Circumferential failure of lockrings

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Background

In recent years, tyres and rims have been involved in more mining fatalities in Queensland than any other single contributor. Various failure mechanisms have occurred and have been studied over time. This safety bulletin was developed after a circumferential lockring failure had been reported to the mines inspectorate.

What happened?

A Caterpillar 992C front end loader left the tyre bay after a new O-ring had been fitted to the position 1 tyre-and-rim assembly. After travelling approximately 100 metres, this same assembly failed catastrophically, resulting in parts being propelled up to 50 metres from the vehicle. No injuries occurred, despite the considerable potential for a serious injury or fatality (see Figures 1 & 2).

The lockring cracked circumferentially through the thinnest section, resulting in two “rings” that were no longer able to keep the assembly together (see Figures 3 & 4).

Figure 1 - General scene

Figure 2 - Position 1 tyre-and-rim assembly

Figure 3 - Lockring; split circumferentially

Figure 4 - Close-up of split lockring

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Other details

Lock ring

- Identification number LR45EM
- Approximately 1700 operating hours since new

Tyre size

- 45/65 - 45

Investigation

In an industry-led investigation, the incident was studied through a combined effort by:

- The owner
- The Original Equipment Manufacturer (OEM) and their local distribution agent
- University of Queensland Materials Performance (UQMP)
- Mines Inspectorate

A broad scope investigation was performed and highlighted both metallurgical and mechanical issues. The mechanical investigation included a finite element stress analysis.

Relevant to this incident, the following items were determined:

- For the lifetime of the lockring, the loader had been used for low duty applications near a coal handling and processing plant.
- The steel lockring was manufactured through a process of cold drawing and rolling approximately three years earlier. It had been in operation for approximately 1700 hours at the time of failure.
- Early in the lockring drawing process, the steel was non-destructively tested for defects. There was no other non-destructive testing (NDT) prior to delivery to the client.
- The rim was 26 years old and the lockring groove had significant, uneven levels of material loss from wear, corrosion and spalling.
- If the same amount of material loss in the lockring groove had been uniformly distributed, it would have increased the lockring stress by less than 10%.
- However, the uneven wear in the lockring groove, over an arc length of 300 mm, increased lockring stress by more than 500%. This stress level locally exceeded the steel’s yield point and was a major contributor to the failure.
- Analysis has shown that the yield point can be reached if the deviation in lockring groove wear depth is as little as 0.4 mm over a groove length of 300 mm.
- The lockring failed circumferentially through a process of lamellar tearing.
- The lockring contained a large quantity of non-metallic elongated manganese sulphide and other inclusions. These inclusions had a significant detrimental effect on the steel’s through-thickness properties.
- The main stress direction was across the profile of the lockring. Therefore, the direction of highest stress had the worst material properties.
- The material specification is Japanese Standard JIS G4051 S33C. Through-thickness properties were not specified.

The risk

A large amount of energy is contained in the compressed air in a tyre. If this air is suddenly released, there is a significant risk of injury or fatality.

This incident involved a 45” rim with an EM profile lockring. Figures 5 and 6 show the lockring and rim assembly cross-sections.

Conceptually, it can occur on any pressurised tyre-and-rim assembly, regardless of the size, industry or type of vehicle. The recommendations in the next section should be considered for all applications, taking individual circumstances into account.

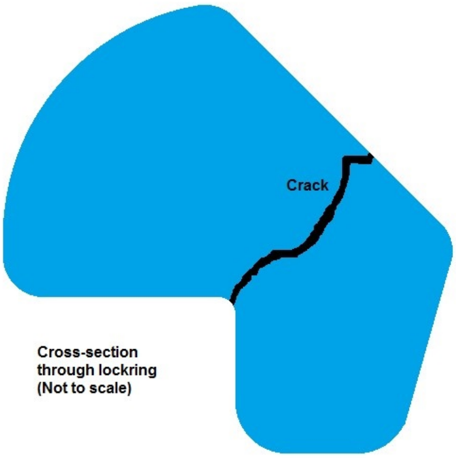

Figure 5 - Lockring cross-section

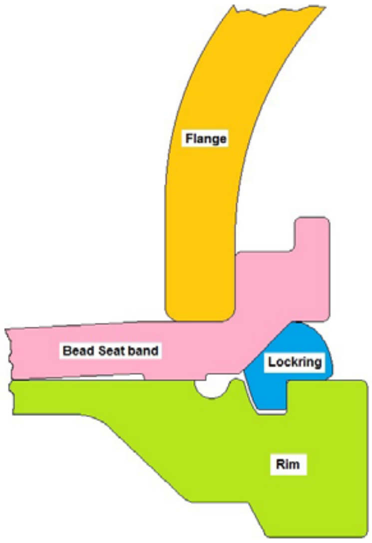

Figure 6 - Cross-section through metal parts of the rim assembly

Recommendations:

Short term

- On a regular basis, inspect rim grooves and lock rings for wear, corrosion or spalling. Uneven material loss and excessive material loss are reasons for concern.
- Where designed to be fitted, install wheel rim locks to limit wear and differential movement between the metallic parts of the rim assembly.
- Metal parts, especially the lock ring groove must be thoroughly cleaned before assembly. Foreign contamination in the groove, such as dirt or corrosion products may load the lockring unevenly, similar to an unevenly worn part.
- To help eliminate uneven loading, machining of rims and bead seat bands needs to be controlled within acceptable tolerances. Note, the quantification of machining tolerances and tolerances for material loss are specialised topics beyond the scope of this Safety Bulletin. For more information, consult a professional specialising in this field in conjunction with the OEM.
- An appropriate method of NDT needs to be applied at or near the final stage of manufacturing. NDT needs to be considered for lockrings already in use which have not been non-destructively tested after manufacturing.

Medium term

- Through-thickness mechanical properties need to be specified, especially for lockring materials (for example, steels with a 20% Short Transverse Reduction of Area (STRA) or greater, as measured by ASTM A770, were found to be very resistant to lamellar tearing).

Long term

- The tyre-and-rim assembly involved in this incident is not designed to fail to a safe state. Designers and manufacturers are encouraged to consider this aspect in future designs. The goal should be to design a tyre-and-rim system such that if a failure occurs, it results in a controlled release of energy to a safe state.