Wear of Dragline Wire Ropes

D Dayawansa[1], M Kuruppu[2], F Mashiri[1] and H Bartosiewicz[1]

ABSTRACT

Wire ropes are one of the most heavily used components in a dragline. They are subjected to harsh conditions during the regular usage of a dragline in a mining operation. Hoist ropes are subjected to fatigue due to the cyclic nature of load handling as well as due to rope bending over the sheaves and the drum under load. This leads to wire breaks due to fatigue. Accumulation of a number of wire breaks close to each other can have a detrimental effect on the rope. Furthermore, to allow for the increasing demand for higher load capacity coupled with the inconvenience of having very large ropes, the factor of safety is often compromised, which increases the wear rate. Drag ropes are also subjected to heavy loads. More importantly, they are allowed to drag along the rough mine surface subjecting them to external physical abrasion. This makes the life of drag ropes one of the lowest among those used in a dragline. Suspension and IBS ropes are relatively uniformly loaded during their regular usage although they need to withstand dynamic load cycles as well as bending. Hence they tend to last for a number of years on average. The paper analyses the wear types and their severity of each of these rope applications, and suggests methods to determine rope wear rates and the resulting rope life. The paper further gives suggestions for good operating and maintenance practice that can extend the rope life and help reduce the large expenditure associated with every major rope change in a dragline.

INTRODUCTION

There are three categories of dragline ropes namely, drag and hoist ropes, IBS and main suspension ropes, and dump ropes, which differ mainly by their functions. Previous experience on dragline rope maintenance suggest that some of the problems experienced are common to all three categories of ropes while others are more specific to one or more categories.

Common issues

All three categories of ropes are subjected to fatigue loading, corrosion, and abrasive wear in the drums, sheaves and on the floor in case of dump ropes. The average life of all three categories of ropes has reduced over the last decade although, it is very difficult to pin point the factors that have made the most significant contributions to this life reduction. Recent studies conducted on failed rope samples by Maintenance Technology Institute (MTI) highlighted that rope material and quality issues have a significant effect on rope life. The quality of the wires, including material quality and drawing process, is a critical factor that determines the fatigue performance of ropes. These factors may be related to some of the reduction in rope life that has been experienced during recent times. Another key observation made is the significant variability of life between different mines and machines. The possible factors contributing to these differences are operating conditions/characteristics, maintenance practices and equipment design.

Drag and hoist ropes

The records of hoist and drag rope lives at BHP Billiton Mitsubishi Alliance (BMA) for the two common models of draglines, the BE1370 and M8050, over a period of 20 years showed a service life spread between five to 35 weeks (average 17 weeks) for M8050 hoist ropes, ten to 55 weeks (average 32 weeks) for BE1370 hoist ropes, and two to 30 weeks (average ten weeks) for drag ropes. Around 90 per cent of ropes had life longer than one half of the average life. A very significant difference in the hoist rope life performance between the two models of draglines has also been observed. In addition to rope design and manufacturing issues, there are many other factors that can affect the service life of the drag and hoist ropes. These include:

- design of the rope suspension system (ie sheave and drum groove geometry, sheave and drum diameter, spacing between sheaves, boom point swivel torsion bars);
- maintenance practices (ie lubrication, sheave and drum groove shape);
- rope termination and end effects (ie bending and wear at sheaves, sockets and drum);
- ground conditions (mainly applicable to drag ropes);
- mode of operations (chopping, suspended loads, bucket lift and swing angle); and
- rope retirement criteria (including end-to-end and replacement).

In spite of the past investigations of the effect of rope design on rope service life, satisfactory explanations to the problems experienced by the dragline ropes have not been found. The main reason for this has been the limited scope of these studies, which tended to focus only on a few selected factors affecting rope service life under idealised general conditions rather than investigating the rope performance in an actual application. The problem was further hampered by lack of data on the scatter of rope service life and its correlation to the operating and maintenance practices at the mine sites.

IBS and suspension ropes

The IBS ropes in Marion 8050 machines have had several maintenance issues in the past and, in several instances, they have failed during service. Although the boom is able to support itself temporarily without an IBS rope, this can lead to serious consequences in combination with other critical structural weaknesses that may exist simultaneously. Furthermore, these failures would result in significant amounts of downtime and repair costs. It is very important that operators ensure neither main suspension ropes nor IBS ropes fail during operations.

Dump ropes

The dump rope life can vary from one day to approximately two weeks. This service life has been achieved both with new dump ropes and re-used hoist ropes. The short life of these ropes results in many rope replacements costing unscheduled downtime. This leads to significant downtime as each rope replacement could take a few hours (depending on the maintenance crew mobilisation time). Previous MTI studies have shown that the most significant cause of the short life of dump ropes is due to the natural bucket nodding phenomenon, which leads to high bending and fatigue loading in the dump rope. Unfortunately, this cannot be avoided with the current designs of the bucket jewellery.

1. Maintenance Technology Institute, Department of Mechanical Engineering, Monash University (Caulfield Campus), PO Box 197, Caulfield East Vic 3145.

2. MAusIMM, Western Australian School of Mines, Curtin University, Locked Bag 22, Kalgoorlie WA 6433.

Maintenance issues and cost

Recently conducted review by MTI on dragline maintenance costs shows wire ropes (including suspension, IBS, drag, hoist and dump) to be a major driver of maintenance costs. It accounts for ten to 15 per cent of the total maintenance costs and amounts to about $300 000 per annum per machine.

The frequency of major shutdowns for the draglines in the Australian fleet is generally around every five years. Therefore it is preferable to change the main suspension ropes in multiples of five years (say every ten years), covering the duration of one or two shutdown periods. However, the currently used suspension ropes have a wide scatter in life varying from four to eight years (Marion's closer to four years and BE's closer to eight years), and hence require a change over in-between shutdowns. It is interesting to note that lower suspension ropes of BE machines (Marion's only have ropes for upper suspension) can last ten years in most instances but the exact reason for this has not been documented. The cost of lowering the boom alone to replace the suspension ropes, excluding the cost of downtime of ~4 - 5 days, is around $100 000. For most machines, the suspension ropes are generally changed every five years during shutdowns, irrespective of remaining life. The owners/operators are exploring the possibility of selecting suspension ropes that can ideally cover two shutdown periods.

Scope of study

This study focuses mainly on two types of draglines, the BE draglines and the Marion draglines. The accessories that assist the operation of the hoist ropes are the boom point sheaves, the upper and lower deflection sheaves, the mast deflection sheaves and the hoist drum as shown in Figure 1 (a, b and c). For the drag ropes, the accessories that assist in the operation of these ropes include: lower and upper vertical fairlead sheaves, the horizontal fairlead sheaves and the drag drum. Figure 2 (a and b) shows some of the accessories that assist in the operation of the drag ropes. Marion draglines also have most of these components arranged in a slightly different configuration.

HISTORY ANALYSIS

Hoist ropes

In draglines, hoist ropes are used to manoeuvre the bucket during the digging and filling process and to assist in lifting the bucket from the point of excavation to the point of dumping. In so doing, the hoist rope length has to be continuously adjusted to suit the locations of digging and dumping. The adjustment of the hoist rope length, which is primarily held at the hoist drum, also means that the hoist ropes have to constantly pass through deflection sheaves or gantry sheaves as well as the boom point sheaves. Bending over the sheaves occurs at locations such as the boom point sheaves and the gantry sheaves, where the rope has to change its direction. Secondary bending may also occur over the deflection sheaves due to the self weight of the wire ropes, the load carried by the bucket, and the distance between the deflection sheaves. It is mainly the bending over the boom point sheaves that contributes to the fatigue crack initiation and growth that ultimately leads to the fracture of the individual wires in strands of a wire rope. It is the breaking of these wires that finally leads to the discard of wire ropes.

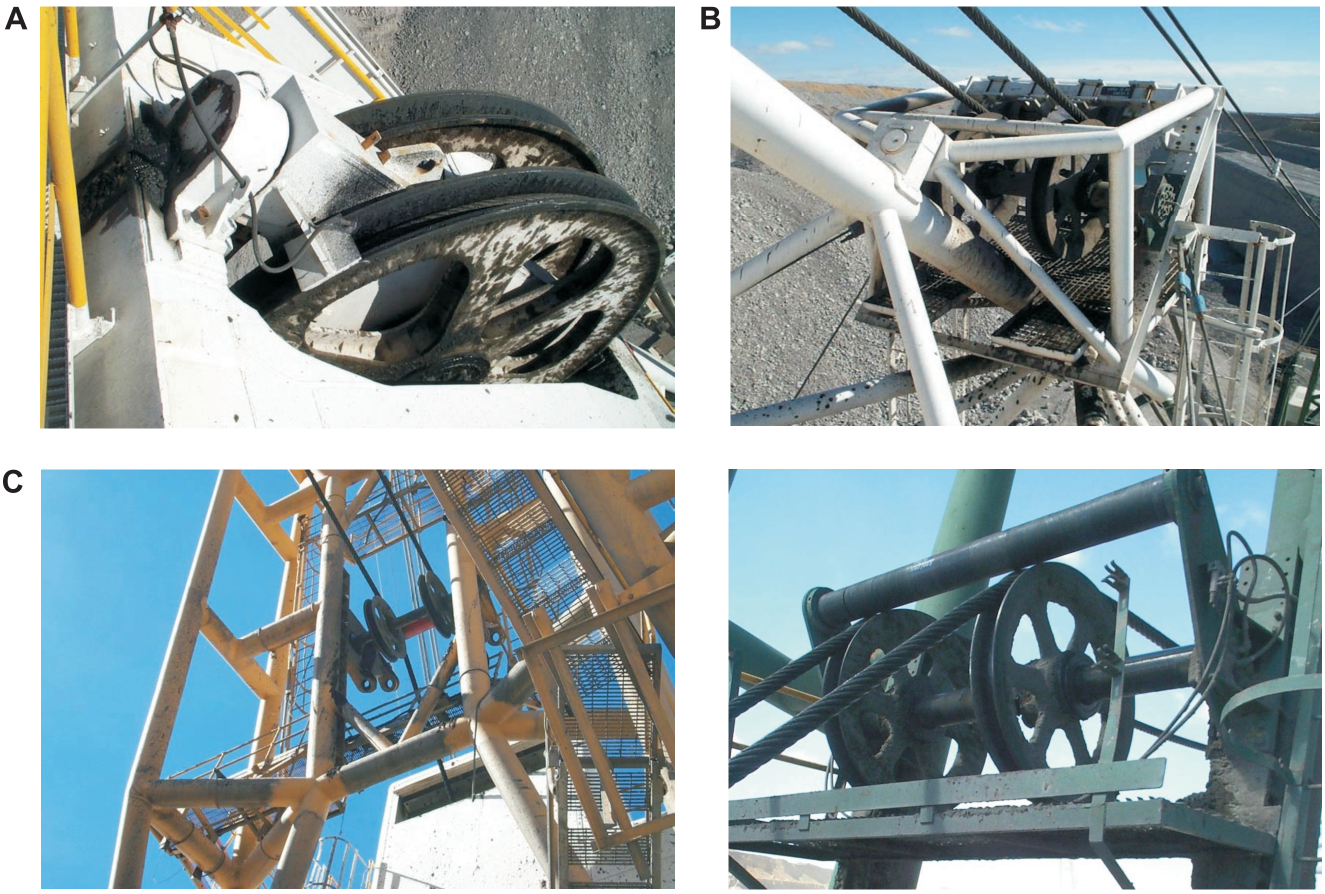

FIG 1 - BE dragline accessories for hoist ropes. (**A**) Boom point sheave, (**B**) boom deflection tower and sheaves, (**C**) mast deflection sheaves.

Marion M8050 data

The average and best hoist rope service lives are obtained by analysing the life of five ropes used on a specific machine prior to a given date. This means that average and best service lives will vary over an extended period of time. Figure 3 shows the moving average hoist rope life for a Marion dragline and demonstrates the variability of hoist rope life over time.

The Marion draglines with a recommended suspended load (RSL) of 130.7 tonnes and 131.5 tonnes use hoist ropes with a diameter of 83 mm, whereas those with an RSL of 137 tonnes use hoist ropes with a diameter of 85 mm. The Marion draglines with an RSL of 137 tonnes also have a larger sized hoist rope drum with a diameter of 2.54 m compared to Marion draglines with an RSL of 131.7 tonnes, which have hoist rope drums that are 2.438 m in diameter. All the draglines currently use six-strand ropes, usually of tensile grade 1770 MPa. The hoist rope drum to rope diameter ratios are 29.4 and 30 for the machines with rope diameters of 83 mm and 85 mm, respectively.

BE 1370 data

Figure 4 shows the average hoist rope service life for a BE 1370 dragline over a long period of time and also demonstrates the variability of hoist rope life over time. The BE draglines have RSLs ranging from 93 tonnes to 163.3 tonnes and use rope sizes ranging from 73 mm to 92 mm in diameter. Six strand wire ropes are also used with steel grades of 1570 MPa and 1770 MPa. The hoist drum to hoist rope diameter ratios in BE draglines ranges from 30.4 to 35.5.

Comparison of hoist rope data

The average hoist rope data for Marion and BE draglines is shown as a scatter in Figure 5. The data shows that BE machines, on average, have a better hoist rope service life as compared to Marion 8050 draglines. Although variability of hoist rope service life is to be expected over a period of time, there is a clear trend in this data. A mean hoist rope service life is about 6.5 million bench cubic metres (BCM) for BE draglines as compared with a mean hoist rope service life of about 4.2 million cubic metres for Marion draglines. The mean service life for hoist ropes in BE draglines in the sample is about 1.5 times the mean service life for hoist ropes in Marion draglines.

Factors influencing service life of hoist rope data

Sheave diameter to rope diameter ratio

One of the factors that influence the bending fatigue strength of hoist ropes bending over sheaves is the sheave diameter to rope diameter ratio. A plot of the average hoist rope service life versus the boom point sheave diameter (D_{bps}) to rope diameter (d_r) ratio is shown in Figure 6. The Figure 6 shows that for the majority of the data a higher D_{bps}/d_r ratio results in better service life for the hoist ropes. However, some of the data shows that although their D_{bps}/d_r ratios are high, there is no corresponding benefit in the service life. This shows that despite the favourable D_{bps}/d_r ratios, other factors can also negatively influence the service life of hoist ropes bending over sheaves in hoist rope systems. The scatter of average hoist rope service life for machines with the same D_{bps}/d_r ratios also confirms that other factors influence the hoist rope service life.

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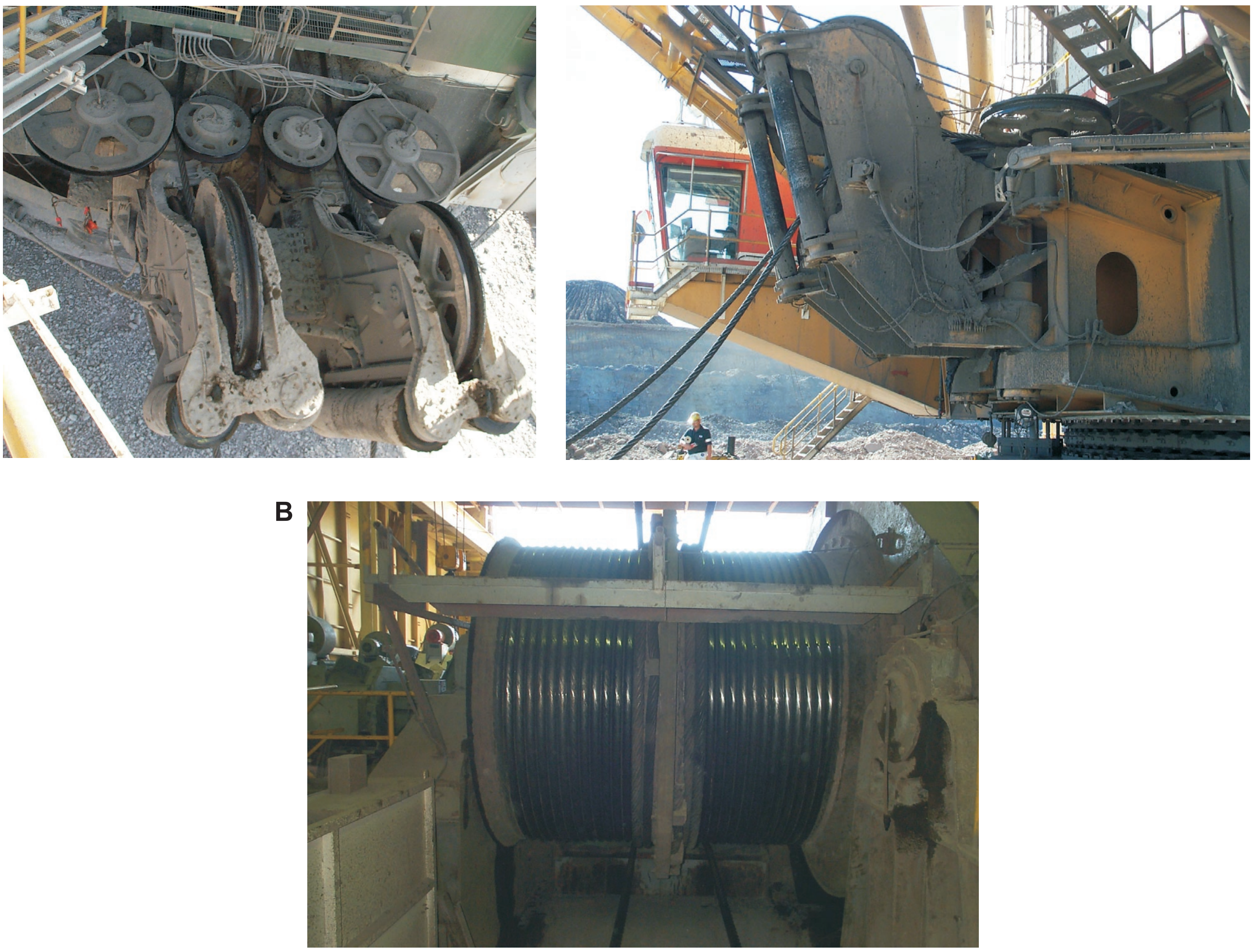

FIG 2 - BE dragline accessories for drag ropes. (**A**) Lower vertical, upper vertical and horizontal fairlead sheaves, (**B**) drag rope drums.

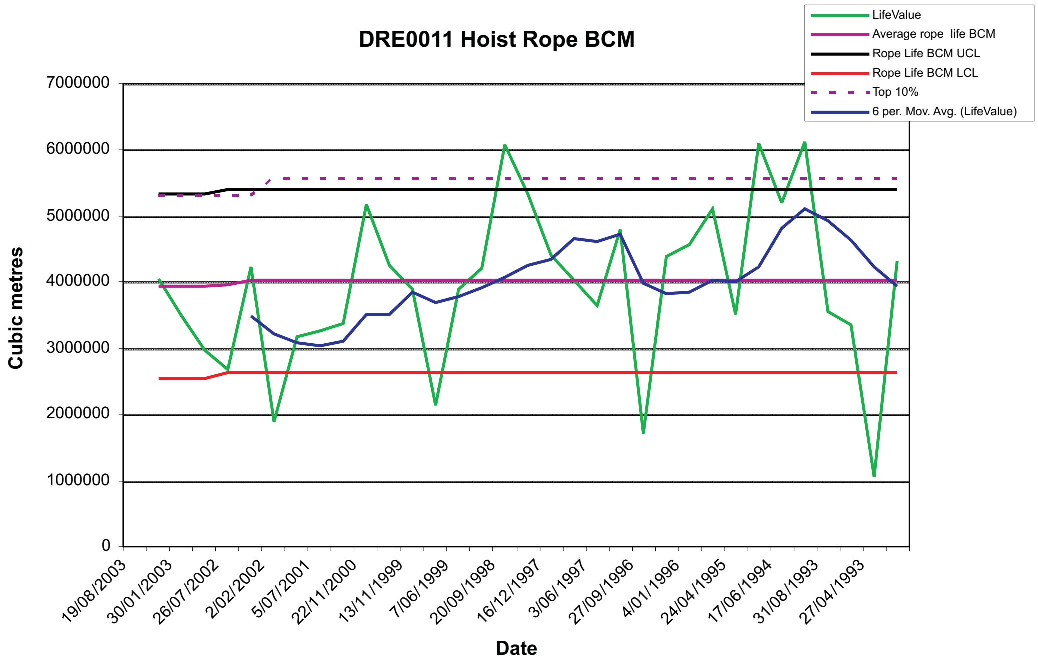

FIG 3 - Variability of hoist rope service life in a Marion dragline over time (ref OneSteel Wire Ropes).

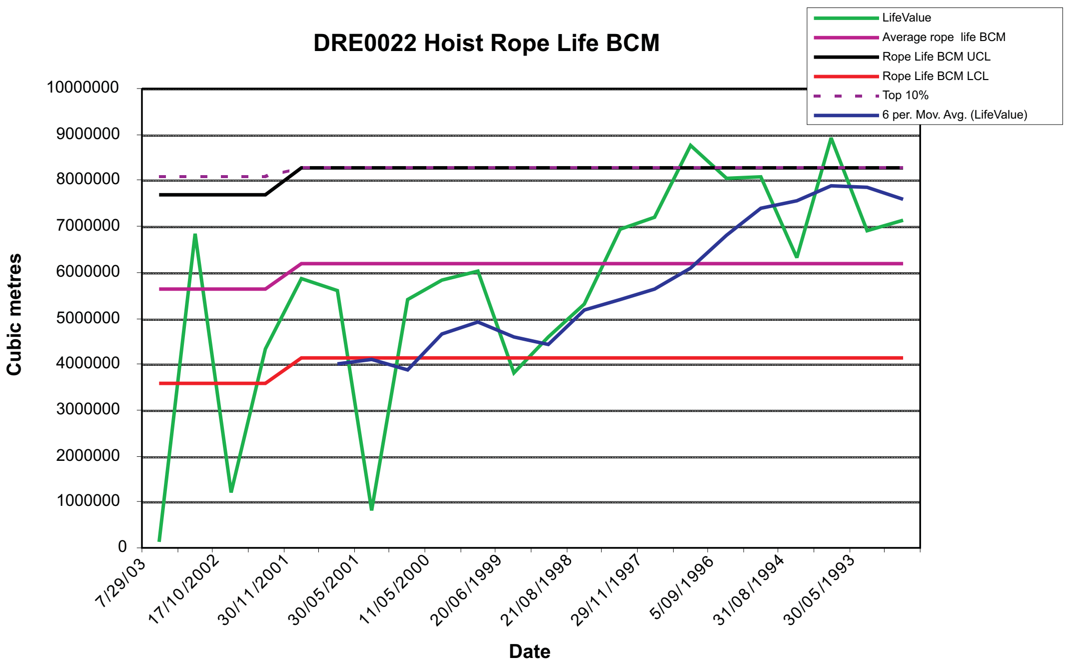

FIG 4 - Variability of hoist rope service life in a BE dragline over time (ref OneSteel Wire Ropes).

Bending at gantry sheaves in Marion draglines

According to the rope configuration, additional bending of the hoist ropes occurs at the gantry sheaves in Marion draglines. This is likely to negatively impact on hoist rope service life resulting in a lower hoist rope service life in Marions compared to BE draglines.

Fleet angle between gantry sheaves and drum

The fleet angle between the gantry sheaves and the hoist drum in Marion draglines also causes wear to occur at the bottom quadrants of hoist ropes. This phenomenon has been observed during rope inspections.

Drag ropes

Drag ropes work in conjunction with hoist ropes to manoeuvre the bucket during the digging process to fill the bucket, during the hoisting of the bucket to the location for dumping as well as during the dumping process itself. In both Marion and BE draglines, the drag ropes bend over the drag drum and the fairlead sheaves and are connected to the bucket through wedge sockets. The positioning of the sheaves and the rope configuration is different in each type of dragline. Although bending over the fairlead sheaves may influence the service life of ropes, it is the wear that occurs due to the drag ropes passing through spoil that is likely to be a major factor in the service life of drag ropes.

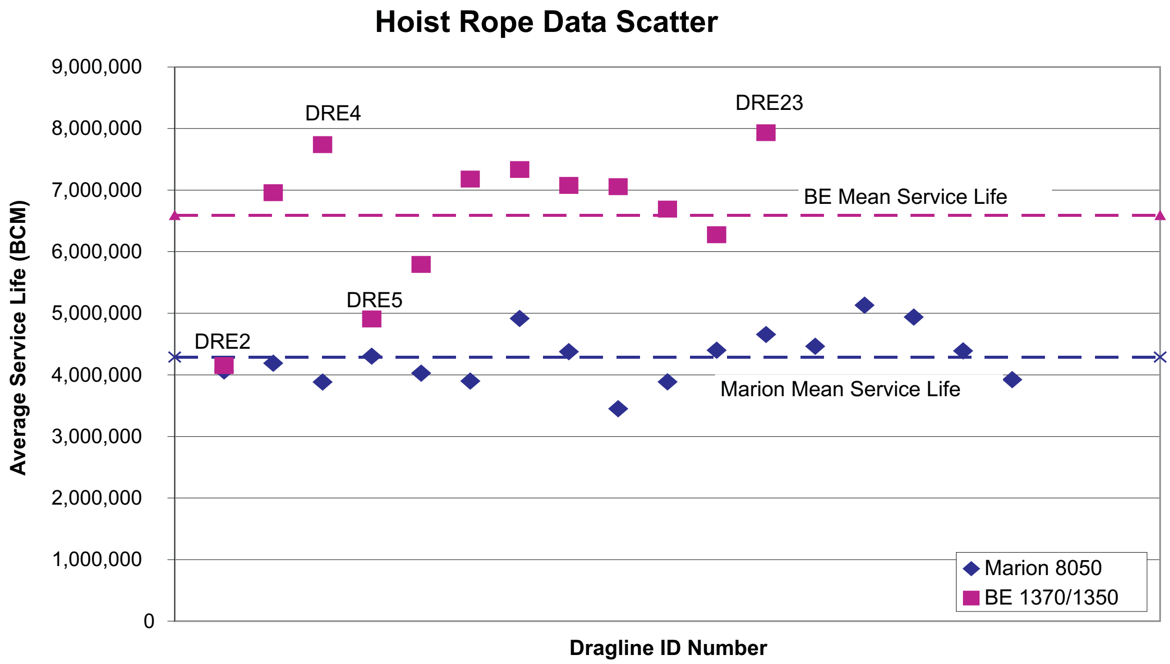

FIG 5 - Hoist rope data scatter for Marion and BE draglines.

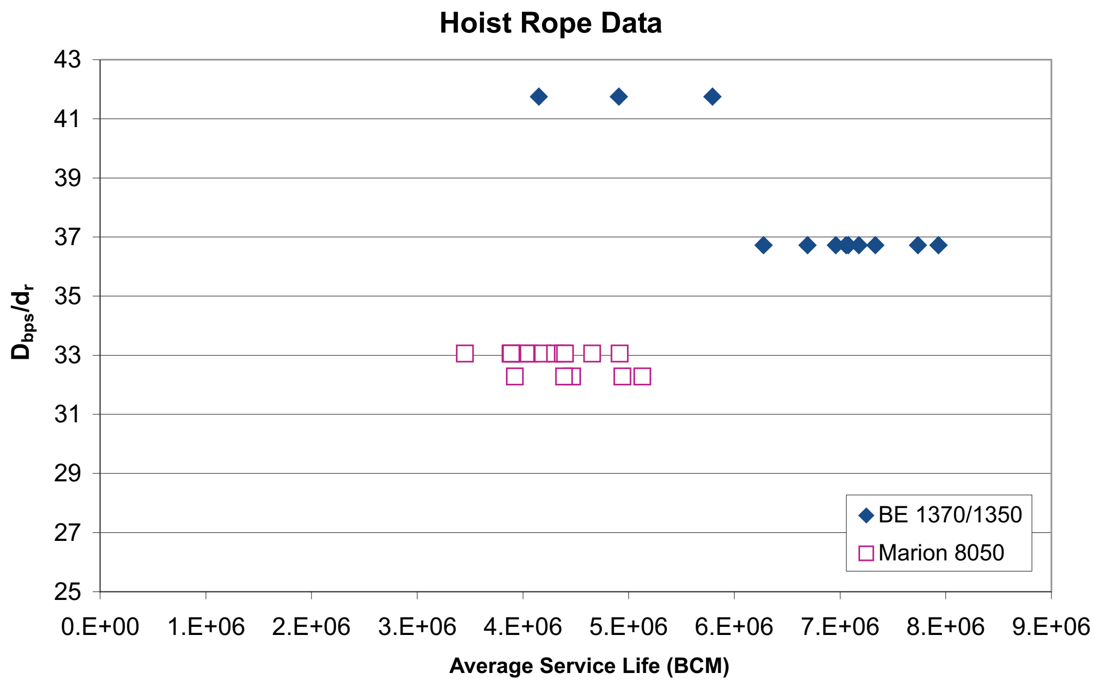

FIG 6 - Influence of boom point sheave to rope diameter ratio on hoist rope service life.

Comparison of drag rope data

The average drag rope service life for Marion draglines is illustrated in Figure 7. The data analysis shows that the mean service life for Marion draglines is slightly higher than the mean service life for BE draglines. A mean service life of 2.7 million cubic metres was obtained for the Marion draglines compared to 2.3 million cubic metres for BE draglines. However, the scatter of the average drag rope service life (Figure 7) shows that except for those average rope service lives that define the upper and lower bound of this data, most of the service lives for the BE and Marion draglines fall within the scatter band between two million and three million cubic metres.

Factors influencing service life of drag ropes

Condition of blasted overburden

The average service life of drag ropes depend on the condition of the blasted overburden. During digging operations, the drag ropes can run through the spoil collecting soil or rock particles on its lubricating surfaces. The soil and rock particles can become wedged between individual wires in a strand or between individual strands. The load in the drag ropes can cause the abrasive soil and rock particles to be compressed between two solid surfaces of the individual wires or strands. The high contact pressure produces indentations and scratching of the wearing

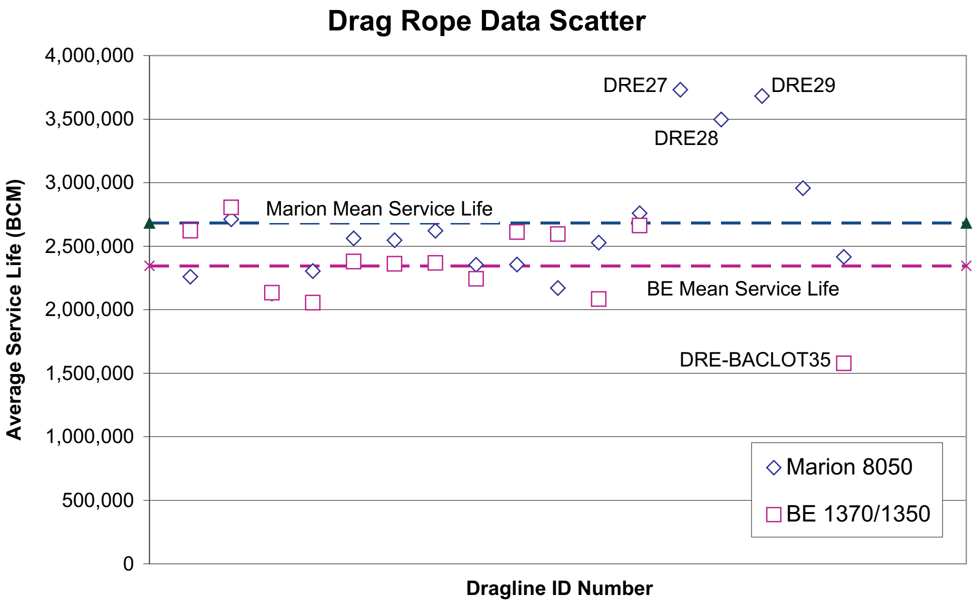

FIG 7 - Drag rope data scatter for Marion and BE draglines.

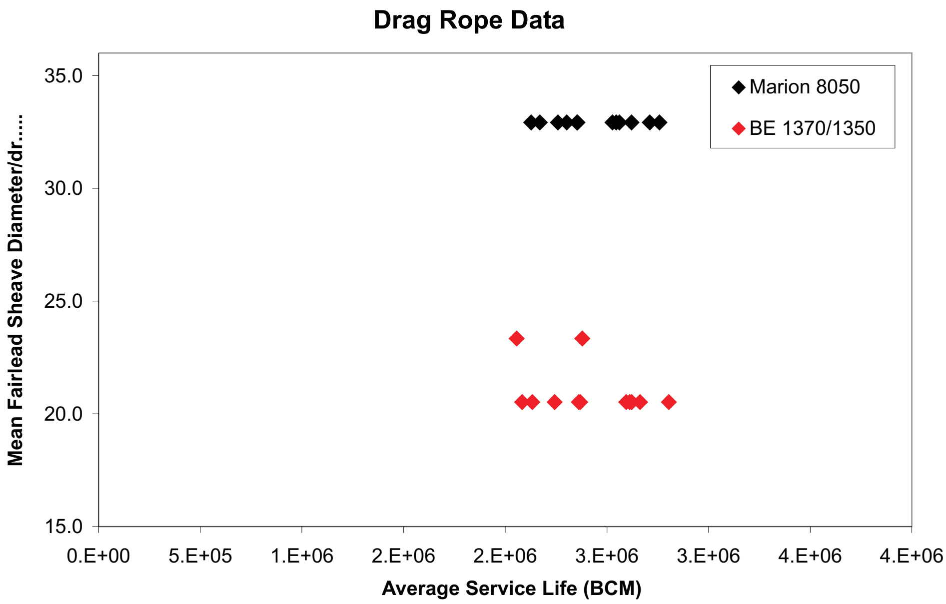

FIG 8 - Effect of mean fairlead sheave diameter to rope diameter on drag rope service life.

surfaces and fractures and pulverises the abrasive ore particles (Hawk and Wilson, 2001). This type of abrasion is classified as high stress or grinding abrasion. The larger rocks that result from improper blasting can result in the wear of drag ropes as well as cutting and tearing types of wear, in which small chips of metal are removed from the wearing surface by the movement of the sharp points of rock, under considerable pressure, over the wearing surface (Hawk and Wilson, 2001). This type of abrasion is called gouging abrasion. Wear of drag ropes therefore depends on the characteristics of the blasted overburden.

Fairlead sheave diameter to drag rope diameter ratio

It is well known that the service life of a rope bending over a sheave depends on the sheave diameter to rope diameter ratio. The average hoist rope service life shows that service life increases as the D/d ratio becomes large. Figure 8 shows that for drag ropes, a higher D/d ratio does not result in an improved service life. Therefore the dominant mode of failure in those ropes is a result of the abrasion that occurs due to the interaction of the rope and overburden during digging operations.

CAUSES OF ROPE DISCARD

Records from OneSteel Wire Rope (2003) show the reasons for discard of some of the wire ropes that are used as either hoist or drag ropes. The major discard indicators classified by OneSteel Wire Rope (2003) are as follows:

1. mechanical damage,
2. damage at sheaves,
3. damage at sockets,
4. removed for operational reason,
5. damage at drum, and
6. influence of equipment operation on wire rope life.

About 26 per cent and 40 per cent of the recorded discard reason for hoist ropes was due to damage occurring at the sheaves in Marion and BE draglines, respectively. A larger percentage of the discard reason for hoist ropes was also due to damage occurring at the sockets as well as mechanical damage. Other reasons for discard such as operator error, worked to destruction, removal for operational reasons, warranty claim and damage at the drums are not very common for discard of hoist ropes.

About 58 per cent and 48 per cent of the recorded discard reason for drag ropes was attributed to damage at the sockets for Marion and BE draglines, respectively. A significant proportion of drag ropes was also discarded due to operator error and mechanical damage in BE draglines. Other than mechanical damage, drag ropes discarded because of operational reasons were also significant in Marion draglines.

In the case of suspension and IBS ropes, the major reason for discard is the wire breaks due to fatigue. In particular, the end sockets are critical points where large numbers of wires tend to fail. However, the failure of ropes is not as rapid as in the case of hoist and drag ropes. The wire breaks usually can be monitored if an appropriate non-destructive method is employed.

FACTORS AFFECTING ROPE LIFE

The key parameters affecting dragline wire rope service life are:

- wire rope loading,
- wire rope construction and mechanical properties,
- sheave and drum design and configuration,
- maintenance of wire ropes and equipment in contact with wire ropes,
- storage and handling of ropes, and
- operator practice.

This section will broadly review each of these parameters in order to establish the reasons for significantly lower service life of hoist wire ropes on Marion 8050 draglines compared to BE 1370 dragline wire ropes.

Wire rope loading

Past analysis of the static rope forces under a range of the hoist and drag rope pay-out lengths using PCDRAG software (Srour and Shanks, 1995) have shown hoist rope tensions in excess of 200 tonnes (for average bucket payload), with the bucket positioned well away from the tightline situation, and in excess of 300 tonnes, when the bucket is positioned near the tightline conditions. Thus, for an 83 mm diameter hoist rope, the average loads per nominal rope metallic area can be in the order of 49.4 kg/mm^2 to 74 kg/mm^2. It is expected that dynamic loading on dragline ropes are likely to be significantly greater and will be governed by digging conditions and operational practices. Typical maximum dragline rope loadings in terms of specific stress and factor safety are summarised in Table 1 and it shows that the actual static and dynamic loading far exceeds the allowable factor of safety.

Wire rope construction

The ropes used for both hoist and drag are 83 mm in diameter. The recommended (BHP ropes) wire rope construction for hoist ropes is 6 × 25 FW (12/6 + 6F/1) and 6 × 49SF (16/16/8 + 8F/1) for drag ropes. BHP ropes have claimed to have trailed some of their own eight stranded products and monitored the performance of the eight stranded ropes supplied by other manufacturers. These tests, apparently, have shown no evidence of any improvement in wire rope life or that they impart any advantage to the operation or maintenance of equipment. However, other studies have shown that the use of eight-strand ropes increases the life of hoist ropes (Golosinski, 1994).

TABLE 1

Typical maximum dragline rope loadings.

Rope type	Factor of safety	Approximate stress (kg/mm^2)
Drag ropes	5:1	36
Hoist ropes	8:1	22

The usual tensile grade for mining ropes is 1770 MPa. However, hoist ropes will generally have the outer wires with a lower grade than the nominal tensile grade for the rope, whilst higher tensile grade wires will be used in the drag rope in order to improve the wear resistance. Note that the fatigue endurance is greatest around 1600 to 1700 MPa. Hence, an increase in drag rope wire tensile strength must be carefully monitored due to the potential of increased fatigue type problems at the sockets. It is well known that ropes having high tensile strength are subjected to increased fatigue (Evans and Chaplin, 1997).

Sheave drum D/d ratio

Sheave and drum size can have a significant impact on the rope bending fatigue and its service life. In general, the rope life will improve as sheave and drum sizes are increased. The rope manufacturers recommend that the sheave and drum sizes are maintained in the range of 25 to 30 rope diameters. Reducing the size of drum and sheaves below 25 rope diameters is claimed to have a profound effect on rope life (OneSteel, 2001).

Maintenance of ropes and equipment in contact with the ropes

The key parameters affecting rope service life from the maintenance point of view are:

- rope condition inspection,
- sheaves/rope drum conditions inspections,
- rope and sheave lubrication practices and inspection,
- rope end for ending practices, and
- re-socketing practices.

Rope condition inspections

Review of dragline inspection schedules has shown that the rope/sheave inspection practices vary significantly between the mine sites. Visual examination of ropes by the dragline operators is generally carried out. The objective is to discover unusual damage caused by some accident, such as broken or damaged wires, a kinked rope or loose rope fittings. End connections and fittings are also checked. Assessment of rope condition requires visual examination of the entire length of rope. This includes cleaning the rope at marked points, noting rope diameter, external corrosion, broken wires and strand slackness. The point of connection of the rope to the drum is also examined carefully for broken wires and slackening of bolts or clamps. The bucket/socket connections are also examined. Where possible, non-destructive tests must be used to determine internal wire breaks.

Sheave/drum condition inspection

The key parameters to be examined are correct groove size and profile, and alignment. Sheaves that are badly worn can pinch a new rope or produce undercut shoulder that will rub against the rope and severely impact on rope life. Uneven wear of the sheave flanges will often indicate an alignment problem. Heavy plastic wear early in the rope's life on the section running over sheaves is also an indication of either undersize sheave grooves, misaligned sheaves or sheaves not rotating freely. Continual use of undersize sheaves will eventually lead to broken wires due to fatigue. These inspections are recommended to be carried out annually or more frequently if rope wear is evident.

Lubrication practices and lubrication system performance inspection

Thorough lubrication of dragline ropes is of great importance in order to achieve good rope service life. According to BHP wire ropes experience, the rope life can be reduced from 40 per cent to 50 per cent if the ropes are not lubricated beyond what was applied during ropemaking. Inadequate lubrication could also seriously impact on the wear of the sheaves and drums. The type of lubricant used and means of lubricant application can also have a significant impact on the rope life.

Rope end-for-ending practices

Most dragline users swap the two ends of a rope about half way through the rope life. The purpose of rope end-for-ending practice is to maximise service life of ropes. The practice recognises the fact that rope wear and its deterioration is not symmetric along its length. The timing for end-for-ending is crucial towards it being successful practice. It was found through experience that the best time for end-for-ending a set of ropes is, in the case of hoist ropes, before any fatigued broken wires occur and, in the case of drag ropes, before a failure of any strand.

Re-socketing

The need for re-socketing arises from the fatigue and wear damage at the socket entry. Drag ropes in particular are prone to this mode of deterioration and are greatly affected by the digging operations occurring at the time. Re-socketing should be carried out before the number of broken wires reaches the rope discard criteria. Regular inspections of rope socket connections are thus required to minimise the possibility of either a strand failure or rope failure at these points. An anchor crop close to the socket can be done if the damaged area is not extensive and this will save on the amount of rope discarded and may give an extra crop.

Storage and handling of ropes

Storage and handling of ropes so as to avoid any damage to the wires and strands is very important. Also the application of lubricants prior to storage will minimise the possible corrosion.

Influence of equipment operation on wire rope life

The operator of any equipment has a role to play in minimising unwanted maintenance problems that can arise due to the operating practice. This is especially true for mining equipment, considering the harsh environment where they are put to use.

Some of the essential points are (OneSteel, 2001):

- Dragging the ropes through spoil piles must be minimised.
- Maintain on line digging wherever possible by aligning the bucket, boom point and the fairleads. Avoid slewing during digging.
- Minimise chopping to avoid rope friction with bucket chains.
- Bucket movements that can cause impact or dynamic loads on the ropes should be avoided.
- Worn, broken or missing bucket teeth will impact on rope loading and should be replaced.
- Do not let the ropes rub against the rock, slope or any foreign body.
- Do not let the rope slack – can cause winding problems on the drum.
- Many machines are fitted with ‘tight line’ limits based on permissible rope loads. The practice of operating away from this situation will reduce the load on the rope and likely increase the operations of the dragline overall.
- Good blasting practice, selecting manageable distance and depth of material removal – they all help minimise the duty on the machine.

CONCLUSION

Proper selection, installation and maintenance of ropes and the related parts is essential for maximising ropes service lives and to improve the reliability of draglines. Maintenance of the rope systems involves condition monitoring as well as preventive actions, such as lubrication, end-for-ending and re-socketing, whenever they are required. Furthermore, operator care impacts on the reliable operation of the draglines and improves the life of ropes.

ACKNOWLEDGEMENTS

This paper is a brief report of an extensive work, which is currently in progress. Supporters for the work include the Australian Coal Association Research Program (ACARP), Monash University, mines using draglines, in particular, the BHP Billiton Mitsubishi Alliance (BMA), the manufacturers of wire rope, in particular OneSteel Wire Rope, and the manufacturers of draglines, in particular, BE International.

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