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Materials for piping systems in gold mines

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SYNOPSIS

This paper reports on a test that was conducted underground in a mine for two years on the following: pipes coated with paint, fusion-bonded powder, metal, or impregnated tape; and aluminium, stainless-steel, 3CR12, and plastic pipes.

It was found that the degree of corrosivity and mechanical damage increases substantially from the shaft of a mine towards the stope. Thus, the range of coatings that can be used successfully is fairly large in the shaft and haulageways, but corrosion-resistant materials, especially corrosion-resistant steels, need to be used close to the stope.

A study of the relative costs involved showed the costs of pipes of low-carbon steel and unplasticized polyvinyl chloride to be lowest, and those of epoxy-coated steel pipes to be highest.

SAMEVATTING

Hierdie referaat doen verslag oor 'n toets wat twee jaar lank ondergronds in 'n myn uitgevoer is op pype wat met verf, smeltverbinde poeier, metaal of geïmpregneerde band bedek is, en pype van aluminium, vlekvrye staal, 3CR12 en plastiek.

Daar is gevind dat die mate van korrodeerbaarheid en meganiese skade aansienlik toeneem van die skag van 'n myn na die afbouplek. Die verskeidenheid bedekkings wat met sukses gebruik kan word, is dus betreklik groot in die skag en vervoerweë, maar daar moet korrosiebestande materiaal, en veral korrosiebestaande staal, naby die afbouplek gebruik word.

'n Studie van die relatiewe koste daaraan verbonde het getoon dat die koste van pype van laekoolstofstaal en ongeplastiseerde polivinielchloried die laagste is, terwyl die koste van epoksiebedekte staalpype die hoogste is.

Introduction

The underground environment in South African gold mines is harsh, being both corrosive and abrasive, and having a detrimental effect on the many kilometres of service piping that form a main artery in the infrastructure of a mine. Work by the Chamber of Mines Research Organization over a number of years has identified the extent and causes of corrosion underground in gold mines[1,2]. The Organization decided to apply this knowledge to the problem of corrosion in mine service-water piping, and to select for testing purposes a range of pipe coatings and materials that have the potential to withstand the environment to greater or lesser degrees.

The purpose of this paper is to report on the establishment of a long-term test pipeline at a mine, and to assess the performance of test coatings and materials after an exposure of two years. Finally, it gives some guidance on the suitability of piping materials for gold-mine applications.

Evaluation of Test Pipeline

Most assessments of the performnce of coatings and materials in corrosive environments are carried out in short-term laboratory tests like the salt-spray test. Such tests are useful for the screening or ranking of materials, but have a number of shortcomings. These include a lack of information on the long-term changes that occur as the result of, say, the absorption of moisture or mechanical damage, the differences between test and service conditions, and the difficulty in relating test performance with 'useful life' in service.

Initial work at the Chamber of Mines Research Organization on coatings and materials to combat corrosion in gold-mine equipment began with laboratory salt-spray testing, but the limitations already mentioned soon became apparent and planning began for a more representative experiment.

Simultaneously, another programme of work was providing important information on the severity and nature of corrosion in gold mines. This programme involved an underground test on a pipeline made of various materials.

In the case of pipes, there are essentially two corrosion problems. The first relates to corrosion that progresses from the inside to the outside of the pipe and is a result of the corrosiveness of the liquid being conveyed. The principal factor in the case of mine service water is pH, which can often be low in mine water because of the presence of salts that were leached from blasted rock in mining operations. Also, with time the content of dissolved solids increases, and there is a corresponding increase in conductivity, which may affect corrosion. The second problem concerns corrosion that progresses from the outside to the inside of a pipe, and the factors affecting this corrosion include humidity, temperature, the presence of corrosive water from seepage or drainage, and the presence of blasting fumes and byproducts. In particular, it has been noted that return airways are more corrosive than intake airways.

In the light of this information, the principal criteria for the new test were defined as follows.

(i) The test must be capable of giving an indication of both the long-term performance of piping materials and coatings, and their deterioration.

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(ii) It must incorporate damage due to mechanical handling that is similar to the damage experienced in practice.
(iii) It must be located in an underground mine site where environmental conditions and water quality can be recorded regularly and controlled.

With these criteria in mind, it was decided that the most representative test would be a pipeline installed underground in a mine and made up of many different types of piping materials and coatings.

Description of the Test Pipeline

A schematic arrangement of the test site is shown in Fig. 1. The test equipment was essentially a self-contained loop supplied by a surface tank. The test pipes were located in an area of the mine that was ventilated by return air from mine workings but was remote from the main production areas. More than 150 pipes of 4-inch diameter, each 1 m long, made up the test loop. Typical operating conditions for the test loop are shown in Table I. The quality of water flowing in the loop was sampled regularly and controlled.

A survey of mine water quality in the South African gold-mining industry has shown that more than half of the mines have service water containing total dissolved solids (TDS) of between 2000 and 4000 mg/l. It was therefore decided that the TDS in this test should be 3000 mg/l. The chloride content was maintained at about 500 mg/l, which is a typical value for mines in the Transvaal. A typical analysis of the water in the test loop, which was always well oxygenated, is shown in Table II.

The range of pipes on test is given in Tables III and IV. Most of the pipes were joined with 'victualic' couplings, although a few were flanged.

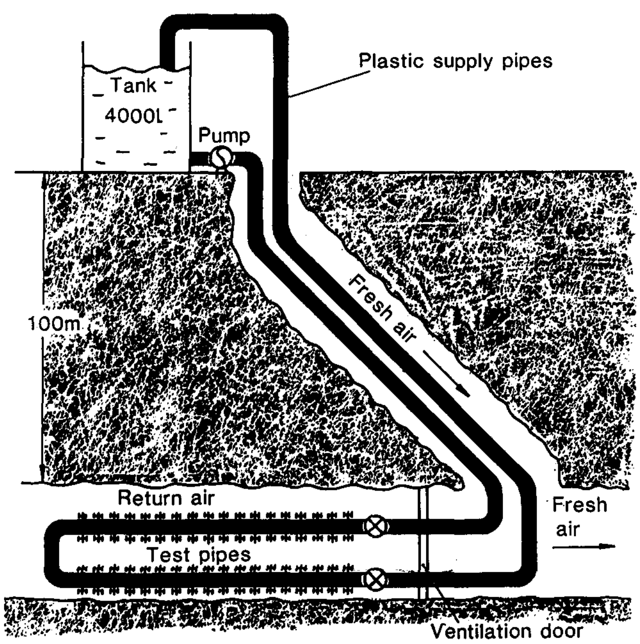

Fig. 1—Schematic layout of the test site

TABLE I
TYPICAL OPERATING CONDITIONS

Pumping station	
Flowrate	7,5 l/s
Pump pressure	250 kPa
Daily volume pumped	200 kl
Water temperature	21°C
Test site	
Temperature	21°C
Relative humidity	98%

TABLE II
TYPICAL ANALYSIS OF WATER IN TEST LOOP

pH	7,1
Conductivity	383 mS/m
Total dissolved solids	2940 mg/l
Suspended solids	4 mg/l
Total hardness as $CaCo_3$	916 mg/l
Chloride	500 mg/l
Sulphate	1280 mg/l
Nitrate	43 mg/l
Dissolved oxygen	8 mg/l

TABLE III
SUMMARY OF PIPES ON TEST

Total number of pipes	152
Plastic pipes	22
Aluminium pipes	3
Stainless-steel pipes	14
Carbon-steel pipes	113

TABLE IV
DETAILS OF CARBON-STEEL PIPES

Uncoated	6
Bitumen coated	7
Galvanized	6
Metal spray-coated	6
Electroplated	18
Plastic lining	2
Paint coating	68

All the coatings were applied by contractors who were considered to be leaders in their particular fields of application, so that the best-quality coatings were obtained. In addition, all the pipes were inspected very carefully for porosity and variations in thickness prior to their installation.

The pipes of corrosion-resistant materials were supplied by a number of fabricators well versed in the requirements of each material in terms of pre-welding or post-welding treatments, heat treatment, and so on.

Performance of Pipes

After two years' exposure, the pipes were removed to surface for thorough inspection. The performance was judged in terms of the number of corrosion sites on the internal and external surfaces, the number of damaged areas on the pipe, the underfilm creep of corrosion at damaged areas, and so on.

Pipes Coated with Paint

The term *paint* is used fairly loosely, since it includes fusion-bonded powder coatings.

All the paint coatings were found to have been damaged mechanically to some degree or other. Since most paint coatings protect by providing a barrier between a corrosive environment and the underlying surface, a lack of resistance to damage is extremely detrimental to coating performance. The paint coating that withstood damage due to mechanical handling much better than others was fusion-bonded epoxy, the thinner coating (about 250 μm) performing better than the thick coating (about 700 μm).

However, two other observations detract from the suitability of this coating for mine piping. Firstly, the materials used to repair damaged areas offer very poor performance in their own right, so that damaged areas remain very weak spots in the coating. Secondly, although epoxy-powder coatings gave excellent resistance to mechanical damage when first installed, they were much less resistant to damage when removed and re-installed after the two years in service. The implication here is that the epoxy coating undergoes some long-term deterioration as a result of interaction with the environment, and the coating becomes noticeably more brittle. Thus, epoxy coating may not be suitable for piping systems that are not permanent installations and must be moved to accommodate mining operations. For more-permanent installations, such as shaft or haulageway piping, epoxy coatings may be suitable.

Most other paint systems suffered badly from mechanical damage and provided incomplete protection. Two paint systems worthy of note, however, are inorganic zinc paints and epoxy formulations suitable for use on rusty surfaces. In the first instance, although the coating sustained damage, it appeared to offer some degree of sacrificial protection, which is beneficial, and in addition is a relatively cheap system to apply. In the second case, a proprietary product that was applied to wire-brushed rusty steel pipes for the purposes of the test performed very well, and the adhesion was good with no underfilm creep at damaged areas.

It is worth noting that the bitumen-coated pipes performed very poorly in this trial. After approximately six months in service, it was difficult to distinguish between bitumen-coated and uncoated pipes since both were heavily corroded.

Pipes Coated with Metal

Several pipes with electroplated coatings were included in the test loop, but in this instance the pipeline was used only as a vehicle for the testing of coatings for other applications. As these coatings were not intended for use with pipes, the results are not detailed here, except to show the potential problem of galvanic corrosion in mine waters. Fig. 2 shows the joint area of a pipe 'protected' by electroplated chromium but, because of incomplete coverage at the sharp corners, a galvanic cell was set up between the chromium coating (cathode) and the underlying steel (anode), resulting in severe galvanic corrosion.

The main metallic coating of interest was the zinc applied by hot-dip galvanizing. This coating performed exceptionally well during the two-year service period, and showed no significant deterioration or damage. This result has been confirmed by experience elsewhere, but a warning must be given. In this test, the pH value of the water remained between 6 and 8, which is probably the optimum for satisfactory performance of galvanized coatings. If water (or the external environment) is very acidic or very alkaline, the galvanized zinc coating will dissolve readily and may be destroyed in a matter of weeks or months. The safe operating range quoted by authorities for galvanized coatings differs, but, as a general guide, the pH value should be in the range 5 to 9 for optimum performance. In particular, it should be noted that galvanized coatings are not generally suitable for stoping environments, where acid water is very common.

Pipes Coated with Tape

Several pipes were coated with a wrapping of tape impregnated with a petroleum-based compound. The tape generally provided very effective protection against corrosion, but was damaged very easily. It seems that the most appropriate use would be for the tape to be applied *in situ* after pipes have been installed and mechanical damage is less of a problem.

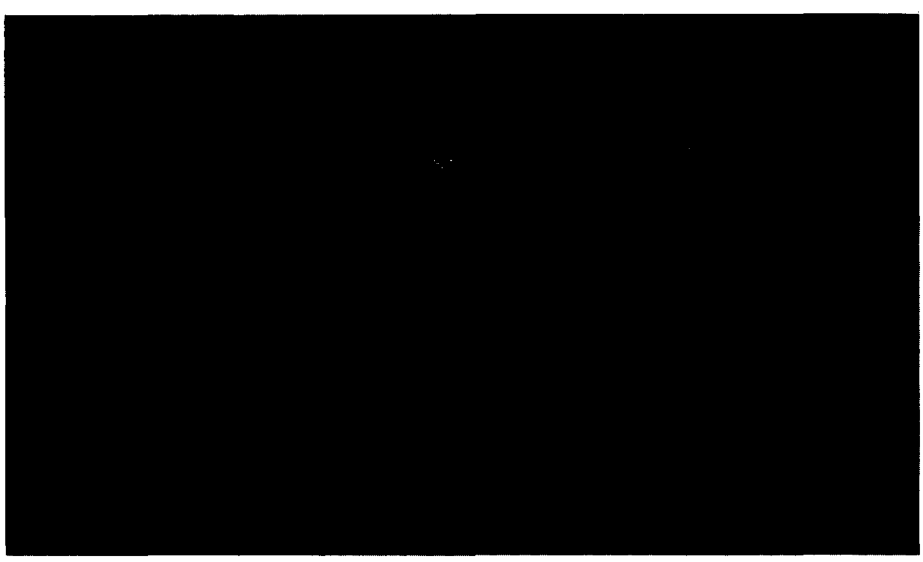

Fig. 2—Galvanic corrosion of the jointing face of a chromium-plated steel pipe

Aluminium Pipes

Several aluminium-alloy pipes were tested and in general performed fairly well. However, they tend to be less robust than steel pipes, and can become dented more easily. In addition, aluminium alloys require careful welding procedures, which detract from the practicality of some jointing systems and on-site fabrication. Indeed, a welded joint failed during the test.

Perhaps the most worrying factor about aluminium alloys is their sensitivity to the presence of trace ions in solution, especially copper and nickel ions. Even at very low concentrations, these ionic species may cause pitting corrosion and pipe perforation in a very short time. The phenomenon was not observed in this test, but has been experienced in other applications.

Stainless-steel and 3CR12 Pipes

The following grades of corrosion-resistant steel were tested: AISI 304L, AISI 316L, AISI 409, AISI 430, 3CR12, and 3CR12 (1,2 % nickel). With the exception of AISI 430, all these materials performed very well.

The lower-alloy grades (AISI 409 and 3CR12) showed some light staining adjacent to the welds, but this was superficial and in no way detrimental.

AISI 430, a steel notoriously sensitive to welding procedures, showed considerable preferential corrosion along a weld on the internal surface. Indeed, at some places the pipe was close to perforation (4 mm wall) after the two-year exposure.

Plastic Pipes

Three types of plastic pipes were installed in the test: high-density polyethylene (HDPE), unplasticized polyvinyl chloride (U-PVC), and polypropylene (PP).

All these pipes were in excellent condition after the two-year exposure. The pipes also stood up to handling with few problems, but some of the U-PVC pipes, the most brittle of the plastics tested, fractured when dropped. Experience at other sites suggests that the disadvantages of plastic pipes include the extra support requirements, the cost of jointing, and the lack of resistance to mechanical damage in production areas.

Piping Materials for the Gold Mines

As a result of the test described, and of other experiences with pipe materials and the gold-mine environment, a few general comments can be made on the suitability of piping materials for various underground applications.

In regard to the problems of mechanical damage and degree of corrosivity of the underground environment at various locations, a qualitative relationship based on experience and testing is shown in Fig. 3. This shows that the degree of corrosivity and incidence of mechanical damage increases substantially from the shaft of a mine towards the stope. As a result, the range of coatings that can be used successfully is fairly large in the shaft and haulageways, diminishing closer to the stope, and no coating will survive the combination of damage and corrosion in close proximity to the working area. In the working areas, all the paint coatings are damaged either during transport or as a result of increased activity, and galvanizing that withstands mechanical damage better than the other materials generally fails because of the acidic conditions found in the stopes. Therefore, close to the stope, the use of corrosion-resistant materials, especially corrosion-resistant steels, is favoured.

Table V gives a comparison of the costs of various piping materials relative to that of low-carbon steel (SABS 62 medium gauge), which is assigned the value 1. One or two points are worthy of note. Firstly, the cost of corrosion-resistant materials can be less than that of a

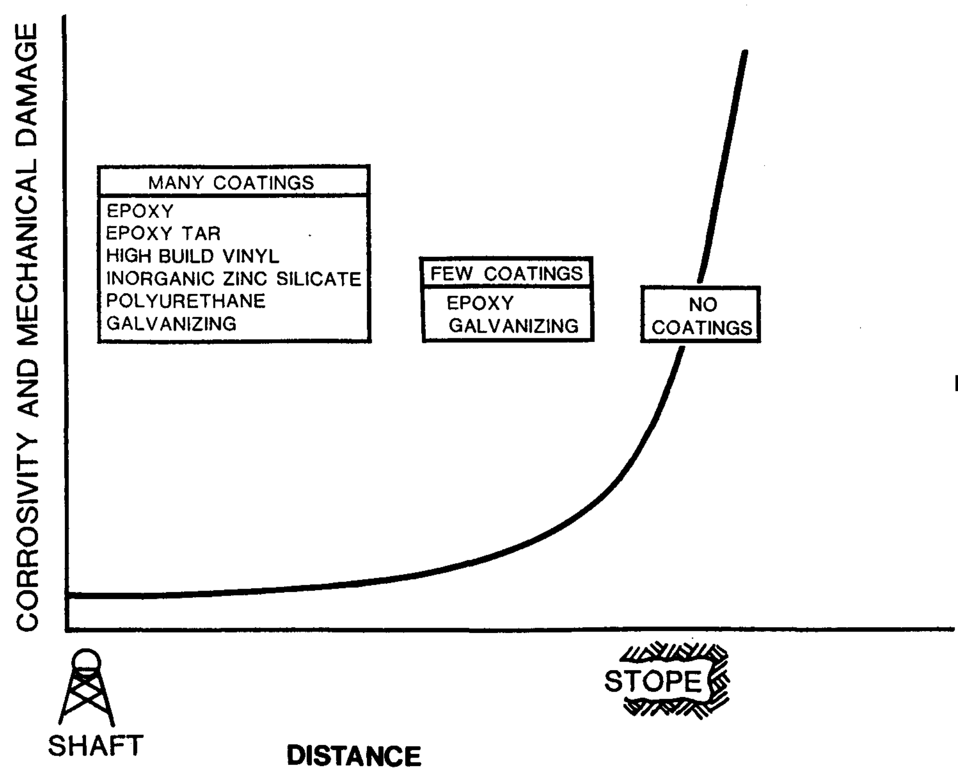

Fig. 3—The suitability of coatings for pipes in gold mines

coated pipe. Furthermore, the cost of the coated pipe is an ex-works price, and does not include either the cost of any independent inspection, or the repair of any damage to the coating on site. Secondly, there is little cost difference at present between 3CR12 piping and 304L piping of the same thickness, although 304L is an inherently more corrosion-resistant material.

In the selection of a piping material, consideration must be given to the effect of pressure. Fig. 4 gives the relative costs of epoxy coatings for carbon-steel pipes of various pressure ratings as percentages of the total costs of the piping systems.

TABLE V

RELATIVE COSTS* OF CORROSION PROTECTION FOR PIPES

Low-carbon steel pipe	1,0
U-PVC pipe	1,0
Low-carbon steel pipe (normalized)	1,15
Galvanized-steel pipe	1,17
High-density polyethylene pipe	1,3
Polypropylene pipe	1,5
3CR12 steel pipe	2,0
304L stainless-steel pipe	2,0
Epoxy-coated steel pipe	1,2

*All the costs are based on straight pipe of 4-inch nominal bore suitable for operation at a pressure of 1 MPa. No allowance has been made for the costs of jointing.

Coating costs are calculated on surface areas of the pipe, and consequently, for a given diameter of pipe, the coating cost is essentially independent of the thickness of the pipe wall. Therefore, the cost of applying a coating can be more than the cost of the low-carbon steel pipe at low pressures (thin wall), but only one-third of the pipe cost at much higher pressures (thick wall). This suggests that paint coatings may be an economic solution for the corrosion protection of high-pressure piping where the incidence of damage is low.

Conclusions

The long-term test highlighted a number of important findings that would not have been apparent from short-term laboratory tests, and has already provided useful information on the suitability of various options for the corrosion protection of pipes. The test loop has been re-installed and will continue running for approximately 18 months, after which it is expected that some of the pipes may have perforated as a result of corrosion. A detailed assessment of life-cycle costs will then be made.

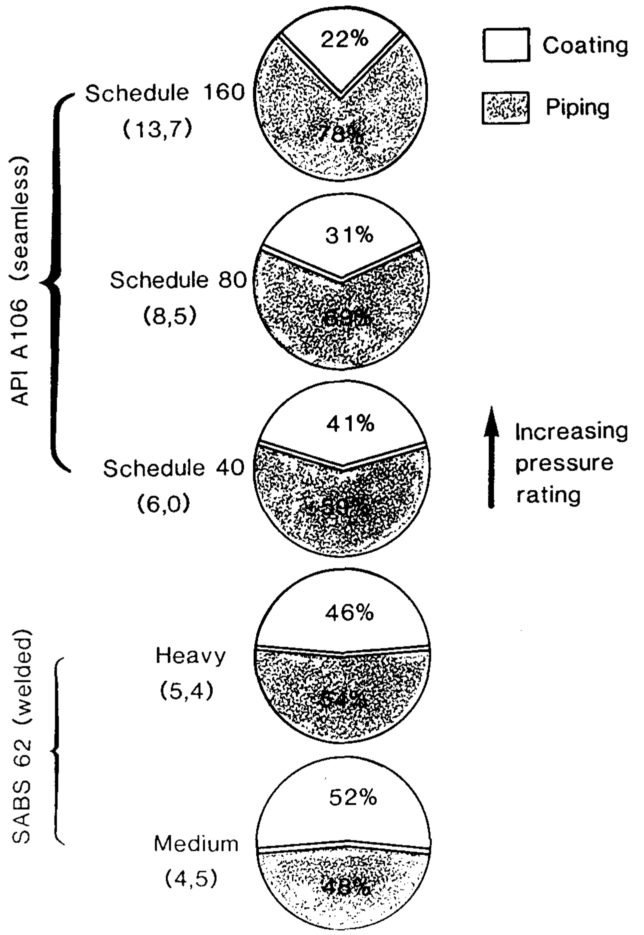

Fig. 4—Variation in the costs of coatings and pipes with increasing pressure rating (the figures in brackets represent pipe wall thickness in millimetres)

Acknowledgements

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