A mine Mining LTD

SAG 2 GEAR FAILURE REPORT REVIEW

Date 10th December 2020	Author	Justin Marwick
	Notes and Review	

Contents

Disclaimer:

This report is based on observations of various operating machines mill girthgears in service. The FEA models depicted are for illustration purposes only the loads and displacements are estimated and simplified for the purposes of demonstration and should not be construed as a design review. Care has been taken in the accuracy of the points of view, however no liability real or implied should be attached to the views proposed in the is report.

1.0 Scope

Review failure analysis papers from METALLURGICAL and an Eminent Metallurgist.

Review PAUT inspection report from IXT

Provide an opinion on most likely contributing circumstances to the failure based on experience with similar failures on gears of the same construction technique.

2.0 Backgound:

A mine's Line 2 SAG mill had a gear installed in about 2016 it was of forged and fabricated construction. After a hiatus due to adverse operational conditions – operations recommenced, at which time a significant slurry event caused by leaking bolts occurred. The girthgear cover seal was never completely installed and therefore the a significant amount of slurry entered the gear guard resulting in accelerated wear and localized indentation damage on the girthgear.

In March 2017 Gearinspec conducted a partial inspection of the SAG mill gear which confirmed that the gear had suffered significant wear during it operational time since installation. During that inspection only 110 teeth were available to be inspected and that tooth 393 was not inspected until March 2019.

The crack is on the unloaded side of tooth 393 mostly in the root region, however, the most advanced part of the crack was on the unloaded side in the dedendum.

Fig 1 Crack on unloaded side of tooth 393 March 2019

This is highly unusual as the bending stresses in that area are predominantly compressive.

Hofmann engineering were contacted to effect a remediation or an amelioration of the gear tooth with whatever techniques they had available.

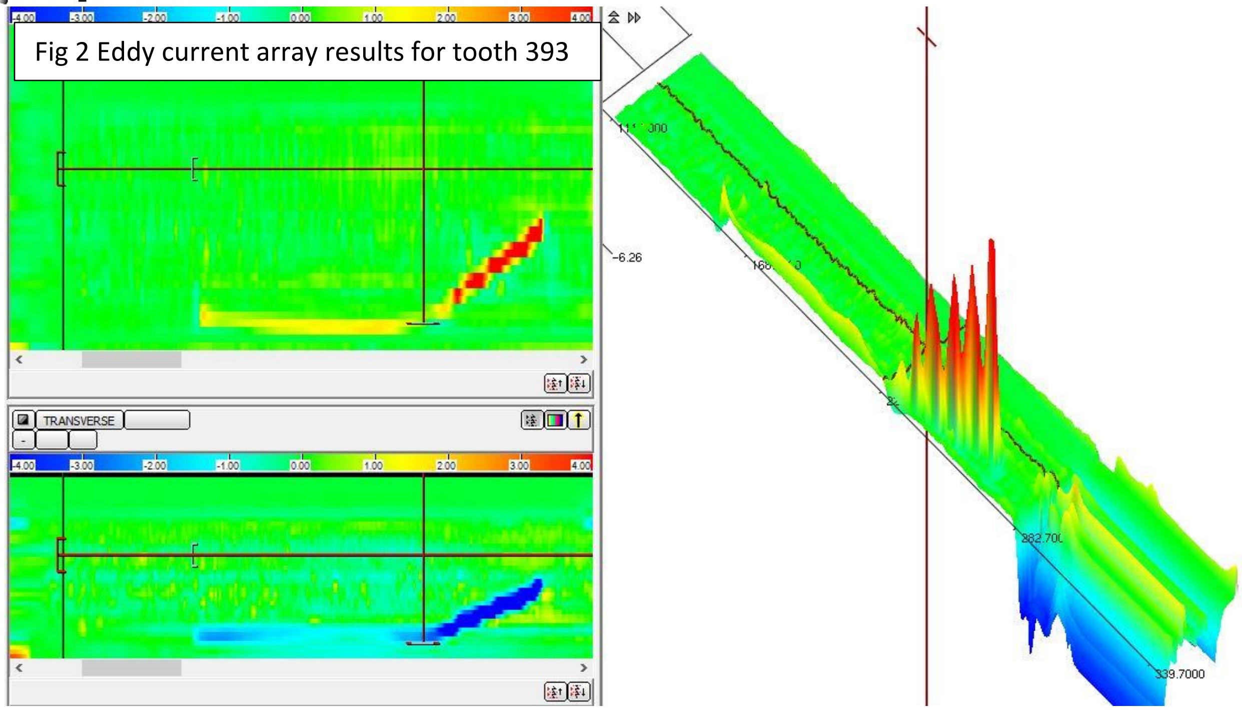


Fig 2 Eddy current array results for tooth 393

The gear was removed from service in March 2020. A new forged and fabricated gear was installed along with new pinions and an improved gear sealing arrangement.

3.0 METALLURGICAL Report

Visual examination: this section speculates that the cracking initiated in the root region and travelled up onto the gear flank. The author did not have the benefit of knowing that the crack was on the unloaded side. The author's description is consistent with a stress regime, had the cracked flank been a loaded flank. It was however; the unloaded flank on a T section gear. The stress state due to gear forces is least right above the mounting flange on the gear. A review of fig 1 above shows that the crack has fretted and is most obvious on the flank part of the gear towards the drive end.

Helical gears have a sliding mode of engagement were as the gear contact progresses along the gear contact surface the gear is flank is deformed resulting in tensile components on the unloaded side.

Fig 4 gives an exaggerated impression of this situation. Given the deformation in Figure 4 the stress condition most likely to initiate a crack on the opposite face would be somewhere just above or in the dedendum – root area in the 1st 1/3 from the Drive end.

Discussion section: There is discussion of the gear flank vs gear root hardness. The general conclusion is that the gear material that could be examined was sufficiently homogeneous so as not to have a material or physical abrupt change that would have caused an increase in stress intensity so as to initiate a crack.

The discussion then roles onto some speculative statement around – presumably split-line bolts being loose. I am not aware of any failures that the author describes. It would be very obvious if one of the mounting bolts or one of the splitline bolts were behaving as the author describes. On a helical gear such as this the contact ratio is seldom more than 2 talk of 4 teeth in contact is a little confused. Finally the engagement of the gear teeth and the rotation of the mill means that the tooth 393 is engaged before teeth 394, 395 and 396 so speculation about loose splitline or mounting bolts is not based on the physics of the situation.

Fig 4 engagement of helical gear tooth

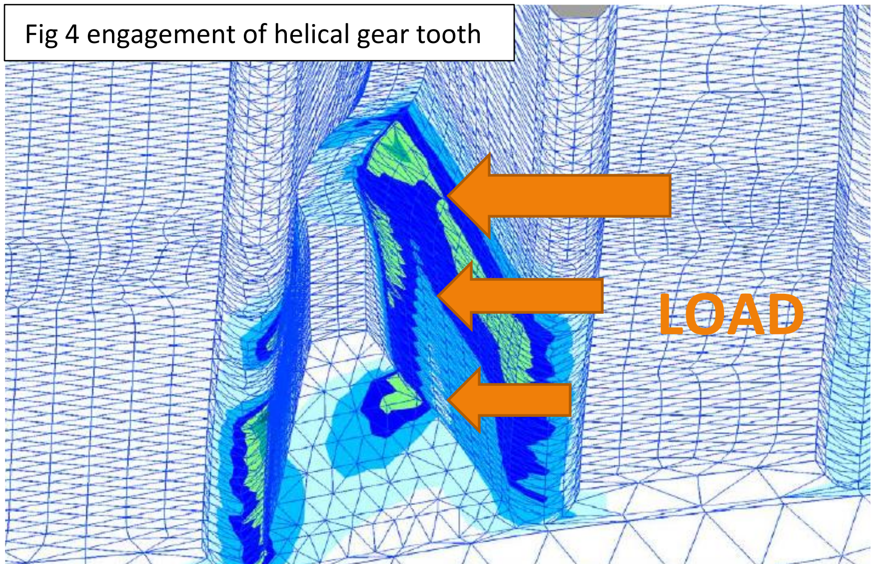


Fig 5 Illustration of deflection mode in relation to splitline

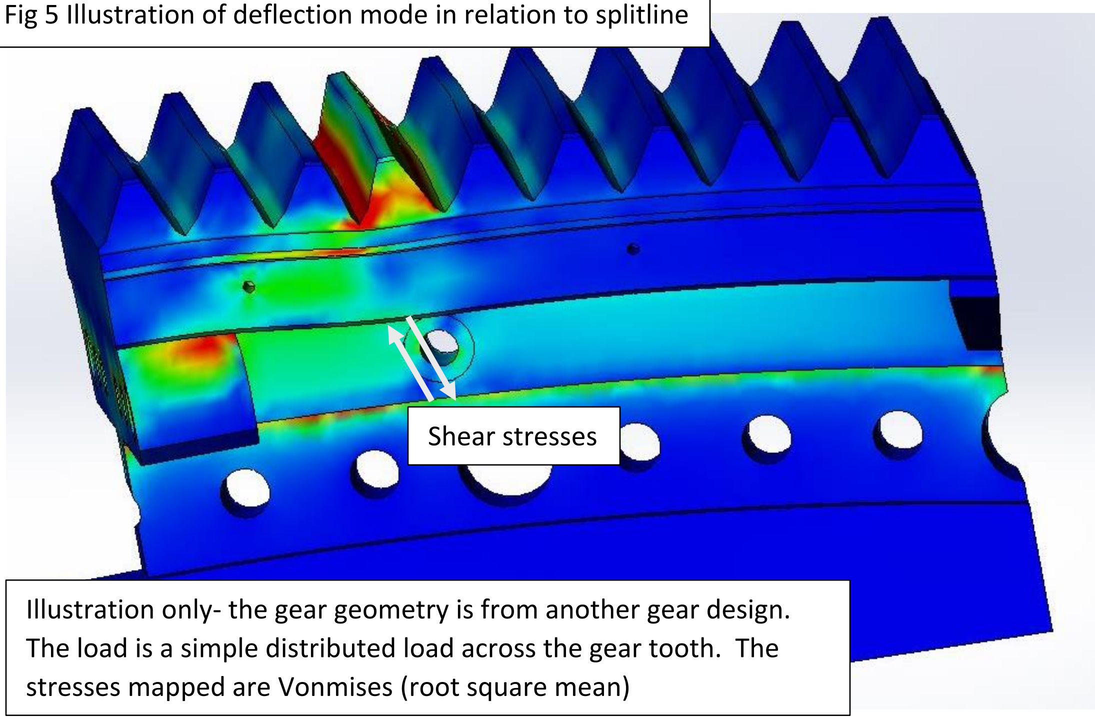


Illustration only- the gear geometry is from another gear design. The load is a simple distributed load across the gear tooth. The stresses mapped are Vonmises (root square mean)

In Summary , the Metallurgical report provides some valuable insight into the metallography of the gear segment, however, the discussion section does not provide valuable insight.

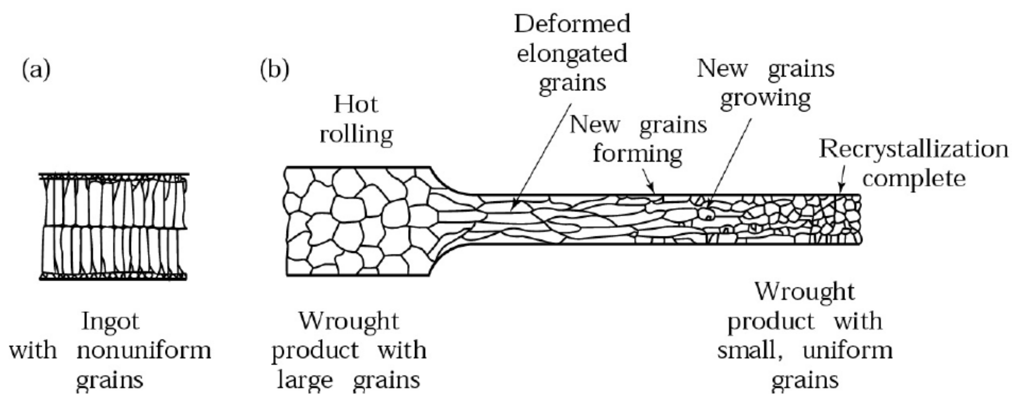
4.0 Eminent metallurgist Summary Of Metallurgical Report

Section 2 The author talks about the mechanical properties of the steel used in the manufacture of the gear rim. Forgings are not amorphous like castings, they have variations in the structure due to the mechanical treatment they endure during manufacture.

Fig 6 hot rolling taken from Materials notes by Dr Valerie Speredelozzi

Flat Rolling Stages

- Hot rolling of *ingot* or a continuously cast slab converts it to a wrought structure called a *bloom* (square) or *slab* (rectangular)
- Bloom may next go to shape rolling
- Slabs may be rolled into plates and sheet



The issues the author describes regarding the poor tribological properties of the low carbon steel used in the manufacture of the fabricated gears have been noted in the past and leads to accelerated wear and compromise of the involute profile (galling and welding when lubricant is not sufficient are also problems).

The statement about gear rim thickness being 1.4 times the tooth depth is an empirical value derived from AGMA standards which are in turn derived from many case studies. In practice Gears of this manufacture are very flexible when being installed. They do not have the intrinsic stiffness that comes with the section sizes required for casting. This flexibility has made fitment of gears to runout standards easier to achieve, however, I suspect that the gear's flexibility means that during installation deformation or rather the gear conforming to the mounting surfaces and then being pushed into deformed shape by jacking bolts causes internal strain which in turn causes imposed stress on the gear rim. When rules of thumb are applied there would perhaps also be some recognition of the width of the gear face compared with the depth of the gear rim.

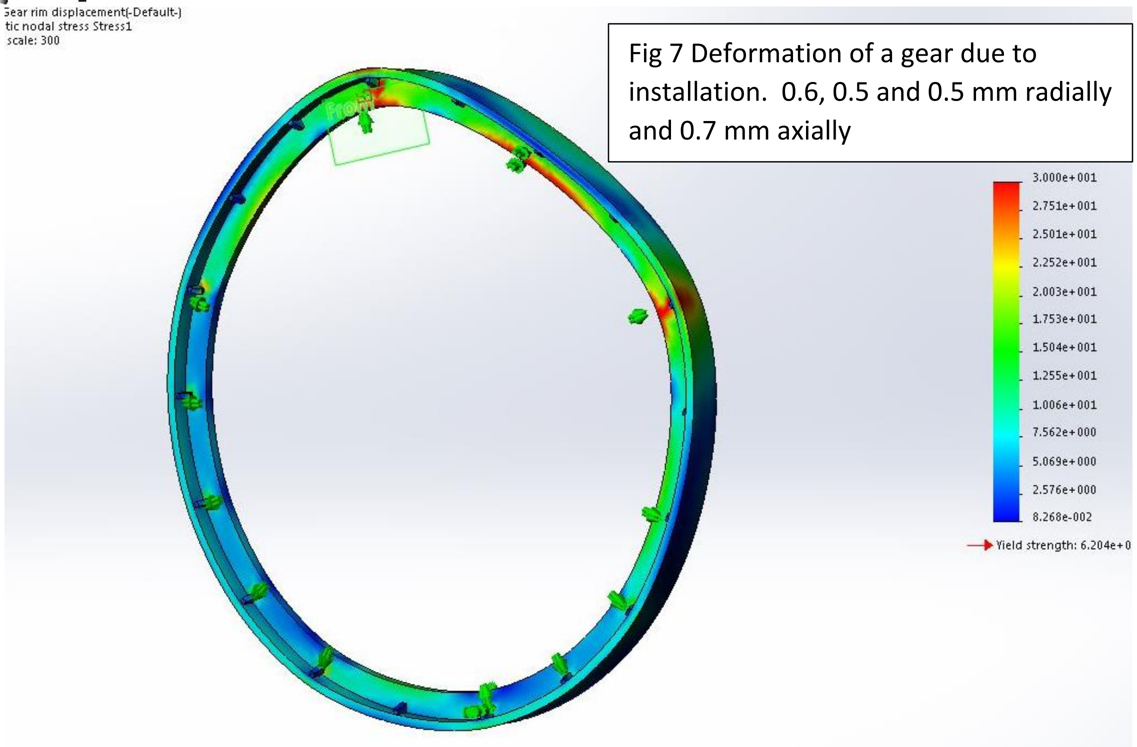


Fig 7 Deformation of a gear due to installation. 0.6, 0.5 and 0.5 mm radially and 0.7 mm axially

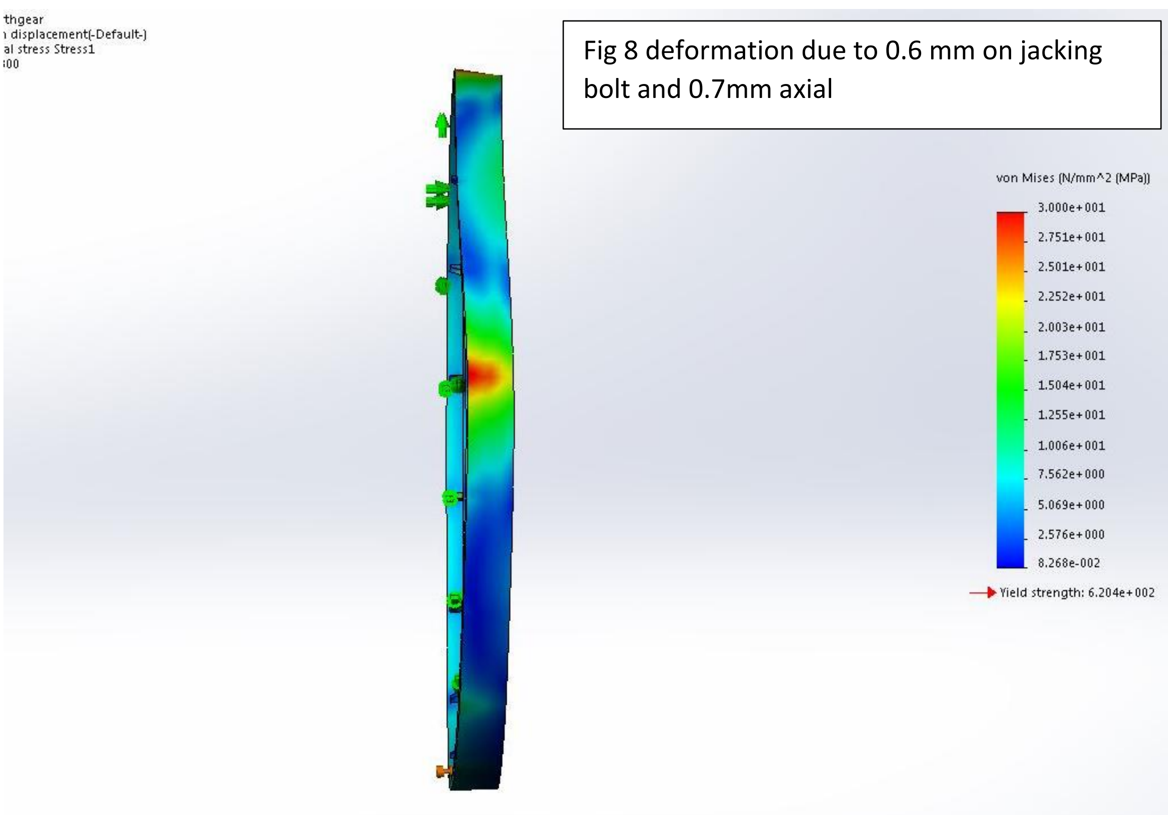


Fig 8 deformation due to 0.6 mm on jacking bolt and 0.7mm axial

As can be seen in Figs 7 and 8 – small displacements can lead to a significant residual stress which can exacerbate pre-existing internal stresses.

Section 2.2 in Laczko's report talks about the metallurgical properties of the material used to manufacture forged and fabricated gears. My observations have aligned with the theory put forward in that paper. In addition to the comments in Laczko's report, I would also suggest that in the regions of significant weld energy (mounting flange to gear rim, stiffener gussets and the splitline hardware, there are the elements contained for dynamic embrittlement. Attached is a paper on this phenomenon.

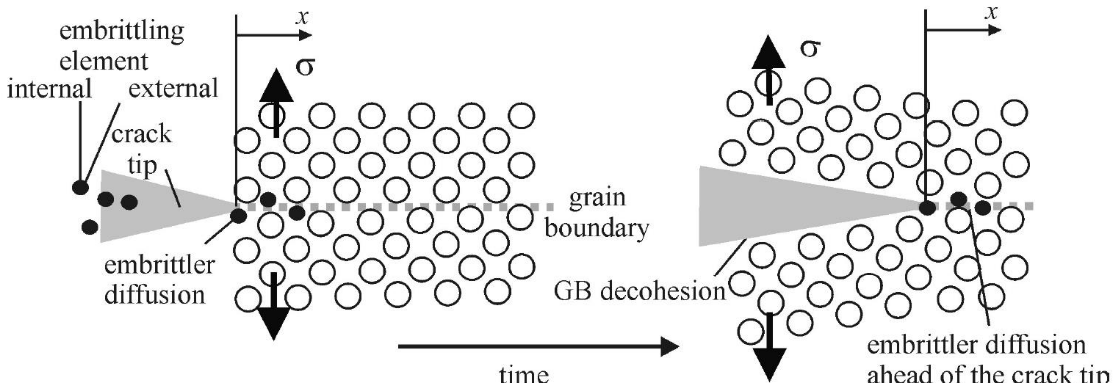


Fig 9 from Dynamic Embrittlement- Induced Intergranular Cracking By Ulrich Krupp

Dynamic embrittlement is usually associated with elevated temperatures, however as with Hydrogen embrittlement in cast ingots the embrittling agents such as Sulphur and hydrogen are present in the heat effected zone of the welded areas. Mechanical stress mobilizes the embrittling agents and inter granular cleavage starts to occur.

5.0 Conclusions

Insofar as the 2 reports are concerned I broadly support the observations in Laczko's report. The metallurgical evidence in the Metallurgical report does not discredit or discount the hypotheses in the eminent metallurgist's report or my observations.

Chief causal factor for this failure likely to be:

Unresolved internal stresses within the gear added to the operational stresses causing the failure by cracking of the gear.

Internal stresses were the result of one or a combination of the following:

- Design – proximity of thick machine elements to relatively thin elements (gear rim to splitline hardware or often gear rim "stiffeners")
- Installation deformation of the gear when installed on mill surfaces
- Residual internal stresses from welding
- Gear rim material properties

If the above causal hypothesis is right, then the following would offer some improvement in prevention of similar failures:

- Include more material so that the residual stress conditions have more volume in which to resolve themselves.
- A higher carbon content gear rim material may also be of benefit to the long term survival of this particular gear design.

