SERVICE FAILURES OF RAILWAY METERIALS.

by

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Service failures were known to occur even before ushering in of machine age but there was no proper understanding of the underlying phenomenon and at best the attempt to overcome them lay in redesigning the components merely by thickening those sections irrespective of poor quality of material or inadequate sectional strength.

In the late twenties, however, with springing up of chemical and metallurgical laboratories and with better understanding of Fatigue phenomenon which is the chief fact or underlying a vast majority of service failures, greater interest was taken in the study of performance and failures of components in service.

STUDY OF THE FAILURES OF SOME NOTABLE COMPONENTS OF THE IRS AND MODIFIED IRS LOCOMOTIVES :

TYRES : Examination of failures of tyres have shown two types of cracks.

1. Fatigue Cracks :— Fatigue cracks generally originate from threaded stud holes which existed on inside and were meant for fastening tyres to wheels with studs. In all cases the fractured surface showed the appearance of Fatigue failure with the initiation of crack at the bottom of one of the threads in the hole. This method of fastening tyre was therefore abandoned and recourse was taken to rivetting them to wheel centre. Later designs adopted fastening with a Gibson ring and still later with clip. The use of rings involved corners in the design of tyres and caused many fatigue failures due to their sharpness. In regard to fastening with clip cases have been recorded of the rotation of tyres through small angles relative to wheel centre when in use.

2. Shatter Cracks :— Shatter cracks are ascribed to hydrogen dissolved in steel which is not given a sufficient opportunity to escape while it cools down to normal temperature after rolling. Existence of shatter cracks in rails acts as nuclei for fatigue cracks which propagate under repeated loads into transverse fissures.

COUPLING RODS :

After about eight years of service during which the rod is estimated to have completed approximately 150 million of stress reversals thus giving rise to fatigue failures, the rod is found to break. The fracture almost always occured at a point nearely 9″ from the centre of the eye of the rod, which point was precisely where the normal section of the rod commenced to enlarge to form the eye end.

The stress reversal in the coupling rod is due to its lateral flexing under nosing movement of the engine and as a result the maximum stress is induced at a particular section where the fracture usually occured. The section of the rod was an I section in which the maximum skin stress by combination of both vertical and horizontal bending would be at the corners of the section. Enquiries made abroad showed that they used rectangular sections with carbon steel. In the revised design of the coupling rod I section was recommended to be replaced by a rectangular one on the basis of stress calculations and the external corners should have $\frac{1}{8}$″ radius which was finally changed to 3/16″ radius in view of location of fatigue nucleii at the corners.

CONNECTING RODS:

In coupling rods also which were breaking in large number, the design was revised by providing a radius of 3/16" for all corners of the I section and the section was also modified along its length in accordance with revised formula for stress calculation.

HOT-BOXES:

Hot-box or heated bearing trouble also caused a huge loss to the rolling stock on railways during the late thirties. At one time the defective bonding of anti-fiiction white metal to the bronze backing shell was supposed responsible for them. Though a few cases of unsatisfactory bonding were revealed but a majority of cases could not be explained. After an exhausitive study of such cases it was found that neither the bearing metal nor the lubricant was responsible for this heated bearing problem. It was, as a matter of fact, found to be the result of a combination of causes pertaining to poor mechanical maintenance of axle-boxes themselves and failure of lubrication in a few cases as a result of faulty servicing.

AXLES:

In past the train crew, in order to avoid hot box failure used to pour water on axle journals as soon as bearing was found to be hot. This practice resulted in incipient cracking of the surface of axle journal which on subsequent service developed cracks. The portion in such cases exhibited a sharp quenching crack followed by an inward area of fatigue failure. However, the practice has been stopped now. Fatigue failures of axle journals owing to lack of sufficient radius at the change of section, rough tool marks on the radius and building up wear by unauthorised welding have also been recorded.

Failures of axles under wheel seats have also been reported though without any particular defect in the axle steel. These cracks typical of fatigue failure were found to start just back within the press fit. Since the stress obtainable in press-fit axles are similar to those with square cornered fillets, hence the endurance limit of the assembly of press-fit axle will be affected in the same manner as a shaft having a square fillet without any radius (endurance limit drops down to 50 or 55% in such cases). Later designs for press-fit assembly of wheels and axles included a boss for the wheel seat.

BOILER STAYS, TUBES & PLATES:

In the States of Cutch, Sourashtra, the western half of Rajasthan and some local areas in rest of India, owing to corrosive nature of boiler waters, tubes and plates were heavily corroded and under alternating stresses imposed on them by heaving boilers, presented cases of corrosion fatigue and had to be prematurely replaced. It is very serious to have pits, notches and groves produced by corrosion simultaneously with the application of repeated stresses. Sometimes products of corrosion trapped inside fine groves and notches, exerted wedge action under the influence of cyclic stresses.

'WP' CLASS LOCOMOTIVES' COMPONENTS FAILURE:

Details about engine— axle load—18.5 tons.

safe speed—72 miles/hour.

burnt non coking coal with 18 to 24% incombustible matter having a calorific value from 5800 to 7000 Cal/gm.

CROSS HEADS:

Failures of cross-heads were very high and on investigation a number of metallurgical defects were noticed. Surface inside-radii joining the neck to the check of cross heads was extremely rough with sharp fins incicating bad moulding practice. The origin of fatigue cracks was always found in this region viz. the inside surface of cheeks of cross heads. Quality of metal was also poor indicating that the material was dirty and in case of annealing treatment of castings, ample evidence was there to show that the treatment was not carried out to a satisfactory conclusion. Apart from that porosity was also a common defect in many of them.

The remedy was found in thickening the walls of cheeks from $\frac{7}{8}''$ to $1\frac{3}{8}''$ in order to cope with calculated stresses which it would have to withstand in service.

COUPLED AXLE-BOXES:

These were castings made in lead-bronze containing 15% lead to IRS specification. On investigation causes of failures were found to be either

(i) design of grease groves with sharp corners

(ii) defective usage and maintenance,

(iii) defective castings,

(iv) a combination of two or more of these factors.

Only a few of the failures, which were found to be defective castings, showed porosity and shrinkage cavities and very coarse structure. A tensile test conducted on one of the typical defective castings indicated that the strength was about 6.8 tons/sq. in. as against a minimum of 9 tons/sq.in. for cast on test piece, laid down in IRS specification for this class of bronze.

The fact that one Railway experienced a very large number of failures indicated defective usage and maintenance. In many cases, the casting had their grease grooves made by machining, which should have been actually cast-in and the modified design had greater radii for the corners of the cast-in grease grooves. The existence of long horizontal grooves in the design of these boxes was also considered undersirable as they lay against the thickest and heaviest section which were more prone to porosity and coarse structure.

TENDER TANKS:

About half the locomotives received from North America were found to suffer from leakage of welded tender tanks. In the beginning the trouble was attributed to bad metal, bad welding and some kind of caustic embrittlement of metal. On investigation, it was found that most of the cracks were in parent metal adjacent to the weld and not inside the deposited weld metal. In regard to chemical composition and physical properties both were satisfactory but hardness test on the heat affected zone adjacent to the weld consistently showed Brinell Hardness Number far above 200 and microscopic examination revealed that the cracks were transcrystalline. Hence the failure was attributed to restraint during welding and improper sequence accentuated by severe stresses during service due to movement of water within the tender tanks, on metal adjacent to weld rendered brittle to some extent while passing through brittle temperature range after welding.

FRONT AND HIND TRUCK CONTROL SPRINGS:

These are helical springs from plain carbon steel having .5 to .6% carbon content. A large number of failures on investigation showed that it was due to either surface imperfections or improper heat-treatment. In many case the B.P.N. was found to be too excessive as high as 540 while for good spring it was recommended near about 350.

Silico manganese steel springs were also found to fail on account of faulty heat treatment. These springs were specially sensitive also to surface defects including inclusion as the steel used for their manufacture was hard. Since the surface of helical spring is stressed in torsion, even longitudinal rolling and marks on the original rod are often responsible for stress concentration beyond endurance limit under service conditions.

BOGIE SPRING HANGERS & SADDLES:

The steel used has been of approximately 0.4% C and was found to be satisfactory. The micro examination revealed coarse and over-heated structure. All cases showed typical fatigue fracture the crack having started from right angle bend of the hanger. It appeared that the surface inside the bend had blemishes which acted as stress-raisers beyond the endurance limit of steel.

Steel of .25% carbon content has also been used in the manufacture of these springs and their failure also has been assigned due to existence of inclusions and coarse structure on account of heat-treatment being not satisfactory. Defective casting technique which gave rise to shrinkage cavities in the portion adjacent to radii between horizontal and vertical portions and also the bad finish of the inside surface of that area, have been responsible for their failure.

RETURN CRANK ARM:

The return crank, which had a limb at right angle to the main body for forming a pin, is made of steel of approximately 0.45% carbon content. The quality of metal though satisfactory, revealed on macro-etching that instead of being forged into its shape, this component was very probably machined to size from straight blanks, with the result that the forging flow-lines, instead of following the contour of the right angled bend ran across the vertical limb. Fatigue cracks have occured at the change of section where, because of the faulty method of manufacture, the fibre of the component had an orientation parallel to the direction of the dynamic stresses working on it instead of being at right angles to them.

KNUCKLE PINS & OTHER CASE-HARDENED COMPONENTS:

The failures of this component in all cases revealed that instead of using steel capable of case-hardening, steel containing 0.35% carbon was employed in place of IRS class I steel. In few cases where case hardening was done, the case was found to be poor in respect of thickness and hardness.

RAILS AND FISH PLATES:

With ever increasing speeds and heavier loads to be carried the track has been renewed with stiffer rails. 90 lbs rails are common at present, in India and the track is designed for 22½ tons axle load. The max. axle load in India is 28 tons for broad guage and weight of heaviest loco is 200 tons and the maximum permissible speed 60 to 65 miles/hour. In India a rail has to give 60 years service but due to wear or damage or sudden failure caused to them resulting from defects in manufacture, they may be required to be replaced earlier. Regarding wear it is to be marked that rail requires to be changed not so much on account of the wear on its head but due to much greater wear on its ends. On account of the blow which the end of a rail receives when the wheel jumps the gap between the rail ends. The surface wear at the ends is reduced by reduction in excessive expansion gaps and through packing of joint sleepers or building battered ends by welding. Damage to rails can be prevented by care in handling of rails by avoiding unnecessary striking of rails while fixing it to sleepers or by minimising overload or bad application of brakes, thereby eliminating slipping and the consequent burning of rails. Slipping or sliding of wheels too violently braked generates intense frictional heat on the surface after which there is rapid cooling resulting in a brittle layer of martensite. As rail bends under traffic, many cracks are formed which grow as fatigue cracks. Skidding results in flat spots on the wheel tread causing flattening and sagging of rail heads resulting in crushed heads. Also since the wheel load is concentrated on an extremely small surface of the rail, hence if the load is heavy enough, stress in the rails exceeds the elastic limit and the metal in the rail flows with progressive cracks starting from the outer surface and working inwards. If locomotives, on starting, are not able to exert sufficient pull to move the train instantaneously, driving wheels slip on the rails and the metal in the rail head is burnt and the crack starts when the overheated piece of steel is chilled.

Apart from failures from excessive wear, rail and batter, corrosion, slipping skidding etc. arising from service conditions, the sudden failure of rails is mostly due to defects in manufacture. 'Split head' type of failures on examination have revealed the presence of 'piped rails' due to chemical segregation in ingots of the size used for rails. A micro-examination of a piece taken from head revealed a coarse-grain banded structure of sorbo-pearlitic and ferrite with several elongated inclusions.

Defects like laps or laminations may be produced by splashing during pouring of molten metal or faulty rolling practice. A number of failures from this cause led to the inclusion in B.S. Specification No. 11 of an impact test on the side of rail head.

Many of the failures, especially on the Southern Railway, have been reported due to either dents or corrosion pits or segregation. Inspite of the quality of the steel being quite satisfactory the fractures have been found to occur at the sections having the maximum corrosion at its foot and web joint primarily due to corrosive environment. Sometimes due to high sulphur and phosphorus content the rail was found to be rendered; brittle thereby reducing its shock resisting capacity.

Another type of failure noticed and causing much concern now is the cracking of rails at the ends in the area concealed from view by fish-plates 85% of the cracks are in the form of horizontal separation between head and web of rail. Such cracks through bolt holes and rail and batter have been attributed to insufficient packing of ballast under joint sleepers and worn fish-plates. More recently this type of failure has been attributed to design of rail-end support which permits over-stressing. It has been found that the negative bending moment of fish plates if greater than the positive thus causing the resultant stress high enough to cause fish-plates failures as progressive fractures at centre of top of fish-plates. It has been investigated that this condition does not arise with girder type fish plates where the load on fishing surfaces is only 1/6 of that with standard joint. Stress concentration is also another factor and since this is high at sharp angles, protection against crack development would appear of lie in comforting of rail-ends especially in the web and chamfering of edges of bolt holes on both sides.

Rail failures from improper welding have also been reported. Welding is used for building up battered heads at rail ends, portions burnt in the rail head due to slipping of wheels, certain parts of worn points and crossings, thereby minimising renewals, and for joining two or more rails thereby eliminating joints. For welding rails flash butt welding has been generally used which though satisfactory have not been upto expectations as the structure of the weld revealed a Widman-Satten structure showing the material was not soaked for proper time at the correct temperature. Improper surface preparation of the ends of rails is also one of the causes as it prevents a close uniform contact. Trimining with emery paper in addition to sawing is necessary in order to give uniform rust-free surface. Post-heating is also required sometimes to releive stresses.

Points and crossings made from ordinary rails have a much lower life than the adjoining plain track on account of battering and crushing of toptable. Trails revealed that heat treated crossings stand up to wear better than untreated ones though pitting and chipping of top table metal occurs in them which shows that at this point the metal has not been heat treated uniformly thus leaving a sharp transition zone from the case to the core which left a plane of weakness in the metal. The worn out points and crossings are made up by welding at site. Previously electric arc welding was used but was not found satisfactory, on account of troubles due to hardening and consequent chipping. Oxy-acetylene process has been used with a success without any crack or flake. The reason is that with excess acetylene, the base metal is carburised thereby lowering its melting point which not only eleminates surface oxidation but also ensures an adequate bond without measurable depth of penetration at a temperature 400°C below melting. By this method the rail metal is disturbed to minimum and there is no adulteration of the deposited metal with the base metal. The diffused heat of flame and the retarded heating and cooling of rails and deposit results in a normalising effect eliminating hard areas.

Regarding the failure of fish plates, the prevailing view so far has been to make the fish plate steel softer than the rail steel so that the wear at the joint should occur on the cheaper replacement item i.e. the fish plate rather than the rail. The fish plates still having composition 0.3 to 0.42% carbon and a maximum of 0.8% manganese should be capable of resisting pulsating load of 22 tons per sq. inch. Stress recorder observations show, however, that infact very high stresses occur in practice. On account of the existing of this high stress the Railways are having under consideration trials with fish-plates of higher quality steel, possessing tensile strength 50 to 52 tons/sq. in. percentage elongation 20 on a 2 inch gauge and a yield point of 35 to 40 tons/sq. inch while the yield point of the present fish plate steel is expected to be about 19.5 tons. The reason for keeping higher yield point is that modulus of section of two fish plates is about half that of the rail section and stress in the fish plates is theoretically therefore almost double that in the rail. In practice, however, other factors come in the picture to reduce the stresses and the actual stress in the fish plate may not necessarily be twice that in the rail. The percentage of elongation is a measure of the capacity of the material to deform locally, a property which enables heavily stressed parts to transfer the load to adjacent parts which are not so heavily stressed. The absolute value of percentage elongation can be known by experience only 20% elongation may not be necessary and it is important to know its value because of the greater cost of high strength steel possessing greater elongation. Ordinary carbon steels when oil quenched can give an yield point of about 30 tons/sq. inch without any great sacrifice of ductility.

In essence, the survey of material failures occuring on railways is but a long tale of fatigue failures, the predisposing cause in many cases being the same kind of surface defect. The metallurgist may have specified the most suitable metal for a particular service and the designer-engineer may have scrupulously avoided in his designs all stresses above the endurance limit, and yet it is a common experience that the anticipated service cannot be obtained from them only because of the existence of stress-raisers. Avoidance of re-entrant angle, a thin fillet, a corner, a keyway, an oil-hole or a sharp changes in section and provision of liberal radii and fillets only means small change here and there in the design and in the manufacturing shops, but such small changes will certainly prevent occurrence of many fatigue failures. Careless machining, absence of desired degree of finish for the surface, presence of scratches, indentation and tool-marks help raise service stresses beyond the endurance limit of materials. If failures are to be effectively checked these defects are to be avoided at all costs.