DEVELOPMENTS IN TYRES FOR QUARRYING

ABSTRACT

Tyres typically account for 25–30% of haulage operating costs in quarries and open pit mines. On particularly demanding operations the figure is often much higher.

This paper discusses significant developments in the technology and operation of earthmover tyres over recent years. These include advances in radial tyre design, pressure control, warranty, rims, protector chains, and the industry's understanding of tyre explosions.

RADIAL TYRES

Improved radial technology has been the most important tyre development for the mining industry over the past 15 years.

History

In 1960 radial tyres comprised only 2% of all tyres – light vehicle and earthmover – running worldwide. One manufacturer, Michelin, accounted for around 90% of these.

During the 1960–70's the use of light vehicle radial tyres became widespread, firstly on passenger vehicles, then on light trucks and finally on heavy road trucks. By 1980 radials comprised the majority of light vehicle tyres in service, but only 5% of earthmover tyres. Since then radial tyre acceptance by the mining industry has increased dramatically. The proportion of radial earthmover tyres rose to 65% by 1990 and is expected to be 85% by the mid-1990's.

A parallel development over the same period was the reduction in the number of major earthmover tyre manufacturers from eight to three. Bridgestone, Goodyear and Michelin account for most of the radial earthmover tyres being produced today.[1]

Benefits

The benefits of using radial tyres in mining applications are similar to those which have ensured radial dominance of the light vehicle market. They are:

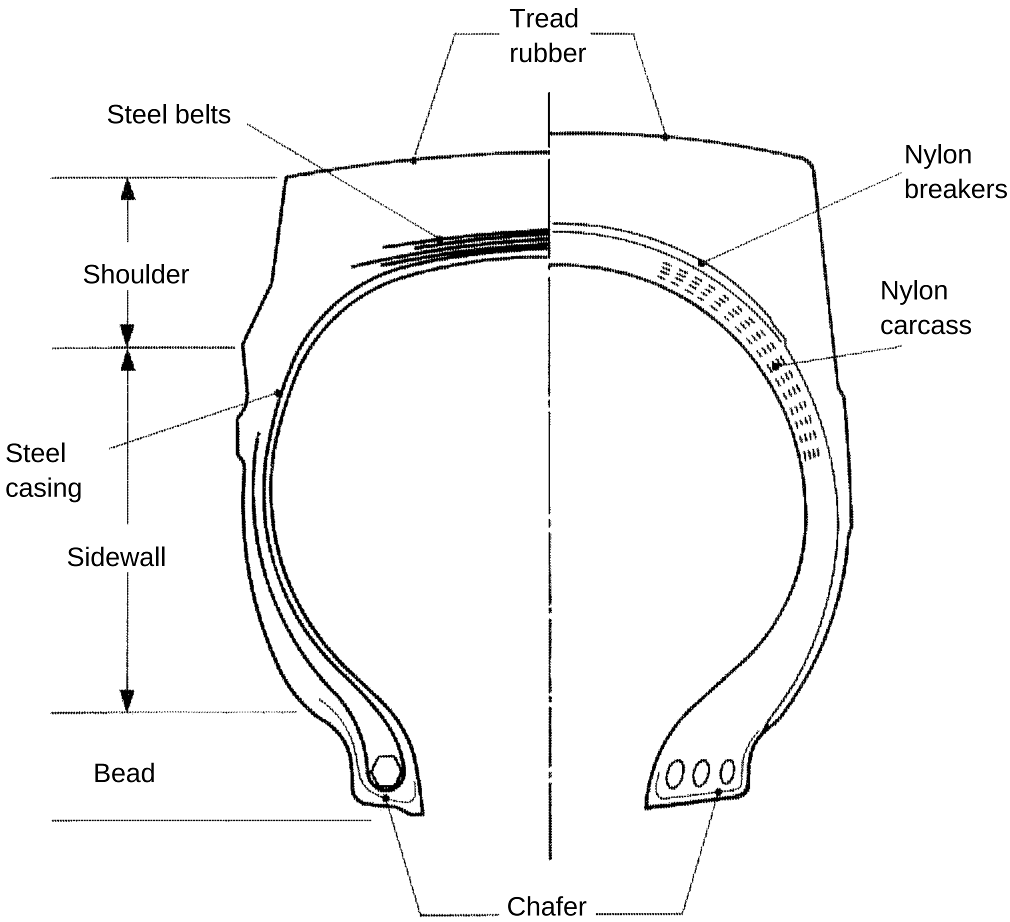
- reduced tread squirm thereby increasing traction and wear-out life,
- steel belts that provide additional resistance to tread damage,
- lower rolling resistance which reduces fuel consumption,
- better flotation characteristics, and
- higher repair success rate.

These benefits arise from the differences in tyre construction.

Bias ply construction

A bias ply tyre has a bulky casing composed of many criss-crossed nylon ply layers as shown in Fig. 1. Tyre flexing that occurs during routine operation causes deformation of the casing and "hour-glassing" of the section of tread in contact with the ground; this results in tread squirm and uneven contact pressure across the footprint area. Tyre flexing also causes "scissoring" of adjoining ply layers increasing casing stress and heat buildup.

[1] Toyo shares manufacturing facilities with Goodyear in Japan but produces relatively few earthmover tyres (radial or bias ply). Yokohama, General, Firestone, and OTR do not manufacture radial earthmover tyres.



a. Radial section *b. Bias ply section*

Fig. 1 – Tyre construction (radial vs. bias ply)

Radial ply construction

In comparison, a radial tyre has a thin casing composed of a single radially oriented steel ply layer which is contained by several circumferentially aligned steel tread belts. Tyre flexing is absorbed by the radial casing ply with little deformation of the tread; the steel belts act like a tank track providing uniform ground contact pressure. The radial's thin casing also generates less heat and stress making it better suited to high speed applications and more amenable to successful repairs, particularly in the sidewall area.

Operating cost

The bottom line is tyre operating cost, which is typically **15% lower** for radials compared with bias ply tyres running in the same application. A radial's 10–20% higher price is more than compensated by its 30–40% higher average life.

Other significant but generally less quantifiable cost savings associated with radials are:

- reduced mining equipment **downtime** as fewer tyre changes are necessary because of higher average life,
- improved tyre **repair economics**,
- lower **fuel costs**[2] due to reduced tyre rolling resistance, and
- increased **productivity**, particularly for loaders and dozers, because of better tyre traction.

Applications

Haultruck applications have been the most widely converted to radial tyre fitment. Radial use on graders and dozers is becoming more prevalent but relatively few are running on big loaders (eg. Caterpillar 992, Komatsu WA800 and larger). There are several reasons for this.

Supply related

Tyre manufacturers produce numerous radial specifications in haultruck tyre sizes, but only a select range for graders, dozers and small loaders; radial tyre options for large loaders remain limited. Goodyear and Bridgestone entered the radial earthmover tyre market in earnest in the mid 1980's, and have had to rationalise production because of the high capital costs involved, eg. $2–3 million for individual moulds. Consequently, market opportunities (haultruck tyres comprise the majority share, followed by graders, dozers and small loaders) have dictated tyre size production priorities.

Demand related

Haultrucks account for a major portion of the tyre bill on most sites, and hence provide the greatest scope for tyre cost reduction. The most tangible benefit offered by radial haulage tyres is their higher tonne kilometre per hour (TKPH) rating which has increased demand for them on long, fast haulage operations; it has also allowed the use of more cut/abrasion resistant compound specifications on many sites.

Much of the rise in demand for radial tyres on graders and dozers has been due to their better traction, particularly in slippery conditions.

Overall, tyre company investment priorities will continue to be a major determinant of the rate at which the industry converts to radials across the full range of tyre sizes.

Teething problems

Tyre designers have overcome many challenges in the development of radial earthmover tyres, most related to stress level reduction in the tread belt, sidewall and bead areas.[3] Ongoing, significant improvements can be expected for several years.

Radials are particularly sensitive to poor **pressure maintenance**. If allowed to run underinflated, radial tyres are prone to bead turnup and belt edge separations and subsequent early tyre failure.

Radials also appear to be less capable than bias ply tyres of handling conditions of **severe overload**, as shown in Fig. 2.

[2] Some tyre companies state fuel savings in the order of 9%, or higher, for radial tyres. Trials in which Otraco has been involved indicate savings of around 4%.

[3] Note that some operators without sophisticated warranty systems in place have contributed heavily to manufacturers' development costs.

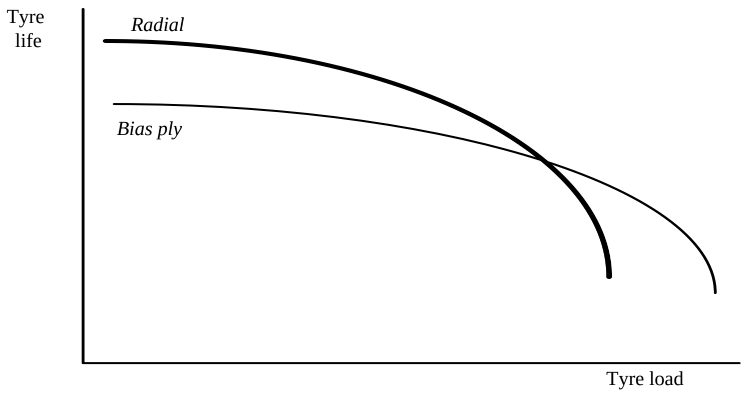


Fig. 2 – Effect of severe overload on tyre life (radial vs. bias ply)

At rated or slightly overloaded conditions the radial tyre's higher load carrying capacity is advantageous. However, because of its steel ply and belt construction, a radial tyre does not have the same "stretching" tolerance that the nylon casing affords a bias ply tyre. A radial is more likely to pull itself apart when subjected to extreme overloading.

Future

Almost all earthmover tyre research and development expenditure is now being directed at radial design and construction. Radial tyre life and economics will continue to improve relative to bias ply tyres.

A properly managed site test tyre program is essential for identifying the best performing tyre specification in each major equipment application on a quarry or mining operation. An evaluation program requires accurate records, correct analysis techniques and needs to be coupled with an appropriate tyre guarantee system.

PRESSURE & TEMPERATURE MONITORING

Maintaining the correct inflation pressure for a working earthmover tyre is the single most important means of maximising tyre life – site tyre life can vary by 30% or more depending on pressure maintenance quality. Good pressure control is particularly critical for radials.

Pressure buildup

As a tyre operates it flexes and builds up heat. The temperature of the contained air rises causing an increase in air pressure – the relationship between air temperature and pressure closely obeys the general gas equation.

Monitoring history

Before the late 1970's there was no means of accurately determining operational tyre pressure buildup, making it difficult to identify leaking or otherwise underinflated tyres. The only reasonably reliable method was to check a tyre's "cold" pressure after it had stopped operating and had been allowed to cool to ambient temperature – a process that takes about 24 hours. Therefore underinflated tyres could run undetected for days (or weeks in the case of continuous shift operations) before being positively identified by a cold pressure check.

P-T system

In 1978 Otraco developed a system which eliminated the guesswork associated with hot pressure buildup. The method, called the P-T (pressure-temperature) system, was described in Gordon (1979) and in Gordon and Cutler (1983). It involved measuring a tyre's internal air temperature by removing the valve core and inserting a probe thermometer into the valve stem. A pressure-temperature chart was then consulted to determine, for the measured internal temperature and for the tyre's reference pressure, what pressure the tyre should have in it. The actual pressure would then be measured and adjusted, if necessary, to the correct setting.

The P-T system was implemented on BHP Iron Ore's Newman minesite in 1978 and has since been adopted by several mines around Australia and overseas.

Monitire

The P-T system is cumbersome, and useful only in the hands of a skilled operator. Otraco started development of the Monitire system in 1983. The system comprised wheel units (one per tyre), a hand-held computerised data logger, and database software running on a personal computer (PC).

The wheel unit was a valve spud that incorporated a temperature sensor and an electrical connector plug; the unit replaced the normal valve spud on each wheel, with the plug being bracket mounted to the wheel's valve stem. The data logger's air chuck would be attached to the valve stem and its temperature connector to the plug mounted on the valve stem. The logger measured tyre air chamber pressure and temperature, calculated correct pressure based on a default or keyed in reference pressure, and displayed any pressure deviation. Tyre pressure would then be adjusted if necessary. At the end of each day readings and calculated deviations were downloaded to a PC database for further analysis and/or printout.

Monitire offered several advantages over the standard P-T system.

- It improved temperature measurement accuracy by sampling air within the tyre chamber rather than in the valve stem.
- It obviated the need to flush air through the valve stem in order to take a temperature reading.
- It reduced measurement and calculation time.
- It eliminated calculation error.
- It provided a record of actual readings, eliminating recording error.
- It provided a computerised database facility.

Monitire was marketed in 1985. However it was beset by battery, calibration, and hardware reliability problems and was withdrawn from sale in mid-1986.

Recent developments

Two air monitoring systems for earthmover tyres are presently being marketed and a third is in its final stage of development.

Dresser[4] has released its *Haulpak Tire Monitoring System* and an English company is selling the *Monityre EM System*. This has no association with *Monitire* which is being jointly redeveloped by Topy[5] and Rimtec[6].

A brief description of each of the three systems follows.

Haulpak Tire Monitoring System

Dresser (Haulpak) bought out Truck Tech Corp. of Canada who originally developed the *Remote Air Pressure Sensor* (RAPS) system. Dresser renamed the product the *Haulpak Tire Monitoring System*. It was released in Australia following its promotion at the AIMEX mining show held in Sydney in October 1991.

The *Haulpak Tire Monitoring System* is telemetry based. Each wheel on an earthmover vehicle is fitted with a sensor which measures air pressure – air temperature can also be monitored if an appropriate sensor is used. The readings are transmitted on a regular basis (determined by the user) to a cab mounted receiver console. The receiver has upper and lower pressure and temperature limits determined

[4] Dresser is an American mining equipment and earthmover rim manufacturer.
[5] Topy is a Japanese manufacturer of steel products including earthmover rims.
[6] Rimtec, an Australian supplier of rims, valves and tyre related products, is a subsidiary of Otraco.

and set by the user. If these limits are exceeded then an alarm is activated. Information can be stored in the receiver module and down-loaded to a suitable computer.

The original version of the *Haulpak Tire Monitoring System* does not correlate pressure and temperature (if monitored), and hence cannot determine whether a detected pressure drop is due to a change in the tyre's operating temperature or because of air loss. A new version is expected to include this function. This system is being evaluated on at least one Australian minesite.

Monityre EM System

The *Monityre EM System* is similar to Dresser's product in that it uses telemetry to continually monitor tyre air pressure. However air temperature monitoring is not an option with the English system. Information on this product is limited although it is understood to be in use on an Australian minesite.

Monitire TMS

Topy and Rimtec started redevelopment of the *Monitire TMS* (tyre management system) in 1990. As with the original Monitire, the new system does not use telemetry; it retains the hand-held computerised data logger.

TMS is a pressure maintenance system rather than solely a monitoring device and retains the advantages of the original Monitire together with several major improvements.

- It uses a single connection to record both pressure and temperature.
- It provides in-service replaceability of the wheel unit.
- It gives longer battery life.
- It allows pressure and temperature checking while inflating.
- It provides unrestricted airflow during inflation or deflation.
- It permits integration with the new Rimtec SLB valve spud.

The system is in the final stage of field-testing on three Australian minesites. It was exhibited by Topy and Rimtec at the Las Vegas mining show in October 1992 and is scheduled to be released in the latter half of 1993.

Explosion monitoring potential

The main reason for air chamber monitoring systems is to alert the user to tyre underinflation, so that it can be rectified before tyre damage occurs. Some products still require improvement in this area.

With further development the telemetry based devices could provide early warning of potential tyre explosions. This would be particularly useful, for example, in the case of vehicle electrification where a tyre explosion could occur minutes or perhaps hours after electrical contact is made. The system would have to be capable of measuring and displaying air temperatures up to 500°C to be effective in this application.

Tread temperature monitoring

A monitoring tool with a different purpose from the above devices is the adaptation by Goodyear Australia of the *Telog system* for computerised monitoring and analysis of earthmover tyre tread-base temperature. The Telog probe is inserted into a hole drilled horizontally from the shoulder of a tyre into the base of the tread. A thin connector leads from the probe to a recording unit that is attached to the wheel rim. The unit can be left in place for as long as two weeks, continually recording tread-base temperature for the operating tyre. Data is downloaded, as required, to a PC for analysis. This system provides detailed information on tyre operating temperature over time and in relation to mine haulage cycles. It is a useful aid for monitoring tyres that are operating at or near their TKPH limits.

Caveat

For all their benefits, none of the above monitoring systems replaces routine checks by operators and tyre servicemen. Tyres still need to be regularly inspected for imbedded rocks, damage, and excessive or irregular wear – and corrective action taken where necessary.

TYRE GUARANTEES

Tyre performance guarantees give protection to the user from loss of tyre life due to manufacturing defects or non-optimal tyre specifications. Guarantees also promote a competitive atmosphere among suppliers which leads to more rapid product development.

The earliest form of earthmover tyre guarantee covered faults in materials or workmanship. Fixed and relative performance guarantees followed – under the former, tyres are guaranteed to achieve a fixed life or operating cost; with the latter, each supplier warrants its tyres against the best performing (lowest operating cost) brand.

Materials and workmanship guarantee

A materials and workmanship guarantee warrants tyres against manufacturing defects; it remains the basic guarantee provided by tyre companies. Reimbursement is usually based on the proportion of original tread depth remaining on the tyre.

This guarantee is appropriate for applications where tyre usage is relatively light and irregular, eg. grader, dozer, loader.

Problems

Materials and workmanship guarantee, when applied to haultruck tyres, encourages the supply of tyres which are over-endowed with heat resistance at the expense of abrasion and cut resistance. This reduces heat and separation damage – the main causes of material and workmanship claims – but can lead to diminished overall life.

In addition, most mining companies are not technically qualified to argue with tyre suppliers over manufacturing defects.

Fixed performance guarantee

Under the most basic system of fixed performance guarantee, only worn-out tyre life is guaranteed. On a hard rock operation where a high proportion of tyres fail through rock damage such a guarantee is unsatisfactory, though better than nothing. A better system is one where batches of tyres are guaranteed to achieve a minimum average life or operating cost irrespective of failure reason.

Problems

The main concern with fixed performance guarantee is the difficulty in getting tyre suppliers to agree to an upward adjustment of the guarantee level if tyre life increases, eg. due to improved site conditions. On the other hand tyre suppliers have, on occasion, made large settlements based on historically set guarantee levels which have become unrealistic because of deteriorating site conditions.

Another problem is that suppliers often press strongly for guarantee exclusions, eg. in relation to pit conditions.

Fixed performance guarantees are particularly unsuited to new sites or changed applications (eg. larger truck size) where there is no historical performance data available upon which to base the guarantee level.

The one circumstance where a fixed performance guarantee is appropriate is where only a single tyre brand is run in a haultruck application, making a relative performance guarantee unworkable. In this case, fixed performance guarantee is generally preferable to materials and workmanship.

Relative performance guarantee

The concept of a relative performance guarantee was proposed by Otraco in 1982 in an attempt to provide an effective and equitable system of warranty for haultruck tyres, and to overcome some of the problems inherent in other guarantee systems. Guarantee exclusions were limited to things such as fire or mechanical damage, providing less potential for argument between the parties.

The "frontrunner" relative performance guarantee evolved in 1992 in association with several mining companies and following consultation with the major earthmover tyre suppliers.

Under this guarantee each supplier's tyres are grouped by fitment period (usually six monthly) and compared with the performance of other suppliers' batches that were fitted during the same period and in the same application. The frontrunner batch is that group of tyres whose average scrap life provides the lowest operating cost, ie. cost per km or cost per hr. Other suppliers must compensate the user for the shortfall in performance of their tyre batches compared with the frontrunner batch. Compensation may be in cash or replacement tyres as agreed between each supplier and the user.

An intent of the frontrunner guarantee is to ensure that the tyre supplier compensates only to a performance level that has been achieved by tyres operating under similar conditions, rather than – in the case of fixed performance guarantee – to a performance level which may not be realistically attainable.

There has been resistance from some tyre companies to frontrunner guarantee due to large warranty settlements early in the radial tyre development period. Still, this warranty provides major advantages over other systems – its bottom line is that a minesite is guaranteed of running all tyres at the same operating cost as that of the best performing brand.

General

A guarantee should compensate the mine operator for the poor performance of a brand of tyres relative to other brands used. Major tyre problems arising from faulty design, manufacture or quality control, while rare, can prove to be very costly unless an effective guarantee is in place.

An appropriate system of earthmover tyre guarantee is:

1. relative performance guarantee for haultruck tyres, and
2. materials and workmanship guarantee for other tyres.

Tyre guarantees receive varying levels of acceptance from different suppliers. However, no company will be prepared to offer a proper guarantee unless it feels that its tyres will be maintained to a certain minimum standard and, in the case of life based guarantees, that accurate tyre life history records are kept.

Analysis techniques such as fitment bias adjustment, whilst not within the scope of this paper, are also necessary to bring objectivity to performance guarantee systems. These methods are described in Gordon and Cutler (1983).

RIMS

Until ten years ago, Goodyear Motorwheel Corporation held 80–90% of the earthmover rim market, with Firestone supplying most of the balance.

Today, neither company produces earthmover rims, largely because neither upgraded their product design and manufacturing processes sufficiently to cater for the new generation of larger tyres and equipment. Competitors saw the opportunities and capitalised on them.

There are now four major suppliers[7].

- Topy – Japanese
- Dresser/CanAm/Titan – American
- Dotson – American
- Rimex – Canadian

Topy hold the major share of both the original equipment (O.E.) and replacement markets worldwide; they have recently released a new design rim. Dresser is the other significant O.E. supplier and supplies a large proportion of replacement rim requirements. Dotson started selling rims after purchasing Motorwheel's production equipment in 1987; they have a limited and decreasing share of O.E. market sales. Rimex entered the Australian market in the past 12 months and are promoting a redesigned heavy-section rim.

Rim life and cost

Whereas life of 35,000 hours or higher is common for 35, 49 and 51 inch diameter rimbases on trucks of up to 120 short ton capacity, life is typically around 15,000 hours for 51 inch rimbases on 190 ton trucks and less than 8,000 hours for 57 inch rimbases on 240 ton units.

Rim maintenance is becoming increasingly important to maximise rim life and safety. Maintenance procedures include cleaning, corrosion prevention and early crack detection using dye penetrants, magnetic particle inspection or ultrasonic techniques.

Sites running these larger trucks are finding that rim costs are accounting for a greater proportion of their operating budget.

Rim design

Before 1980 earthmover rim design involved relatively little technical expertise. The major problems experienced at that time resulted from poor welding control – mainly lack of penetration.

The mid-1980's saw the first 190 ton rear dump trucks and the increasing usage of radial tyres. Some manufacturers designed thicker flanges and machined their mating surfaces to compensate for the higher side-loading of radial tyres. Heavier duty rimbases were also developed; improvements included:

- strengthened back sections and bead seat bands,
- increased back lip height,
- machined O-ring and lock ring grooves, and
- repositioned circumferential welds.

Since the late 1980's rim development has become increasingly important to the mining industry. This has been due to the new era of rear dump trucks of over 200 tons capacity generally being fitted with radial tyres.

Proper design, manufacture and quality control is critical for the larger rim sizes. The latest improvements have included the use of better quality steel and fabrication procedures, improved surface finishing techniques, eg. machining and shot peening, and changes to basic rim design.

Rim design is an area where there has been a divergence in philosophy among the various rim companies. Some producers have raised rim strength by increasing section thickness considerably. This approach has led to problems with clearance and with the removal of demountable style rims from wheel hubs. It also increases unsprung weight and fuel consumption, and may reduce wheel bearing and brake system life. By comparison,

[7] Wheel & Rims Engineering, a Brisbane based company, also supplies earthmover rims in Australia.

at least one manufacturer has used finite element analysis to identify and rectify high stress areas with minimal weight increase.

There are also significant design variations in relation to the height of the back lip. Some manufacturers incorporate a very high lip in an attempt to increase strength and reduce fretting fatigue due to flange contact; others argue that excessive back lip height will increase bending moment stresses at the corner of the back section promoting cracks in this area.

Performance monitoring

Rim performance needs to be closely analysed – particularly on sites running large capacity haultrucks – to determine which of the above design approaches prove to be the most effective.

Minesites that operate trucks of 190 ton capacity or larger should consider implementing a rim component life recording system to assist in the control of this potentially high cost centre.

PROTECTOR CHAINS

Protector chains are designed to reduce the susceptibility of earthmover tyres to damage in severe hard-rock quarry and mining operations.

There are four major brands; all are available in Australia.

- Rud – German
- Erlau – German
- Tiretrac/Union – Swiss
- Pewag – Austrian

Operating cost

Tyre chains are very expensive, eg. in the order of $40,000 each to suit 45/65x45 tyres running on loaders of the size of a Caterpillar 992C; hence they can be justified only if the average life for unprotected tyres is exceedingly low – around 1,800 hours in the case of 45/65x45 tyres – and only after other options (different tyre specifications, waterfill, improved working areas) have been investigated.

In severe applications chains can lower tyre usage and downtime dramatically. Their fitment to the front tyres of two Komatsu WA800 loaders on a Western Australian minesite reduced front tyre cost[8] by 35% – saving $130,000 per annum in operating costs, as well as reducing machine downtime.

Industry acceptance

High maintenance and downtime costs have been the major problems associated with chains in the past. Acceptance of chains by mine operators has increased over recent years largely due to improved chain design which has reduced both the incidence of chain damage and the downtime required to rectify damage when it occurs.

Fitment of a chain to a 45/65x45 tyre can be accomplished in two to three hours by a properly trained tyre serviceman. Chain retensioning is generally required bi-monthly, depending on the application, and takes only a few minutes, as does the replacement of a damaged link.

Suitable applications

The heavy, closely meshed chains required for loader applications are not suited to extensive tramming because under these conditions they are prone to stretch damage and excessive wear. Hence they should not be fitted to machines used on load and carry operations, nor to loaders that regularly travel to different, widely separated working areas during a shift. Tramming speed must also be limited to 15 km/h.

Chains improve tyre traction and loader productivity, especially when used in slippery floor conditions. They also crush loose rock and assist in maintaining a cleaner loading area that poses less danger to haultruck tyres. However loader operators must be discouraged from thinking that working area cleanup is no longer as important because of the fitment of chains – otherwise existing costly tyre damage will be replaced by equally (or more) expensive chain damage.

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[8] Comparing unprotected tyre cost per hr with tyre and chain cost per hr.

In applications where chains are needed, fitment would normally be required on front tyres only.

Summary

In those relatively few operations that require the application of protector chains, their use can generate substantial savings in operating costs and production downtime.

TYRE EXPLOSIONS

Until recently the mining industry's knowledge of the processes involved in tyre explosions was limited. Explosions were often mislabled as tyre "blowouts" thought to be caused by a buildup in internal chamber pressure due to simple heating of the contained air. Conversely some blowouts have been mislabled as explosions.

Tyre fire and explosion seminar

In 1987 the first seminar on earthmover tyre fires and explosions was held in Newman, Western Australia. Much useful information was collated before and during the seminar (Mines Department of Western Australia et al, 1987).[9] The dissemination of this knowledge has increased industry awareness of the causes and dangers of tyre fires and explosions. However, there is still much that is unknown.

Recorded incidents

The following record of earthmover tyre explosions was compiled for a report on an explosion in Western Australia (Otraco, 1990).[10] The list, by no means comprehensive, notes explosion locations, dates, and causes.

- Cleveland Tin, Tas., 1981, oxyacetylene heating of wheelnuts
- Colombia, South America, 1986, wheel fire initiated by brake overheating
- Hunter Valley, N.S.W., 1986, vehicle contact with 33kV overhead power line
- Kalgoorlie, W.A., 1987, tyre fire initiated by diesel fuel fire
- Ipswich, Qld., 1987, lightning strike to vehicle
- Leigh Creek, S.A., 1987, not positively established – possibly tyre internal heating due to separation
- Newman, W.A., 1987, brake damage and overheating
- Pine Creek, N.T., 1989, lightning strike to vehicle
- Argyle, W.A., 1989, vehicle contact with 33kV overhead powerline
- Mt Pleasant, Kalgoorlie, W.A., 1990, vehicle contact with 33kV overhead powerline
- Nottingham, England, 1990, oxyacetylene heating of wheel brakes

At least two more tyre explosions have occurred since this list was compiled.

- Fimiston, Kalgoorlie, W.A., 1992, vehicle contact with 33kV overhead powerline
- Ontario, Canada, 1992, vehicle contact with 33kV overhead powerline

Seven people have been killed and one seriously injured in the above incidents.

Explosion mechanism

A tyre explosion is the result of the ignition of an explosive mixture of gases created within the tyre's air chamber. The heat source is normally one of the following.

- vehicle contact with powerline
- welding or oxyacetylene heat application to wheel components
- brake, wheelmotor or wheelhub overheating
- lightning strike to vehicle
- tyre fire (usually initiated by one of the above)

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[9] Mines Department of Western Australia, Otraco, Mt Newman Mining Co., 1987. Summary of proceedings of the seminar on tyre fires and explosions (unpublished).

[10] Otraco, Report to Argyle Diamond Mines on 33.00R51 tyre explosion, 1990 (unpublished).

Heat is transmitted to the tyre by:

1. conduction and radiation, in the case of welding, oxyacetylene application, brake/wheel overheating, or tyre fire, and
2. electric current passing through the tyre, in the case of vehicle electrification, ie. powerline contact or lightning strike.

Analysis work commissioned by Otraco has shown that if the heat buildup is sufficient to raise the temperature of a section of the tyre's inner liner above **250°C** then this material may undergo pyrolysis forming volatile gases including styrene vapour and butadiene. An explosion is likely to occur if both of the following conditions prevail:

1. explosive vapour comprises **1–8%** of the gas mixture within the tyre's air chamber, and
2. "hot-spot" temperature within the air chamber exceeds **430°C**.

Uncertainties

Presently there is no safe means of determining when, or if, a tyre explosion will occur. Tyres have reportedly exploded **instantaneously** (Pine Creek lightning strike and Fimiston powerline contact), several **minutes** after powerline contact (Hunter Valley, Argyle and Ontario), and several **hours** after a truck has been parked up (Leigh Creek).

Most explosions following vehicle electrification have been limited to one tyre. However in the Fimiston incident two tyres exploded almost simultaneously, and in the Ontario case several tyres exploded over a period of time.

Misconceptions

Three common **misconceptions** are that an explosion cannot occur:

1. with a **deflated** tyre,
2. with a tyre that has been inflated with **nitrogen**, or
3. once the **heat source** has been removed.

Deflated tyres, eg. due to valve cap and core removal, penetration or unseated beads, are as susceptible to explosion as fully inflated tyres. An explosion does not happen because of an excessive increase in inflation pressure; it results from the catastrophic combustion of an explosive gas mixture and hence does not require a totally enclosed environment.

Nitrogen inflation of tyres reduces risk but provides no guarantee against explosions. Firstly nitrogen fill does not prevent inner liner pyrolysis and the formation of explosive gas. Secondly an explosion can occur if oxygen content exceeds 5.5% due to the ingress of air, eg. as a result of the tyre going flat.

Tyre explosions can take place well after the heat source is removed. The Wabco 170C tyre explosion in Colombia occurred 35 minutes after extinguishment of a brake fire, killing three people.

Emergency procedures

All minesites should have emergency procedures to cover vehicle electrification, tyre fires and potential explosions. These procedures should incorporate the following major elements.

1. Operator is to immediately notify supervisor by radio.
2. Machine is to be parked up as soon as possible in a designated area providing good access for a water truck or rescue vehicle.
3. Machine is to be shut down once parked.
4. Where machine is in contact with a powerline, operator is to remain in cab until advised by supervisor that it is safe to vacate.
5. Operator is to vacate to safe area as far away from machine as possible – operator is not to attempt to extinguish a tyre or wheel fire with a portable extinguisher.
6. Supervisor is to ensure that the area within at least 200m radius of affected machine is vacated of all unauthorised personnel – roadblocks are to be setup.
7. Any attempt to extinguish a fire is to be done with full shielding of fire-fighting personnel – flying debris is not the only danger, an explosion's airblast can kill.

8. After extinguishment of the fire or abandonment of the machine, the machine is to be quarantined for 24 hours.

Tyre fire and explosion emergency procedures should form part of the induction training for all quarry and pit operators.

Summary

The industry's understanding of tyre explosions has improved significantly since 1987, although much remains to be learnt. Education will reduce the level of potentially dangerous misconceptions that are still prevalent on many operations. Existing or new tyre monitoring systems need to be developed to provide early warning of possible explosions.

CONCLUSIONS

Earthmover tyre advances discussed in this paper have extended the capability of rubber-tyred mine equipment and reduced operating costs and production downtime. The developments covered are still evolving and will continue to serve the industry. Other innovations are presently being applied to smaller equipment, eg. airless puncture-proof bobcat tyres. These provide the prospect for additional, longer term benefits to quarry and mining operations.

ACKNOWLEDGMENTS

Historical and technical information supplied by the following companies is gratefully acknowledged – Bridgestone Earthmover Tyres, Goodyear Australia (including material on tyre monitoring systems), Michelin, Rimtec, Rud Chains and Topy Industries. The author also wishes to thank Otraco and colleagues for their support and assistance.

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