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Erosion, corrosion, and abrasion of material-handling systems in the mining industry*

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SYNOPSIS

A survey was conducted so that the degree of corrosive, erosive, and abrasive attack on material-handling systems in the mining and mineral-processing industry could be assessed, and so that the areas of research and development that would be relevant to the needs of the industry could be determined.

Of the 59 different mines that were invited to participate in the survey, 41 returned completed questionnaires, giving a return rate of 70 per cent. The total number of completed questionnaires amounted to 45.

An analysis of the results shows that attack by erosion or abrasion is considered to occur more often than attack by corrosion. However, all three types of attack must be regarded as significant problems within the mining industry, since 52 per cent of the participating mines reported pump failures due to the inability of the materials of construction to withstand the operating conditions, and almost 90 per cent reported piping failures due to corrosion (22 per cent) or to erosion and abrasion (78 per cent).

SAMEVATTING

'n Opname is gedoen om die mate van korroderende, eroderende en skuuraanval op materiaalhanteerstelsels in die mynbou- en mineraalverwerkingsbedryf vas te stel en die terreine vir navorsing en ontwikkeling wat op die behoeftes van die bedryf betrekking sal hê, te bepaal. Een en veertig van die nege en vyftig verskillende myne wat gevra is om aan die opname deel te neem, het die ingevulde vraelyste teruggestuur, wat 'n terugsendingskoers van 70 persent gee. Daar was altesame 45 ingevulde vraelyste.

'n Ontleding van die resultate toon dat daar gereken word dat aanvalle deur erosie of skuring meer algemeen as korrosieaanvalle voorkom. Al drie soorte aanvalle moet egter as belangrike probleme in die mynboubedryf beskou word, aangesien 42 persent van die deelnemende myne pompfalings as gevolg van die onvermoë van die konstruksiemateriale om die bedryfstoestande te weerstaan, aangemeld het, terwyl byna 90 persent van die aangemelde pypfalings aan korrosie (22 persent), of aan erosie en skuring (78 persent) te wyte was.

Introduction

Before conducting some fundamental research on erosion and corrosion, the Council for Mineral Technology (Mintek) decided to undertake a survey within the mining and mineral-processing industry to assess how serious this type of attack was considered to be. Questionnaires based on that of Upfill-Brown and Stead[1] were distributed, by courtesy of the consulting mechanical and electrical engineers at head offices of the mining groups, to the resident engineers and metallurgical superintendents at individual mines and mineral-processing plants. A total of 59 operating mines were contacted in this way. Seven mining houses were approached, and several divisions of these mining houses cooperated with Mintek in distributing the questionnaires and ensuring that they were completed and returned for analysis.

So that the maximum amount of information could be extracted from the survey, the questionnaire asked for detailed information on piping and pumping systems and the history of their performance. It was envisaged that the survey would reveal the extent of the problems due to erosion and corrosion experienced within the mining industry, and would highlight areas of research that would be relevant to the needs of the industry.

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It was accepted that the various mines or processing plants would have different operational characteristics, and that therefore any generalization should be subject to extensive reservations. Also, the technical expertise of the personnel completing the questionnaire was expected to vary considerably. This diversity of experience was taken into account in the construction of the questionnaire and the interpretation of the results.

For several reasons, the area of interest covered by the survey was restricted to material-handling systems, which include pumps, valves, piping, bends, and other pipe fittings. In slurry-handling systems, the pipe and pump units experience a high degree of turbulent flow, and are more sensitive to attack by abrasion and erosion than other units. Also, piping and pumps lend themselves more easily than other equipment to investigation since, as discrete units, they can be removed and examined at regular intervals. The erosion or corrosion of piping, especially bends, is dictated by factors such as the velocity, composition, and degree of turbulence of the carrying fluid, and the size, shape, nature, and position of the suspended solids.

In the erosion and corrosion of pumps, the variables involved are complex and interact with one another: for example, a pump can fail when the protection afforded by the gland or seal breaks down and particles of slurry enter the bearing assemblies; alternatively, if the pump motor trips, the solids can settle out in the pump cavity, and restarting of the pump without flushing can result in aggressive attack on the liner or metal surface of the impeller by the bed of settled solids through which it is driven. These examples indicate that pumps can fail as the result of a range of defects associated with operation in an erosive or corrosive environment.

A more detailed account of this survey and its results is given in a previously published report[2].

Results of the Survey

Fig. 1 illustrates the types of mines and mineral-processing plants involved in the survey. Mintek received a total of 45 completed questionnaires from 41 mines. The plants and mines were grouped according to the metal or material that they produce.

Materials Handled

The materials handled by the pumps and pipes in the mining industry are shown in the form of a histogram (Fig. 2), from which it can be seen that the major area of use is the handling of water and slurries. Of the 45 replies, 10 were from coal plants. The results for coal and ore slurries show that the personnel of 33 of the 35 non-coal mines and plants and all the coal plants considered that the handling of slurries deserved an important rating of 2 or 3.

The handling of materials destined for heavy-medium separation (magnetite in the coal industry and ferrosilicon in the diamond plants) was also allocated a high degree of importance.

The movement of chemical solutions (only in the gold-and-uranium, diamond, zinc, tin, copper, platinum, and nickel industries, comprising 29 mineral-processing plants) was given a rating of 2 or 3 in 20 of the 26 replies. Hence, the handling of chemical solutions appears to be considered less important than the handling of waters and slurries.

Materials of Construction

The materials of construction currently used in the mining industry for pump impellers, piping, and pump casings are listed in Tables I to III respectively. In these tables, the number of plants that use a particular material for a specific duty is indicated in the various columns. The total number of materials used for piping, pump impellers, and pump casings does not tally with the number of replies because certain materials, e.g. concrete linings, were also quoted, but so rarely that they were omitted from the tables. Certain plants were also reported to have more than one pipe system or pump operating.

The most popular combination of units to move water appears to consist of a brass or bronze impeller, a cast-iron pump body, and a mild-steel piping system. For the handling of slurries (ore and other slurries), the participants appeared to favour a rubber-lined impeller and pump casing; unfortunately, there appears to be little agreement on the most suitable material for the piping system: 20 use mild steel, 18 use rubber linings, 16 use plastic—i.e. 11 use high-density polyethylene (HDPE) and 5 use polypropylene or polyvinylchloride (PVC)—and 3 use stainless steels.

Problems in the handling of mine and plant waters appear to have prompted the use of impellers made of materials other than brass or bronze: 5 use Ni-hard alloy, 7 use plastic coatings, 17 use rubber linings, 14 use stainless steels, 27 use cast iron, and 5 use cast steel. This is in addition to the 54 brass or bronze impellers reported.

For the pumping of chemical solutions, usage appears to be divided between rubber-lined (17) and stainless-steel (10) systems.

The pump impellers and casings for the handling of coal, magnetite, and ferrosilicon slurries appear to be distributed between Ni-hard alloy (12), cast-iron (5), and rubber-lined (2) systems while, for the piping, HDPE (7), rubber-lined material (3), or mild steel (13) is used.

The majority of the piping for all duties comprises polymers (21 per cent), rubber linings (17 per cent), and mild steel (54 per cent).

Areas of Failure

The analysis of areas of failure at various degrees of occurrence is shown as a histogram in Fig. 3. Corrosion and abrasion in piping were reported by 33 participants, and the abrasion of pump impellers and casings was reported by 39. It appears that the cavitation of pump impellers (8) and casings (10) was not observed extensively. External attack on pumps and pipes as a result of environmental conditions was reported (26) but was not regarded as a serious problem. It is noteworthy that the corrosion (23) and abrasion (25) of pipe fittings are not rated as highly as their incidence on piping, possibly because the participants were somewhat confused by the classification of bends, T-pieces, etc., as pipe fittings.

However, it must be pointed out that the appearance of an area subject to purely corrosive attack in an environment with fast-flowing impinging or turbulent fluids is similar to that caused by abrasive attack[3]. The erosive nature of fast-flowing corrosive solutions greatly accelerates the rate of metal loss, and leads to the formation of undercut pits, which are of the horse-shoe shape that is also typical of pot-holes in river beds.

The validity of the above observation is confirmed by the few reported instances of corrosive attack on pump impellers and casings. In pumps, owing to the high velocity and turbulence of the fluid, general corrosion would rarely occur, and it can be assumed that the abrasive attack on pumps observed *in situ* would include any erosion or corrosion component. In pipes, where the degree of turbulence is lower than in pumps and is generally dictated by the number and position of the bends, the velocity of the fluid, and the irregularities on the surface, significant general corrosive attack was reported.

Causes of Failure

One of the survey questions required plant personnel to assess the primary causes of failure under the headings supplied. The answers are shown in Fig. 4, from which it appears that the majority of plant personnel thought that abusive service conditions were the main reason for the failure of pipes (30), fittings (27), pump casing (36), and pump impellers (32). A smaller number considered that the selection of the wrong material had resulted in the premature failure of pipes (24), fittings (22), pump casings (17), and pump impellers (17), and even fewer thought that poor maintenance was to blame. Poor installation and faulty design and manufacture were not considered to be significant causes of failure.

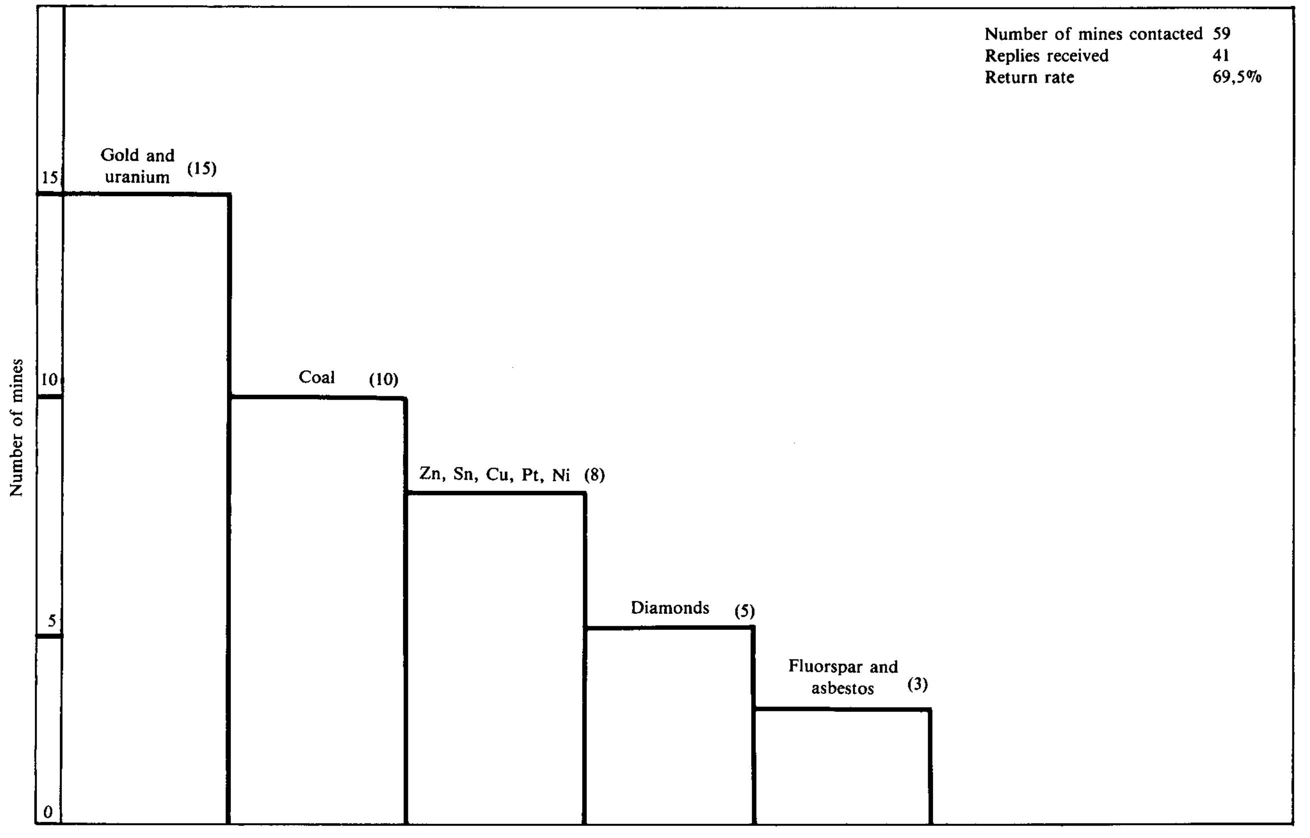

Fig. 1—Types of mines that participated in the survey

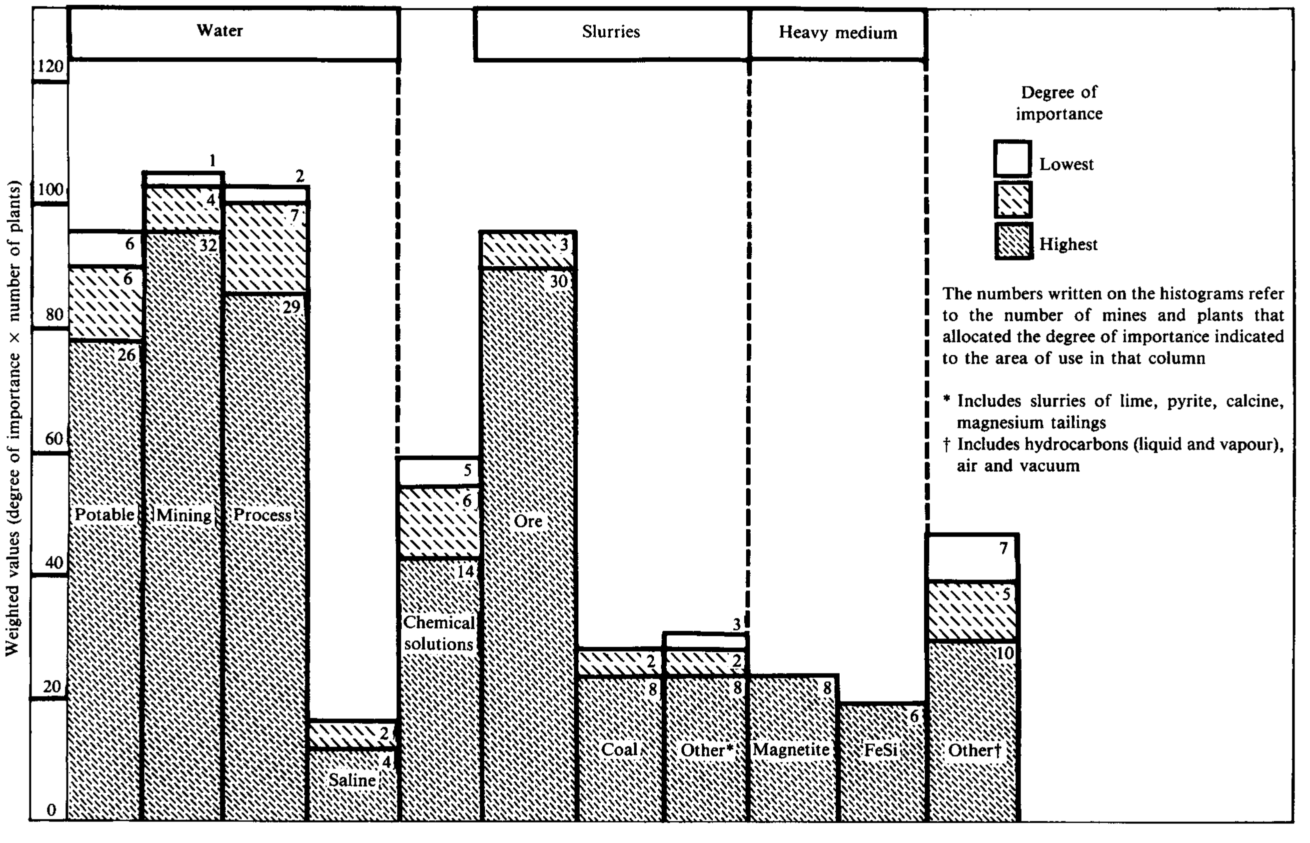

Fig. 2—Areas of use and degrees of importance

TABLE I

MATERIALS OF CONSTRUCTION FOR PUMP IMPELLERS

Material of construction	Water				Chemical solutions	Slurry			Heavy medium		Other
	Potable	Mining	Process	Saline		Ore	Coal	Other	Magnetite	FeSi	
Brass or bronze	24 00000000 00000000 00000000	17 0 00000000 00000000	12 0000 00000000	1 0	1 0						2 00
Ni-hard	1 0	1 0	2 00	1 0		3 000	5 00000		4 0000	3 000	
Polymer lined	4 0000	1 0	2 00		2 00						
Lined with rubber	1 0	5 00000	10 00 00000000	1 0	15 0000000 00000000	24 00000000 00000000 00000000		6 000000		2 00	2 00
Stainless steel	4 0000	5 00000	3 000	2 00	11 000 00000000	1 0		2 00			3 000
Cast iron (including high-chromium)	9 0 00000000	8 00000000	8 00000000		4 0000	1 0	3 000		2 00		3 000
Cast steel	2 00	1 0	2 00		2 00		1 0				2 00

TABLE II

MATERIALS OF CONSTRUCTION FOR PUMP CASINGS

Material of construction	Water				Chemical solutions	Slurry			Heavy medium		Other
	Potable	Mining	Process	Saline		Ore	Coal	Other	Magnetite	FeSi	
Ni-hard	2 00	1 0	2 00	1 0		4 0000	6 000000		4 0000	3 000	
Polymer lined	3 000	1 0	1 0		2 00						
Lined with rubber	1 0	4 0000	9 0 00000000	1 0	18 00 00000000 00000000	23 0000000 00000000 00000000		7 0000000		2 00	2 00
Stainless steel	3 000	4 0000	3 000	2 00	8 00000000						2 00
Cast iron (including high-chromium)	23 0000000 00000000 00000000	15 0000000 00000000	20 0000 00000000 00000000	1 0	3 000	2 00	3 000	1 0	2 00	2 00	4 0000
Cast steel	5 00000	8 00000000	5 00000		1 0	2 00	1 0				3 000

TABLE III

MATERIALS OF CONSTRUCTION FOR PIPING

Material of construction	Water				Chemical solutions	Slurry			Heavy medium		Other
	Potable	Mining	Process	Saline		Ore	Coal	Other	Magnetite	FeSi	
PVC or polypropylene	4 0000	5 00000	5 00000	2 00	6 000000	1 0	2 00	2 00			
Ni-hard							1 0				
HDPE			8 00000000		4 0000	6 000000	4 0000	1 0	2 00	1 0	
Lined with rubber		1 0	5 00000	3 000	8 00000000	14 000000 00000000		4 0000		3 000	
Stainless steel					7 0000000	2 00		1 0			2 00
Cast iron (including high-chromium)			1 0		2 00						
Mild steel	29 00000 00000000 00000000 00000000	27 000 00000000 00000000 00000000	23 0000000 00000000 00000000	1 0	5 00000	13 00000 00000000	6 000000	1 0	4 0000	3 000	7 0000000

HDPE = High-density polyethylene

Abusive service conditions (as opposed to poor design) would cover conditions such as changes in process conditions, the use of unskilled operators, and changes in operational duty, as well as the conversion, for financial reasons, of a dual-metal plant, e.g. for the treatment of gold and uranium, to the production of the more economically attractive metal alone. In the latter instance, units that operate satisfactorily under the conditions for which they were designed would be subject to a different and perhaps more aggressive environment. A similar situation would arise for units that were subjected to substantially increased or decreased fluid velocities and changes in primary feedstock or process additives. Certain trace elements associated with the introduction of new feedstock or additives could increase the corrosion rate of a particular metal to such an extent that erosive or corrosive conditions could cause premature failure within a few days.

In theory, however, a range of process variations and possible mistakes by unskilled operators should have been anticipated at the design stage, and the system should have been arranged to accommodate them. From the specific reference to abusive service conditions rather than to design faults as the reasons for failure, it can be inferred that process conditions vary beyond the range estimated at the design stage (possibly as the result of experimentation by process staff), and that the training of operators leaves much to be desired.

Successful Applications

It was hoped that the answers (7) to this section of the questionnaire would reveal the extent to which new technology and materials have been introduced into the mining industry. The comments received are summarized in terms of materials used in Table IV.

The use of materials such as stainless steel, Ni-hard alloy, and plastic for piping and pumps indicated the willingness of the mining industry to experiment with newer and more expensive materials in an attempt to increase the operating lives (mostly for slurry environments) of the various material-handling systems.

The areas in which replacement pipes and pumps are being applied successfully are summarized in Table V.

Although 9 of the plant personnel felt that they had nothing to record in regard to successful applications, 15 of the remaining 36 reported that they were happy with the slurry-handling systems (most of which are rubber-lined). The interpretation of some of the comments was very difficult, since it was not clear which materials were being handled by the various types of piping or pumps.

Unsuccessful Applications

Ten of the questionnaires indicate that no pump failures worthy of mention had occurred. The comments on the failure of pumps due to various causes are summarized in Table VI.

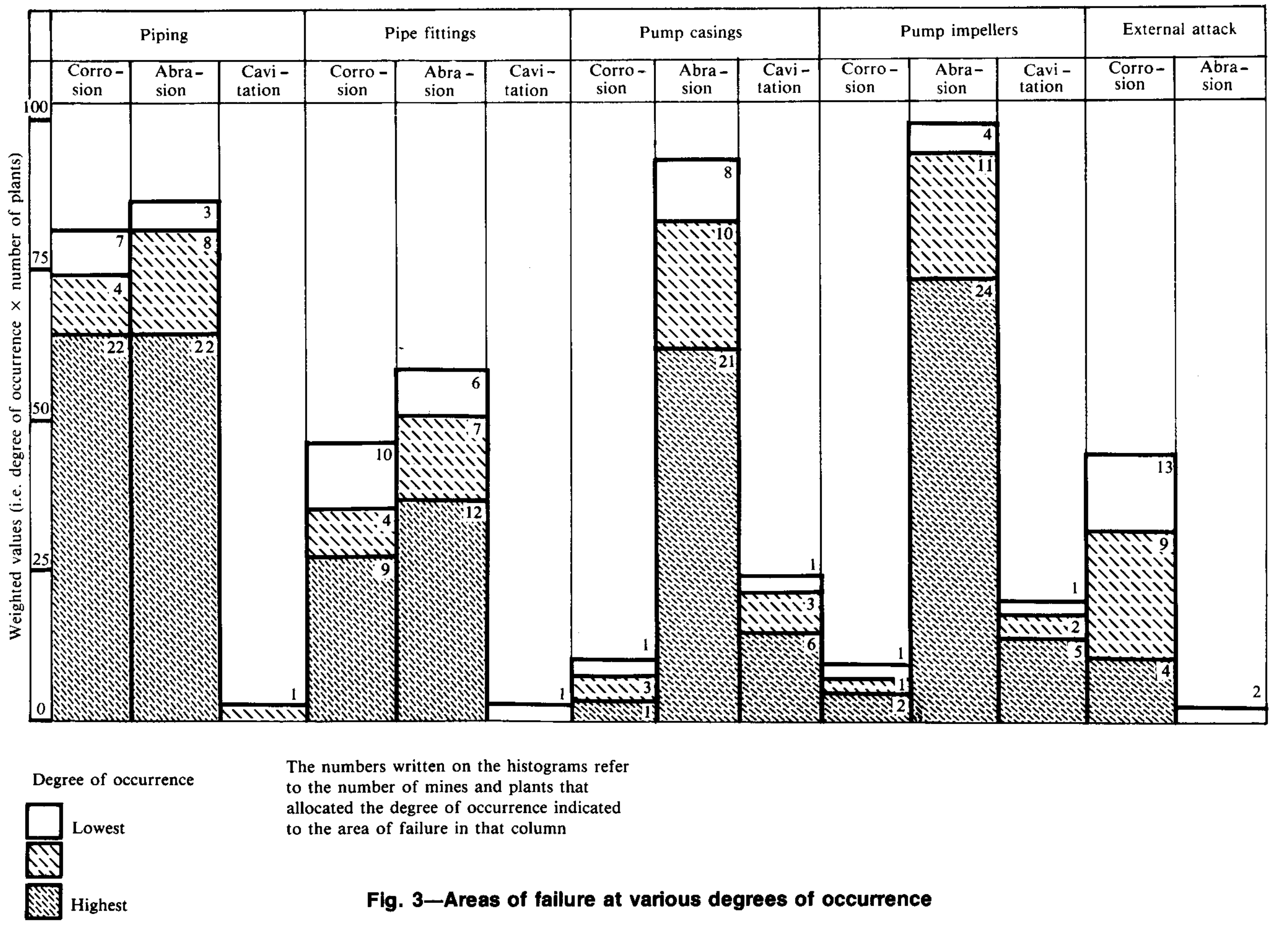

Fig. 3—Areas of failure at various degrees of occurrence

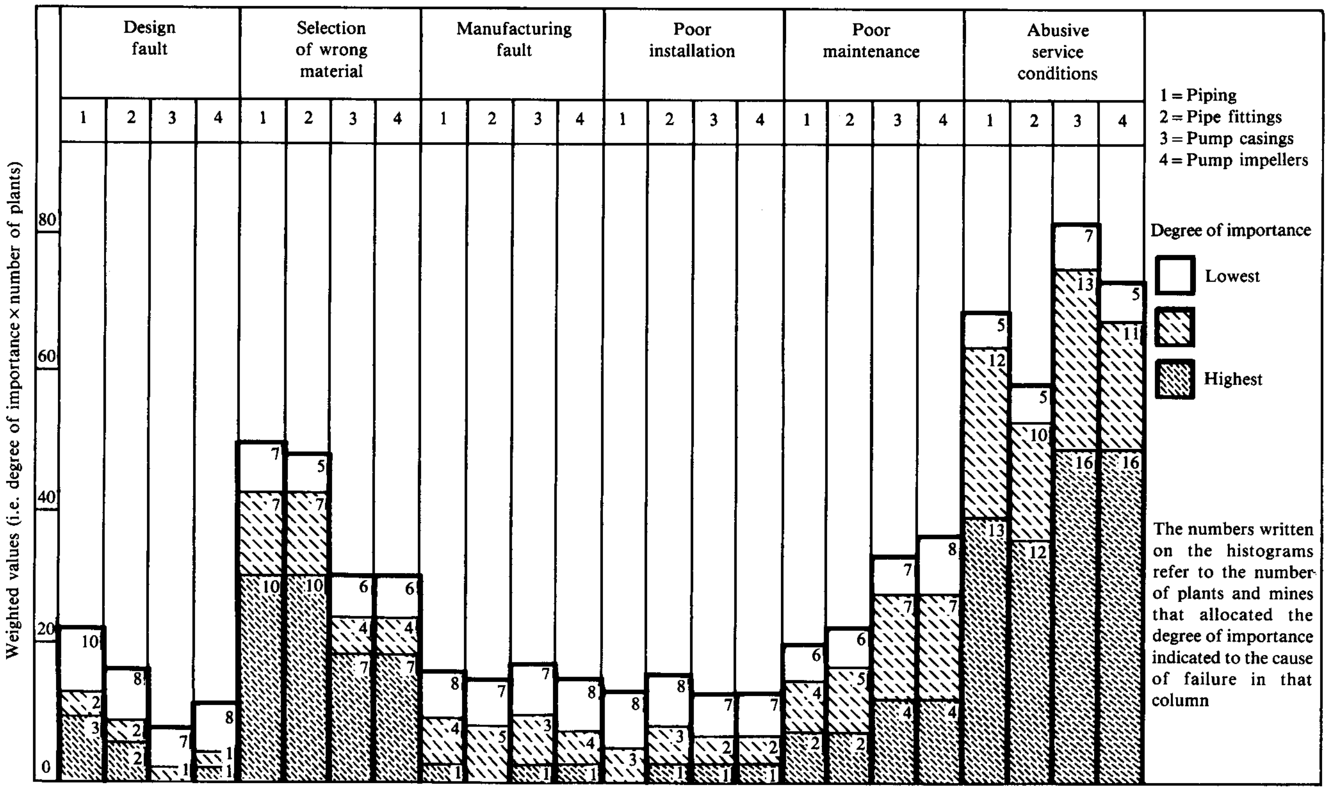

Fig. 4—Causes and degrees of importance of failure

TABLE IV
MATERIALS USED IN SUCCESSFUL APPLICATIONS

Application	Rubber lining	Ni-hard alloy	Polypropylene lining	HDPE	Brass–cast iron pumps	Stainless steel	Cast iron
Piping	7	1	2	2	–	–	–
Pumps	14	5	1	–	6	2	2

TABLE V
AREAS IN WHICH APPLICATIONS ARE SUCCESSFUL

Water			Chemical solutions	Slurries	Heavy media
Mining	Clear	Saline			
2	3	1	3	15	3

TABLE VI
SUMMARY OF COMMENTS ON PUMP FILURES

Cause of failure	Number of times mentioned
Manufacturing defects	3
Ingress of mud into clear-water systems	3
Incorrect operation	5
Incorrect choice of material	5
Failure of bearings, shafts, seals, balancing discs, etc.	11
Abrasive attack	6
Corrosive attack	2

Particular materials were mentioned in conjunction with pump failure. These are summarized in Table VII.

TABLE VII
SUMMARY OF MATERIALS ASSOCIATED WITH PUMP FAILURES

Material associated with pump failure	Number of times mentioned
Ni-hard alloy (longer lives required)	3
Scaw 30	1
Cast steel	2
Rubber lining	9
Cast iron	2

Unfortunately, some of the answers to the question on piping failure were incomplete, and the materials of construction of several of the piping systems are therefore not available. The piping failures are summarized in Table VIII.

The failure of mild-steel piping due to corrosion occurred mostly on water lines. It is of interest that most of the failures in all the piping systems were estimated to be due to abrasion and erosion in the handling of slurries.

The performances of polymers (polypropylene, PVC, and HDPE) and rubber-lined systems are compared in Table IX.

TABLE VIII
CAUSES OF PIPING FAILURES

Mild Steel			HDPE	PVC	Rubber-lining
Corrosion	Abrasion	Replaced by HDPE	Abrasion	Abrasion	Abrasion
9	11	4	9	2	11

TABLE IX
COMPARISON OF PERFORMANCE OF PLASTIC AND RUBBER-LINED PIPING SYSTEMS

Application and performance	No.
Plastic piping systems (Table III)	47
Handling of slurries	19
Rated as successful on slurry systems	8
Rated as unsuccessful on slurry systems	11
Rubber-lined piping systems	38
Handling of slurries	21
Rated as successful on slurry systems	7
Rated as unsuccessful on slurry systems	11

It appears that, for the handling of slurries, a similar number of rubber-lined and plastic piping systems are used and, in both instances, over 50 per cent of the applications were rated as unsuccessful.

Areas for Development and Other Comments

The remarks supplied by the plant personnel when asked whether they thought that any areas warranted further invesigation and development were collated, and it was found that, of the 45 plant personnel who replied, 11 felt that no areas were worthy of development; the remaining 34 comments are rationalized in Table X.

TABLE X
AREAS IN WHICH INVESTIGATION AND DEVELOPMENT ARE WARRANTED

Area	Number of times mentioned
Valves for slurry service	5
Descaling of pipes	5
Handling of slurry (general)	17
Corrosion-protection systems	8
Specific alloy investigations	6
Specific polymer investigations	5
Specific materials handled	6

Discussion

The results of the survey indicate that the failure of piping and pumps in the mining industry due to abrasion, erosion, and corrosion in the handling of slurries is significant, and justifies further investigation and development. It has often been said that research into any area of practical technology is justified only if the final result produces a more cost-effective system. However, the replacement of a unit that causes regular breakdowns on an operating plant requires much more than an estimate of cost savings.

The replacement unit should have a longer operating lifetime (proved in similar operating conditions), an adequate number of high-quality spares should be readily available, and maintenance and operating procedures for pumps should be clearly documented and easily carried out. Any replacement unit should be compatible with the current operating systems and should not interfere with the integrity of the plant as designed. Once these conditions have been fulfilled, the cost-effectiveness of the unit can be estimated.

In summary, any investigation in which the resistance to abrasion of material-handling units is determined, and in which certain parameters of fluid dynamics and solid materials are taken into account, could result in cost savings if the information obtained were made available to the mining personnel responsible for selecting replacement units. The problems involved in the selection of the correct material-handling systems at present are reflected by the results obtained in the present investigation, which show that more than 50 per cent of the rubber-lined and HDPE piping systems are rated as unsuccessful applications, and that approximately 40 per cent are claimed as successes. Unfortunately, because of the wide range of pumps that are used to move slurries, the only single trend detected is general disillusionment with the abilities of the pumps to operate for adequate periods without some form of maintenance.

Conclusions and Recommendations

The results of the survey indicate that the sections for the handling of slurry and water are the two most important systems on mines and mineral-processing plants. Purely corrosive attack of pipes and pumps is considered to be insignificant compared with the number of failures due to abrasive and erosive attack.

The degree of erosive and abrasive attack is certainly significant within the mining and mineral-processing environment since, of all the mines and mineral-processing plants involved in the survey, 42 per cent reported pump failures due to the inability of the materials of construction to withstand the operating conditions, and almost 90 per cent reported piping failures due to corrosive (22 per cent) or abrasive and erosive (78 per cent) attack.

In summary, the materials of construction used by the mining industry at present (Tables I to III) are as follows.

(i) For water-handling systems, brass or bronze pump impellers, cast-iron pump casings, and mild-steel lines are used in over 50 per cent of all reported systems.
(ii) For slurry-handling systems, rubber-lined pump impellers and casings (over 55 per cent) or Ni-hard alloy pumps (almost 30 per cent) are used with mild-steel (38 per cent), rubber-lined (30 per cent), or plastic (27 per cent) piping.

To complement the work already in progress, Mintek, using the results of this survey, proposes to construct a laboratory-testing device to investigate the erosive and abrasive effects of waters and slurries. The waters will be typical mine waters with and without mud, and the slurries will be typical of the larger ore deposits (usually with particles smaller than 2 mm) and of specific environments such as magnetite and ferrosilicon. The effect of these environments on such materials as mild steel, cast iron, stainless steel, Ni-hard alloy, and plastics (including polyurethane) will be assessed in terms of fluid dynamics, as well as the size and composition of the solids in suspension. A further development of the laboratory-testing system will include the testing of the performance of pumps, pipes, bends, and valves in a pilot-plant slurry-handling system so that the laboratory results can be compared with those obtained under simulated on-site conditions.

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References

1. Upfill-Brown, S.H., and Stead, G.R. Corrosion protection of steel pipelines by organic coatings and lining materials. *Corrosion and Coatings S. Afr.*, May and Jun. 1983.
2. Carter, A.M.F. A survey of the erosion, corrosion, and abrasion of material-handling systems in the mining and mineral-processing industry. Randburg, Council for Mineral Technology, *Report* M186.
3. Wranglen, G. *An introduction to corrosion and protection of metals.* 1st edition. Institut für Metallskydd, 1972. p. 121.