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The design of rotary-mill liners, and their backing materials

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SYNOPSIS

An evaluation was made of the wear and performance characteristics of lifter bars, and the cost–life effectiveness of backing materials for rotary-mill liners.

In a large run-of-mine mill in which the lifter bars were mounted on grid liners of austenitic manganese steel (AMS), the liners had an average life that was five to six times that of equivalent unprotected liners. For a single mill, this is equivalent to annual savings in the cost of materials of up to R320 000, and to a downtime of 100 hours.

Of the five materials tested in a large pebble mill grinding quartzitic ore, AMS grids and 'white iron' blocks performed best on a cost–life basis, with possibly improved performance from a real white cast iron. (The 'white iron' was shown by microstructural analysis to contain flake graphite and pearlite, being in reality a grey cast iron.) The high-chromium white iron had by far the longest predicted life, with mild steel a surprising second. Rubber was shown to last well in this type of mill.

The wear rates of liners change during their lifetimes. The protective effect of lifter bars was clearly illustrated by the reduction of over 40 per cent in the wear rates of the liners when the lifter bars were renewed to a height of 80 mm from a fully worn height of 35 mm.

SAMEVATTING

Die slytasie- en werkverrigtingeienskappe van ligstawe en die koste–lewensduurdoeltreffendheid van steunmateriale vir draaimeulvoerings is geëvalueer.

In 'n groot meul vir onbehandelde erts waarin die ligstawe op roostervoerings van oustenitiese mangaanstaal (OMS) gemonteer is, het die voerings 'n gemiddelde lewensduur gehad wat vyf tot ses maal langer as dié van ekwivalente onbeskermde voerings was. Vir 'n enkele meul is dit gelyk aan 'n jaarlikse besparing van tot R320 000 in die materiaalkoste, en van 'n staantyd van 100 uur.

Van die vyf materiale wat getoets is in 'n groot rolklikmeul wat kwartsitiese erts maal, het die OMS-roosters en 'witysterblokke' op 'n koste–lewensduurbasis die beste gewerk, met 'n moontlik beter werkverrigting deur egte witgietyster. 'n Mikrostruktuurontleding het getoon dat die 'wityster' vlakgrafiet en perliet bevat en in werklikheid 'n grysgietyster is.) Die chroomegte wityster het verreweg die langste voorspelde lewensduur gehad met sagtestaal verbasend genoeg tweede. Daar is getoon dat rubber goed in hierdie soort meul hou.

Die slytasietempo van voerings verander gedurende hul leeftyd. Die beskermende uitwerking van ligstawe blyk duidelik uit die verlaging van meer as 40 persent in die slytasietempo van die voerings nadat die ligstawe tot 'n hoogte van 80 mm hernuwe is vanaf 'n heeltemal verslete hoogte van 35 mm.

Introduction

This paper evaluates the wear and performance characteristics of lifter bars in relation to their height, together with the cost–life performance of the backing materials used for liners in rotary mills.

South African gold mines use 688 rotary mills to grind about 110 Mt of ore annually. The gold occurs principally in very hard, abrasive quartzitic ore. This fact, together with the high mill speeds that are employed, causes the linings within the shells of the mills to wear rapidly. The gross overall average wear of liners in all the mills on the gold mines is 85 kg per day per mill[1], and results in a total annual usage of 20 kt of metal at a cost of about R40 million. The total energy[1] used in milling is 2400 million kilowatt-hours at a cost of about R140 million.

It was felt that the use of more suitable materials for mill liners and improved design could considerably reduce these costs and the high downtimes required for the frequent replacement of worn liners.

Although several studies have been made of the installation of lifter bars in rotary mills, the wear rates of lifter bars and backing blocks, and the effect of lifter bars on the overall performance of the mill, have not been fully investigated. In one study, for example, lifter bars were successfully installed in a large, high-speed run-of-mine (ROM) mill but, because this was done in conjunction with a change in backing-block materials, it was not clear as to which change had given rise to the improved liner life. It has been found that the ratios of lifter-bar height to mill diameter, and lifter-bar height to lifter spacing, have an important influence on the wear rate of liners and the performance of mills. However, the most suitable ratios have not been established for the different types of local mills.

It can be seen from the above summary that there are gaps in our understanding of the effect of lifter bars on the performance of mills and the wear rate of liners. As the use of the correct liner configuration and materials[2] can considerably reduce downtime and liner wear, and improve mill operation, it is important that the optimal conditions for these two factors should be established.

ROM mills are used for over a quarter of all the milling done on South African gold mines, and all new mines are installing these mills. It is therefore important that the liner lives as experienced in these mills at present should be improved. Investigations have indicated that considerable improvements are possible[3], which means

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that the optimal lifter-bar configuration and backing-block material should be firmly established for these mills.

The function of milling is to reduce ore to the optimum size for efficient processing in downstream extraction operations, and hence any change in liner configuration must maintain or improve a mill's performance. The theory underlying the influence of liner design on the motion of a mill-load has been extensively studied and is published elsewhere[4]. The conclusions from that work and the results of other investigators[5] were taken into consideration when the present experimental work was designed.

The specific aims of the present work were as follows:

(a) to assess the effect of lifter bars on the life of the liner in a ROM mill and the performance of the mill, and

(b) to test the suitability of currently available materials for backing blocks by the measurement of their relative wear rates when used in conjunction with lifter bars of a suitable configuration.

The tests on (a) were conducted in the number 1 ROM mill at Deelkraal gold mine, which had been newly fitted with lifter bars mounted on flat grids. Those on (b) involved the installation of five different materials in a single pebble mill at Kloof gold mine.

Experimental

A liner-wear monitor (Fig. 1) was developed that could be used to take many readings rapidly from both grid and solid block liners, thus minimizing downtime. The interface between the lifter bar and the backing block forms a constant reference point, and the monitor spans two adjacent lifter bars. The problem of erosion under the edges of the lifter bars was overcome by the attachment of a horizontal foot to the monitor, which could be pulled up under the base of the lifter bar.

The liners were measured at intervals of six weeks, which allowed time for a measurable amount of wear to occur. The solid blocks were measured at three fixed points (the grids on the grid bars), and the height of the lifter bar was measured on the leading side of the backing block. Two sets of these measurements were taken near either end of each liner. Unevenly mounted lifter bars necessitated the monitoring of a fixed sample, and any lifter bars that had been mounted asymmetrically were excluded. The arm that was used to measure the height of the lifter bars was set parallel to the top of a new lifter bar. The lining of the mill was hosed down thoroughly to give a clear surface. The measurements required about two hours.

Problems

Each block or grid should have been measured at the same points each time but, as rocks and scrap steel tended to become wedged under the leading edges of the lifter bars, this was not always possible. Some scatter in the measurements is therefore inevitable since the blocks and grids do not necessarily wear evenly along their length. In this type of work, it is well worth the slightly increased downtime and effort to make sure that the lifter bars are installed squarely upon, and flush against, the backing liner.

The lifter bars tended to have been misaligned during their installation, or to have had objects wedged under them. Lifter bars standing proud of the liner seriously affected the reference line, and this was generally more of a problem with backing grids than it was with solid blocks. Lifter bars should not be allowed to wear to below a height of 40 mm since they then tend to lift up and change the reference point.

The strongly rounded wear profile of the bars that make up the grids meant that the measuring points had to be precisely relocated. Therefore, it was found to be better to measure a few grids accurately so that the measurement points were always the same, rather than to monitor a large number of grids less accurately. It was

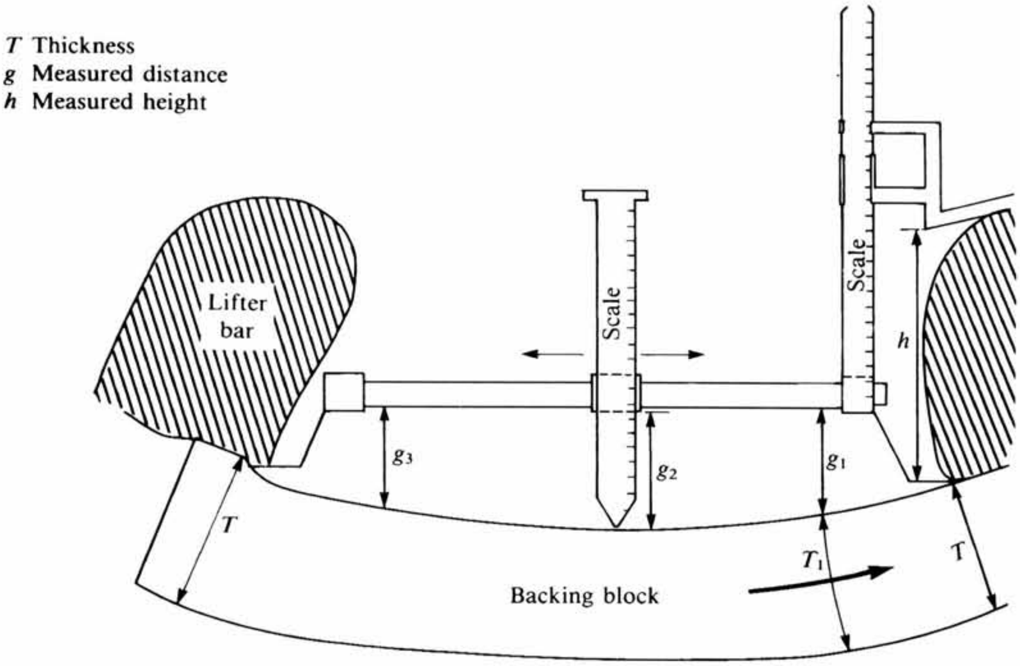

Fig. 1—The liner-wear monitor

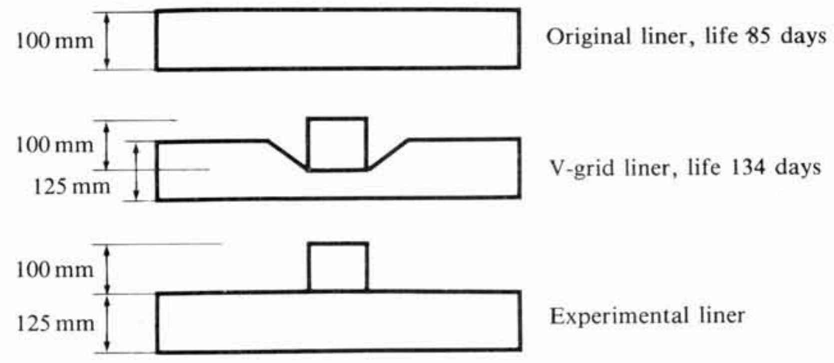

Fig. 2—Profiles of the three types of linings

shown to be preferable to measure the lowest point on a grid bar, which is easier to locate and gives a better reflection of the maximum wear rate of the grid.

Tests at Deelkraal

This investigation concerned the way in which lifter bars mounted on top of a grid liner would affect the wear rate of the lining in a large ROM mill. The 4,8 by 12,2 m mill ran at 81 per cent of the critical speed, and was lined with 24 rows of austenitic manganese steel (AMS) grids. The mill was charged with 5 to 10 per cent 100 mm balls, and was run at 45 per cent charge filling. It was advantageous to use a mill of slower speed since this is suited to perpendicular lifter bars.

The mill had originally been lined with a flat-profiled grid with an average life of 85 days. It was then fitted with V-grids, with a lifter bar mounted in the groove and protruding just above the grid. The life of these grids averaged 134 days, with one change of lifter bars. For the experimental work, a flat 125 mm thick grid was used, with a 100 mm lifter bar mounted on top of it (Fig. 2).

Course of the Investigation

The measurements began in May 1987 but, because of a shortage of special lifter bars, the need to run the mill at double capacity for a month (by increasing the ball charge to about 20 per cent), and extensive repairs that the mill had to undergo, the monitoring of the liners could start only in December 1987. Six sets of measurements were taken up to June 1988. Six rows running the full length of the mill were monitored, 384 readings being taken at a time.

Problems were experienced with the breakage of lifter bars because of poor castings. It is therefore important to ensure that good-quality lifter bars are used in a mill of this size.

Results

The progressive grid thicknesses are given in Fig. 3. These are the measurements taken at the centre of the grid, which is the fastest-wearing region. The values used are averages of all six grids measured in a single ring, any missing measurements being a consequence of broken lifter bars. It is clear that ring 5 was thinner than the other rings, which is not a reflection of the wear rate but rather an indication of the installation date since the rings were installed over a period of months. The inlet edge of ring 3 wore to a thinner profile because the old linings in ring 2 were much lower than ring 3 for a long period.

The progressive heights of the lifter bars are shown in Fig. 4. The dotted lines link the data for the second set of lifter bars that were installed in April. Because of the problem with broken lifter bars, insufficient data were available for rings 1 and 2. From ring 3 onwards, there is not a significant difference in the wear rates of the different rings of lifter bars except for the end of ring 8.

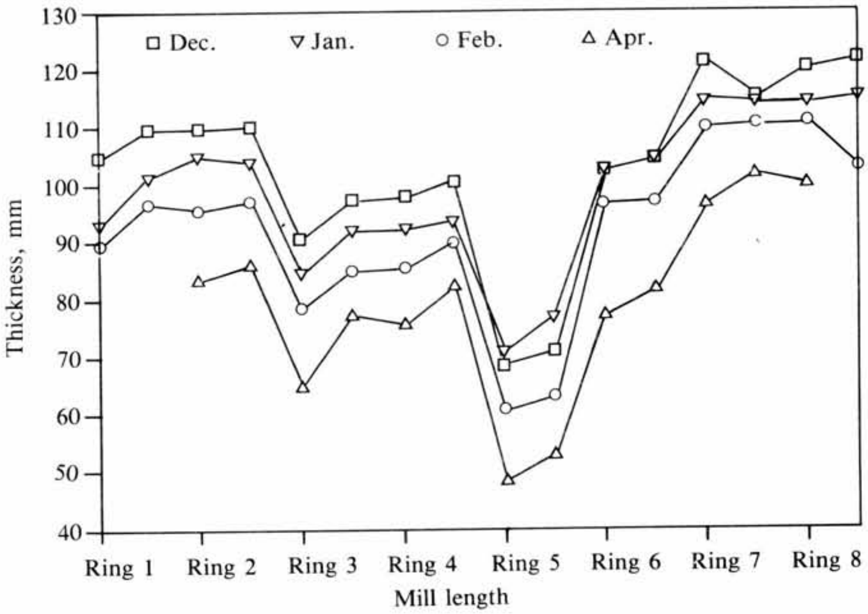

Fig. 3—Progressive average grid thicknesses

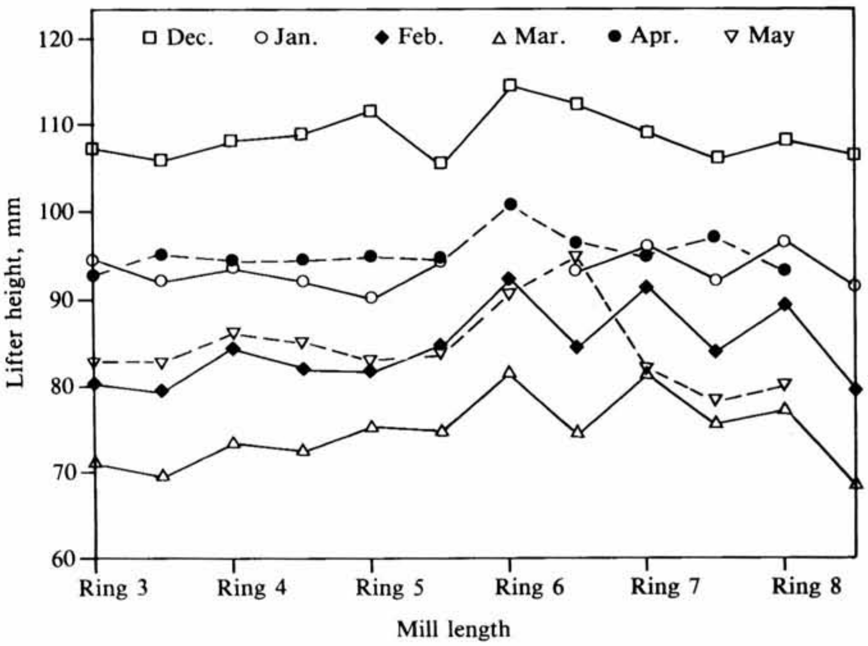

Fig. 4—Progressive average heights of lifter bars

Analysis of the Results

After 6 months of monitoring, it can be predicted that lifter bars under these conditions will last 192 days on average, wearing down from 100 to 60 mm. It can also be predicted that the grids will take 665 days on average to wear down from 125 to 30 mm. This is five times the life of the previous grids, and nearly eight times that of the original flat-profiled 100 mm grids without lifter bars. The actual life of the grids was 656 days on average; the lifter bars averaged 180 to 200 days over a three-year period.

The improvement in the lives of the lifter bars and grids represents substantial savings in the cost of materials and downtime on the mine. A current cost of each liner block and lifter bar was calculated, based on a price of R2,54/kg for AMS; the weight of each type of liner was obtained from plant personnel. The breakdown of weights and costs is given in Table I.

TABLE I
COST ANALYSIS OF DEELKRAAL LINERS

	Per liner block			Complete mill cost/annum
Liner	Weight kg	Cost R	Life day	R
V-grid	145	368	134	192 500
Lifter bar	119	302	67	315 900
Total				508 400
100 mm flat grid	192	488	85	402 300
125 mm flat grid	240	610	665	64 300
Lifter bar	132	335	192	122 300
Total				186 600

The short life of the lifter bars that were used with the V-grids (only 67 days) was due to their low protrusion (about 30 mm) above the surface of the grid. This allowed the material to slip over the lifter bars and resulted in a high rate of wear. Once the lifter bars had been worn to below the upper surface of the grid, they were discarded, leaving a large quantity of scrap.

From the experimental liner, it is calculated that the saving in the cost of materials over a one-year period is R322 000, and the downtime is about 75 hours (or 10 shifts) less than it was when the V-grids were used. The savings over the original flat grids are estimated to be R216 000 and 100 hours downtime annually. The higher cost of the V-grids is due to the short lives of the lifter bars.

Unfortunately, the effect of lifter bar height on power draw and throughput could not be monitored meaningfully because of problems with changes in the size of the feed and fluctuating milling conditions. However, the plant personnel claim that there was no apparant change in the performance of the mill after the experimental lifter bars had been installed.

Instead of extending the life of the lining, thinner grids can be installed; grids of 75 mm will last about a year, and the internal available volume of the mill will be increased by 4,4 per cent. The mining community claims that an increase in the volume of a mill yields a noticeably higher throughput, which can be observed when the linings of a mill are well worn.

Tests at Kloof

The object of this part of the work was to compare the performance and cost effectiveness of a range of commercially available lining materials. So that the wear rates of different materials could be compared directly, the linings were installed in a single mill. This approach overcame the problem of changes in feed and milling conditions that are encountered in different mills over the extended periods required for such a field test. In addition, the testing time is greatly reduced if a number of materials are tested simultaneously.

Course of the Investigation

A secondary pebble mill at Kloof gold mine, 4,3 m in diameter by 6,7 m long, and running at 83 per cent of the critical speed, was fitted with five different liner materials that were protected by lifter bars (Fig. 5). Because the wear of the liners is uneven down the length of a mill, all five materials were installed in the same ring. In addition, a buffer ring was fitted on either side of the test ring to prevent the wear of the adjacent liners from affecting the results. All the liners had the same flat profile, were 80 mm thick, and were mounted under identical AMS lifter bars that were 80 mm high. These lifter bars isolated adjacent rows of materials from one another, and ensured that each material was subjected to identical conditions of wear.

As white cast iron is too brittle to be bolted down, it had to be wedged in place by AMS key bars. Because of the widely different weights of the various types of backing blocks, three of the materials were each divided into two groups and placed on opposite sides of the mill. The normal stagger along the edge of each ring (designed to prevent wash between the rings) had to be straightened out along the edge of the 'white iron'* blocks to allow for the fact that they were wedged between lifter bars. Oversize lining blocks had to be placed in the rows on either side of the set of 'white iron' to compensate for the half-block mismatch. Because of these problems, the 'white iron' was placed in a single group, with the high-chromium white iron (HCWI) on the opposite side of the mill.

The AMS was cast as a grid since this is its standard form when used in this type of mill, and the rest were cast as solid blocks. The materials were bolted centrally under the lifter bars, except for the 'white iron'. A rubber lining is usually clamped down between special lifter bars. To enable it to fit in with the experimental arrangement, three lugs were welded onto a 5 mm thick mild-steel plate for the lifter bar to be mounted on, and the rubber was cast onto this backing (Fig. 6). This configuration is far from ideal for rubber, but it was felt that the test would still serve to indicate whether rubber linings can last in large, high-speed mills grinding quartzitic ores. Mild steel is not normally used as a mill lining, but was installed to demonstrate the way in which a relatively soft low-carbon steel would perform when protected by lifter bars.

All the liners were numbered on the back with an angle grinder, and then individually weighed on a suspended electronic scale accurate to 1 kg. The position of each liner was noted as it was installed in the mill. The installation of the experimental liners took 2 days, compared with the normal 8 hours of downtime that are required to replace two rings. The relining gang experienced some difficulty in handling the solid blocks, which each weighed about 250 kg. The oversize grids and mild-steel blocks that were required to fit in on either side of the 'white iron' were well-designed and fitted easily, but were

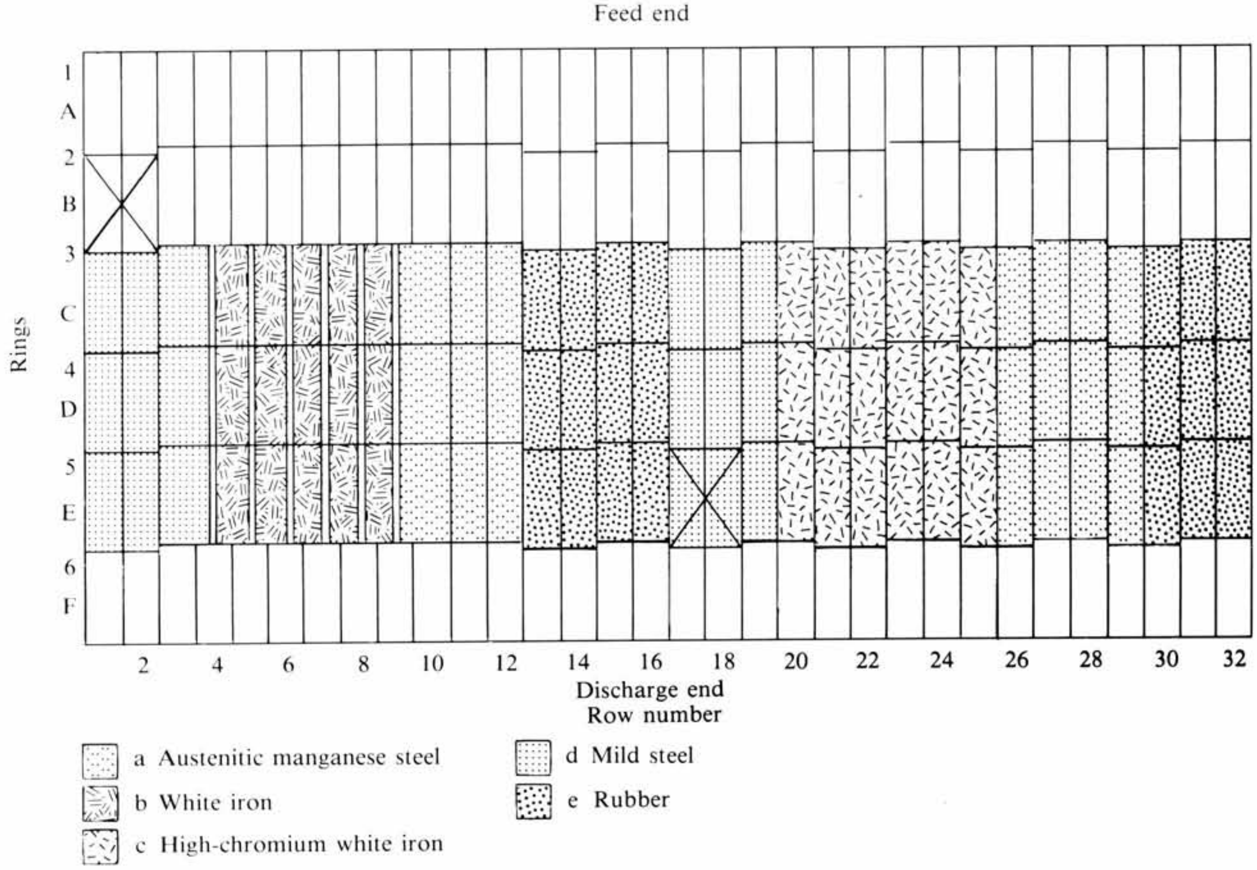

Fig. 5—The lining of the Kloof experimental mill

a AMS to SABS 407, type 2, containing 11,5 to 14,5 per cent manganese and 1,0 to 1,3 per cent carbon

b HCWI to BS 4844 pt 3, grade 3D, containing 27 per cent chromium

c 'White iron' containing 2,4 to 3,4 per cent carbon and 0,5 to 1,5 per cent silicon

d Mild steel (carbon steel, grade A2)

e Rubber to Skega specifications

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* Actually grey iron shown by microstructural analysis to contain flake graphite and pearlite.

cumbersome to handle. The experimental lining and measurements are illustrated in Figs. 7 and 8.

After six months, the lifter bars were changed, four of the materials were removed after 13 months in service, and the HCWI was removed after 2½ years. After a thorough scraping down and washing to remove the remaining dirt, the old liners were weighed so that their weight loss could be determined (Fig. 9). Because the 'white iron' blocks were securely packed in with slurry, their impact toughness was put to the test in the removal process (Fig. 10). None of them appeared to be any the worse for the pounding they had received from the sledgehammer.

Results

All the materials performed well for the first 13 months, and those materials which were not expected to last through to the next changing of lifter bars were removed. The AMS grids were fully worn through to the backing plates; the rubber was holed through in some places and heavily impregnated with thin strips of wire and scrap steel (Fig. 11). The 'white iron' blocks were worn down to nearly 24 mm at the centre but showed no sign of cracking. This meant that they could probably have been worn down to less than 20 mm. The mild steel had plenty of life left in it and could have lasted to the next change of lifter bars.

The wear modes of the various materials is discussed briefly in the Addendum. The progressive average wear profile of the 'white iron' is shown in Fig. 12. The lifter bar is shown on the left, and each set of bars is represented by separate vertical lines. A systematic wear pattern can be observed, but it should be noted that the time intervals between readings were not regular. The average thicknesses of all the materials on the centre line between the lifter bars except for the grids, which were measured off centre, were reduced fairly steadily (Fig. 13). It is important to observe that, because all these thicknesses were measured from the shell, they include the backing plates of the grids and of the rubber.

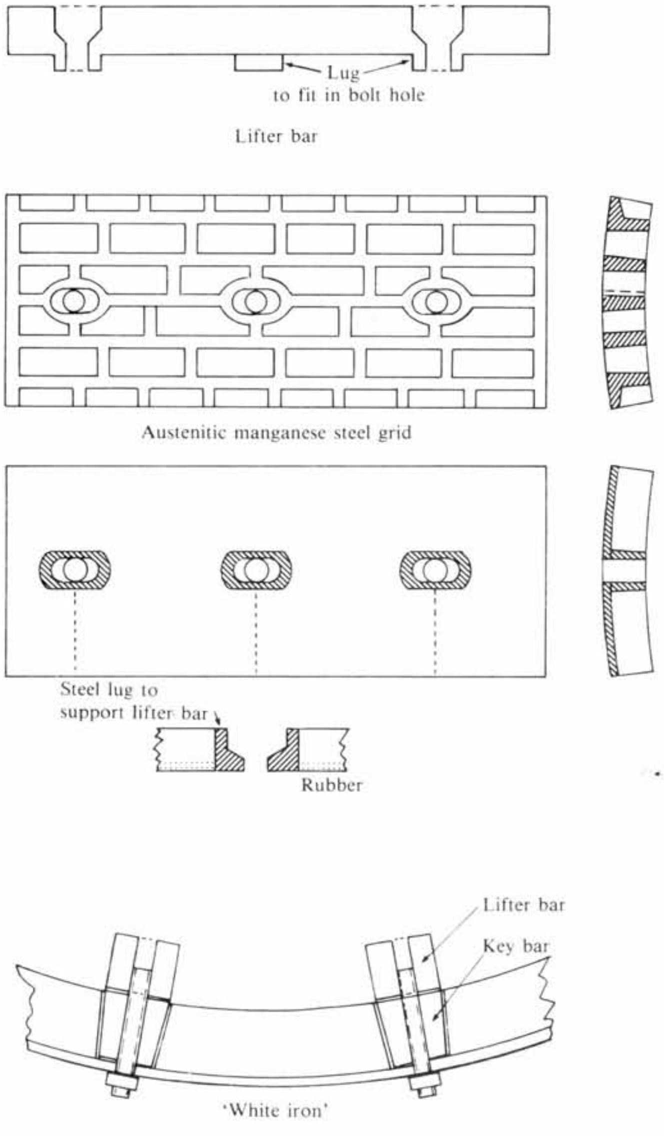

Fig. 6—Configurations of the test linings

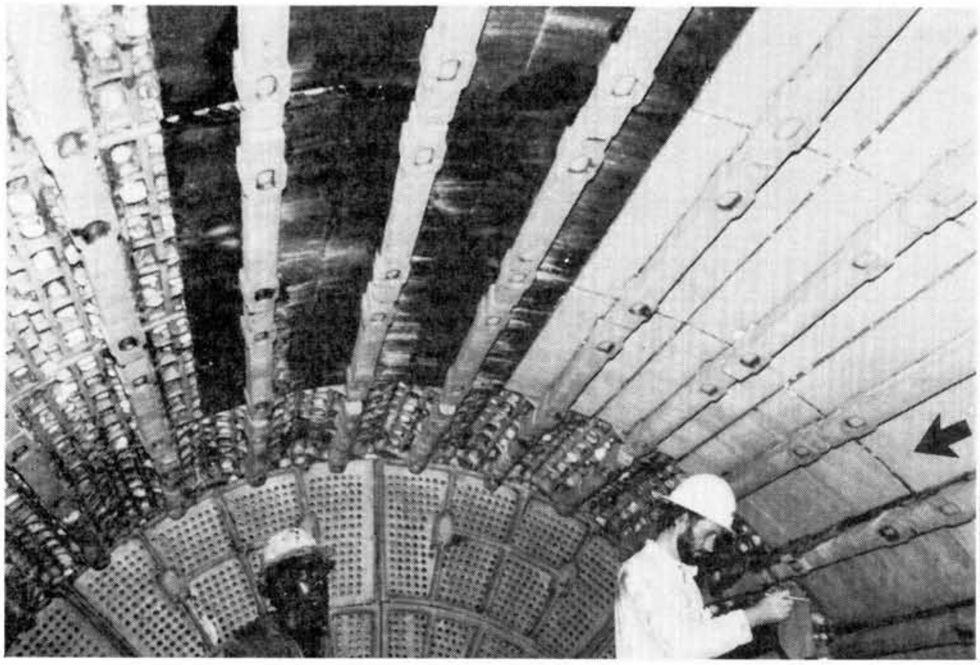

Fig. 7—An interior view of the Kloof mill, showing the discharge grate in the background. The materials are, from left to right, AMS grids, rubber, mild steel, and 'white iron'. The over-size mild-steel block is arrowed

Fig. 8—Taking measurements of the HCWI blocks

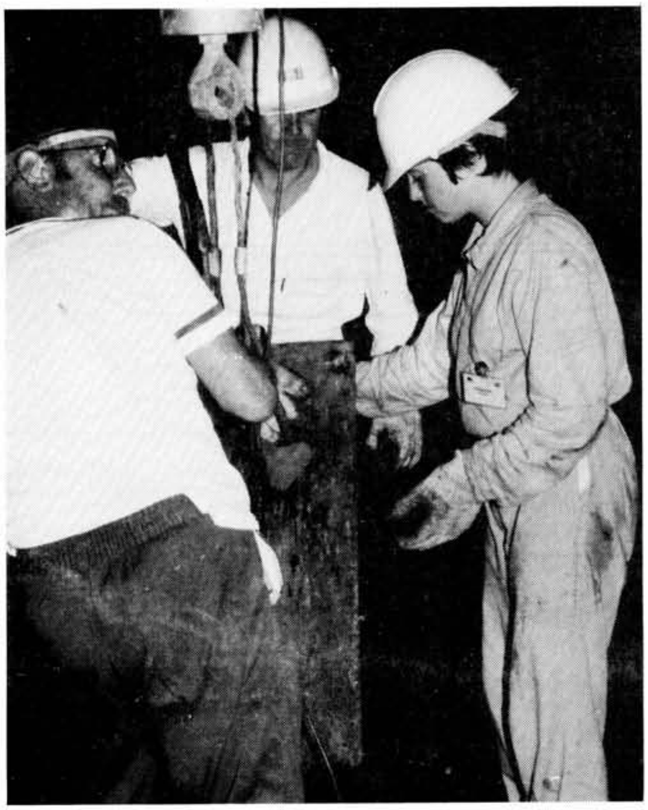

Fig. 9—The worn blocks being weighed

Fig. 10—'White iron' blocks during removal

The surface and bulk hardnesses of the materials were measured in an effort to assess the degree of work hardening that they had undergone while they were in the mill (Table II). The 'white iron' had a scatter in hardnesses because of its uneven composition and porosity, and no significant difference could be found between its surface and its bulk hardness, as was expected; the unexpectedly low hardness values indicated that this was not a white cast iron. A microstructural analysis was therefore carried out[6], which revealed the microstructure of flake graphite and pearlite that is typical of a grey cast iron. A white cast iron would consist of hard cementite and pearlite. The AMS had work-hardened fairly well, but not to its full potential of an HV_{10} of around 500. This indicates that it should perform even better, when compared with the other materials, under more severe impacting conditions. These results demonstrate that impacting in a pebble mill of this size is not as severe as one might

Fig. 11—A fully worn section of the rubber liner, showing the massive amount of steel that pierced it

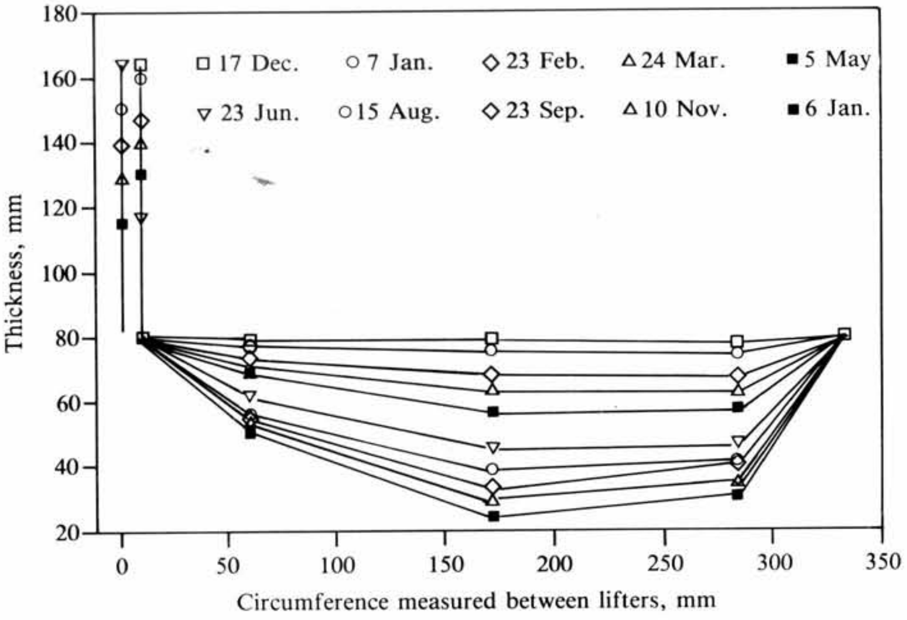

Fig. 12—The progressive average wear profiles of the 'white iron'

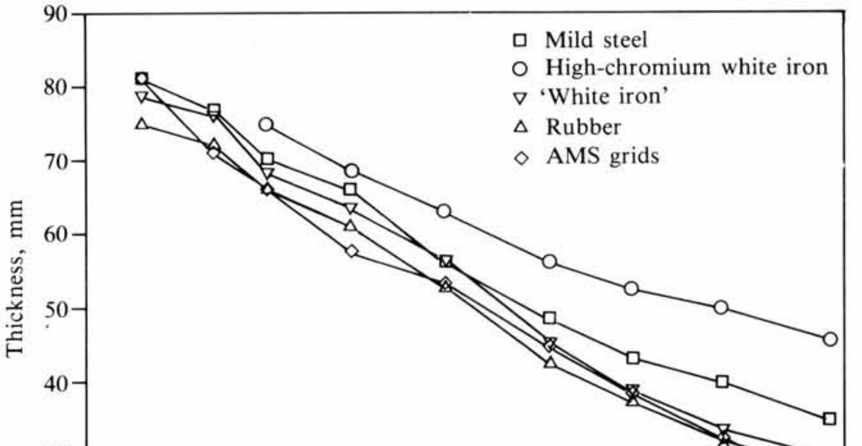

Fig. 13—Average material thicknesses throughout the testwork

TABLE II
HARDNESS MEASUREMENTS

Material	Hardness, HV_{10}	
	Bulk	Surface
Mild steel	166	232
Austenitic manganese steel	240	390
'White iron'	225	225 (194 to 252)
High chromium	620	620

expect.

Analysis of the Results

After each measurement, the wear rates and predicted lifetimes of each material were calculated. The weight losses in the central liner blocks, which give a true representation of the wear rates, were averaged for each material. These were then converted to volume losses so that the various materials could be compared (Table III). The density of the rubber was found to be 1,16 g/cm^3, 'white iron' 7,10 g/cm^3 (porous casting), and the other alloys 7,7 g/cm^3. The net average density of the grids was taken to be their initial weight divided by the total volume of an equivalent solid block, which yielded a value of 2,8 g/cm^3.

TABLE III
COMPARATIVE WEAR RATES OF MATERIALS

Material	Weight loss kg	Volume loss litre	Daily wear rate ml	Predicted life day
Mild steel	83,1	10,8	27,2	563
'White iron'	90,6	12,8	32,1	420
Rubber	17,3	14,9	37,6	421
AMS grids	38,2	13,6	34,3	384
High chromium	124	16,1	17,6	917

When the blocks had worn down to a minimum thickness of 10 mm they had a volume loss of about 16 litres, and the 'white iron', when it had worn down to 20 mm, had a loss of about 14 litres. The profiles were measured with vernier calipers on a few blocks of each material, and these volume losses were calculated from the estimated final profiles of the fully worn blocks. Because the grids were completely worn, their volume loss was taken to be what had been calculated when they were removed. This volume loss was 13,6 litres for a minimum thickness of 20 mm on the bar closest to the centre. The predicted lives can be calculated from these figures. For the HCWI, the lower wear rate of 0,0617 mm per day after the initial 6-month wear-in period was used.

The calculated lifetimes were compared with the lifetimes predicted by measurements of the height loss (Table IV). In general, there is an excellent correlation between the lifetimes predicted by height losses and those predicted by volume losses. The discrepancy for the rubber could have arisen from its uneven wear characteristics. The slowest-wearing material had a life of just over twice that of the fastest-wearing material, which is a typical result when dealing with very abrasive quartzitic ores. The difference can be expected to increase dramatically in the grinding of softer ores.

TABLE IV
COMPARATIVE LIFETIMES PREDICTED FROM HEIGHT- AND VOLUME-LOSS

Material	Life based on height loss		Life based on volume loss day
	Mt	day	
Mild steel	0,72	561	563
'White iron'	0,54	422	420
Rubber	0,59	458	421
AMS grids	0,51	396	384
High chromium	1,20	935	917

The progressive predicted lifetimes (Fig. 14) tended to drop over the life of the first set of lifter bars, but then settled into a steadily increasing regime in which all the materials yielded progressively longer predicted lives with increasing wear. This indicates two important points. Firstly, it appears that the lifetime of a lining cannot be predicted from its initial wear rate since this changes with time, especially when lifter bars are used. Secondly, it is apparent that the height of lifter bars influences the wear rate of liner blocks.

Fig. 15 illustrates the effect of changes in the height of lifter bars on wear rates. The wear rates were measured from each change of lifter bars so that the influence of the lifter bars is emphasized. The wear rates of all the materials, with the exception of the grids, increased and then levelled off until the lifter bars, which were worn to a height of about 35 mm, were changed. A dramatic drop in the wear rate, averaging more than 40 per cent, was observed in all the materials directly after the lifter bars had been renewed to a height of 80 mm. This demonstrates the substantial protective effect that lifter bars have on the lining.

After the lifter bars had been changed, three of the materials experienced a general decrease in wear. It is thought that, as the materials become thinner, they are afforded more protection by the lifter bars since they are then much lower than the top of the bars. The wear rate of the rubber liners continued to increase because they could not effectively absorb the impacting once they had worn to below a thickness of 10 mm, at which stage the rubber tended to become holed through. The grids were still well packed with pebbles up to the first change of lifter bars, but they lost the ability to be packed with rocks as the pockets became too shallow. Lacking that added protection, they showed an increasing rate of wear.

Cost Analysis

A cost analysis based on height-loss life predictions is set out in Table V. As the experimental conditions did not allow for a fair testing of the rubber, it is not included in the cost comparison. It must be stressed that the costs are based on quotations supplied for a single relining of the mill, and could therefore vary if large orders were placed. The costs are also based on the experimental configurations of the lining blocks that were used. The costing for the mild steel is particularly uncertain since the costs were based on cast mild steel, which is not the usual fabrication method for the material. If low-carbon

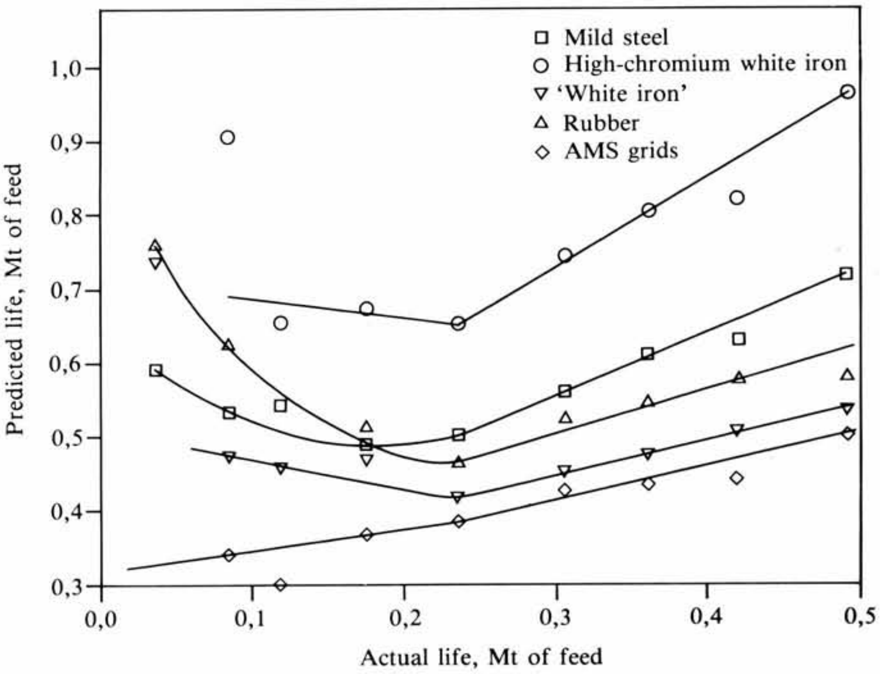

Fig. 14—The progressive predicted liner lives

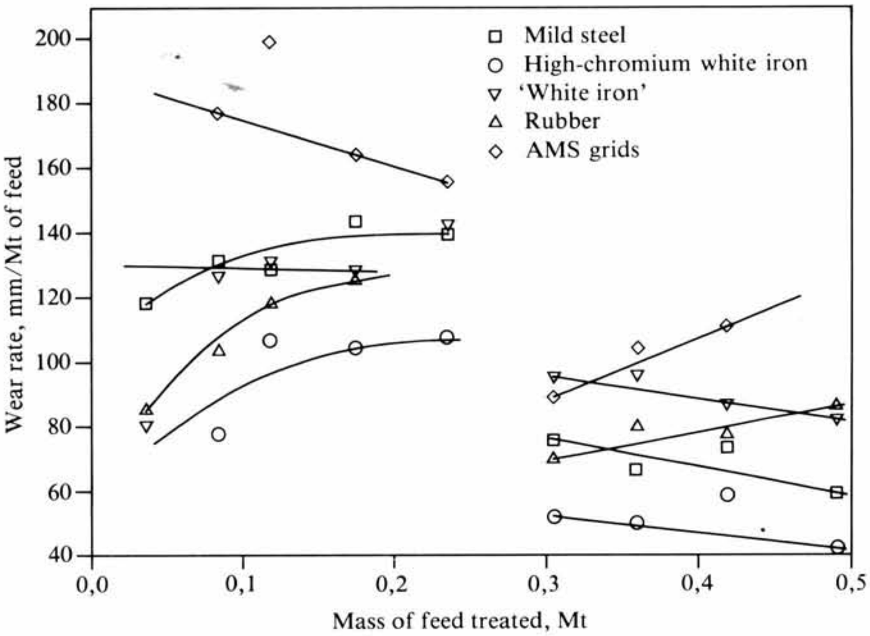

Fig. 15—The progressive average wear rates measured after each change of lifter bars

(mild) steel or medium-carbon steel is considered to be a promising lining material, it may be possible to find an appropriate fabrication route for wrought material, which would be cheaper.

For materials with a longer life, lifter bars still have to be changed at the same intervals, but a saving in downtime of some hours is afforded each time. The real cost of downtime is dependent upon the conditions in a particular mine, such as the grade of the ore and whether the plant is coping adequately with the tonnages that are demanded. This cost, therefore, was not calculated.

These results, illustrated in Fig. 16, indicate that, although the AMS grids and 'white iron' have the shortest predicted lifetimes, they are the cheapest on a cost–life basis. The HCWI has an excellent lifetime; however, its

TABLE V

COST–LIFE COMPARISON

Material	Block cost R	Cost of relining c/t	R/year*	Relative
AMS grids	289†	11	53 000	1,0
'White iron'	315‡	11	53 000	1,0
Mild steel	847	23	106 000	2,0
High chromium	1136	19	87 000	1,6
Rubber	1049	–	–	–

* This excludes the cost of lifter bars, which is R59 000 per annum and is calculated on the wear rate of ring 4

† R65 is included to allow for a backing plate that lasts for three changes of grids

‡ R54 is included to allow for an AMS key bar that lasts for three changes of blocks

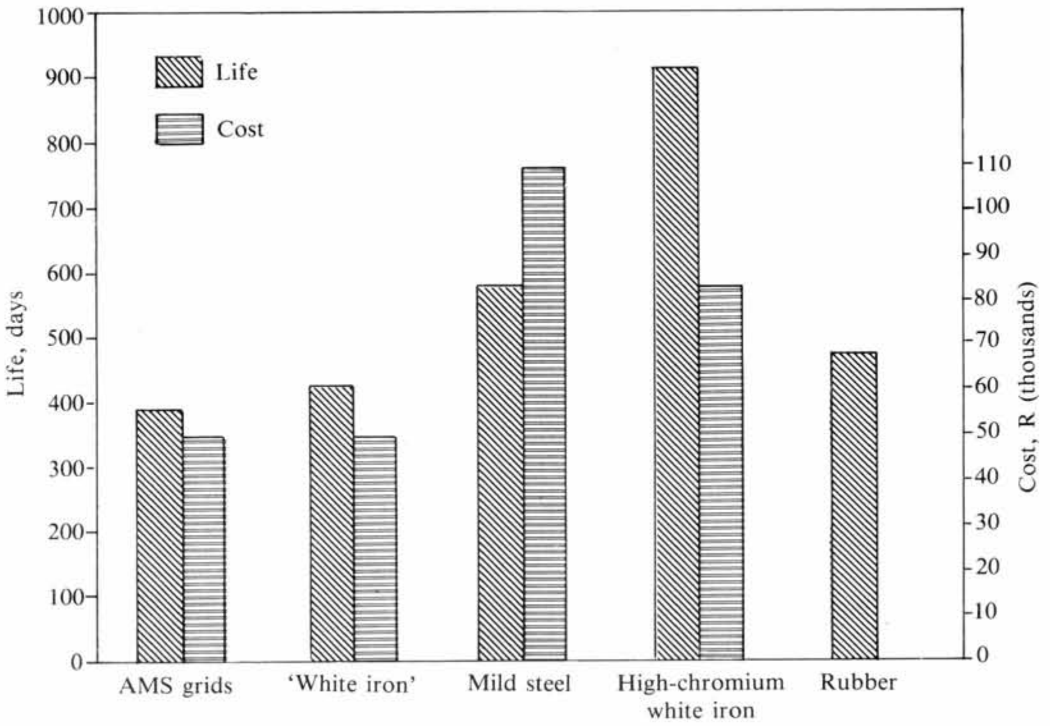

Fig. 16—Comparison of the life and cost of five materials

high initial cost renders it uncompetitive. Rubber suffers from a high material cost when compared with metals, and would therefore need to perform much more satisfactorily to be competitive on a cost–life basis. This performance could be tested only with the correct configuration for the rubber, which should give it an improved life.

The experimental set-up and procedure worked well and yielded good comparative results. The comparisons of the height- and volume-loss figures are encouraging, but they highlight the importance of knowing to what extent liners can be worn down.

The incorrect composition and microstructure of the 'white iron' compromises the results for this material. The cementite component of white cast iron results in its having a higher wear resistance than the grey cast iron that was supplied for this test.

Recommended Future Work

The most important continuation of this work would involve tests on the effect of lifter bars on the performance (throughput and grind) of a mill. Another natural continuation of the work is the testing of further materials in the Kloof pebble mill, and this work has already begun with the installation of three new materials in the mill. It is also necessary to repeat the earlier tests on true white cast iron and to ensure that its composition and microstructure are correct before it is installed in the mill. It would be useful to conduct similar tests in a large ROM mill since the results obtained on the pebble mill are not necessarily transferable. The conditions are considerably more severe in ROM mills, particularly because of the impacting of balls and large rocks. Now that it has been established that rubber can last in a high-speed large-diameter mill grinding quartzite, it would be useful to test rubber in an integral unit mounted under lifter bars of the appropriate design.

Discussion

The work showed that there is a substantial reduction in the wear of linings when lifter bars are installed in a ROM mill, since the grids have a lifetime that is five to six times that of unprotected grids. Lifter bars have more than double the lifetime of the original flat-profiled grids. This reduction in the rate of wear leads to substantial savings each year in the cost of materials—up to R266 000—and in downtime—75 to 100 hours—for a single mill. This study avoided the confusion of earlier work[3], in which improvements in the life of liners were attributed to changes in liner material instead of to the installation of lifter bars. The possibility exists that thinner liners can be used in conjunction with lifter bars, which would provide a greater internal volume to the mill and therefore increase its capacity.

Of the five different liner materials protected by lifter bars and installed in a single pebble mill, the AMS grids had the shortest life (396 days), the high-chromium white iron the longest life (917 days), and the mild steel the second longest (561 days). On a cost–life basis, the AMS grids and the 'white iron' blocks were the cheapest, at 11 cents per ton, for the full mill lining. The high cost of the HCWI made it uncompetitive at 19 cents per ton and, although rubber had a good life, it turned out to be rather expensive in this application.

This testwork has given only a cost comparison of liner materials. There are other plant-dependent factors that should be considered before a liner is chosen. For instance, only the rubber lining prevented the lock-up of gold concentrate, which is reported to result in a major tie-up of capital[7], and the 'white iron' caused a substantial lock-up.

It was noted from the progressive readings taken that the initial rate of wear was not the same as the total average wear. This indicates that one cannot predict the life of a lining from its initial rate of wear, but can obtain only an initial ranking of various materials.

A dramatic reduction in the wear rates of linings (over 40 per cent) achieved by the installation of lifter bars of an adequate height was apparent when worn 35 mm lifter bars were replaced with new 80 mm bars.

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Addendum

Fig. A1 compares the modes of wear of mild steel and 'white iron'. The deep gouging and plastic flow of the mild steel is in strong contrast to the much shallower abrasion tracks on the surface of the considerably more brittle 'white iron'.

The scanning electron microscope (SEM) photograph in Fig. A2 illustrates the random-direction, gouging abrasion of the AMS and the cracking away of the worn surface layer.

The left photograph in Fig. A3 shows the leading wear edge of the mild steel. Extensive deformation and flow of the steel are evident, and numerous gouges and indentations in the steel highlight the severity of the abrasive wear. On the right of the figure is a polished 11° section through the surface of the 'white iron', which gives an idea of the profile of the wear tracks. The exposed blocky section that is evident on the centre right edge was almost wholly removed; the polished section shows the porosity of the casting and the surface cracking.

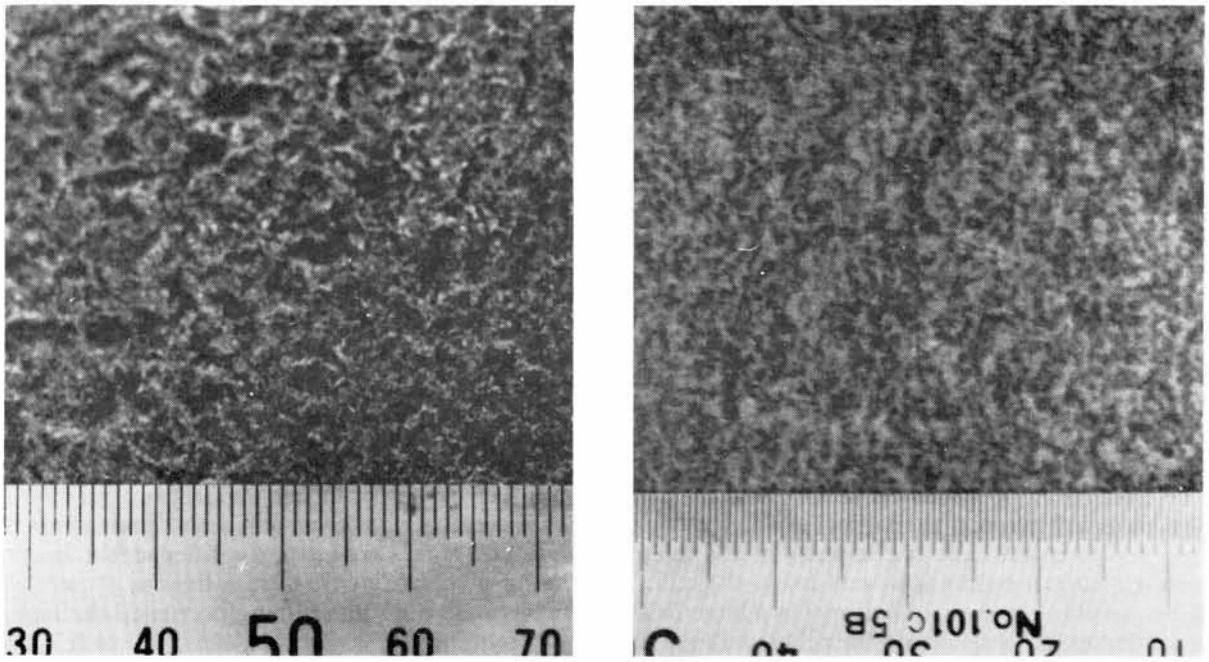

Fig. A1—The wear tracks on the mild steel (left) and 'white iron'

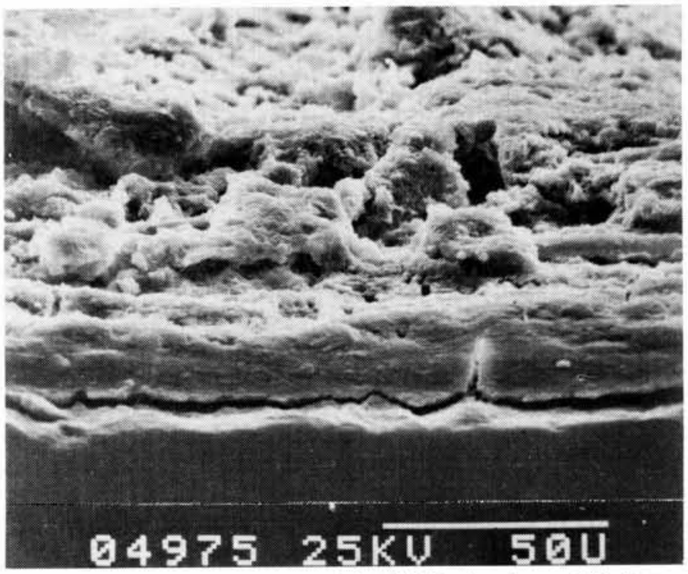

Fig. A2—Cross-section through the AMS, showing a 45° view of the wear surface

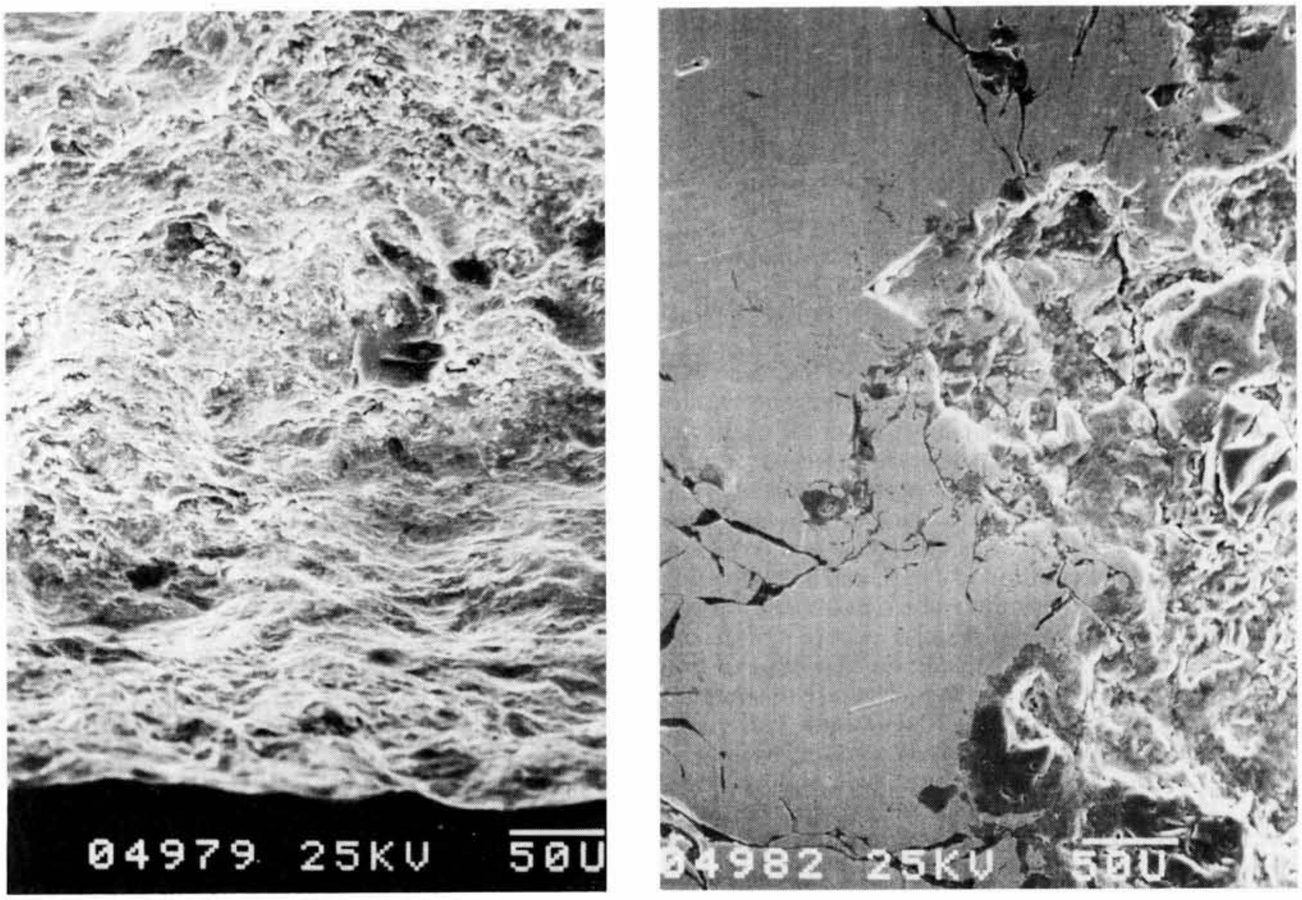

Fig. A3—The worn surface of the mild steel (left) and an 11° polished section of the 'white cast iron'