

Reduced maintenance costs resulting from the use of wear resistant materials

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Journal Paper

Synopsis

The use of ceramics to protect equipment subjected to wear in abrasive and corrosive applications has been accepted by most plants as the industry norm. Little is, however, known about alternative special ceramic based products which are available for the protection of plant assets.

With careful engineering, impact resistant ceramics can be used in high impact zones using modern ceramic technology. Properly selected and properly installed, ceramics will provide a tough wear resistant lining for protection against abrasion and impact.

Basalt, on the other hand, is widely used in coal washing plant process pipes with varying degrees of success. Basalt is normally not used for the lining of bends, 'T' pieces or reducers due to the reduced wear resistance compared to alumina ceramic. The advantage is a much reduced initial capital cost.

A patented ceramic composite non-return valve solved an old problem encountered in the operation of medium sumps. The design approach overcomes the lack of functionality of alternative designs and reduces valve wear while preventing medium settlement during plant shutdown periods.

Direct bonded ceramic pulley lagging is becoming the industry norm, eliminating most of the problems encountered with conventional pulley lagging systems.

The success of alumina ceramics in impact areas

For a number of years now, ceramics have been steadily gaining a place in wear resistant applications as a premier, sacrificial wear resistant lining. Traditionally, however, most engineers have shied away from using them in any high impact situation. This attitude has retarded the application of this superior lining material. Increasingly of late, however, ongoing R&D and test work on plant wear and impact applications has led to the conclusion that, with careful engineering, unique impact resistant ceramics can be used in high impact zones using modern ceramic wear resistant linings and ballistic armour technology.

General

In many applications, linings and components are subjected to considerable physical attack. However, the concern that ceramic wear resistant materials would be too fragile under such conditions is unfounded.

Properly selected, but above all, properly installed, ceramics will provide an extremely tough lining material. Ceramic wear resistant linings can be subjected to tremendous physical abuse with minimal degradation.

The magnitude of such impact resistance will vary with conditions encountered. It would depend on the size and bulk density of materials handled, impact angle, height of drop and quantity handled per given time.

In this context it would also be interesting to know that the alumina ceramics are also effectively used during conflicts to line vulnerable areas of combat vehicles, tanks, and helicopters as well as pilots' seats and other operating personnel carriers. Police, worldwide, use ceramic bulletproof vests as personnel armour protection for most hazardous conditions.

To achieve this impact resistance, as stated above, proper methods of installation are critical.

Theory of wear

For over twenty years, these ceramics have been applied to the wearing surfaces of equipment in the minerals and metals processing industries, power stations, and various other bulk materials handling plants. In designing the specific wear resistant solution, cognisance is taken of a matrix of factors causing wear, namely:

* *Multotec Wear Linings (Pty) Ltd.*

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- *Abrasion*—this mechanism of wear can be found wherever there is a moving body of material exerting both downward and forward pressure (Figure 1).
- *Erosion*—this mechanism of wear can be found wherever materials are striking a surface at an angle. (Figure 2).
- Corrosion—this mechanism of wear can be found wherever the wear surface is subject to chemical breakdown and is one of the most neglected causes of wear. (Figure 3).

There are several factors that must be integrated into the lining design to design a lining that will be resistant to all of these types of wear, whether simultaneously or in isolation. These are:

1. Hardness ratio, liner to abrasive
2. Particle size, liner to abrasive
3. Particle shape
4. Impact angle and energy
5. Velocity and pressure
6. Lining integrity.

Points 4 and 5 are those that have been considered to rule out the use of ceramics, and those that this paper seeks to show have a bearing on the design and manufacture of the ceramic lining, but which need not necessarily preclude ceramics due to current designs.

It has long been considered that the hardness of ceramics that contributes to its brittleness makes it a material only usable in sliding abrasion and erosion conditions. The data, are, however, still relevant in impact situations, i.e. attempts remain to reduce the impact angle to as little as possible when designing impact wear resistant panels. However, another dimension has been added in that we also try to

- Reduce the cross sectional impact area of the tiles by reducing their dimensions as much as practical and
- Provide a resilient, impact absorbing bonding mechanism.

Impact and wear resistant ceramics

Standard technical ceramics manufactured through dry pressing or casting do not have the impact resistance of currently designed impact blocks. Composite impact panels are assembled using cobblestone shaped ceramic blocks produced by means of high-pressure extrusion on a machine specially developed for the purpose of producing oxide ceramics. The extrusion process and ceramic formulation provides maximum toughness combined with the normal exceptional wear resistance of alumina ceramics (Figure 4).

Twenty-nine years of experience in the manufacture of this product has proven that the shape of the block is just as important as the ceramic formulation and the method of

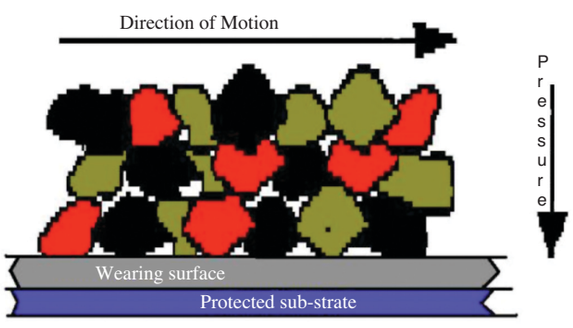


Figure 1—Abrasion

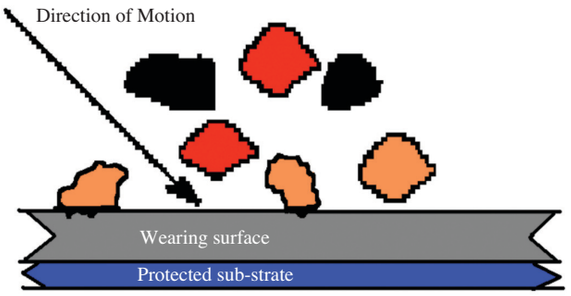


Figure 2—Erosion



Figure 3—Corrosion



Figure 4—A selection of extruded impact blocks—note the binding groove and rounded edges

manufacture. The blocks are grooved at the bottom to guarantee maximum mechanical adhesion to the polyurethane without sacrificing the resilience of the system.

The shape of the groove is critical in order to prevent shearing of the polyurethane while retaining the impact resistance of the blocks. Grooves in the block act as a mechanical lock, which reduces the possibility of tearing the blocks from the system. The working face of the block is rounded substantially to prevent chipping while presenting the maximum working area for resistance against abrasion.

The blocks are bonded into a specially formulated polyurethane matrix, thoroughly proven in the armour industry where bonding is critical to achieve the specified performance. The gaps between the blocks are sufficient to prevent mechanical damage caused by direct contact between blocks but also not too large to promote wear of the unprotected polyurethane. By creating joints between the hard ceramic impact blocks that are sufficient to provide a strong bonding mechanism for the blocks but small enough to prevent the large particles being in contact with the soft polyurethane, the polyurethane will be protected (Figure 5).

The composite liner has a resilient or rigid steel backing to act as a frame for retaining the blocks and for fixing to the component which needs protection. Steel frames also absorb mechanical stresses on the blocks during impact.

The overriding theory is that the blocks with enhanced impact and wear resistant properties must be allowed to 'float' in a resilient matrix, which prevents any contact with any solid body, which could exert excessive force onto the ceramic blocks (Figure 6).

In all cases where a liner is required to prevent both wear and impact, the tried and tested ceramics must be engineered to take into account, the impact energy that it may be required to absorb. To achieve this task, the following calculations need to be made before selecting the specific thickness and type of ceramics required for the specific application.

Calculation of impact energy

The total height (Ht) of a vertical drop shall be defined as the vertical level difference between top of discharge and impact area.

The minimum value of impact energy (E), to be absorbed at the receiving point, shall be calculated as follows:

$$\text{Min. value of } E = \tfrac{1}{2}M \times V^2 \text{ Nm} \quad [1]$$

where:

M	=	Mass of the nominal lump	Kg
V	=	Impact velocity of the above lump	m/s
V	=	$(2 \times 9,807 \times Hf)^{0,5}$	
Hf	=	Equivalent free fall height	(m)

Impact energies shall be grouped in the following categories:

Category 01:	Low impact	E	=	8.0 Nm or less
Category 02:	Medium impact	E	=	8.1 to 60 Nm
Category 03:	High impact	E	=	60.1 to 150 Nm
Category 04:	Severe impact	E	=	150.1 or more Nm

As a general rule, therefore,

- Category 01 and 02 impact dictates a minimum of 25 mm thick impact blocks
- Category 03 a minimum of 50 mm and
- Category 04 a minimum of 75 mm.

Other considerations

Brittleness

Critical strain is evident in ceramic when a fracture occurs,

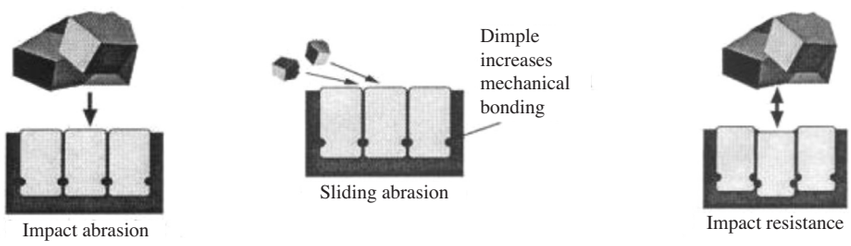


Figure 5—Mechanisms of panel impact and wear resistance

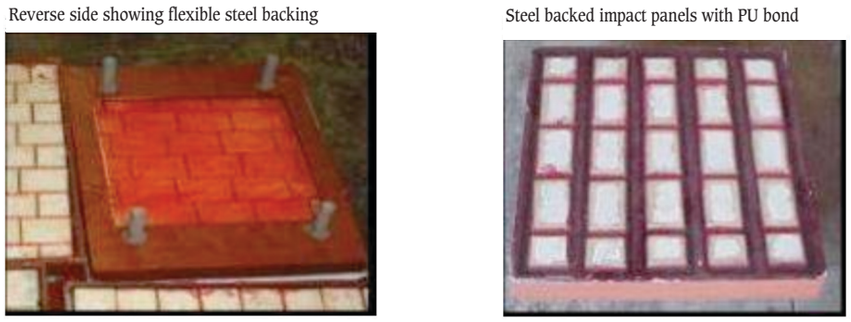


Figure 6—Steel backing for impact panels

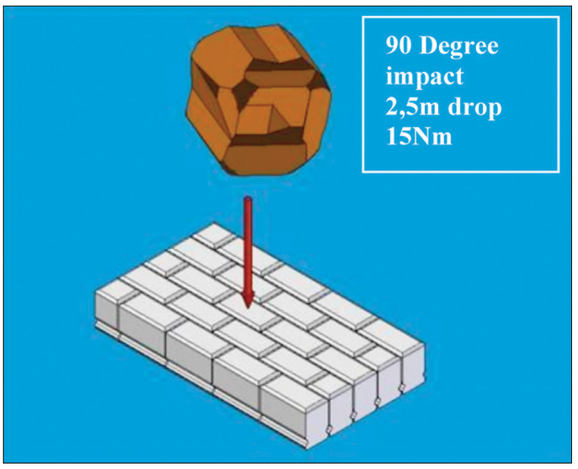


Figure 7—Impact energy with panel horizontal

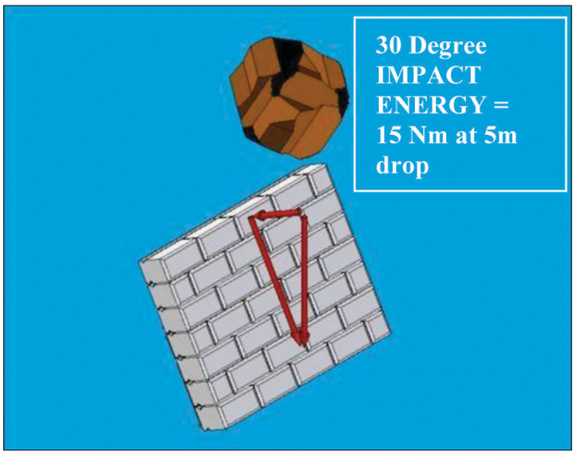


Figure 8—Impact energy with panel at 60 degrees to the horizontal

usually by surface crack propagation. This lack of ductility prevents the ceramic from accommodating stress concentrations with consequent poor impact resistance. Design should, therefore, eliminate these stress concentrations by avoiding sharp corners and adding a radius or chamfer to the edges exposed to impact.

Mechanical strength

Alumina ceramics have ten times the strength in compression compared to the tensile strength. Designs should be based on using compressive forces where possible.

In the case of Alumina ceramics, as noted, a range of compositions is manufactured, normally containing from 85% to 96% Al_2O_3. Changing from a badly wearing steel liner component to a highly wear resistant Alumina ceramic, is usually a giant step forward.

Test work

Prior to introducing the concept into field trials, a Relative Impact Abrasion Resistance Test was initiated to test the theory and to provide substance to the proposed designs. high density alumina impact resistant ceramics are often tested in normal mining applications but an assessment of the relative wear life can normally be made only after extended periods of testing due to the extreme wear resistance of the products. The Portland Cement Institute was therefore commissioned in 1985 to conduct accelerated wear tests on four control panels (Table I).

Two 65 mm thick impact resistant ceramic panels with ceramic impact blocks embedded in white cement and two 65 mm thick concrete panels, andesite stone and Kendall sand at 85 MPa were tested in a tumbling device, which exerts extreme impact and abrasion onto the panels (Figure 9).

The specimens were tumbled for 40 hours, 68.5 hours and 104.25 hours and the volume loss or amount of wear was measured by filling the abraded void with standard sand. The results were expressed in grams of sand used, which is equivalent to the volume loss.

Table I

Comparison between the properties of concrete and alumina ceramics

Property	Concrete	Alumina
Colour	Grey	White
Type	Precast, high alumina concrete	94% extruded blocks
Compressive strength	90 MPa	2450 MPa
Bending strength	10 MPa	270 MPa
Tensile strength	5.5 MPa	165 MPa
Water absorption	Surface porosity	0%
Porosity	Gas tight	Gas tight
Coefficient of expansion	$9x10^{-6}$/°C(400°C)	$70x10^{-7}$/°C(500°C)
Coefficient of thermal conductivity	1.15 W/mK(600°C)	11 W/mK (100°C)
Chemical resistance	Poor resistance to acids and low resistance to alkalines	Good resistance to acids and alkalines excluding hydrofluoric acid
Maximum temperature	1100°C	1200°C
Impact resistance	Refer to text	Refer to text
Hardness (Moh)	5.5 to 6	9
Density (g/cc)	2.75	3.6

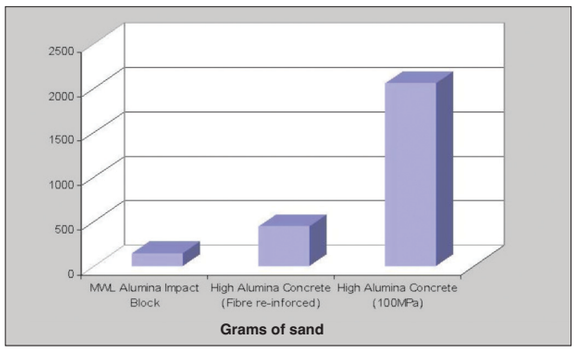


Figure 9—Impact and abrasion test

It was found that the tile wear was 9.2% of that determined for the two andesite panels. If this wear is compared with the average value established for 85 MPa concrete, the tile wear would represent approximately 13% of that for 85 MPa concrete.

The tests repeated in 1996 presented similar results. One can assume that the wear rate will be relatively linear on both the concrete as well as the ceramic panels.

In high impact applications, the moment of inertia of the alumina ceramic becomes unimportant and the bulk of the ceramic is under attack. The resistance to fracture of the ceramic is furthermore improved enormously by mounting it in a resiliently flexible medium, which can absorb the strain energy of the impact by elastic/plastic deformation.

Hence, for high impact resistance, the alumina liner system is designed with the lowest impingement angle, optimum geometric shape of the alumina components, lack of stress concentration points in the ceramic, maximum bond strength, as well as mounting in a resiliently flexible medium with sufficient deformability to absorb the bulk of the energy transposed to the liner.

Field trial in a coal application

A test was carried out at a coal washing plant where a 980 x 980 mm panel was installed in a severe impact area on a sharp bend of an enclosed chute directly after a coal gravity separation drum. The feed to the drum is nominally minus 50/100 to plus 12 mm and, depending on the particular plant, the sinks can be as much as 65% and as little as 20%, at a rate of approx 250 t/h. This shale and rock is discharged with a drop of about 2 metres into a launder for removal from the drum (Figure 10).

The impact and erosion are significant as a result, so the principles of wear and impact resistant ceramics were again applied, namely

- Small cross section—100 mm long x 75 mm wide tiles
- Category 3 impact—50 mm thick tiles
- Impact absorption using polyurethane and cobblestone pattern.

The results speak for themselves:



Figure 10—Steel backed impact panels with PU bond

- Maximum life expectancy of previous 3 weeks
  50 mm thick hard metal liner
- Life of ceramic impact pad (still in operation) 78 weeks
- Relative cost of 980 x 980 mm hard metal liner 1
- Relative cost of 980 x 980 mm ceramic impact pad 1.8
- Relative annual cost hard metal vs. 12:1
  ceramic impact pad.

Cost comparisons were based on the actual costs of the panels only. Removal and installation labour costs as well as plant downtime costs were not taken into consideration.

Attributes of dense alumina ceramics

The inherent attributes of dense alumina ceramics are hardness accompanied by brittleness. The former property provided a solution to many wear related problems but the brittleness led engineers to shy away from high impact areas. However, because of increased knowledge of wear mechanisms, more studies on the specific designs needed to counter wear, and also innovative manufacturing technology, modern systems can now be designed that offer both wear and impact resistance.

In the field of armour ceramics, the very brittleness has been used in the high impact zone of projectile penetration resistance to provide protective solutions for varied applications, and the hardness and lightness of the ceramics to offer a variety of mobility-effective body and vehicle armour.

All of these solutions need innovative bonding and absorption mechanisms, and thus improved resin and polymer bonding systems in wear resistant engineering and resin bonding and aramid fibre technology in armour protection systems have all had a major part to play in the development of these application technologies.

None of the developments would have been possible without the input of the engineers behind the concepts, but there is no doubt that they are able to achieve amazing results using the principles discussed in this paper.

Cast basalt

Fused cast basalt is dense natural rock, which is crushed to grain sizes of 20–50 mm and melted at a temperature of 1250°C. Working in a continuous operation process, the liquid basalt flows from a furnace into a receiver equipped with various refining mechanisms. From here the fused basalt flows into sand or cast iron molds.

The castings are moved into a tempering and cooling furnace immediately after casting. The resulting castings are, because of their structure and hardness, suited for moderate to high abrasion-resistant linings (Table II).

They exhibit varying external characteristics and mineralogical compositions. Table II is on extract from DIN 28062 (edition of Sept '76) converted to SI system where applicable.

Friction

Unlike other materials, which roughen up as more material is passed over them, basalt polishes up. In many cases bunker linings have become sufficiently polished after a few weeks' operation has removed the traces of sand left from moulding.

Table II

Average composition of fuse cast basalt

Approx. 45–48% SiO_2	Silica
Approx. 14–16% AL_20_3	Alumina
Approx. 12–14% Fe_20_3 and Fe0	Iron oxides
Approx. 10–12% Ca0	Calcium oxide
Approx. 8% Mg0	Magnesium oxide
Approx. 6% K_20 and Na_20	Potassium oxide and sodium oxide
Approx. 2% $Ti0_2$	Titanium dioxide
Traces of Mn and S	Manganese and sulphur
About 45% of the iron is in a magnetite compound, Fe_30_4, about 55% in silicates (primarily augite)	

Table III

Properties of basalt vs. alumina ceramics

Property	Basalt	Alumina
Sp. gravity	2.9–3.0	3.6
Comp. strength	535 MPa	2400MPa
Water absorption	0% by mass in accordance with DIN 52103	0% by mass in accordance with DIN 52103
Bending strength	45 MPa	280 MPa
Tensile strength	35 MPa	165 MPa
Hardness	8.5 Moh's scale	9 Moh's scale
Wear abrasion	2.15 cm^3/h per standard grit blasting test	0.22 cm^3/h per standard grit blasting test

Temperature

Basalt will successfully withstand temperatures up to 450°C. At this temperature slight crazing may appear, but this does not affect the mechanical wearing properties.

Life

Life of basalt linings is estimated at approximately six to seven times that of cast iron, but much depends on the degree of impact occurring. In an application where a pure sliding action, with no impact, is encountered, basalt should last the life of most plants. Alumina ceramics, on the other hand, have a life expectancy that exceeds that of basalt by a factor of 10. The cost ratio of alumina to basalt is approximately 2.5 to 1.

Basalt is widely used in straight coal washing plant process pipes with varying degrees of success. Basalt is not suitable for the lining of bends, 'T' pieces or reducers as can be seen in Figures 11 and 12. Standard designs are also not suitable for severe wear applications where an abundance of foreign objects are present, as shown in Figures 11 and 12.

Special ceramic designs are available for significant reduction of wear caused by foreign objects. A typical example is shown of a standard segmented long radius bend with an extended back lined with thick impact resistant ceramics (Figure 13).

The 'multi-aerator' dual-action non-return air valve

A novel patented ceramic-composite valve design succeeded in solving a thirty-year-old problem encountered in the operation of medium sumps. Many valve designs have been tried but none have so far worked acceptably, overcoming both the severe erosion encountered in this application as well as standing up to the extreme mechanical loads placed on the valve during start-up. A unique design approach coupled with high density alumina wear parts overcomes the lack of functionality of earlier designs and increases the life of the valve dramatically.



Figure 11—Damage caused by objects shown above



Figure 12—Damage to Basalt linings by foreign objects



Figure 13—Ceramic lined bend with thick ceramic lined extrados

- The unit is essentially a dual action non-return valve with internal components designed for operation under harsh conditions (Figure 14).

Mechanically agitated sumps

Capital acquisition costs are high due to the large drives that are required. Rotor shafts are long with associated problems. After power failures, the magnetite settles and restarting torques can be extreme, often resulting in some form of mechanical failure. Paddles wear and require maintenance or replacement.

Compressed air agitated sumps

Compressed air is introduced centrally through the bottom of the sump to keep the material in suspension. During power failures, the air supply is interrupted and material flows into the compressed air lines if unimpeded, leading to blockages. Depending on the severity of the blockage, the entire sump may have to be mechanically emptied and cleaned, resulting in substantial losses in production capacity and efficiency.

Operation and design

The dual closure valve promotes improved air agitation and flow.

The top ceramic valve is designed to:

- Seal completely and to keep slurry out of the main valve body and the compressed air feed pipe after loss of air pressure
- Close if the air supply pressure drops below a given value
- Deliver the same volume of air at a given pressure into the vessel compared with a single air pipe feed
- Open under the pressure of settled pulp, which can have a head of several metres.

The mass of the ceramic valve, stem, and impact disc is therefore critical due to the requirements stated above.

The bottom valve diameter is critical to achieve opening of the top valve when the air pressure exceeds the minimum value stated above.

The bottom valve is not attached to the valve stem and can move freely for a distance of approximately 5 mm. This free movement has three functions:

- The lower valve will impact against the bottom of the impact disc to assist in the opening of the top valve.
- The bottom valve will always close, even if the top valve remains open due to an object becoming stuck in the top valve seat.
- Accumulation of material on the tank sides is minimized as a result of the free movement of the valve stem. Varying resistance caused by material displacement causes the valve head to rotate and air is deflected through the side angles of the ceramic head towards the tank sides.

Field trial results

The first valve was installed in a 450-ton gold plant Pachuka tank on 2 November 2000 and has since been operating without failure or signs of wear. A number of power failures and compressed air disruptions have occurred during the test period, the longest of which lasted for over 8 hours. The test valve opened immediately after each service disruption when the compressed air supply was reestablished, while the remaining tanks had to be emptied and cleaned manually with the aid of high pressure water jets in order to commence normal operation.

A number of valves were also installed in magnetite sumps at a coal plant with great success in preventing settlement in the sumps during plant shutdown periods.

Advantages of the dual-action non-return valve

The taper on the top valve seat and matching valve body creates a rotating cone of air, which agitates the entire contents of the tank and keeps the material in suspension. The ceramic valve breaks the air into numerous smaller

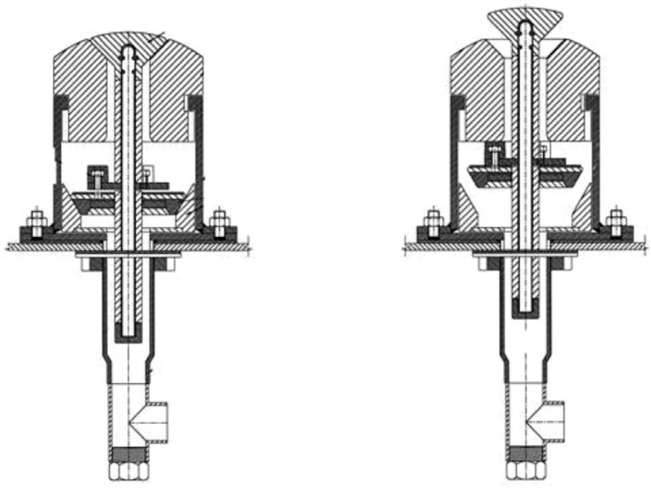


Figure 14—'Multi-aerator' dual-action non-return air valve

bubbles, which result in much improved aeration and agitation. Refer to Figure 15 for schematic representation of air flow.

Direct bonded ceramic pulley lagging

Traditional approach

- Conveyor pulleys are traditionally lagged with rubber to prevent wear and belt slip.
- Rubber pulley lagging progressed from smooth to diamond shapes, with grooves for increased traction and water dispersion (Figure 16).

First improvements

- Rubber backed ceramic pulley lagging solved the wear and traction problems.
- The benefits were:
  - Speed of installation, by placing sheets of lagging onto primed surfaces with an adhesive.
  - Can be installed with the pulley *in situ*.

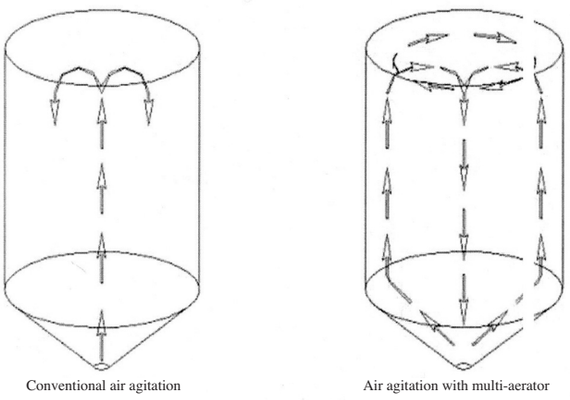


Figure 15—Conventional air agitation vs. multi-aerator valve

Results

- This system proved to be successful in most applications with limited starting loads and low belt tensions.
- Limiting factors are:
  - Rubber shear strength
  - Adhesion of steel and ceramics to rubber.

Modern approach

- These limitations resulted in the development of a system to apply ceramic tiles directly onto the pulley steel shell.
- Many tests were conducted focusing on:
  - Sheer strength
  - Adhesion of ceramic to steel
  - Flexibility.

Sheer strength and adhesion

- A special Hi-bond epoxy was developed for this purpose
- 11 Epoxies were tested
- Hi-bond outperformed the other samples by a minimum margin of 20% (Figure 17).

Flexibility

- Hi-bond was compared with 5 alternatives.
- Hi-bond was selected for superior bending strength and flexibility (Figure 18).

Advantages

Studded ceramic lagging for drive pulleys has the following advantages:

- It will not slip, therefore minimal wear to ceramics and the belt.
- Adhesion is at least 20 times stronger than that of rubber onto steel (SABS specification for rubber

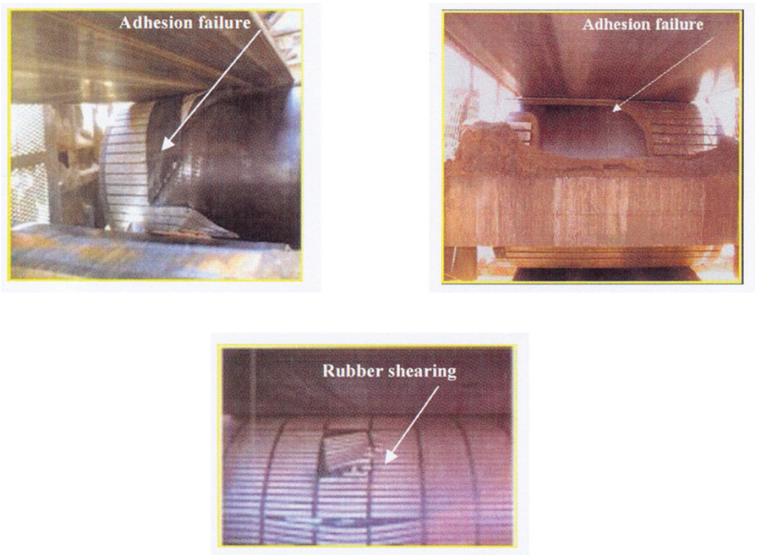


Figure 16—Failure patterns of rubber backed ceramic pulley lagging

Reduced maintenance costs resulting from the use of wear resistant materials

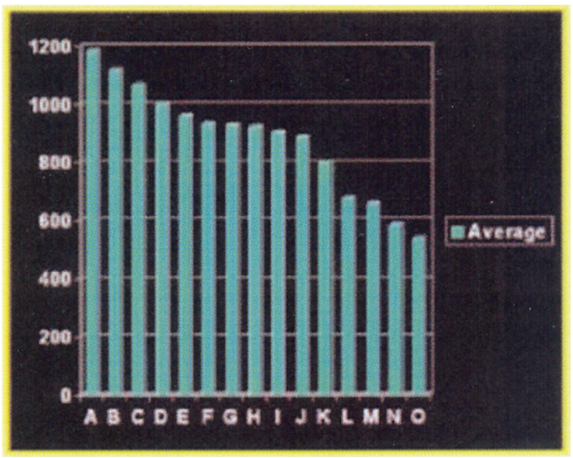


Figure 17—Comparative epoxy shear test results

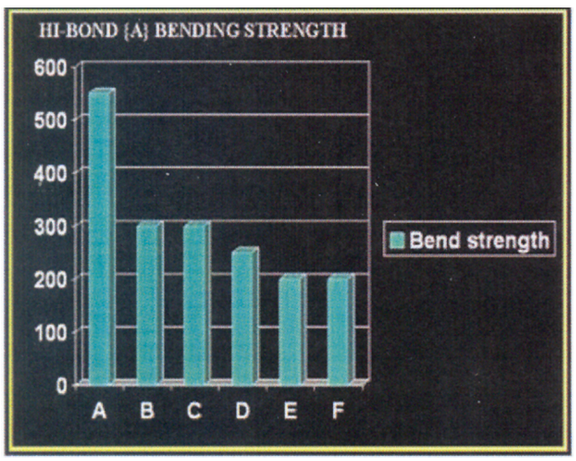


Figure 18—Comparative epoxy flexibility test results

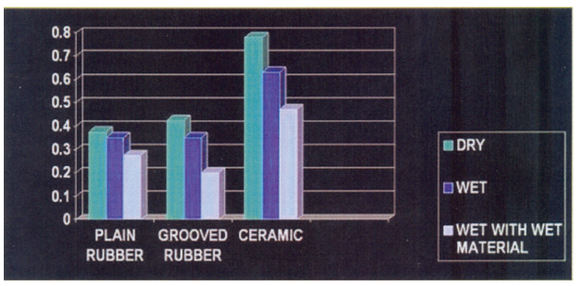


Figure 19—Coefficient of friction comparison between studded ceramics and rubber

adhesion to steel is 12 N/mm, the minimum value achieved with Hi-bond is 240 N/mm.

- Ease of maintenance. Small areas can be repaired. (Figure 19).

Case history 1

- Rubber drive pulley lagging lasted 6 months with severe slipping on a feed conveyor transporting 80 mm iron ore.
- No wear on ceramics after three years.
- Spillage of large rocks is normal in this application, so localized repair had to be possible (Figure 20).

Case history 2

- 'Greenfields' dense medium separation coal plant. Ceramics specified during design phase
- Figure 21 shows ceramic drive pulley tiles installed with Hi-bond epoxy.
- After 36 months of usage, no wear can be measured and surface coverage still at 100% (Figure 21).

Case history 3

- Tail pulley lined with 6 mm ceramic tiles in an iron ore application.
- Rubber lagging lasted 6 months.
- Ceramic wear is less than 1 mm after being in operation since 1996 (Figure 22).



Figure 20—Studded direct bonded ceramic lagging in an Iron ore application



Figure 21—Ceramic pulley lagging in a coal application

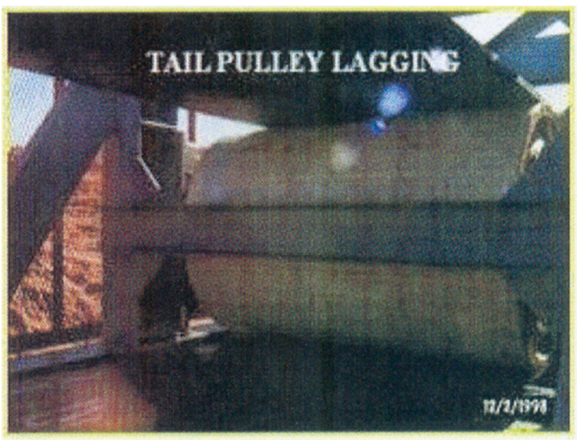


Figure 22—Smooth ceramic pulley lagging in a non drive application

Conclusion

Industrial wear resistant alumina ceramics have traditionally been categorized as exceptional but expensive wear resistant materials with limited impact resistance.

Alumina ceramic developments have dispelled both misconceptions. Alumina, compared with wear resistant steels, has become very reasonably priced and can be applied at much lower costs than wear resistant steel, of equivalent thickness, in most cases.

The impact resistance of alumina ceramics with the added advantage of exceptional wear resistance has made the selection of this product a logical alternative to impact resistant hard steels.

Special and standard ceramics can be used in numerous mining applications to reduce downtime and maintenance costs. ◆

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TBM 210
MOISTURE MONITOR





COALSCAN 2100
ASH MONITOR

Scantech's analysers measure coal quality. The COALSCAN series of analysers are the industry standard, installed in over 40 countries. They provide real time process control for stockpile management, automated blending/sorting and reclaim. The benefits are reduced maintenance costs, more efficient plant operations and improved coal utilisation.