Rolling Contact Fatigue Behavior of Rail under High Axle Load Conditions

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Synopsis

Rail is a very special constituent of Track. It gets direct interaction with wheel and thus faces all ill-effects of wheel and various loads coming over it due to whatsoever reason. Increasing Axle loads has therefore introduced various defects in rail due to higher contact stresses. Small defects in wheel or rail, in heavier axle load condition, leaves larger impact on rail. The paper discuss various cause of rail defect faced due to CC+8+2 in CIC section of DHN division and few suggestions of combat in this situation.

Introduction

Indian Railway has introduced heavy freight loading (CC+8+2) on existing track with minimum existing track parameter of 52Kg/72 UTS Rail and M+7 PSC sleepers having minimum ballast cushion of 250m with 100mm clean since 18 July 2006. And due to incremental loading targets the freight traffic has been increased double only in 3 years. Resulting annual GMT carried by track has also reached more than twice in GC and more than thrice in CIC, only 3 years. For example in yr. 2006-07 annual GMT for GC was 42.98 in UP/L and 33.55 in DN/L which in year 2008-09 reached 96.521 in UP/L and 67.218 in DN/L. Similarly in CIC annual GMT in yr.2006-07 was 22.21 and 10.40 in DN/L and reached to 71.175 in UP/L and 32.689 in DN/L. In addition there were many unwanted and unclaimed behavior was also noticed in the rail and weld after introduction of CC+8+2. For example excessive corrugation on rail surface, surface flaks, rail head fatigue, excessive wear in gauge face, gauge corner defects, flattening of wheel top, flow of material of rail head, premature failure of aluminothermic weld are all attributed to the higher axle loads on rail.

1.1 The benefit of high axle loads:

- Fewer wagons will be needed to haul the same load, leading to lower capital cost and possible reduction in wagon maintenance cost, fewer locomotives,
- lower fuel consumption per net tonne,
- reduction in train wagon kilometre operated,
- fewer crew deployment entailing savings in wages.

The railways in North America, Australia, South America, South Africa and Sweden have all increased axle loads to obtain significant savings in operating cost. **These savings have been achieved despite increased cost of maintaining tracks, greater track component damages and shorter component lives.**

The raising of the axle load from 22.5 tonnes to 30.5 tonnes yielded 40 per cent savings in transportation cost in the US.

But any increase in axle load without corresponding increase in TLD will have a marginal effect on the throughput.

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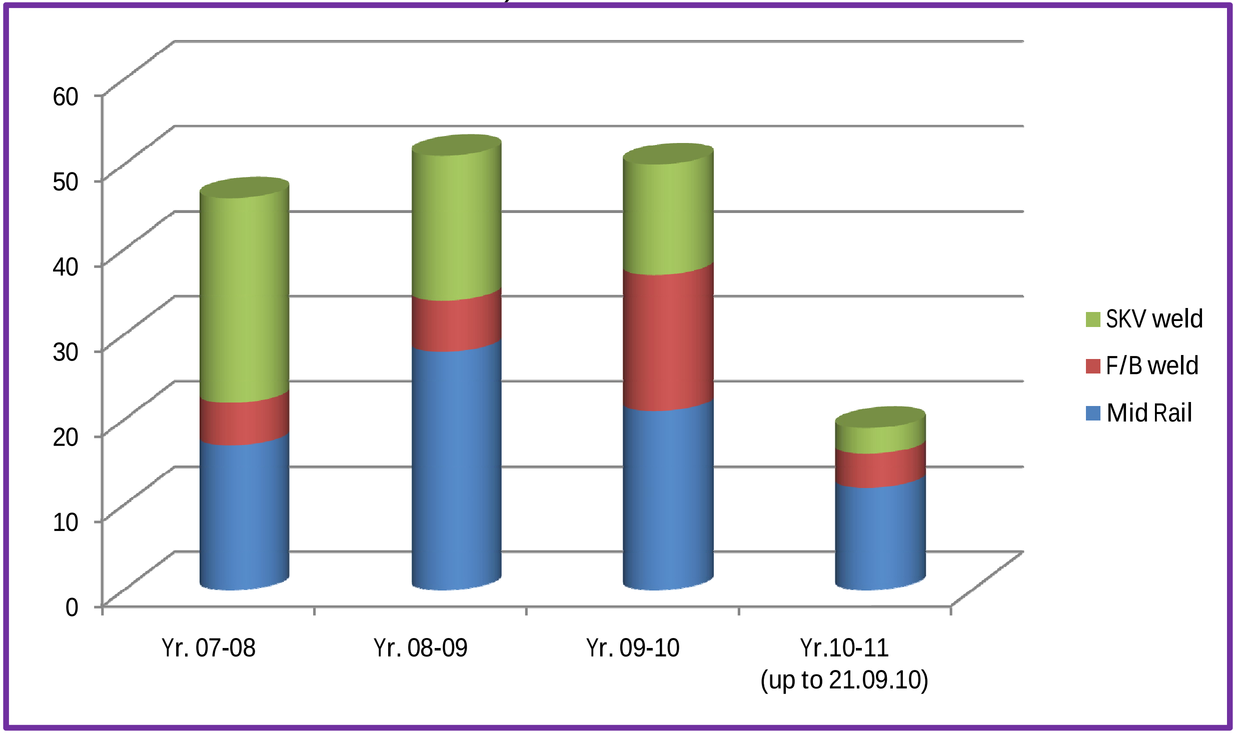
2.0 Effect of heavier load on rail wheel interface (a case study)

The primarily effect of heavier axle load on track have been reflected in terms of increased Rail/weld failure. Rail/weld failure analysis was done with the help of last 4 year rail/weld fractured data for CIC section from Rae to Garhwa Rd. (UP/L) stretch nominated for CC+8+2 loading. Few facts revealed after analysis:

- Rate of AT weld failure have been increased drastically just after introduction of CC+8+2 loading and later stabilized in subsequent year. Most of the weld were comparatively old and of year 1988-89 or before. After that SKV weld of yr.2000 and earlier started failing. These are also crossed its 70 to 75% of life (SKV weld life has been considered 50% of Rail Life)



- Rate of Flash Butt Weld failure was little initially but increased substantially after first year of introduction of CC+8+2. These flash butt Welds were comparatively new and of yr. 2000 make. These are also crossed hardly 30 to 40% of life (Flash butt weld life has been considered equal to Rail Life). Most of the fractures were fresh failure.

- Rate of Mid Rail failure was increased with the passage of traffic. Also it has increased alarmingly in the area with higher degree of curve and gradient. Almost all rail failures were attributed to internal flaw of code 211 i.e. internal defect in rail head, transverse breakage. These fatigue failures in rail were mainly due to high contact and shear stresses.

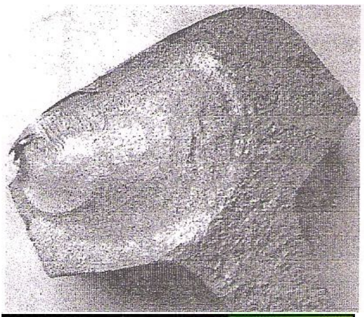
- There are several cases of flat tyre in the section in loaded and empty conditions. Study shows that flat tyre cause abnormally high impact forces and in case of high axle loads such loads cause premature fatigue and failure of rail/weld. It effect has been noticed even serious, if track with poor or in-effective rubber pad between rail seat and sleepers and stiff bed under sleepers/ballast.

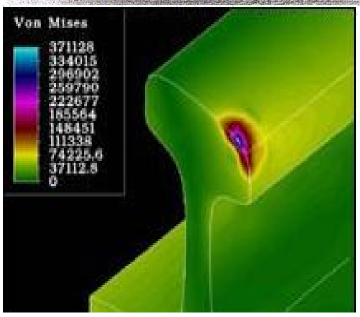
  Interestingly, these defects could not be detected in USFD testing.

3.0 Defects in Rail due to Rail-Wheel Contact

- Gauge corner defects
- Rail head fatigue
- Excessive wear in gauge face
- Rail Head cheeks
- Rail surface Corrugation
- Longitudinal Horizontal Cracks
- Flattening of wheel top
- Premature failure of aluminothermic weld

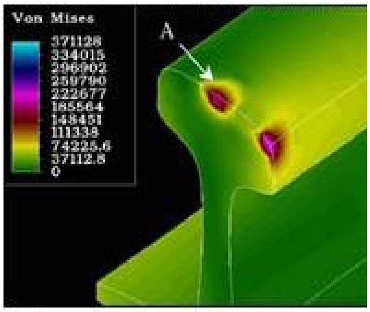
3.1 Gauge Corner defect





- This is also wheel contact defects at one point location and propagates silently in side the rail head.
- It is also most predominantly in curved track of higher degree. It occurs due to excessive dynamic load on rail surface due to heavier axle load at higher speed.
- Similar to the above, extreme dynamic loads, leading to the initiation of isolated defects, are more likely to occur on tangent track, while curved track conditions will favour fatigue crack growth, when contact geometry and vehicle tracking combine to concentrate higher stress cycles in the initiation zone.
- Due to sharp edge of wheel tread at higher speed enhance the contact pressure and minor horizontal checks converted into gauge corner leading to fracture.
- This can only be detected by USFD retro-fitted with special probe.
- Solution: Remaking the rail profile and greasing of the gauge face.

3.2 Rail head fatigue



- Rolling contact fatigue defects occur in wheels and rail used under high axle load conditions.
- It occurs due to excessive dynamic load on rail surface due to heavier axle load at higher speed.
- It also propagates through the micro horizontal cracks and lead to the fatigue failure of rail.
- Extreme dynamic loads, leading to the initiation of isolated defects, are more likely to occur on tangent track, while curved track conditions will favour fatigue crack growth, when contact geometry and vehicle tracking combine to concentrate higher stress cycles in the initiation zone.
- A series of studies in world railways has revealed that rail fatigue is an exponential function of axle load Q, and stresses developed within the rail are proportional to the parameter Qa where the exponential 'a' takes values in the range of 3 to 4 and closer to 4. Thus any increase in axle load results in a much larger increase in track structures fatigue.

3.3 Excessive wear in gauge face

- Excessive wear has been noticed especially the track having >1D curve. It mostly appears in the outer rail of the curve by traction, creepage and flange force.
- It also appears in lower rail of curve due to lateral friction and spin creepage by wheel.
- It also occurs in straight track having gauge difference of defective subgrade.
- Due to defect in wheel and its defective movement unintentionally creates wear at any location of rail.
- It is important once the wear start in all wheels mostly follow same path further aggravates the wear.
- By reducing the section of rail head increases the stress and finally results to rail failure.
- Solution: Remaking the rail profile and greasing of the gauge face.
- Rail profile grinding generates artificial wear and developed micro cracks is removed.
- China Railway has started a project for mechanical greasing to enhance the life of rail.

3.4 Rail Head Checks

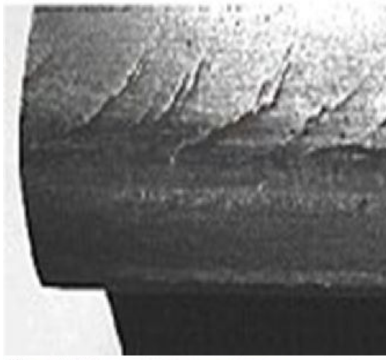
- Head Checks or Surface flacks occur primarily on the gauge corner and between the gauge corner and crown on the high rail in curves with high shear stress and relatively low wear (as in case of 90 UTS rails).
- Flakes similar to head checks, usually slightly inclined or parallel to the direction of travel, can also be found on low rail (inner rail) surface in curve.
- The defects start immediately under the surface (~1/10 mm), develops immediately and reaches the surface quickly.
- Under traffic load this defect grows at an acute angle to the rail surface, initially following the layers of ferrite in a perlitic rail steel down into the rail and it may turn downwards with a risk of multiple breakages.
- It is relatively difficult to predict the development of this kind of defect.
- A mixed gain can only be seen in USFD testing.
- Rail fractures from head checks have been observed in high speed passenger track and are also common on heavy haul lines.
- Preventive rail treatment (grinding, milling, planning) on stretches with tendency to develop rolling contact fatigue defects is usually recommended to preventively correct this type of defect.

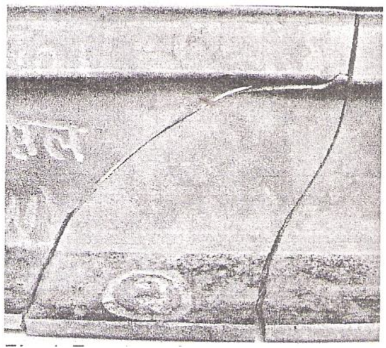
3.5 Rail Surface corrugation

- Rail Surface corrugation is a frequently occurring rail wear pattern that arises mostly in curves, although that it’s also possible on tangent track.
- Rail Surface corrugation is considered with wavelengths between 20 mm and 200 mm.
- The wear pattern results in reduced rail and wheel lifetime and it can lead to urgent safety measures (rail replacement).
- At the wayside, wheel/rail noise creates uncomfort to the passengers and nearby community.
- The passage of a bogie in small curve leads to important dynamic forces between wheel and rail in all directions: tangent, axial and vertical.

- These forces are due to important friction between wheel and rail due to curving (tangential and radial friction forces) due to flange friction on high wheel and poor subgrade or ballast underneath, loose/ineffective fittings,
- Rail and wheel imperfection due to misalignment in wheelset, difference in diameter between wheels of same set, band axle misalignment & kink in rail/weld.

3.6 Longitudinal Horizontal Crack





- Longitudinal horizontal cracks can occur in the rail head or web, or in the transition area between the rail head and the web or rail web and base.
- These are advanced longitudinal cracks in the rail parallel to the longitudinal rail axis. The crack may propagate upwards or downwards before breakage occurs.
- Longitudinal horizontal cracks on the rail can have serious consequences in case of rail breakage since loss of rail guidance may result. Longitudinal cracks can occur over long sections and thereby results in several breakages.
- In case of high residual stresses, these cracks can spread into rail web area relatively quickly.
- The defect may be caused by internal segregation linked to the manufacture of the materials.
- It may also be caused by the defects in welded joint in rail web area. Longitudinal Horizontal Cracks can also be caused by micro cracks on rail ends.
- Thermal cuts without preheating increase the risk of crack formation**.**
- Solution: It is required to have reliable USFD testing and defect management system resulting in positive reduction of rail failures /breakages.

3.7 Flattening of Rail top

- Due to heavier axle load in lower hardened rail with lower section, rail top gets flatten especially in curved track with higher super elevation.
- It is predominant in inner rail of curve with Super elevation of 75mm or more.
- Flow of material due to flattening of Rail head further disturbs the rail symmetry and finally weakens and creates extra stress on Rail web, resulting buckled rail.
- Head hardened steel with heavier rail section minimum 60Kg/90UTS should be used and if permits 68kg section should be ideally used.

3.8 Premature failure of aluminothermic weld

- Under high axle load conditions with heavy impact load premature failure of existing AT weld have been increased.
- In case of aluminothermit welds (which have the impact strength of 7-10% of parent rail) in LWR territories, during winter season, when the full tensile stresses are present in rail section, the situation becomes alarming.
- Spate of weld failures due to running of flat tyres under these conditions aggravate the situation.
- There is a need to review the existing method of welding and its quality control. In few studies early failure (within 2-3 years) have been notice more in numbers.
- Mobile flash butt plant is the demand of the time and its acceptability in high traffic condition may also be studied.
- Frequency of USFD testing for weld to be increase. Also testing technique also to be studied.

4.0 Role of USFD Testing

Quality Monitoring and inspection of rail with the help USFD is still a most reliable system. USFD testing plays significant role in determining health of Rail. Therefore frequency of quality testing by USFD has to be increased especially AT weld and gauge corner defect testing. With the limitations of the currently used USFD machine, it may not really judge actual health of Rail head fatigue. More emphasis is required on USFD testing and more sophisticated and higher sensitive instruments for on track flaw detection. Also expert team of USFD engineers is demand of the time. in not

5.0 Rail Renewals

Codal life for rail renewal have been fixed 800GMT for 60Kg/90UTS and 525MT for 52Kg./90UTS & 72UTS based on wear criteria. However due to higher axle loads and increase in fatigue fractures etc. these codal lives of rail need to be reviewed and more practical approach to be adopted while deciding Rail Renewals. It is advisable to replace all rails with 72UTS in track on immediate measures and provision should be made to replace all 52Kg/90UTS rails into 60Kg./90UTS. In one study it was revealed that Rail section of 65Kg. is more suitable for axle load of 25MT to 30MT. This can also be point of discussion.

6.0 Monitoring & Patrolling of Track

Monitoring of track behavior by USFD testing fractured piece analysis will help to pinpoint the reasons of failure. At the same it is also important to employ need based track patrolling to check the behavior of rail due to higher axle loads. Any failure may lead to serious repercussion of suspension of track and delay in restoration.

7.0 Rail Profiling

Above all, Rail Profiling, to make proper rail profile, is main safety measure to prevent all such fatigue failure due to rail-wheel contacts. Although this is new concept in Railway but in present scenario, it becomes dependable aspect. Infra structure viz. Rail Grinding Machine etc. is to be strengthen accordingly.

8.0 Greasing of Gauge face of Rail

In recent study in Chinese Railway, it was revealed that to minimize the stresses due to rail wheel contact, greasing of gauge face of rail at certain interval, is one of the instant viable solution. This may enhance the life of rail by minimum 20% of its life assessed, due to rail fatigue. A system for mechanical rail greasing need to be introduced in all sections with higher axle loading after study in Indian condition.

9.0 Installation of WILD (Wheel Impact Load Detector)

Dynamic Impact load, due to defect in wheel or track, has great significant in contact stresses on rail fatigue. Therefore to detect the dynamic impact load on track, installation of WILD is important. It will help in detection of culprit wheel/wagon and timely detachment of such wagons from load can be ensured. Thus defects due to dynamic impact load can be minimized. Also study for acceptability of wheel flat in terms of dynamic impact load on rail and its threshold value for Rail/Weld failure is also required, as no such knowhow available in field. At present, installation of WILD is very limited and is under control and as per requirement of Mechanical department. Involvement of P-way engineers need to be encouraged for better result.

10.0 Conclusions

1. From the consideration of bending stresses and contact shear stresses, upgraded class rail need to be thought off. At curve more than 1°D high hardened rail to be provided to check heavy wear, gauge corner defect and rail top flattening.
2. Higher sleeper density track is the demand of the time. However maintenance practices should also be reviewed for higher sleeper density track.
3. The maintenance parameters in terms of GMT of the track to be reviewed for heavier axle loads and throughput to be increased proportionately.
4. Maintenance inputs are required to be increased. Rail grinding is to be carried out at predetermined intervals.
5. Lubrication of running face of rail must be carried out regularly to minimize rail-wheel contact stress. If needed mechanized lubrication equipments to be introduced for effective.
6. Frequency of quality inspections, track patrolling and increased USFD testing are required. USFD need to be done frequently.
7. Use of WILD to be more rationale and frequent.

11.0 References:

1. Anirudh Jain, Parmeshwar Funkwal, " Streatagies for enhancing Service life of Rail under Heavy Axle load." IPWE seminar. Vol. II, pp 228-244, Ministry of Railways, India.

2. Report no.445-A-09, 445-B-09, 429-2009, 79/09, 498/0 of MET. & CHEM. LABORATORY - Jamalpur on Rail/weld failure investigation.

3. Narendra Kumar, A.K. Chakraborty, Effect of Heavier Axle Load on Track Structure and Track Maintenance input" IPWE seminar. Vol. II, pp 338-357, Ministry of Railways, India.

4. P.J.Mutton, E.F.Alvarez, "Failure Modes in Aluminothermic Rail weld under High Axle load condition." Institute of Railway Technology, dept. of Mechanical Engineering, Monash University, Australia.

5. RDSO Civil Engg. Report No. C.55, Investigations on Determination of Intensity of Pressure on Railway Formations- BG Tracks.

6. W.J. Wang, J. Guo, Q.Y. Liu, M.H. Zhu and Z.R. Zhou, Study on relationship between oblique fatigue crack and rail wear in curve track and prevention , Tribology Research Institute, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China

7. J Fail. Anal. and Preven. (2007), Impact loads at rail joints and at switches and crossings, and also from wheel flats, contribute to high-frequency vibrations of the track and the train.

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