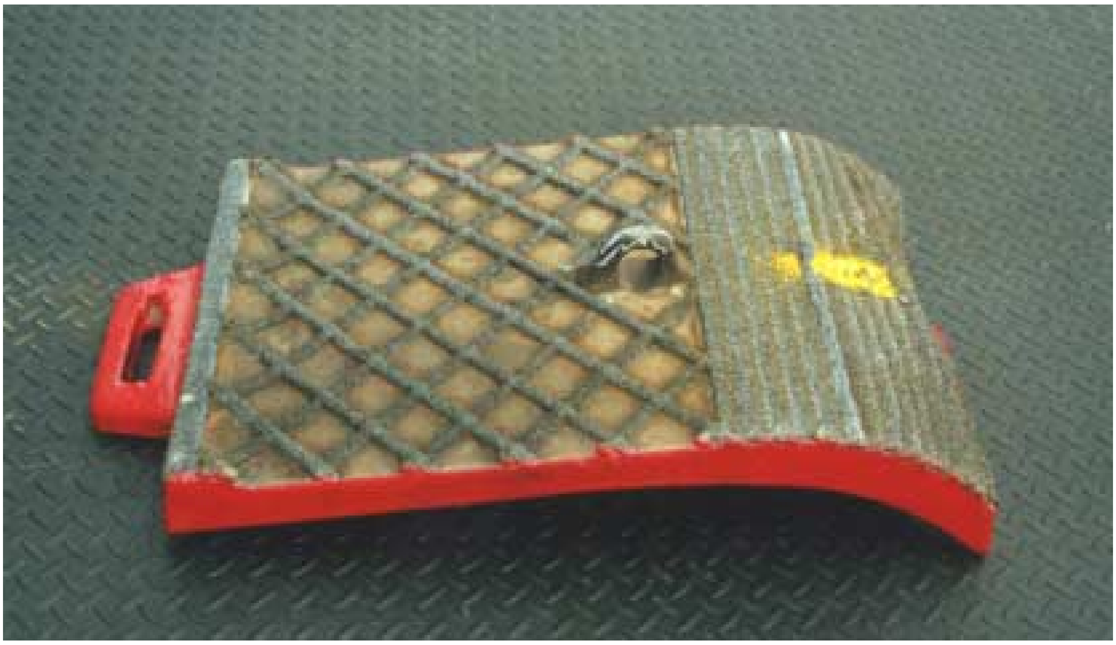
Appendix 8:A.R.M's hardfaced heel package

Appendix 9:A.R.M's hardfaced shackle protectors

Appendix 10:A.R.M* hardfaced dragline shackle



Appendix 11:A.R.M* hardfaced jaw shroud



Appendix 12: A.R.M* hardfaced adaptor nose protectors

Appendix 13: Standard ESCO quicktip worn out after approx. 25,000 BCMs (not at BHP Gregory)

Appendix 14:A.R.M* Hardfaced quick tip after approximately 550 000 BCMs at BHP Gregory – still going fine.