OIPEEC

Institut für Fördertechnik und Logistik

Universität Stuttgart
Germany

Proceedings of the
OIPEEC Conference 2009 / 3rd International Stuttgart Ropedays

Innovative ropes and rope applications

A celebration of 175 years of wire rope

18th and 19th March 2009

Alte Stuttgarter Reithalle, Stuttgart, Germany

Editor: I.M.L. Ridge

Published for OIPEEC by:

Dr I.M.L. Ridge, Haddon Lodge, Sires Hill, Didcot, Oxfordshire, OX11 9BG, UK

ISBN: 978-0-9552500-2-6

Website: http://www.oipeec.org

ORGANISATION INTERNATIONALE POUR L'ETUDE DE L'ENDURANCE DES CABLES
INTERNATIONAL ORGANISATION FOR THE STUDY OF THE ENDURANCE OF ROPES
INTERNATIONALE ORGANISATION ZUM STUDIUM DER BETREIBSFESTIGKEIT VON SEILEN
ORGANIZZAZIONE INTERNATIONALE PER LO STUDIO DELLA FATICA DELLE FUNI

J. van Rensburg[1], R. Rontgen[1], G. Rebel[2] and B. Schmitz[2]
[1] Driefontein Gold Mine, Gold Fields Limited
[2] Rope consultants

ODN 0853

Update concerning The premature discard of 45 mm ropes operating on a Blair multi-rope rock winder

Summary

Driefontein Gold Mine installed four 2500 m long 45 mm diameter round strand ropes on the No. 2 Shaft Blair Multi-Rope (BMR) Rock winder, located southwest of Johannesburg. The rope with eight compacted outer strands and a plastic coated steel core was selected for hoisting of ore in a 2043 m deep vertical shaft.

In May 2006, two of the ropes on the one BMR drum had to be discarded due to excessive broken wires in the outer strands detected during routine magnetic testing. These ropes, as a pair, had completed only 35,000 cycles. The two ropes on the other BMR drum showed no damage at this time. On 20 June 2006 the remaining two ropes were discarded at 38,000 cycles also due to excessive broken wires in the outer strands.

This follow–up paper describes:

- the history of ropes used on the winder prior to the installation of the round strand ropes;
- the aspects relating to the use of round strand ropes;
- the findings of the investigators; and,
- a detailed discussion of the failure mechanism.

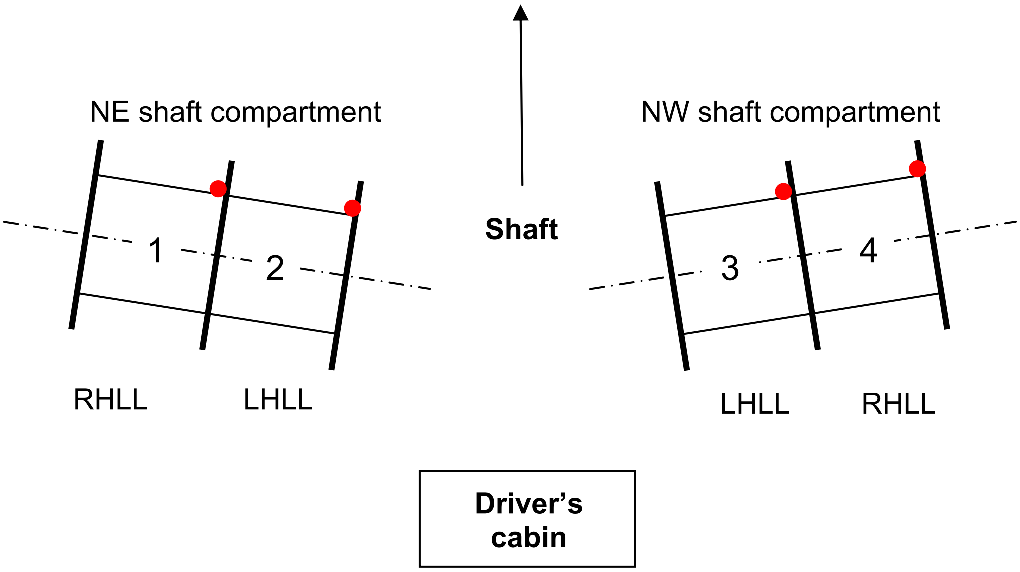
1 Driefontein Gold Mine – No. 2 Shaft BMR rock winder

The rock winder is a BMR winder installation at Driefontein No. 2 Shaft. The shaft, headgear and the winders were commissioned in 1972 and are responsible for hoisting circa 160,000 tonnes per month of gold-bearing ore which represents 62% of the Driefontein Gold Mine monthly production. The most important shaft data is shown in Table 1 below. Figure 1 shows the Driefontein No. 2 Shaft BMR rock winder and Figure 2 the winder drums layout in relation to the shaft.

Parameter	Value
Blair Multi Rope (BMR) rock winder Year installed	1971
Hoisting depth	2043 m
Drum diameter	4.27 m
Sheave diameter	4.27 m
Rope diameter	45 mm
Skip mass including attachments	13,022 kg
Payload	17,250 kg
Hoisting speed	15 m/s
Two separate motors electrically coupled	8,250 kW
Type of drum coiling	LeBus

Table 1: Driefontein No. 2 Shaft BMR rock winder data.

Figure 1: Driefontein No. 2 Shaft BMR Rock Winder. The winder has two separate 8,250 kW electrically coupled drum motors and each drum has two winding ropes.



NB: both drums are overlay, red dots indicate positions of the hawse holes

Figure 2: Driefontein No. 2 Shaft BMR rock winder layout. Note that the BMR winder has two separate drums and each drum has two ropes, one RHLL and one LHLL.

Each of the two winder drums has two ropes. It is therefore necessary to ensure that each rope in a pair carries its equal proportion of the skip mass and payload. A load compensating sheave is fitted on top of each of the two rock skips that is free to rotate and thereby ensures equal load sharing, Figure 3.

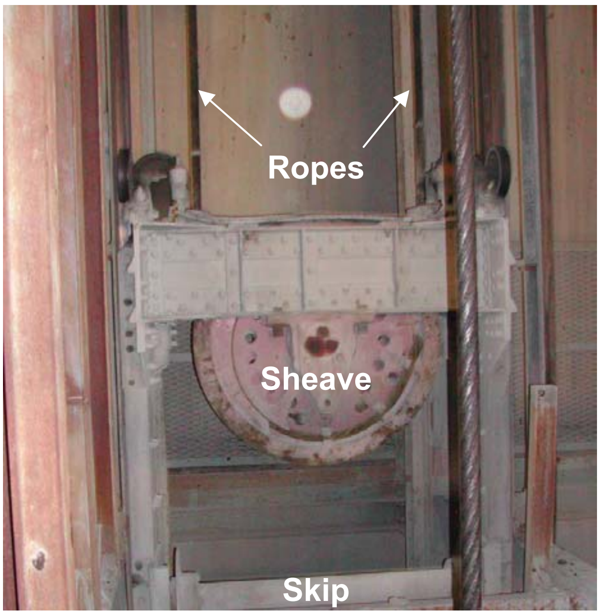


Figure 3: BMR rock winder rope load compensating sheave mounted on top of the skip.

2 Rope history on the winder

2.1 Triangular strand ropes

Standard ropes used on the rock winder are triangular strand winding rope, Figure 4. These ropes achieved an average lifetime of 13 months or 66,000 cycles. This average is based on 19 previous ropes sets (Figure 5). The best lifetime achieved by triangular strand ropes was 19 months or 94,000 cycles. The reason for discarding the triangular strand ropes was mainly due to broken outer wires.

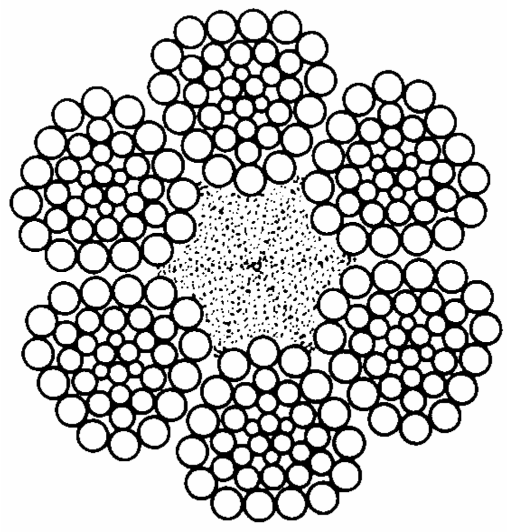


Figure 4: Typical triangular strand rope cross – section.

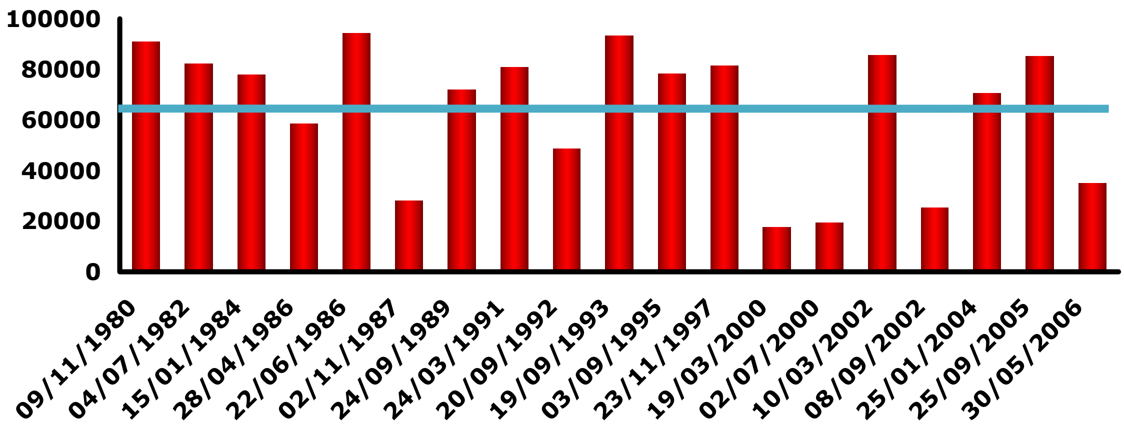


Figure 5: The average ropes cycles achieved on different rope sets.

2.2 Round strand rope

In September 2005 the mine installed four eight-strand winding ropes, the specifications of these new ropes as well as the previous triangular ropes are detailed in Table 2 below.

Rope construction	Round strand rope	Triangular strand rope
Nominal rope diameter	45 mm	45 mm
Rope length installed	4 × 2500 m	4 × 2360 m
Rope lay	Right and left hand Lang's Lay	Right and left hand Lang's Lay
Layers on drum	5	4
Tensile grade	1770 MPa	1800 MPa
Wire finish	Galvanised	Bright
Rope terminations	Compensating sheave at skip, cow hitch on drum shaft	Compensating sheave at skip, clove hitch on drum shaft
Rope mass	9.08 kg/m	8.71 kg/m
Minimum breaking strength	1588 kN	1489 kN
Rope factor of safety	4.81	4.61
Rope capacity factor	10.69	10.03

Table 2: Round strand and triangular strand rope specifications for No. 2 Shaft BMR Rock Winder.

The round strand ropes used are characterised by eight compacted, equal lay outer strands and a fully lubricated independent wire rope core (IWRC). The core is enclosed by a plastic layer which also insulates the outer strands from one another. This plastic layer between the steel core and the outer strands (Figure 6) gives the rope high structural stability; avoids internal rope destruction; and protects the core against corrosive environments.

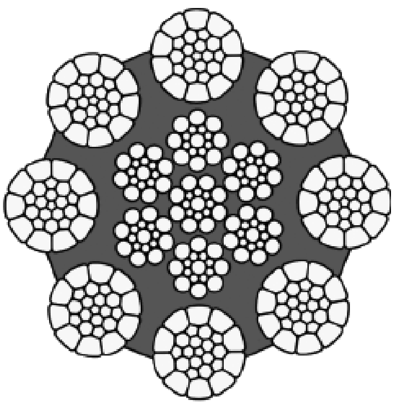


Figure 6: Typical round strand rope cross-section with compacted outer strands.

Experience in other shafts has shown that from an operational point of view these plasticated winding ropes are maintenance friendly due to the easy handling characteristics of these ropes. They have very low rotation when no load is present due to the locking effect of the plastic which stabilises the construction and in the process enhances safety when handling.

The other major advantages are:

1. No outer strands touch one another due to the plastic carrier.
2. The ropes have a high structural stability as the strands are held permanently in position.
3. The plastic cushions the rope against impact forces.
4. The core is protected from the corrosive environment and the lubrication in the core is sealed in for the whole lifetime of the rope.
5. Rope stretch is significantly reduced when loading conveyances. This has the benefit of reducing spillage at the shaft bottom loading positions.
6. Wire crossovers inside the rope are eliminated by the intermediate plastic layer.

Possible disadvantages are:

1. The high structural stability could probably be a disadvantage when seen from a rope wear point of view, as the same rope position might be impacted during a wind. The higher the radial load the more disadvantageous this could be.
2. Ropes with higher stiffness will accumulate slackness in the dead turns faster than ropes with a low stiffness. It is generally assumed that triangular strand and eight strand ropes show a similar magnitude of back slip per cycle on a given winder. The axially stiffer eight strand rope will therefore be more susceptible to loss of tension in its dead turns than a triangular strand rope.

The higher radial stiffness of the eight-strand rope (which normally is an advantage) turned out to be a major disadvantage here: All ropes which had been used on this winder before had reduced in diameter significantly on the top few hundred meters immediately after installation. In this condition they wore down the groove radii by about 2 mm in the live drum sections. When finally a radially stable eight-strand rope was installed, it would not reduce in diameter and would therefore be the first rope on this winder which would not fit into the grooves.

3 Round strand rope installation and events up to discard

In March 2005 Driefontein ordered the eight strand ropes for the reason that the manufacturer offered a rope life guarantee of 165,000 cycles (2.5 times the average TSR life on the winder). The average cycles historically achieved with triangular ropes at No. 2 Shaft were 66,000 as mentioned above.

On the 25th and 26th September 2005 the four eight strand ropes were installed on the two drums.

3.1 Sequence of events:

1. On rope installation concern was raised by the rope manufacturer about the LeBus sleeve sizes (Figure 7). The Industry SANS Code of Practice 10294 [**1**] recommends 47.7 to 48.6 mm for a 45 mm nominal diameter rope. The mine was notified on the 4th October 2005 of the problems associated with these reduced dimensions, namely that a severe reduction of rope life was expected. Details of this were shown in the previous paper [**2**].

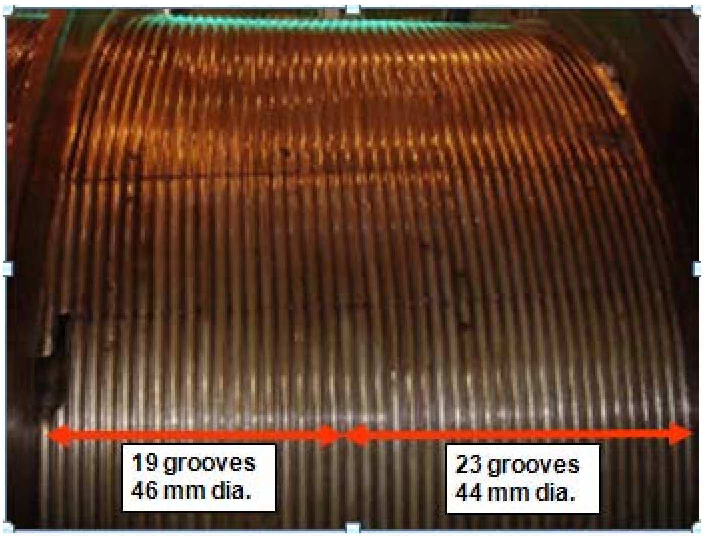


Figure 7: Different groove diameters on the LeBus drum. The first 19 grooves from the hawse hole have a diameter of 46 mm, the remaining 23 grooves have a diameter of 44 mm.

2. On 25th Oct 2005 a second magnetic rope test was done - no problems were found on the ropes.
3. On 3rd Dec 2005 the front and back-ends were cut.
4. On 24th January 2006 a third magnetic test was undertaken, the front and back-ends were cut.
5. On 14th March 2006 a fourth magnetic rope test was carried out. Again, no problems were found.
6. On 25th March 2006 the front and back-ends were cut.
7. On 4th April 2006 a fifth magnetic rope test was carried out. No problems were found.
8. On 30th May 2006 a sixth magnetic rope test was carried out. Numerous broken wires on different strands were found at the back-end on the left hand drum NE shaft compartment on both ropes (Figure 8). No 1 and 2 ropes were removed after 35,021 cycles and replaced with triangular ropes.

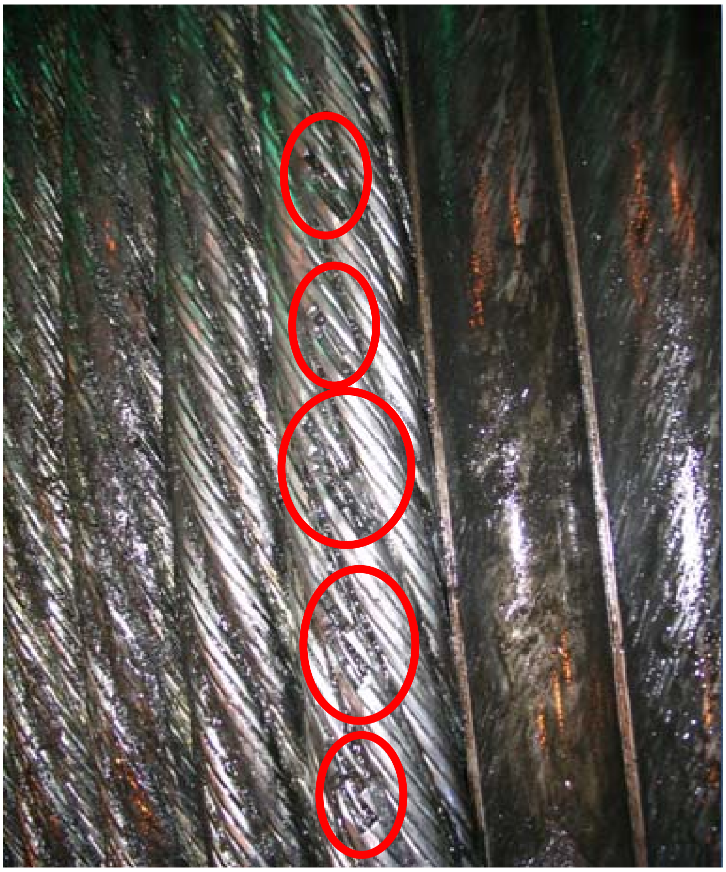


Figure 8: Numerous broken wires were found on different strands at the back-end of the rope.

9. No broken wires were found on the right hand drum NW shaft compartment, but a decision was made to remove 120 m of rope from the two longer eight strand ropes in order to equalise the rope lengths with the two new triangular strand ropes which were fitted to the NE shaft compartment.
10. On the 20th June 2006 the other two NW shaft compartment ropes deteriorated to such an extent that they had to be removed immediately. Ropes No. 3 and 4 were discarded after 38,000 cycles

4 Investigation on causes for the premature discard of the round strand ropes

4.1 Rope samples cut for investigation

Rope samples including areas with broken wires were sent for examination to both the rope manufacturer and the Council for Scientific and Industrial Research (CSIR) laboratories in Johannesburg, South Africa. Additional rope sections were sent to Wire Rope Technology in Aachen, Germany for SEM analysis. Pieces were cut from sections A, B, B/B and C as indicated in Figure 9. Figure 10 shows sections A, B, B/B and C relative to the winder and headgear mounted sheaves. Various tests on samples were conducted to obtain a clear understanding as to why the ropes deteriorated so fast.

Samples "A" were taken from the dead turns on the drum adjacent to the hawse hole which were in Ø 46 mm grooves.

Samples "B" were taken from the dead turns on the drum adjacent to "A" which were in Ø 44 mm grooves.

Samples "B/B" were taken from the live turns from the drum, B/B samples operated variously between the drum and over the head sheave and into the shaft (see Figure 10 below).

Samples "C" were taken from the second layer turns above B/B.

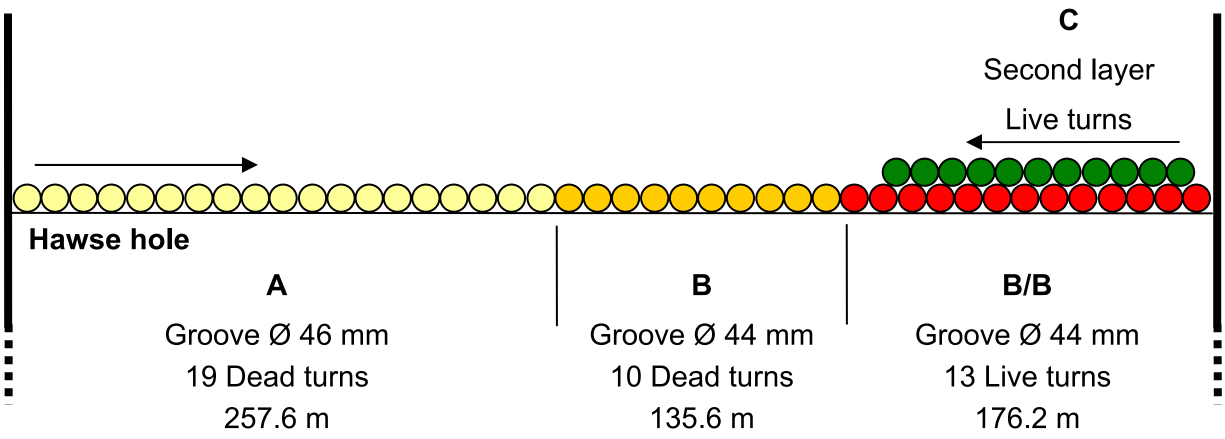


Figure 9: Discarded rope sections relative to drum coiling positions at rope installation.

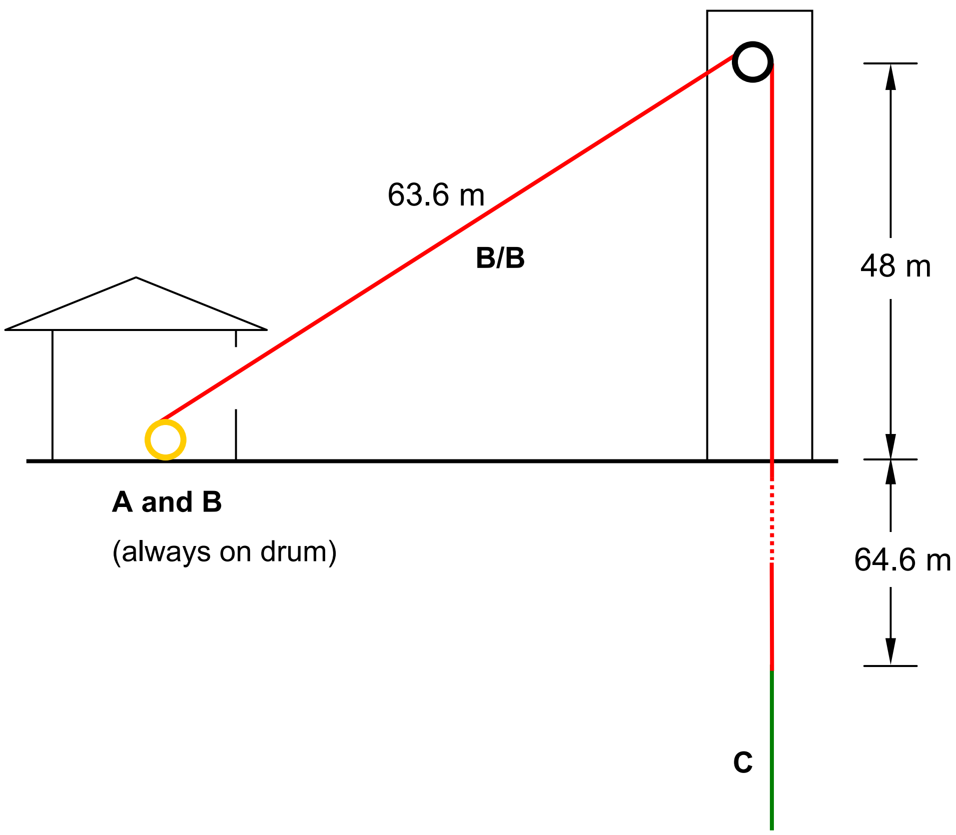


Figure 10: Rope sample positions relative to the BMR winder, headgear sheaves and mine shaft.

4.2 Analysis of the rope geometry

The rope geometry was analysed both by the rope manufacturer and by CSIR and proved to be correct.

4.3 Analysis of the rope wire

Wire samples from the different sections were analysed by CSIR [**3**] and an independent laboratory chosen by the rope manufacturer.

Both institutions concentrated their efforts on analysing the delta layer, a hard and brittle alloy layer between the basic wire material and the zinc coating. For the outer wire diameter of the rope, this ‘delta’ layer was at the upper end of the permissible thickness tolerance. It was therefore suspected that wire cracks might have initiated in the delta layer and led to cracks in the wire material (Figure 11).

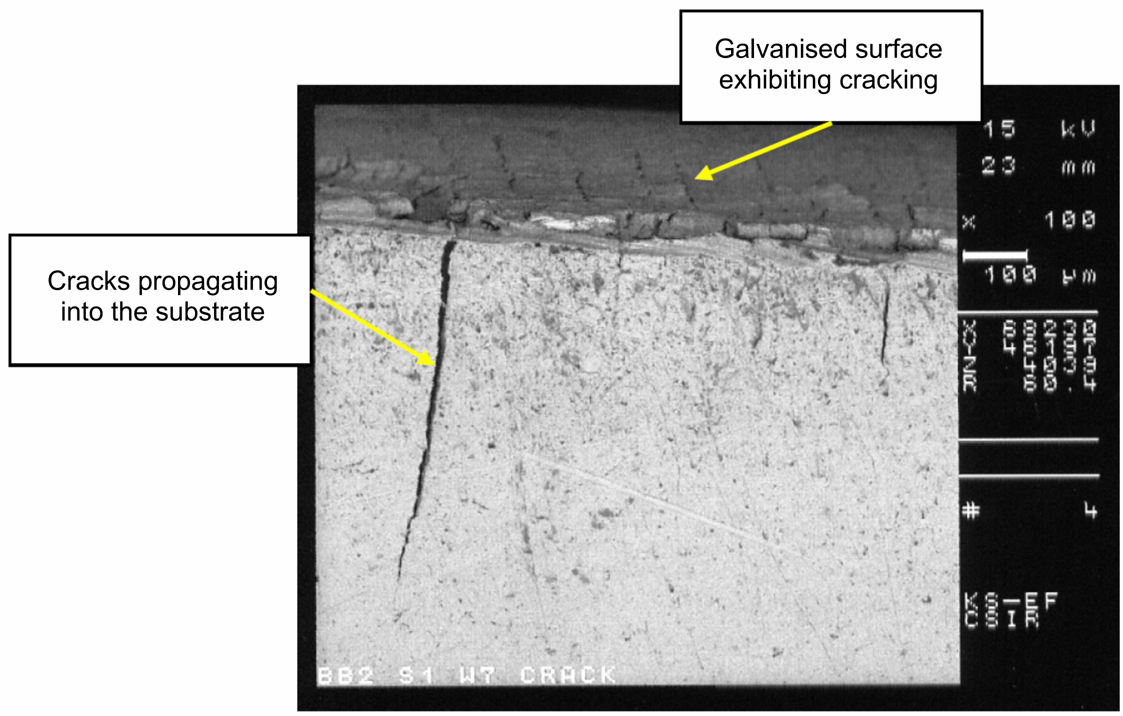


Figure 11: Sample B/B wire at ×1000 magnification. (Photo CSIR from [**3**]).

It was found, however, that the delta layer was cracked in all sections of the rope (which is normal for a drawn galvanised wire), but the cracks had only propagated into the wire material in sections A, B and B/B. These were exactly those rope sections which got the dynamic blows from the second layer as it spooled on and off the drum.

The rope sections C, which were constantly spooling on and off the drum and over the head sheave, had no crack propagations into the wire material.

It was therefore concluded that the delta layer thickness might be a contributing factor but by no means the main cause for the premature wire breaks.

4.4 SEM analysis

Scanning electron analysis of rope wires from the areas A, B and B/B were carried out at Wire Rope Technology in Aachen, Germany.

A typical wire break is shown in Figure 12. The top part of the wire has sheared off as a result of always being impacted in the same location.

Figure 13 shows a detail of Figure 12 at a magnification of ×210. At the point where the longitudinal crack changes direction, a round object can be seen.

Figure 14 shows this object at high magnification (1200 times). The object turned out to be a manganese sulphide ball which can sometimes be found in rope wire. These balls have a melting temperature of more than 1600 °Celsius, are extremely hard and survive the wire drawing process without any deformation. This time, however, the repeated impact of the second rope layer hitting onto the first layer has split the ball right in the middle, revealing a break surface typical for a hard and brittle material. The split ball can be seen as a clear evidence of high impact forces acting on the rope wires.

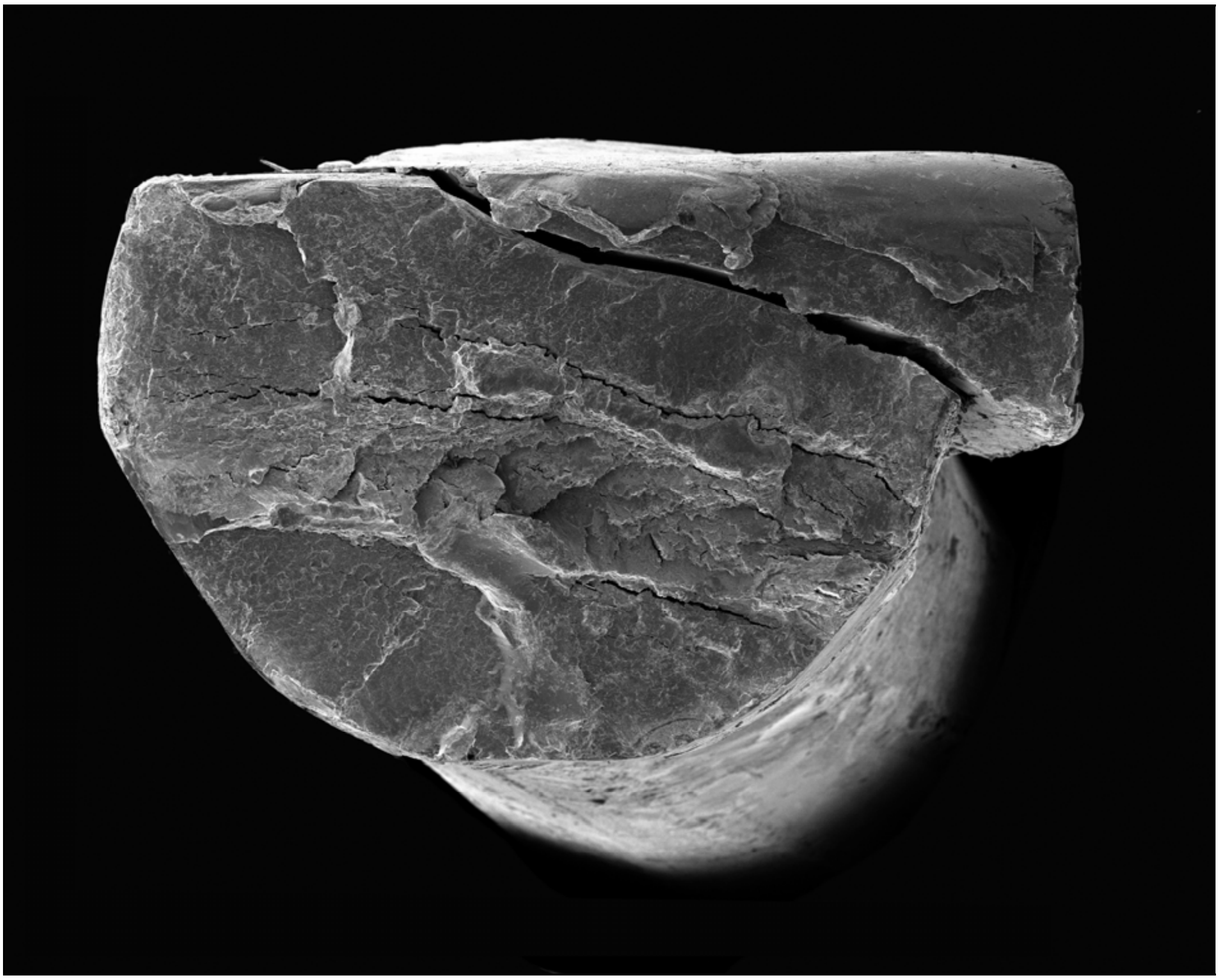


Figure 12: Typical wire break in zone B/B. Magnification ×21. SEM Photo © Wire Rope Technology Aachen.

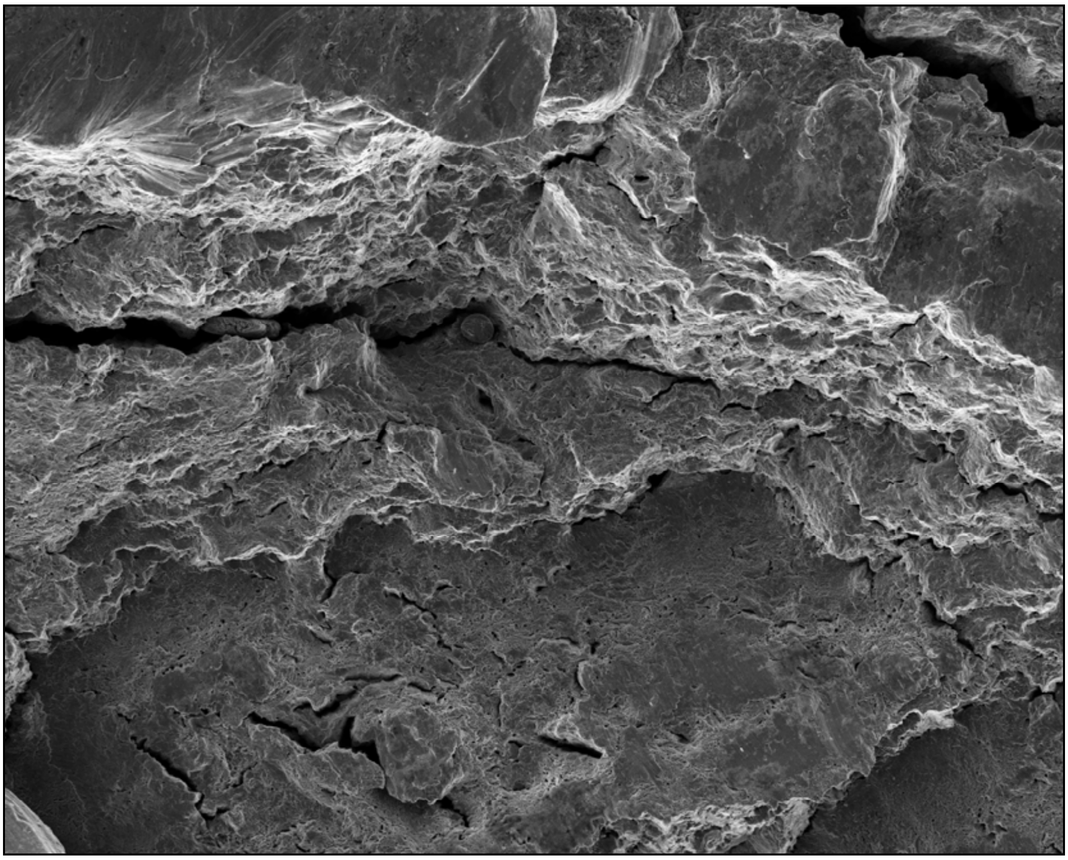


Figure 13: Magnification ×210. SEM Photo © Wire Rope Technology Aachen.

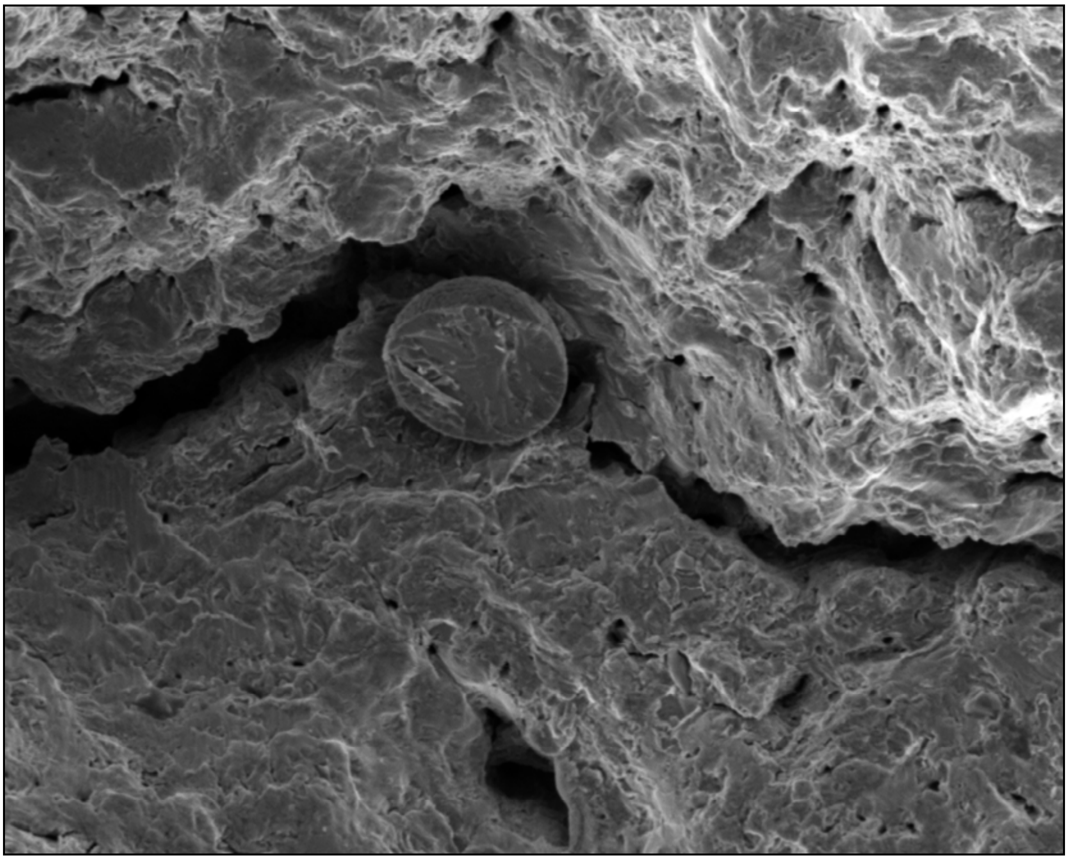


Figure 14: Magnification ×1200. SEM Photo © Wire Rope Technology Aachen.

5 Discussion

The investigations carried out by the different institutes revealed that the rope itself was manufactured according to the specifications and according to the rules of workmanship.

The outer rope wire was found to have a delta layer thickness at the upper end of the tolerance but the fact that the most worked rope section C had no wire cracks was seen as proof that the delta layer was not the primary cause for the premature wire failures.

A comparison between the bearing pressures on crane drums (with D/d ratios of about 20 and safety factors of about 3) and mine hoisting drums (with D/d ratios of about 100 and safety factors of 3) shows that the bearing pressures are about 5 times as high on cranes. Yet round strand ropes perform very well on crane drums.

The hoisting speed, however, is tremendously higher in mining applications. Therefore dynamic effects such as impacts might play a much more important role than the magnitude of the static bearing pressure itself. This is also proven by the SEM photographs shown above. The wires show very little plastic deformation (which would be expected if the bearing pressure had exceeded the yield stresses of the wire material) but cracks with almost no deformation as a result of sudden impacts.

In one of the wires, a very hard inclusion, a manganese sulphide ball, was found split in two by high impact forces.

So dynamic forces could clearly be identified as a major contributing factor to the premature discard of the ropes.

During the time of this investigation, a set of ropes of the very same design in another shaft showed premature wire breaks after again only about 36,000 cycles on another shaft of the company. Instead of discarding these ropes as well, the damaged rope sections were moved by cutting the back ends and great care was taken thereafter to maintain the rope tension in the dead turns by doubling down the ropes not once (as it is normally done) but twice.

After doubling down for the first time, a chalk mark was drawn across the drum. The displacement of the chalk line after the second doubling down was proof that the rope had stretched even further. A third doubling down showed no significant additional stretch.

It was therefore decided to continue to double down twice each time the back ends were cut. In addition, the period of doubling down was reduced. The result of this revised maintenance policy is the fact that the ropes which had almost been discarded after 36,000 cycles have now already performed 160,000 cycles and are still in good condition.

This experience is further proof for the initial theory that a loss of pretension was the major contributing factor for the early discard of the wire rope discussed here.

As mentioned above, before the round strand rope only triangular strand ropes had been used on the Driefontein No 2 Shaft. Immediately after installation, these triangular strand ropes would unlay in the upper rope sections and thereby reduce their initial diameter from about 46 to 44 mm. Over the years, they wore down the 46 mm grooves to 44 mm.

This has never been a problem, because every new rope would again behave the same way. It only became a problem when for the first time a torsionally and radially much more stable rope design was installed. This new rope did not reduce in diameter immediately after installation and as a consequence did not fit into the 44 mm grooves.

When this new rope was spooled onto the drum, it fitted into the 46 mm grooves in section A, but it did not fit into the 44 mm grooves in sections B and B/B (Figure 15). As a result, the rope would coil on a bigger drum diameter in sections B and B/B.

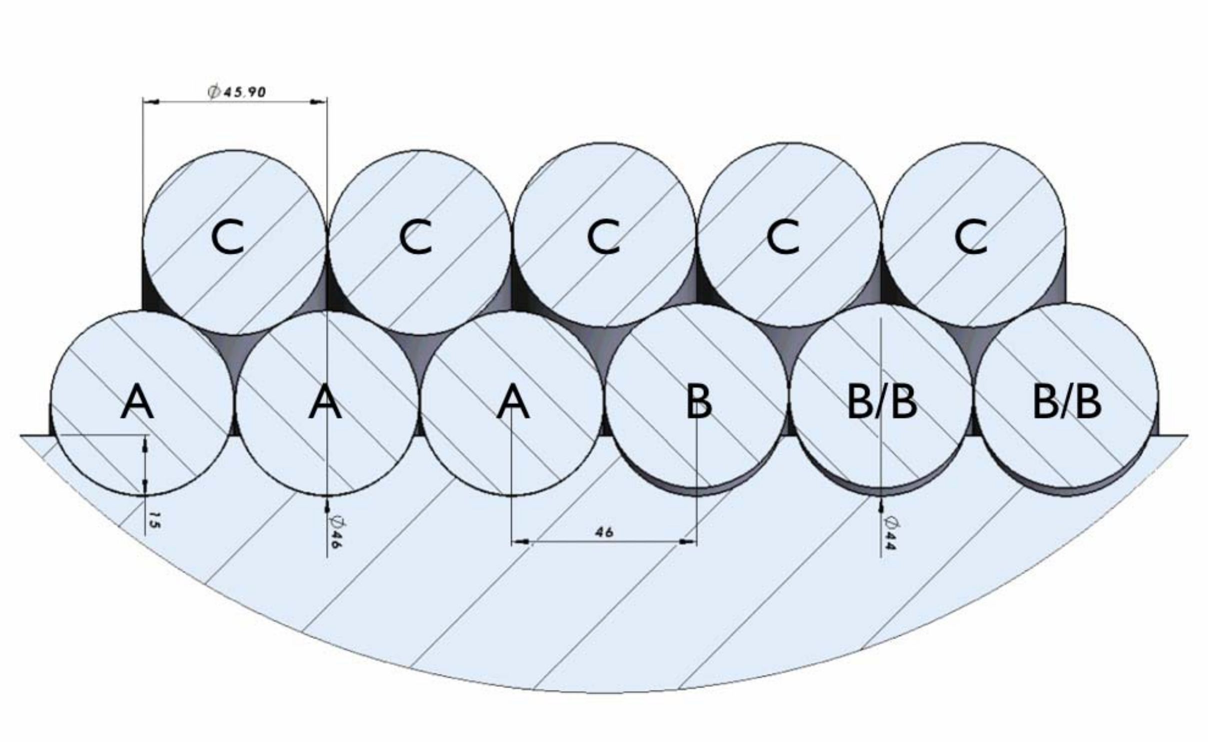


Figure 15: 46 mm grooves in section A and 44 mm grooves in sections B and B/B. The rope coils on a bigger drum diameter in sections B and B/B.

After climbing into the second layer, the rope would spool back over sections B/B and B, pressing the previous layer down into the groove, thereby damaging the drum grooves on one side (Figure 16) and creating a loss of pretension in the first layer by reducing the circumference.

This loss of pretension was milked forward via sections B/B and B into the dead turns in section A.

This mechanism leading to the loss of pretension in the first layer of the drum was identified as the second, and probably most important factor leading to the premature discard of the ropes.

Figure 16: Groove damage on one side – section B/B.

6 Future activities

Many characteristics of the round strand ropes obviously are superior to those of the triangular strand ropes. When it comes to bearing surface between two rope layers, however, the triangular strand ropes seem to have a great advantage.

In order to combine the advantages of the two rope types it was decided to flatten the surface of the round strand ropes using a rotary swager, thereby increasing the bearing surface between two rope layers (Figure 17).

Ropes of such a design have already successfully been used in critical crane applications. Their improved geometry together with a revised maintenance programme will now help to increase the number of hoisting cycles also on the Driefontein No. 2 Shaft.

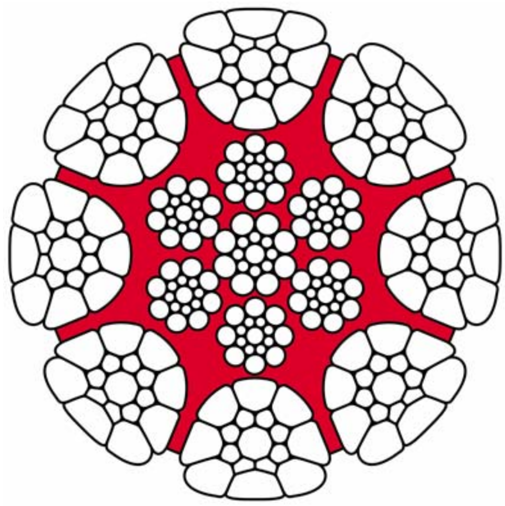


Figure 17: Swaged round strand rope with increased bearing area.

7 Conclusions

After extensive investigations into the damage and premature discard of the round strand ropes operating on a multi-rope BMR, the following points may be concluded:

1. The ropes had been manufactured in accordance with the specifications.
2. The presence of cracking in the delta layer in the galvanising on the wires whilst possibly being a contributing factor could not be the main cause of the problem.
3. No wire breaks were found in sections of rope which had not been in contact with the drum grooves.
4. Examination of the wires showed clearly that the rope had been subject to high dynamic forces.
5. Most critically, a mechanism which lead to the loss of pretension in the dead turns on the drum has been identified, which combined with high dynamic forces, lead to accelerated wire damage and failures in the dead turns.
6. This mechanism (forcing the rope coil into too small a groove) had also contributed to loss of tension in the live turns B/B on the drum, which were then also damaged.
7. From the lessons learnt, the rope manufacturer has been able to produce an improved rope design which is more resistant to the high impact forces which will be experienced in this application.
8. Revised maintenance procedures are in place to ensure that the dead turns on the drum are kept properly tensioned.

Co-operation between the rope manufacturer and the rope user has lead to an improved understanding of the behaviour of round strand plasticated ropes in the application of the BMR – and in the long term to the successful exploitation of this type of rope in mining applications.

8 References

[**1**] SANS 10294 *The performance operation, testing and maintenance of drum winders relating to rope safety*, Standards South Africa (a division of SABS).

[**2**] Greyling, P., Rontgen, R., Rebel, G. and Schmitz, B. *Premature discard of 45 mm ropes operating on a Blair Multi-Rope rock winder,* Proceedings of the OIPEEC Conference ‘How to get the most out of your ropes’, September 2007, Johannesburg, pp. 155-174, ISBN: 978-0-9552500-1-9.

[**3**] Carter, T.J. *Examination of Winding Rope from Driefontein Consolidated Mining No. 2 Shaft,* Confidential CSIR document KS(06)MC5586 / Report No.: 060065, Engineering Forensics (Metallurgy & Corrosion), CSIR Knowledge Services, Johannesburg, February 2007, pp. 1-90.