

## Study on fatigue failure and stress analysis with safe life on railway axle- A Review

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### ABSTRACT

The objective of this paper is to present review on the axle used in railways to have better performance with minimum losses to railways . There are various material which is used for manufacturing axle. This paper gives the summary and range of various material used in the railway axle and our aim is to find stresses on axle and is to reduce the maintainence cost stresses as well as increase the life cycle of axle. This paper also gives the approach to increase the efficiency of axle .

### KEYWORD

Railway axle, crack growth, fatigue, corrosion

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### INTRODUCTION

Railway axles are commonly operated over a service life of 30 years or more which refers to a very high number of loading cycles in the order of  $10^9$ . Railway axle designed for a long term of operation. However, there are known cases of their failure, which are caused by defects that arise during the operation and serve as a source of origin and development of crack to critical size [20-21]. During 20<sup>th</sup> century the number of failures of railway axles was reduced to about 5% [23] due to improved steels and assessment concepts. According to the railway safety performance report of the European Railway agency (ERA) of 2011 [19] the number of broken axle in the European Union between 2006 and 2009 was in total 329. Related to the number of about  $1.66 \times 10^{10}$  train kilometres over these four years this refers to one fracture event per 50.45 millions train kilometres. Various reasons are responsible for these differences including the average age of the fleets, maintenance and inspection issues of the rolling stocks, the state of the tracks, different average axle loads, etc.; but also the statistically rather small reference period of 4 years only should be kept in mind. Railway axles were investigated at the very beginning of fatigue research and design. Fatigue failure of axle has been a source of difficulty for engineers since the railway service started in the early part of the 19<sup>th</sup> century. Derailment caused by fatigue of railway axles is very rare in Japan. Railway axles are, however, one of the most important components in railway systems since a fail safe design is not available. In order to maintain the safety of high-speed railway system, a large number of investigation and experiments have been carried out by outstanding research ever since, and many improvements have been made in the material, manufacturing, heat treatment and design method. Axles in service are regularly checked by ultrasonic testing and magnetic particle inspection. To increase the fatigue strength of the press fitted part of the axle, which suffered from fretting fatigue, heat treatment of induction hardening method has been applied successfully in Japan. It is known that in-service defects in the cylindrical bodies, especially in the axle of railway transport, often take the form of semi-elliptical surface crack [20,21,22]. One of the main parameters that characterize the fatigue crack growth (FCG) is the stress intensity factor (SIF). Press fit technology is commonly used for an attachment of components of railway wheel sets, i.e. axles, wheel and traction gears. Besides design of axles and press fitted joints including optimum dimensions, material selection and surface treatment are important issues. According to EN 13261, steel EA1N

and EA4T are mentioned as standard materials, first of them being a low strength carbon steel with 0.4%C. EA4T is a low alloyed steel fairly high strength. The axles are subjected to rotary bending and the geometrical transition are at the press fits of either the wheels or gears. Railway axles are safety relevant components usually designed for up to 30 years of service. Despite of a proper axle design, a possibility of damage initiation due to corrosion, ballast impact or metallurgical defects during service cannot be fully excluded. It is therefore common practice to regularly inspect railway axles by means of visual inspection or NDE techniques. Railway axles are mechanical component whose failure can produce catastrophic consequences. Axles and wheels are a couple of the most important components in railway vehicle with regard to safety.

## LITERATURE REVIEW

**1 S. BERETTA<sup>a,\*</sup>, A. GHIDINI<sup>b</sup>**[etal] The scope of this paper is to study the scale effects in fatigue limit and in crack growth rate for a high strength steel used for high speed railway axles. Fatigue limit tests on micro-notched specimens led to the determination of fatigue thresholds for small cracks of the examined steel. This paper has addressed the scale effect in fatigue limit and in crack growth rate for a high strength steel used for high speed railway axles. The series of crack propagation tests on small scale specimen lead to the definition of an EPFM crack propagation model which has been successfully compared with propagation data on full-scale components. These result support the application of the crack propagation model for the determination of axle inspection intervals.

**2 S. BERETTA<sup>\*</sup>, M. CARBONI**, The present paper deals with a probabilistics application of the NASGRO crack growth algorithm to estimate the propagation lifetime of railway axles.

The result can be so summarized-

- The dispersion of threshold experiments is much larger than the typical dispersion of crack growth data in the so-called Paris region.
- Two statistical models has been fitted to propagation and threshold data obtaining very similar results.
- The distribution of propagation life times under spectrum loading could be obtained by a random variable approach in which the distributions of  $\Delta K_{th}$  and  $\log_{10}C$  were discretized.
- Present random variable method could be successfully applied to a probabilistic evaluation of inspection intervals as well as to the comparison of two steel grades used for manufacturing railway axles.

**3 M. MADIA<sup>a,\*</sup>, S. BERETTA<sup>a</sup>**[etal] This paper summarized the result the result of fatigue crack growth investigation on a hollow railway axle which were undertaken as a joint research project between Italy and Germany within an activity of ESIS-TC24. It was found that the effect of rotary bending, although existent, was rather moderate whereas the press fits had a large and detrimental effect. The fatigue crack growth originating from the geometrical transition of a hollow railway axle was investigated. Stress intensity factor both the deepest and the surface point of semi-elliptical surface cracks, were established for rotary bending.

**4 S. BERETTA<sup>\*</sup>, M. CARBONI** [etal] In this paper the effects of corrosion by rain water on the fatigue behaviour of A1N steel, has been studied .The pit to crack transition and the crack propagation mechanism were then analyzed together with crack growth measurements on surface cracks. The effect of corrosion by rain water on the fatigue behaviour of A1N steel subjected was studied and the result-

Fatigue properties of A1N steel are strongly affected by the presence of a mild corrosive environment like artificial rainwater, and the corrosion-fatigue crack growth model enables us to obtain a fairly precise prediction of the the S-N diagram of A1N steel under corrosion-fatigue sustained by the free corrosion of the material.

**5 J.F.ZHENG, J. LUO**[etal]In this paper say that fretting damage was of the most important reasons for the failure of the railway axle fretting wear(tangential fretting mode) test of a railway axle steel(LZ50 Steel). Fretting regimes behaviour of LZ50steel subjected was studied and the result-

- The fretting regimes of the LZ50 steel were strongly dependent up on the imposed normal loads and displacement amplitudes. The running condition fretting map of LZ50 steel was built up according to a great deal of experimental results.
- The variations of the ratios of  $F_t/F_n$  in the different fretting regimes were quite different. In partials lip regime, the curve of the ratios of  $F_t/F_n$  presented relatively lower values during the whole fretting cycles. In mixed fretting regime and slip regime, five stages can be defined. In the curve in the steady stage increased with the increase of the displacement amplitudes at a given normal load.

**6 A.S. WATSON<sup>a,\*</sup>, K. TIMMIS<sup>b</sup>** [etal] In this paper all British railway axle require a regular non-destructive testing to ensure that no dangerous cracks on axle. To testing and calculating probabilistic fracture mechanics a stress histogram is used by the British railway vehicle and other parameters of stress for axle is-

- Axle stress spectra can be predicted using a combination of simulation and empirical data.
- For solid axle, even if the operating stress are significantly below design limit, very little useful weight reduction can be achieved by reducing the diameter to increase the stress to the allowable limit.

**7 U. ZERBUST<sup>a,\*</sup>, M. SCHODEL<sup>b</sup>** [etal] This paper provides a discussion on damage tolerance option applied to railway axles and factors influencing the residual life time as well as the required inspection interval. Parameters affecting axles loading such as the press fit, rotating bending, load history and mixed crack opening modes are discussed. The influence of the initial crack geometry on residual lifetime is simulated.

**8 IMAN SALEHI<sup>a,\*</sup>** [etal] In this paper fatigue crack initiation analysis is performed at the edge of the weld collar of an aluminothermic weld, in order to examine one of the failure modes that occur in this weld type under high axle load condition. The fatigue assessment is performed using thermo-structural finite element analysis followed by the Dang Van multi-axial fatigue criterion implemented as a customized computer code. The finite element simulation is validated through the strain gauge measurement, and the results of fatigue analysis are compared with the location of fatigue cracking and failure modes that occur in service.

**9 S. BERETTA<sup>\*</sup>, M. CARBONI** In this paper the problem is dealt with by regular axle examination in the form of non-destructive testing inspection, whose periodicity is calculated on the basis of the propagation life time of given initial defect. This paper also discussed the application of predictive crack growth algorithms to the propagation of cracks in A1N steel axles. In particular, constant amplitude crack propagation test on small scale and "companion specimens" were carried out together with experiments on full scale axle. The result showed a negligible load – interaction effect on "companion specimen" and a significant retardation on full scale axles. The consequence resulting from the application of predictive models to a full-scale axle under service spectra were then analysed.

**10 M. LUKE<sup>a,\*</sup>, I. VARFOLOMEEV<sup>a</sup>** [etal] In this paper the basic fatigue crack growth data both in the range of stable crack propagation near the threshold have been experimentally determined for the heat treated railway axle steel 25CrMo4(EA4T) & 35CrNiMo6+QT under constant and variable amplitude loading at relevant stress ratios. The result is employed for predicting fatigue crack growth in a reference railway axle with in the shaft and in the fillet zone near a fit and crack growth data were experimentally derived for surface cracks in 1:3&1:1 scale axle with varying crack position and loading regimes. A reference wheel set axle has been defined for further investigation.

**11 U. ZERBUST<sup>a,\*</sup>** [etal] This paper gives a brief overview on the most important potential failure scenarios driven by fatigue crack initiation and propagation and discusses the effect of important influencing factors such as vehicle weight and speed, track quality and environmental condition.

**12 S. BERETTA<sup>\*</sup>, M. CARBONI** [etal] In this paper crack initiation and growth in full scale railway axle in A1T mild steel have been studied, under three points rotating bending loading conditions and artificial rainwater as corrosive environment. A surface plastic replication technique has been used along with optical microscopy and scanning electron microscopy to monitor the environment assisted fatigue at various stages. The corrosion

fatigue crack growth model enables us, also to obtain a fairly precise prediction of the S-N diagram of A1T steel under corrosion – fatigue sustained by the free corrosion of the material.

**13V LINHART, I.CERNY\***In this paper High-cycle fatigue test with an evaluation of fatigue limit were carried out on large model components of bar with press fitted hubs of diameter 63/59mm bar of made of three railway axles steel EA1N, EA4T&34CRNIMO6 with different strength from 586mpa to 1041mpa detection and measurements of crack growth under hubs by ultrasonic method was performed during the test. The result is –

- Comparison with the EA1N steel with the lowest strength, fatigue life of bars of EA4T steel with the medium strength is somewhat higher at higher load amplitude of S-N curve.
- While short crack initiation under press fit is determined by cyclic fretting mechanisms.

**14 M. MADIA<sup>a</sup> S. BERETTA<sup>a</sup>**The aim of this paper is a collection of stress intensity factor solution for cracks in railway axle geometries. These solutions comprise closed form analytical as well as tabulated geometry functions they refer to solid as well as hollow axles and various crack sites such as the T-and V-notch and the axle body.

**15TAIZO MAKINO<sup>a,\*</sup>[etal]**In this paper, the fatigue tolerance of the high-speed railway axle in Japan is reviewed. In this fatigue strength of the axle is studied to maintain safety norms. The crack propagation behaviour of the induction hardened axle is studied based on the fracture mechanics. To maintain the safety record of railway system, much effort has been paid to the improvement of the axle manufacturing process, design, testing, maintenance.

**16O.YASNIY<sup>a,b,\*</sup>,y. LAPUSTA<sup>b</sup>[etal]**In this paper techniques of modelling of fatigue crack growth in the material of railway axle under regular and random loading was developed, taking into account statistical characteristics of mechanical properties.

**17BING YANG\*,YONGXIANG ZHAO** In this paper behaviour of dominant effective investigated by a replica technique with seven smooth hour glass shaped specimen of railway LZ50 axle steel. The most importantly the crack growth rate exhibited deceleration twice in micro – structural short crack stage. The process of crack initiation and growth are subjected to the competition between the intrinsic resistance from the barriers and increasing driving force from the growth crack size.

**18U. ZERBST<sup>a,\*</sup>S.BERETTA<sup>b</sup>[etal]**In this paper gives an overview on safe life and damage tolerance method applied on railway axles. It describes failure scenario due to fatigue crack initiation and propagation. The common aspect which reduces the fatigue strength of axle is corrosion, impact damage from flying blast etc with respect to damage tolerance general lines of fracture mechanics residual lifetime analyses are introduced.

### FIGURE ON AXLE

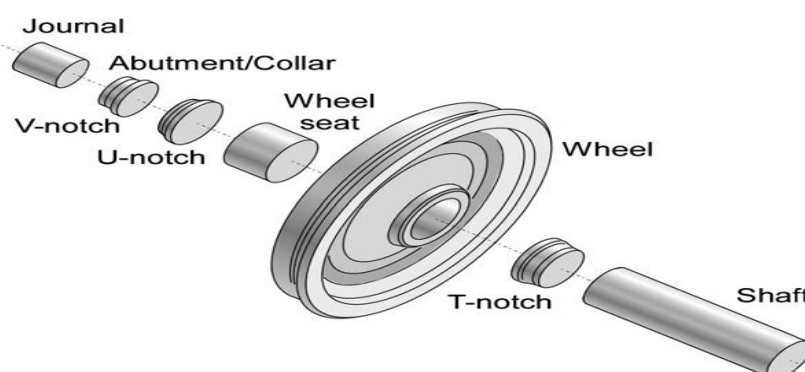


Figure 1: Schematic drawing of various section of a railway axle. [18]

**TABLE :-Chemical composition of axle (wt%)**

	<b><u>LZ50</u></b>	<b><u>52100</u></b>	<b><u>EAIN</u></b>	<b><u>EA4T</u></b>	<b><u>34CRNIMO6</u></b>
<b>C</b>	0.48	1.00	0.40	0.26	0.352
<b>Si</b>	0.20	0.25	0.24	0.29	0.228
<b>Mn</b>	0.70	0.30	0.95	0.70	0.60
<b>Ni</b>	0.20	0.20	-	-	1.32
<b>Cr</b>	0.20	1.50	-	1.0	1.37
<b>P</b>	0.03	0.02	0.0027	0.020	0.015
<b>S</b>	0.03	0.02	0.0017	0.007	0.026
<b>MO</b>	-	-	-	0.20	0.19

## CONCLUSION

This paper presents the summary of literature on stress and fatigue analysis in the axle. In many of the literature, effect on life cycle of axle with other parameters which help to increase the efficiencies of axle performance is discussed. In this paper the main approach is to get better result on the account of life cycle of axle and also study the behaviour of stress and fatigue on axle. Since the literature available for railway axle is appreciable, and further more work can be possible for better performance.

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