Do the Benefits OutWeigh the Risk ?
or
How to use Aluminium in Underground Coal Mines.

By

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Summary

As part of ACARP project No.3066, ACIRL in conjunction with MineRisk have developed a risk benefit assessment process that is a refinement of the risk assessment process. The risk assessment process has been recognised by the mining industry as a useful tool in managing risk in various aspects of operations. In this instance ACIRL and MineRisk have adapted the risk assessment process to provide a means to balance risk with benefit. This paper will outline the development of the process and how the process can be practically applied in underground coal mines to assist in reducing manual handling injuries.

The risk benefit process can be used in a variety of applications where there is some risk due to the use of some device, but the benefits of using the device may outweigh the risk. The process developed by ACIRL and MineRisk is designed to assist management in a structured way, to make a logical decision as to whether to use a device in an application at their mine. The paper presents case studies showing how the process can be applied to assessing the risk and benefits involved in using aluminium in underground coal mines.

1. INTRODUCTION

As part of ACARP project No.3066, ACIRL in conjunction with MineRisk developed a risk benefit assessment process that is a refinement of the risk assessment process. The risk assessment process has been recognised as a useful tool for managing risk in the mining industry. In this instance ACIRL and MineRisk have adapted the risk assessment process to balance risk with benefit. The process developed by ACIRL and MineRisk is designed to assist management in an ordered and structured way, to make a logical decision as to whether to use a device in an application at their mine. This paper will outline the development of the process and how the process can be practically applied in underground coal mines to assess the widespread use of Aluminium.

In assessing the merits of the widespread use of Aluminium ACIRL investigated;

- Documented history of explosions attributed to the use of Aluminium.
- Experimental data on the probability of generating an incendive spark due to the contact of Aluminium on rusty steel.
- The US experience of the free use of Aluminium in underground coal mines.
- The benefits available from the use of Aluminium.
- The development of a risk/benefit assessment process in conjunction with MineRisk.

2. THE RISK

2.1 Explosion History

The risks associated with the use of aluminium alloys are created by the capability of high energy impacts of aluminium alloys on rusty steel objects to cause an incendive spark. Twelve incidents occurred between 1950 and 1955 in which such a spark was the source of an ignition of methane. Of these 6 occurred in the UK, 4 in Germany and 2 in Japan. Ten were attributed to the use of roof supports in a longwall face utilising aluminium and steel friction wedges (Schlom's Bar). A Schlom's bar is an Aluminium alloy roof support used in the early development of longwall mining systems. The alloy bars supported the roof and had to be manually moved and wedged into position. The wedges used were made of ordinary steel and quickly rusted in the mine environment. This system was designed in such a way that rusty steel and Aluminium were guaranteed to come into contact and that a high energy impact was guaranteed to occur. The positioning of the Schlom's bar, at the goaf edge of a longwall, is also the place where an accumulation of methane is most likely to occur.

The causes of the other two were; a hand held drill (made from 93% magnesium alloy) dropped onto a rusty roof support girder, a stone passing through a ventilating fan and striking an aluminium alloy fan blade. Later research on the incident with the drill concluded that the probability of the explosion occurring would have been reduced, had the drill been made from Aluminium instead of Magnesium. The report on the fan concluded that the ignition would have occurred, whether the fan was made of Aluminium alloy or steel.

A further explosion occurred in the UK in 1962 in which it was thought, but not conclusively proven, that aluminium wrappings on rusty steel rails may have been one of the ignition sources. It was for these reasons that the use of aluminium was restricted, but not prohibited, in the UK. The report on this explosion "*recommended that Aluminium and its alloys should be excluded from all face workings, return roads and any intake roads within 275m of a coal face*" [1]. However the prohibition on Aluminium introduced in the British mining industry was far more stringent than this recommendation. Legislation practices in New South Wales and Queensland reflect the UK position. US experience is discussed in section 2.3.

2.2 Experimental Research

Experiments have shown that if light alloys (alloys containing Aluminium, Magnesium or Titanium) impact on rusty steel, there is a probability that an incendive spark, that is capable of igniting an explosive mixture of methane gas, will occur. The mechanism that generates the incendive spark is attributed to the "thermite" reaction, a reaction between aluminium and rusty iron that generates heat. However the exact circumstances in which an ignition will actually occur varies with; energy of impact, alloy content, alloy hardness, angle of impact, amount of rust, and methane concentration. A major portion of this work was conducted by Titman in the UK [2], with Aluminium impacting on rusty steel. The greatest probability of generating an incendive spark occurs when a hard piece of Aluminium with a high Magnesium content, strikes a rigid rusty steel plate generating high contact pressures at an angle of 50 degrees in a methane atmosphere of 6.4%.

Bailey [3] reported from German test work "*that if the Aluminium alloy and rusty steel are reversed in the drop test, i.e a rusted steel weight falls on to an Aluminium plate, no sparks or ignitions occur*" and referred to some other work conducted by Titman where "*no ignitions occurred in 250 drops of rusted steel test heads on to the Aluminium target.*" With impacts of Aluminium on steel Bailey [3] also stated that "*in order to obtain ignitions at all, the target plate had to be mounted with absolute rigidity, e.g. a heavy steel structure set in concrete. Without this, sparking could not be obtained.*"

As well as ignitions caused by impacts, frictional smearing is another cause of incendive sparking. Frictional smearing occurs when high specific pressures are generated between rusty steel and Aluminium in operations such as driving wedges in and out of early designs of longwall roof supports (Schlom's bars).

2.3 US Experience

A study tour of coal mining operations in the United States of America was undertaken to assess the use of aluminium alloys underground. This showed widespread use in applications which ranged from the coal face to outbye areas. The only prohibition is on its use as a ventilation control device (stopping). There is also a restriction on the alloy content of external rotating parts on permissible electrical equipment (< 0.6% magnesium) in a hazardous zone (Aluminium scrubber fans were observed on Continuous miners). This recognises that alloys with high magnesium content are more incendive, and that rotating parts are more likely to be involved in high energy impacts.

Aluminium would not be used in the US unless there was some benefit associated with its use. It is used where it had been selected as the most suitable engineering material for manufacture. It is principally used to reduce weight (either to reduce the potential for manual injuries or for engineering reasons). It is also relatively easy to cast, is easier to machine than steel, has better heat transfer properties than steel, and it also has good corrosion resistant properties. For these reasons a range of commonly used components are commercially available in Aluminium and are used by US equipment manufacturers (particularly hydraulic components and heat exchangers). Manufacturers supplied the same equipment to any mine, whether it was considered gassy or not. Aluminium components were used on the entire range of any manufacturers equipment, irrespective of whether the equipment was used in the return, at the working face, or outbye.

A review of British research by US legislative agencies determined that to create an Aluminium/rusty steel explosion required quite extraordinary circumstances, on this basis Aluminium was not restricted as it was considered highly unlikely that an explosion would occur in actual working conditions. They have taken the view of reasonable probability versus cost of compliance.

Examination of MSHA's ignition database showed that in the period from 1959 - 1991, there were 2071 ignitions recorded in the United States. None of these ignitions were attributed to incendive sparks caused by aluminium contacting rusty steel.

The study shows that the level of risk associated with the use of Aluminium Alloys in underground coal mines in the US is extremely low (high uncontrolled use - no ignitions).

2.4 Summary - The Risks

The documented history shows that to generate a mine explosion due to the contact between Aluminium and rusty steel requires a number of precise conditions to occur simultaneously. Ten out of the thirteen documented explosions occurred due to frictional smearing in equipment that was deliberately designed to ensure that a high pressure frictional contact occurred between rusty steel and Aluminium. One explosion was due to the use of Magnesium and the probability of that explosion occurring would have been reduced had Aluminium been used. Another explosion, although involving Aluminium would have occurred anyway, no matter what material had been used. This leaves only one explosion that has been attributed to the accidental contact of Aluminium on rusty steel, however it must be emphasised that in this case, this was only one of several possible occurrences that may have caused the explosion.

The explosions all occurred in the 1950's and early 1960's. The technology of coal extraction, mine planning and ventilation practices have changed significantly since then. Specifically, mine ventilation quantities have increased significantly and continuous gas monitoring is now possible with modern electrical equipment. Also longwall chocks have changed from handset devices to automated hydraulically set chocks. The probability of these conditions occurring in a modern continuous miner or longwall mine with powered supports was considered by examining practices and experience in the US. Site visits to four US underground longwall mines (of similar size and type to Australian mines) showed that Aluminium is used extensively throughout the entire mine, even in the return. It is proposed that where similar equipment and conditions exist in underground coal mines in Australia, the level of risk is comparable.

3. THE BENEFITS

A recent study by the Victorian Institute for Occupational Safety and Health (VIOSH) to establish the OH&S priorities for the coal industry showed overwhelming evidence that overstrain injuries are a significant problem to the underground coal mining industry both in Queensland and NSW. The study identified that the highest safety priority for underground workers, is "Improved ergonomics of manual handling tasks".

The major potential benefit is a reduction in manual handling injuries. Weight of items is a contributory factor in strain related manual handling injuries. Significant benefits may be obtained in terms of reduced injuries, by investigating the use of Aluminium to make equipment lighter and easier to handle. Reduced mass and bulk when carrying items can also assist in the reduction of slip/trip incidents. Additional ergonomic benefits can be gained by;

- reducing the bulk of equipment (emergency blankets).
- improving the lifting position of equipment (provision of aluminium scaffold).
- improving maintenance access (larger aluminium explosion proof box covers).
- replacing poorly designed equipment with purpose designed equipment manufactured in aluminium (belt splicing equipment, Dowty props).
- reducing noise levels (aluminium engine sumps and rocker covers).

Benefits will accrue either during normal use or during equipment maintenance. Mass savings on individual components could be up to 60%, although on complete products, where only some components are substituted in aluminium, mass reductions may only be in the order of 10-20%. The use of the following equipment if made of Aluminium would assist in reducing the incidence of occupational injuries in the underground coal mining industry (weight reductions shown in brackets);

- Air tools such as impact wrenches and jack hammers
- Conveyor structure & roller sets
- Conveyor splicing equipment and roller set removal devices
- Explosion proof boxes and/or covers (40-60% reduction)
- Emergency blankets (99% reduction)
- Engine components
- Fluid couplings (44% reduction)
- Handheld bolters
- Hydraulic drill rigs
- Hydraulic valve banks
- Jacking devices such as floor jacks and hydraulic (Dowty) props
- Ladders
- Lifting appliances, chain blocks and pull lifts
- Longhole drilling equipment (drill rigs, drill rods)
- Monorails
- Pipe systems, water and air
- Pumps - Hydraulic/Grout/PUR/Water/Slurry
- Survey equipment (without special boxes)
- Scaffolding (No reasonable alternative)
- Trailing cable connectors (48% reduction)
- Tensioning device for AFC chains

Note: *The list is not exhaustive and other items could bring benefits.*

As well as OH&S benefits there are engineering benefits from using Aluminium;

- less weight reduces mechanical stress and inertia and improves power to weight ratio
- it is easy to cast and machine
- has good heat transfer characteristics
- can reduce noise and vibration in some applications.
- improved corrosion resistance.

The use of Aluminium in the following equipment would produce engineering benefits;

- hydraulic components (ease of machining/corrosion resistance)
- fluid couplings (reduced mechanical stress/inertia)
- fan blades (reduced mechanical stress/inertia)
- heat exchangers (better heat transfer)
- vehicle body panels (better power to weight ratio)
- engine sumps/rocker covers (improved structural rigidity)
- small explosion proof housings (easy to cast and machine)
- long hole drill rods (reduce vibration, increased drilling distance)

Unless there is a specific engineering or OH&S benefit, generally Aluminium components are chosen on cost and for commercial availability. If the OH&S or engineering benefit is great, then an extra cost may be justified. Cost savings for individual items may range from thousands of percent to ten percent. Individual items such as lock nuts have been remanufactured for $25 when the original nut would only have cost a few cents, typically however most hydraulic components cost between three to ten times more when Aluminium is replaced. For larger items where Aluminium is only partially replaced cost savings are in the order of 10-20% (e.g roof bolters). Expanding this to complete machines, savings of between 2-4% on the capital cost of major capital plant can be achieved (e.g. diesel vehicles, continuous miners).

Remanufacture of commercially available aluminium products results in a direct cost of equipment replacement, however the indirect cost of sourcing and re-engineering components is an overhead cost which cannot easily be accounted for in dollar terms. Equipment manufacturers expend a large amount of time in identifying Aluminium components and organising replacements. There is also lost opportunity costs where equipment that is commercially available (for use in general industry), either cannot or will not be produced of non Aluminium components, as some manufacturers refuse low production run orders. Small production runs also significantly increase supply lead times.

4. BALANCING RISK WITH BENEFIT

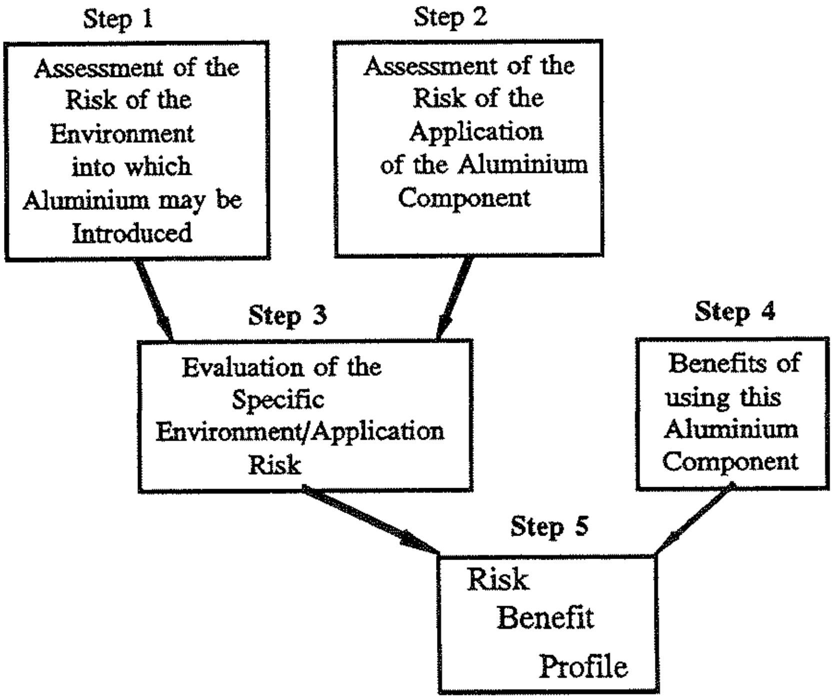
The project has established that a degree of risk does exist, but there are significant potential benefits. The original intent of the project was to provide a definitive answer as to the risks and benefits of using specific aluminium products in underground coal mines. However it was recognised during the project that the risk will vary from mine to mine. Therefore a generic risk benefit assessment process was developed by *ACIRL* and **MineRisk** personnel, to allow individual mines to make their own assessment.

The assessment procedure considers all the factors relevant to the use of aluminium alloys below ground, any benefits associated with its use and gives a ranking of risk and benefit. The procedure uses standard risk ranking techniques and accounts for factors associated with the environment in which an aluminium alloy may be used, the nature of its design and use, and benefits, if any, in either manual handling, engineering or cost reductions. The risk of an ignition is dependent on a number of conditions occurring simultaneously.

- The presence of ignitable fuel (gas).
- The presence of ferrous oxide (rust).
- The presence of exposed aluminium.
- A high energy contact of the aluminium object onto the ferrous oxide.

4.1 Five Step Risk Benefit Process

A five step process was developed to cover all risk scenarios and to balance these with the defined benefits. The process uses a series of standard 5 x 5 risk management matrices to reduce all the variables to one risk/benefit ranking. A flow chart of the process is shown below.



Step 1

The first step in the process is to evaluate the environment into which a light alloy may be introduced. The two factors to consider in this regard are:

- The presence of Ignitable Fuel (Gas)
- The presence of Ferrous Oxide (Rust)

The probability of an ignitable level of gas and the presence of rust will vary from place to place and from mine to mine, hence it is essential to define the place where the aluminium may be taken.

Step 2

The next step is to consider the risk associated with the specific application. The two factors to consider in determining the application risk are:-

- The amount of exposure of aluminium to the environment.
- The likelihood of a high energy impact of an Aluminium alloy on rusty steel during operation. (Note that an impact of rusty steel on aluminium involves minimal risk.)

Step 3

The overall risk is a combination of a specific application of light alloy in a specific environment. This is done by coupling the environment risk and application risk into one matrix, and defines the overall risk.

Step 4

An assessment is now made as to the benefits to balance these with the risks. There are three categories of benefits, manual handling, engineering and cost. In this model manual handling is weighted by a factor of 3, engineering by a factor of 2 and cost benefits are unweighted.

Step 5

The final step is to evaluate the benefits against the risk. This will allow an informed decision as to the value and risks associated with a specific application of light alloy in a specific environment. This is done by using a standard 5 x 5 risk management matrix.

Benefit Rank

Specific Application Risk

1	2	4	7	11
3	5	8	12	16
6	9	13	17	20
10	14	18	21	23
15	19	22	24	25

High Risk/Low Benefit

Low Number

Low Risk/High Benefit

High Number

This has refined all the variables to one risk benefit number, for a specific application in a specific environment. As a general rule it can be said that scores in the top left hand corner of the matrix (1-6) have the highest risk and lowest benefit and therefore may not be acceptable. The risk benefits scoring in the bottom right hand corner of the matrix (20-25) represents the highest benefit for the lowest risk and Aluminium alloys should be capable of being used in the relevant specific application. The areas in the centre of the matrix (7-19) represents medium risk benefit scenarios. Full details of the risk benefit process is detailed in ACARP report No. 3066.

The process has been trialled by several colliery groups (1 Queensland, 1 NSW) to assess the usefulness of the process. The detailed score sheets and the reasons for scoring, both for the risks and the benefits, are attached in Appendix 5 of ACARP report No. 3066. The results of the trial are summarised below;

1. Use of fluid couplings during changeout at the tailgate of the longwall.

Specific application/environment Risk= 6 Benefit= 20 Risk/Benefit= 16

The main benefit was seen as a reduction in weight (44%).

2. Use of fluid couplings during normal service at the longwall tailgate.

Specific application/environment Risk= 24 Benefit= 8 Risk/Benefit= 22

The benefit in use is an engineering benefit, so the benefit score has reduced. However the risk benefit score has improved as a much lower risk is attributed to the fluid coupling when fully enclosed during normal use.

3. Use of high tension plugs at the 11 kV outbye transformer during installation.

Specific application/environment Risk= 14 Benefit= 13 Risk/Benefit= 17

The main benefit was seen as a reduction in weight (48%).

4. Use of inspection covers on the longwall shearer during an inspection.

Specific application/environment Risk= 15 Benefit= 8 Risk/Benefit= 13

The main benefit was seen as a reduction in weight (approximately 45-50%). In this case hinges cannot be used because of the AFC spill plates.

5. Use of a ladder at the working face of a continuous miner section.

Specific application/environment Risk= 10 Benefit= 14 Risk/Benefit= 12

The main benefit was seen as a reduction in weight (55%). The bulk of the ladder contributes to the manual handling difficulties when moving a ladder.

6. Use of aluminium emergency blankets on the longwall face.

Specific application/environment Risk= 9 Benefit= 15 Risk/Benefit= 12

The weight of wool blankets is not an issue, their bulk contributes to manual handling problems. Both weight and bulk can be reduced by 99%. Aluminium blankets also provide better heat retention (80% of body heat).

7. Use of aluminium emergency blankets in the crib room.

Specific application/environment Risk= 22 Benefit= 15 Risk/Benefit= 24

The benefits are the same as example 6, however the risk has significantly reduced in the crib room.

8. Use of aluminium scaffold to put up wooden sleeper chocks at longwall changeovers.

Specific application/environment Risk= 14 Benefit= 16 Risk/Benefit= 20

This application was seen to have enormous benefits in reducing manual handling injuries at this mine sustained whilst building wooden cribs at the mine. Back and muscle strain injuries increased considerably during longwall changes. The mine had tried to find alternatives, however no reasonable alternative exists.

4.2 Industry Feedback on the Process

The trial groups indicated that for accurate risk benefit assessments, complete details of why each individual score has been assessed (accurate definition of application and environment) would be required. Hard data of the benefits would also be required; by using accurate OH&S Statistics, real engineering data and accurate capital/ownership cost data. A competent multi discipline team would also be required to provide an accurate assessment.

The trial groups found the process to be useful tool, as it logically progressed through several individual stages of assessment. Logical arguments could be provided at each stage of the assessment providing justifiable answers. Such a tool could be used universally by all coal mines and various bodies such as regulators and designers.

The groups were surprised at some results being scored higher than intuitively expected. This is because the assessment process ranks the possibility of contact as highly as the possibility of the presence of gas. i.e. if there was a high probability of contact but a low possibility of gas, a high risk ranking still occurs. Hence the model provides a very conservative process. At the end of the process the overall risk benefit scores fall into a high, medium or low risk benefit scenario. Some flexibility is allowed in the medium risk area, where specific applications may be used after more careful consideration.

The group supported the process and thought it should be used by the industry to introduce a more widespread use of Aluminium in underground coal mines. A more widespread use of Aluminium in underground coal mines was viewed favourably by the trial groups. The groups also thought that the process could be used for assessing other risks other than Aluminium. The groups saw the process as a method of risk assessment that a mine could use to seek approval to use of Aluminium in their underground coal mine.

5. CONCLUSIONS

In both Queensland and New South Wales the use of risk assessment and evaluation of controls has played an important role in the current approval process for Aluminium alloys. The risk benefit assessment developed through this project provides a procedure for assessing the risks and benefits associated with aluminium alloys and gives a safe, conservative ranking. It is recommended that the risk benefit process, developed as part of this ACARP project No. 3066, be conducted on all aluminium equipment where significant OH&S benefits can be achieved, to assist in reducing the incidence of occupational injuries in the underground coal mining industry. These assessments need to be conducted on specific applications at specific mine sites.

The process assesses risks and benefits on a case by case basis. The risk will vary with different scenarios and the exact benefits will also be different for each application. This results in a very conservative risk benefit assessment process as the overall benefits may be greater than when assessed on an individual basis. The risk ranking is also a very conservative process, as the probability of contact is ranked as highly as the possibility of the presence of an ignitable level of gas i.e if there is a high probability of contact and a very low probability of gas a high risk ranking is scored.

REFERENCES

1. Some examples of How the UK Mining Electrical Engineering Industry Responded to the Challenge Presented by Major Disasters. G Goodlad, Mining Technology, May 1995, Vol 77 No 885.

2. The Ignition Hazard from Sparks from Cast Alloys of Magnesium and Aluminium. H Titman, Safety in Mines Research Establishment, Research Report No. 90, February 1954.

3. Frictional Sparking of Aluminium. J C Bailey, Transactions of The Institution of Mining Engineers Vol. 118 Part 4 January 1959.