Rails for Heavy Axle load Operations

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Rail in heavy axle load operations are subjected increased stresses and are used more rigorously due to which they suffer degradation in terms of wear and rolling contact fatigue in curves as well as tangent tracks. To optimise service life of rails use of head hardened rails with suitable grinding strategy has been recommended for curves. In Indian Railways through various research projects micro-alloyed (Nb, V, Cr-V, Cu-Mo and Ni-Cr-Cu) rails have been developed which are in various stages of trial. These rails have shown excellent mechanical properties which make them suitable for use on heavy axle load routes on Indian Railways.

1.0 Introduction:

Indian Railway has large railway network comprising of over 63,000 route kilometre and over 1,08,700 track kilometre. It carries over 850 million tonnes of freight traffic and over 7 billion passengers annually. Broad gauge network of Indian Railway comprises of IRS 52 kg/UIC 60 kg rails on Mono-block Pre-stressed Concrete sleepers laid on stone ballast cushion of 250-300 mm. Rail is vital and one of the most stressed component of track which carry train load down to the sleepers then to ballast and formation. The rails have to bear severity of wheel impact which is compounded by overloading, rolling stock defects i.e. flat tyre, and ineffective suspension, brake jamming causing wheel skidding and wheel slippage due to poor hauling capacity. With growth of traffic and increase in axle load the task of rails has become more demanding. In order to match demands of traffic, improvement in quality of rails is necessary. Further, with growth of traffic corridor available for maintenance and renewal has decreased, it is therefore necessary that rails with more service life and requiring less maintenance and giving uninterrupted service with few failures are laid to ensure maximum availability to traffic.

2.0 Rail Stresses due to Running of Heavy Axle Load

In heavy axle load operations the rails are not only subjected to high bending and contact stresses but their cycle is also repeated more frequently with increase in speed. The stresses in rail due to various axle loads of different rail sections due to rolling stock are given in Table 1 as under:

Table 1: Rail Stresses for different Rail Sections at Various Axle Load and Speed in Kg/mm^2

SN	Rail Section/Axle load & Speed	75 KMPH				100 KMPH		
		20.82 t	22.82 t	25 t	30 t	20.82 t	22.82 t	25 t
1	IRS 52 Kg	21.66	23.6	25.72		23.5	25.62	27.93
2	UIC 60 Kg	18.4	19.97	21.68	26.95*	19.31	20.97	22.77
3	UIC 68 Kg				25.31*			
4	UIC 71 Kg				24.19*			

The permissible bending stress of 90 UTS rails in LWR track due to rolling stock is 25.25 Kg/mm^2 and total permissible rail stress is 46.8kg/mm^2 for all factors for Rails of IRST-12-1996 specification. The above table indicates that 52 Kg 90 UTS rail is not fit for operation of 25 t axle loads at 75 KMPH speed and 60 Kg rail is not fit for operation of 30t axle loads at 75 KMPH.

3.0 Rail Sections for Heavy Axle Load Operation:

Use of higher rail section becomes essential for operation of high axle load due on consideration of bending stresses caused by movement of rolling stock as it exceeds maximum permissible limit of stress in that grade of steel. Use of higher section in addition to giving more service life by way of increased dimensions of head to provide sufficient margin for grinding but also provide better stability to track by increase in track modulus and track frame stiffness. This results in better distribution of wheel load on more track length which is especially helpful in case of weak formations. The dimensions of various rail sections are given in Figure 1 and Table 2 below:

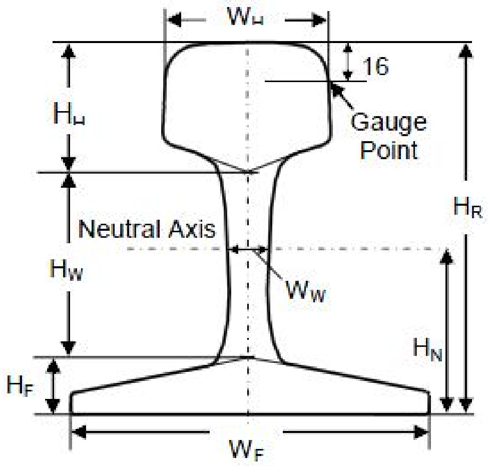


Figure 1: Schematic Showing Main rail Dimension

Table 2: Main Dimensions of Some Heavy Duty Rail Sections (mm)

Main Dimension of Various Rail Section (in mm)							
Rail Section	W_H	W_W	W_F	H_H	H_W	H_F	H_R
IRS 52 Kg	67	15.5	136	51	89.5	31.5	156
UIC 60 Kg	74.3	16.5	150	51	90.8	30.2	172
UIC 68 Kg	74.6	17.5	152.4	49.2	106.4	30.2	185.7
UIC 71 Kg	74.4	17.5	152.4	54.7	104	30.2	188.9
RE 136 68 Kg	74.61	17.46	152.4	49.21	106.36	30.16	185.73

4.0 Comparison of Hardness of Rail and Wheel

The hardness of wheel plays important role in wear characteristics and degradation behavior of rail therefore the hardness of rail and wheel used on Indian railways are compared as under:

- Hardness of wheel:-
- Goods and coaching stock : 260-320 BHN
- Locomotives : 300-340 BHN
- Hardness of 72 UTS rails : 220-235 BHN

- Hardness of 90 UTS rails : 260-280 BHN
- The above comparison clearly shows that hardness of 72 UTS rail is clearly out of pace with hardness of wheel whereas hardness of 90 UTS is slightly lower than hardness of goods and coaching stock and considerably lower than hardness of locomotive wheels.
- For heavy axle load there is clear cut requirement of harder rails due to consideration of wear resistance and resistance to rolling contact fatigue.

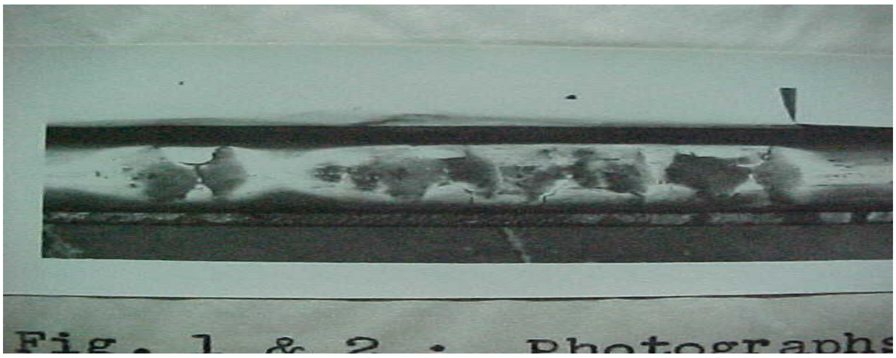
5.0 Effect of Running of Heavy Axle Load on Rails

The condition of rail gets deteriorated due to running of heavy axle load and also on routes with high GMT with heavy goods traffic. The following kinds of rail degradation occur.

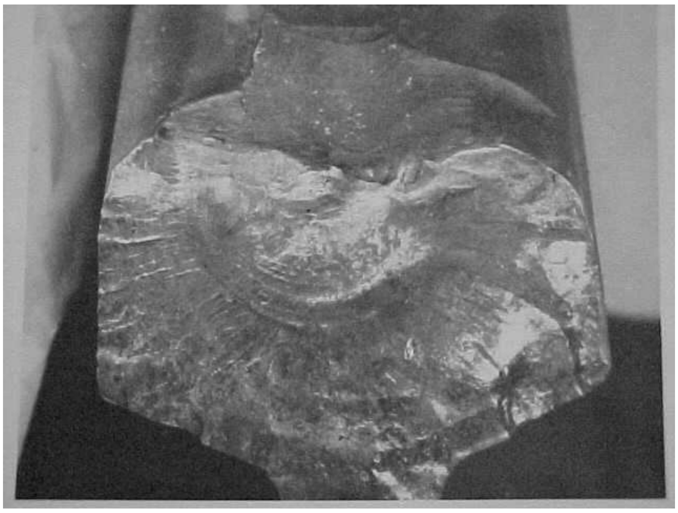
5.1 Rail Degradation due to heavy Axle Load Operation:

(i) Wheel Burns and Scabbing:

Rail Scabbing occurs due to skidding due to in appropriate brake application and wheel burns occur due to slippage of locomotive wheels as a result of inadequate powering. The scabbing/ wheel burn eventually results in sudden fracture of rail due to repeated heavy impact loading as shown in the Fig. 2(a) & (b) below.



(a)



(b)

Figure 2 (a) & (b): Showing Scabbing and Subsequent fracture

(ii) Rail Plastic Deformation

Plastic deformation of rail material occurs if the applied wheel /rail contact stresses exceed the yield strength of steel in compression. Gross plastic deformation of rail occurring in uncontrolled manner leads to (a) mushrooming of rail head and (b) surface corrugations.

(a) Mushrooming of Rail Head

Gross plastic flow of rail steel is usually observed under higher nominal axle load in excess of 20 tonnes. Plastic flow of rail metal on gauge side and / or field side of rail occurs in the form of mushrooming of rail head as shown in the Figure 3 below. This lead to tightening of gauge which may lead to higher wear and excessive lateral hunting of wheel set at higher operational speed in mild curves and tangent tracks.

Fig 3: Mushrooming of Rail Head

(b) Rail Corrugation

Higher nominal load operation in excess of 20 tonnes can lead to development of longer pitch corrugation on the running surface of rail as illustrated in Fig. 4 below which is due to plastic flow of rail material on account of wheel rail contact stresses exceeding material shake down limit, together with combined vertical resonance of wheel set's unsprung mass and the track. The development of corrugation is major concern as they increase dynamic wheel loads and vibrations, increasing rate of deterioration of track and vehicle components. The rail corrugation occurs when compressive stresses in rail head at the contact point goes beyond yield point and plastic deformation of rail top takes place which forms wave due movement of trains and subsequent work hardening. This condition generally found in case of 72 UTS rails whose yield strength is lower for movement of locomotive and BOX'N' wagons.

Figure 4: Showing Corrugation of Rail

(iii) Rail Wear (Vertical and lateral) :

Rail suffers lateral and vertical wear due to movement of rolling stock which is more pronounced in sharp curves due to higher lateral load applied on rails by wheels. As the ratio of lateral load to vertical load increases the rate of wear also increase as shown in Fig 3 below.

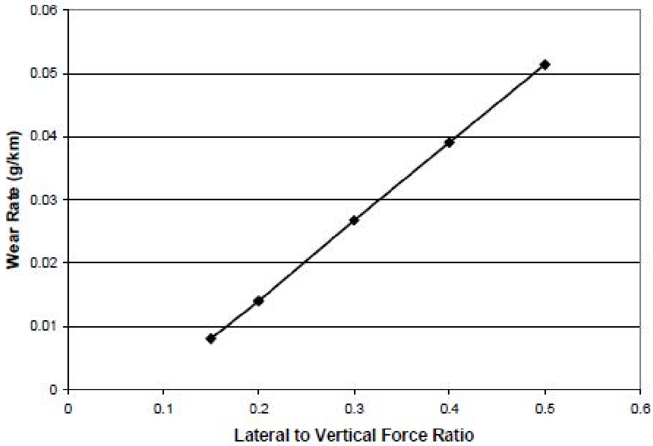


Figure 5: Relationship Showing Wear Rate Vs Lateral to Vertical load ratio

Wear can also occur on both higher and lower rail on curves either due to normal wheel / rail interaction and / or due to rail maintenance activities i.e. grinding. Figure 6 given below illustrate severe wears of rail both lateral and vertical.

Figure 6(a) Figure 6 (b)

Fig 6 (c)

Figure 6 : Showing Severe Wear of Rail

(iv)Rolling Contact Fatigue :

Rolling Contact Fatigue (RCF) refers to range of defects that occur mainly due the development of excessive shear stress at or close to the wheel / rail contact which exceed the shear limit of rail material. The RCF defects which occur in gauge corner region are as under:

(a) Gauge Corner Cracking or Head Checks:

The gauge corner cracking is surface condition of rails in which fine surface cracks appear in the shape of fish scales towards gauge side of rail. The gauge corner cracks are initiated at rail surface or very close to it and occur at an interval of 2- 5 mm along the rail and can grow to the same depth at downward angle of about 10^{0}-30^{0} to the rail surface gradually spreading across the rail head. Once they occur they usually break out as small wedges or spalls as shown in Figure 7 below. Though gauge corner cracking mainly occur on outer rail in curves but it can also occur on mild curves and tangent tracks where wheel set / bogie / vehicle tends to exhibit lateral dynamic or hunting behavior and where there is negligible gauge face wear of rails.

Figure 7 (a) & (b) : Showing Gauge Checking Cracks and subsequent Fatigue Fracture

(b) Shelling:

Shelling is internal defect that is initiated at a depth of 2-8 mm below the gauge corner of generally outer rail in curved track. Shelling defects do not form regularly along the rail as gauge corner cracking defects. Shelling cracks develop on a horizontal or longitudinal plane consistent with shape of rail at gauge corner. The cracks can continue to grow in longitudinal direction on that plane for some distance at an angle of 10^0-30^0 to the rail surface and either spalls out in a shell or turns down as shown in Figure 8 (a) and causes transverse defect which eventually results in fracture as shown in Figure 8 (b) below.

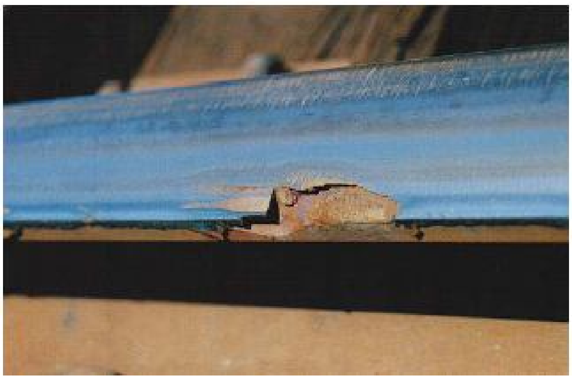


Figure 8(a)

Figure 8(b)

Figure 8 (a) & (b) : Small Transverse Defect in the Gauge Corner of the Rail Head Initiated from Shelling (Arrows Indicate Initiation Zone)

(c) Flaking:

Flaking or running surface checking is another type of rolling contact fatigue defect that occurs on running surface of inner and / or outer rails. Initially the defect occurs as a mosaic or snake skin like pattern on rail head. In the later stage spalls are produced that can be up to 10-15 mm wide and up to 3 mm deep and can be continuously along the rail. Minor flaking associated with minor spalling is shown in figure 8 below. They may lead to failure if not detected in time, particularly in case of transverse defects initiated from shelling of inclusions. They may mask ultrasonic signals during routine inspection and prevent detection of larger and deeper defects in rail head.

Figure 9: Minor Flaking and Spalling

6.0 Rail Grades and their Mechanical Properties and Microstructure:

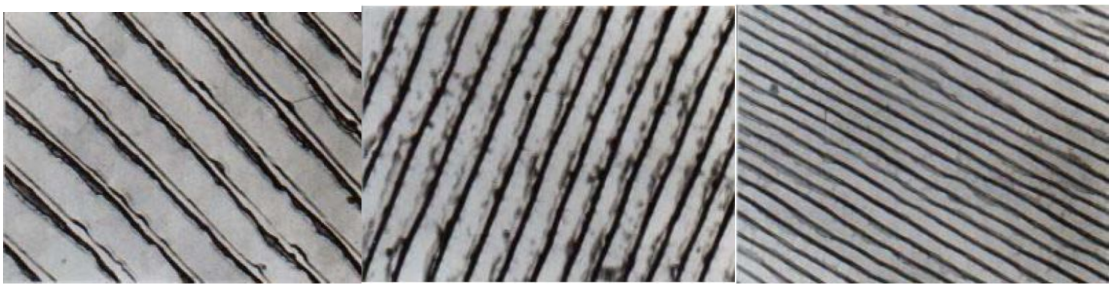
Following rail grade (other than special rails) are provided in Indian Railway Standard Specification for Flat Bottom Rails IRS T-12 2009. The rail grades in IRS T-12 2009 have been defined on the basis of ultimate tensile strength (UTS) in MPa. Table 3 shows different rail grade with their chemical composition along with their mechanical properties. On Indian Railways 72 UTS i.e. 710 grade medium manganese rail steel was in use till recent past and now 90 UTS i.e. 880 grade Carbon Manganese rails are being used. International standard have switched from strength based gradation to hardness based gradation. In the hardness based gradation they are called R 220 and R 260 respectively. The R 260 grade rails have fully pearlitic microstructure whereas R 220 grade rails have ferrite and pearlite. Ferrite structure is soft which imparts ductility but is prone to wear.

Table 3 : Showing rail Grade along with their Chemical Composition and Mechanical Properties

Grade	C %	Mn %	Si %	Cr %	S %	P %	UTS (MPa)	EL %	Hardness (BHN)
710	0.45-0.60	0.95-1.0	0.04-0.50		0.05 max.	0.05 max.	710	14	220

880	0.60-0.80	0.80-1.30	0.10-0.50		0.03 max.	0.03 max.	880	10	260
1080 Cr	0.6-0.8	0.8-1.2	0.5-1.1	0.8-1.2	0.025 max.	0.025 max	1080	9	320-360
1080 HH	0.6 -0.8	0.8-1.3	0.1-0.5		0.03 max	0.03 max	1080	10	340-390

R 260 grade rail steel though has given good service but they are prone to wear and fracture and also to RCF degradation. Therefore better rail grades with higher hardness and greater toughness have been developed by addition of micro-alloying elements or / and heat treatment. The addition of micro-alloying elements results in lowering transformation temperature due to which during normal cooling process fine grain microstructure is formed which give higher strength and higher hardness and in some cases better toughness. In case of heat treatment fine grained microstructure is obtained by controlled cooling. The heat treated rails are also called head hardened rails when only rail head is subjected to heat treatment. The comparison of microstructure of standard C-Mn rail [in Fig 10(a)], micro-alloyed rail [in Fig. 10(b)] and head hardened rail [in Fig 10 (c)] is as under:



(a) **Standard C-Mn Rail** **(b) Micro-alloyed Rail** **(c) Heat Treated Rail**

Figure 10: Showing Microstructure of C-Mn Rail, Micro-alloyed Rail, Heat treated Rail

To get still higher strength and hardness micro-alloyed rails are heat treated. The comparison of strength of HH rails and micro-alloed HH rail with standard Carbon – Manganese rails is shown in Figure 11 as under:

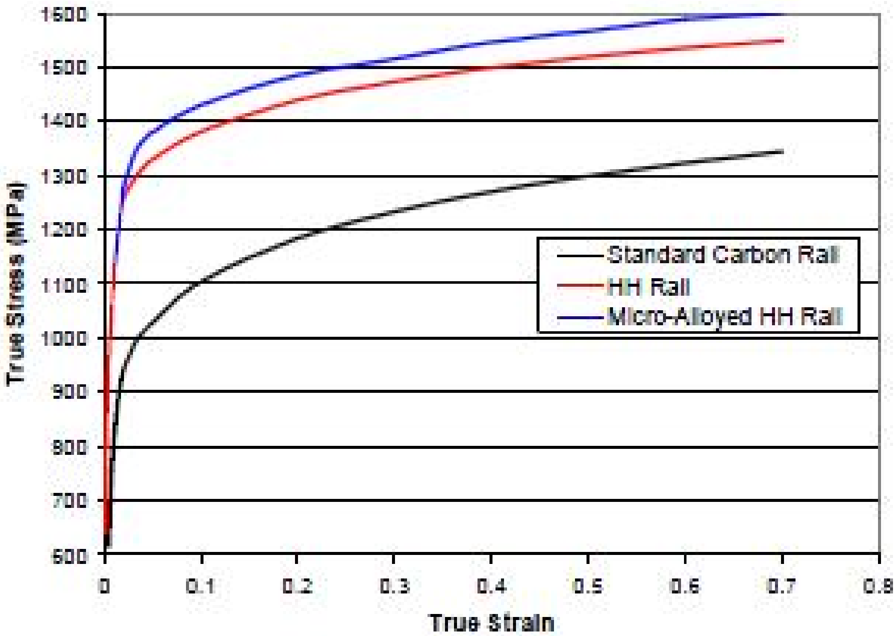


Figure 11: Stress – Strain Curve of C-Mn, HH and Micro-alloyed HH Rails

7.0 Effect of Mechanical Properties of Rails in Controlling Rail Degradation:

The mechanical properties of rails are dependent on chemical composition and microstructure of rails. Increase in carbon content (upto certain limit) results in increased UTS and increase hardness and also increase brittleness in terms of reduced elongation. The finer micro-structure results in increase of UTS and hardness at the same time maintaining or improving toughness. Strength and hardness are also related i.e. as the strength increases hardness also increases. The increased hardness results in better wear resistance and better resistance to rolling contact fatigue as shown in Figure 10 and figure 11 below.

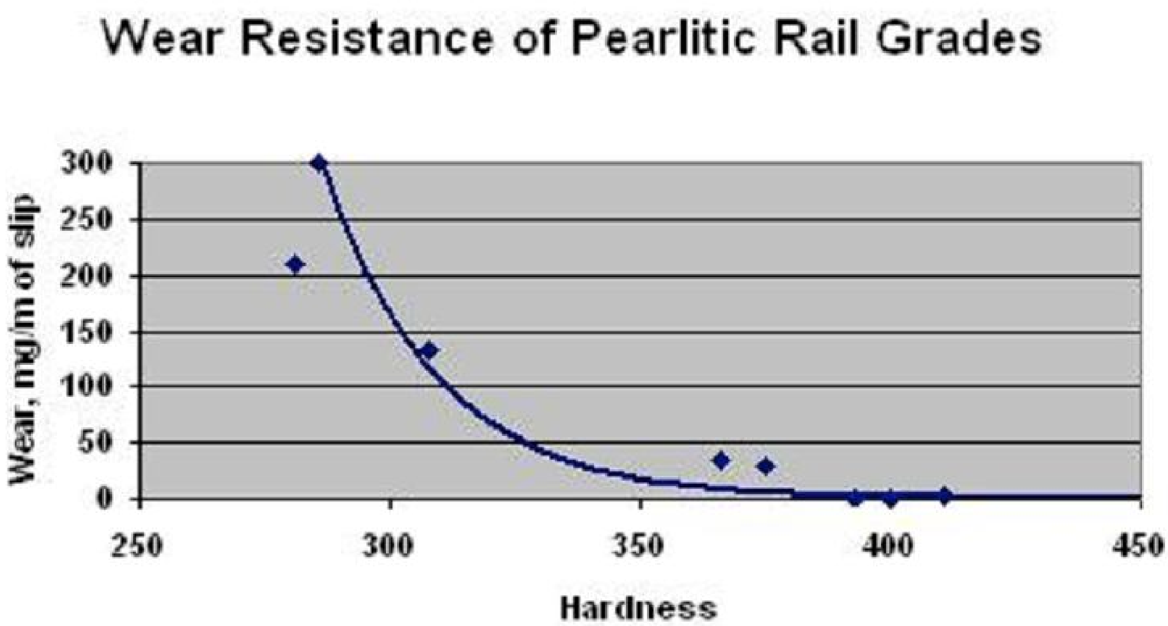


Figure 12: Relationship between Hardness and Wear Resistance

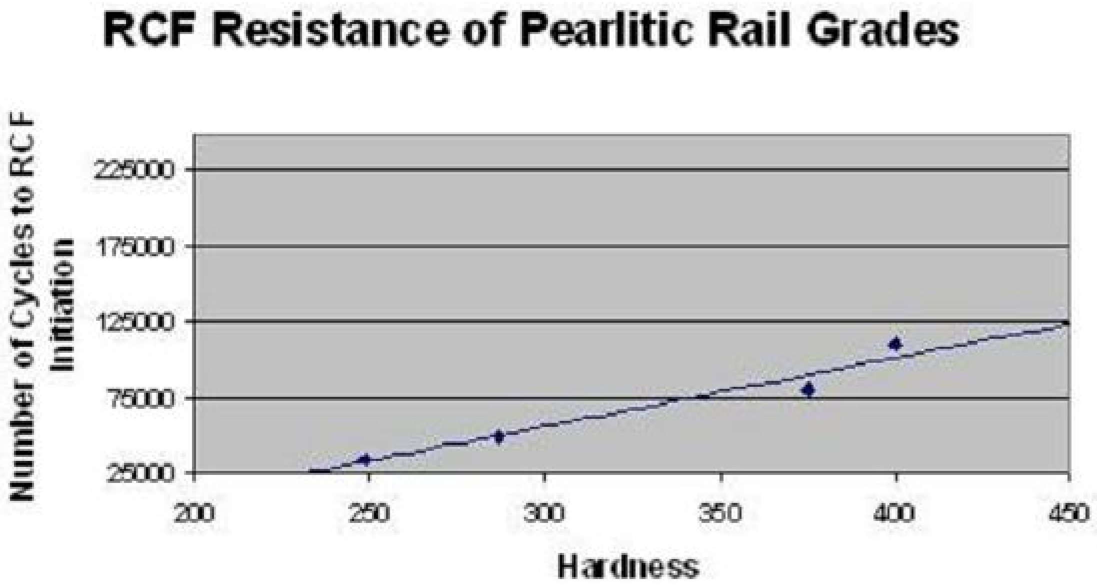


Figure 13: Relationship between Hardness and RCF Resistance

The above chart indicates that hardness of rails has direct relationship with wear resistance and RCF resistance of pearlitic rails (i.e. the one widely used on rail road presently). Higher the hardness better is the wear resistance and RCF resistance.

8.0 Recommended Rails for Heavy Haul:

In European Union, Innovative Track Systems (INNOTRACK) Project funded under European Union Research 6th frame work and coordinated and disseminated by UIC was undertaken to develop cost effective, high performance track infrastructure aimed at providing innovative solutions towards significant reduction in investment and maintenance of infrastructure cost. As a part of this project, a Sub-Project (SP 4) was undertaken to develop guidelines for selection of rail grades for different duty conditions. Based on results of large number of different track tests and results of laboratory tests, recommendation for selection of rail grade has been developed and published in report no. D4.1.5GL. In the report two types of recommendations are made (a) one based on radii and other based on (b) rail degradation mechanism.

(a) Radii Based rail Grade Recommendation:

The radii based INNOTRACK recommendations for steel grades are illustrated in Figure 14 and 15 below. Figure 13 gives overall view whereas figure 14 illustrates detailed recommendations.

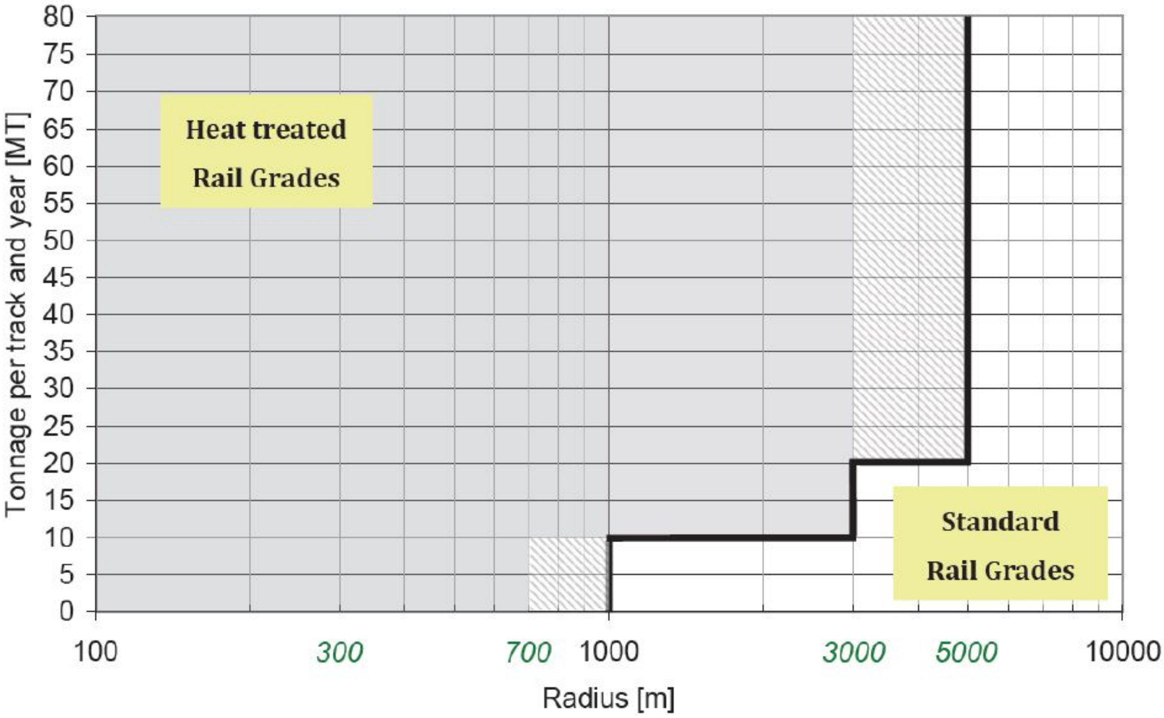


Figure 13: Radii Based Rail Grade Recommendation (Overview)

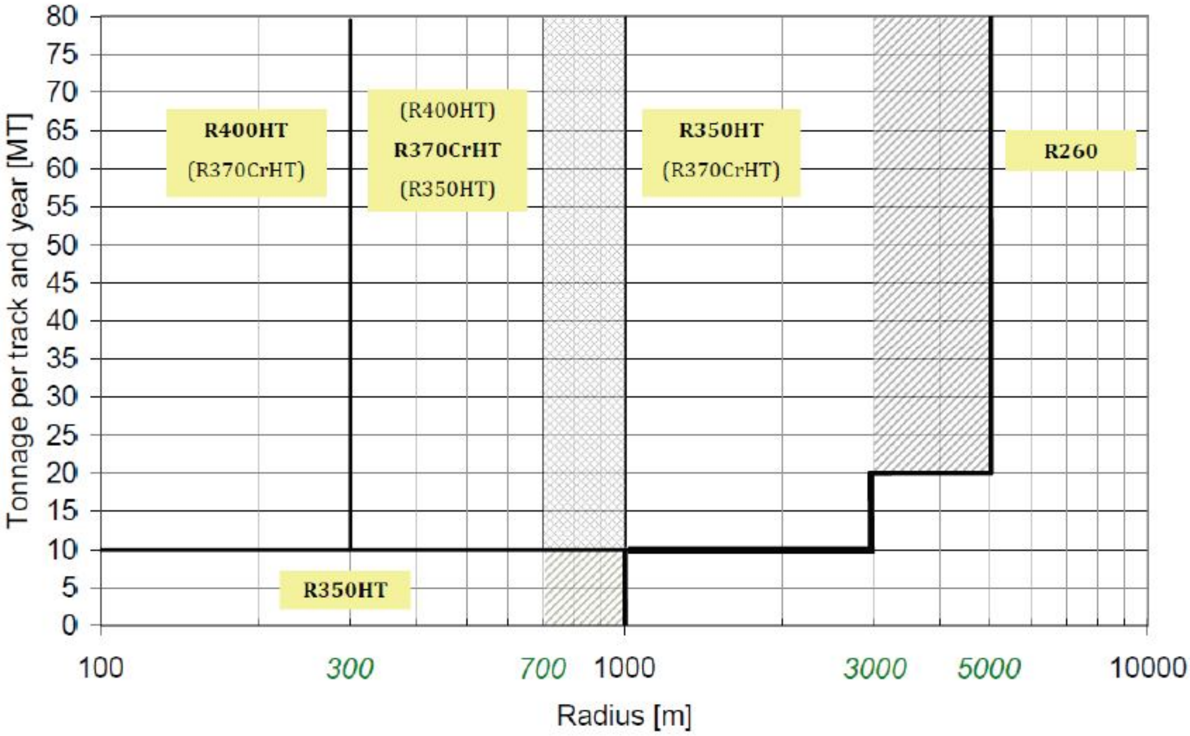


Figure 14 : Radii Based Rail Grade Recommendation (Detailed)

The INNOTRACK recommendations for heavy and moderately loaded tracks are summarized as under:

(i) For sharp curves of radius R > 300 m the recommended rail grade R 400 HT.

(ii) For moderate curves of radius between 300 m and 700 m – R 370 Cr HT grade (for heavily loaded tracks R 400 HT grade may also be used), followed by 350 HT steel grade with increasing radii upto 700 m.

(iii) In case of heavily loaded tracks R350HT steel grade is also proposed to be used in mild curves with radii between 3000 m and 5000m. However standard R260 grade may represent appropriate solution if RCF is negligible.

(iv) For lightly loaded tracks R 350 HT steel grade in curves with radii upto 700 m to 1000 m depending upon local boundary conditions may be used.

(b) Rail Degradation based Recommendation:

Rail degradation based recommendations of INNOTRACK are illustrated in Figure 15 as under:

Actual Installed grade **R260**			**DETERIORATION BASED RAIL GRADE SELECTION**		
WEAR	45^0 wear rate on high rail - calculated out of the absolute wear measured in track	**SEVERE** > 15mm/100 GMT	**R400HT**	**R400HT**	**R400HT**
		HEAVY ≤ 15mm/100 GMT	**R370 CrHT**	**R370 CrHT**	**R400HT**
		MODERATE ≤ 5 mm/100 GMT	**R350HT**	**R350HT**	**R370 CrHT**
		LIGHT ≤ 2 mm/100 GMT	**R260**	**R350HT**	**R370 CrHT**
The rail deterioration behaviour of the actual installed rail steel defines the appropriate choice of rail grade to be inserted with the next track relaying action in order to achieve optimum rail degradation behaviour. In case of			**LIGHT** ≤ 0.5mm/100 GMT	**MODERATE** ≤1 mm/100 GMT	**HEAVY** ≤3mm/100 GMT

	Head Check Depth rate - Calculated out of measured crack depth detected in track **ROLLING CONTACT FATIGUE**

Figure 15 : Showing Rail Degradation Based INNOTRACK Rail Grade Recommendations

In the above chart actual installed rail steel grade is R260. The ordinate in case of wear is 45^0 wear rate on outer rail, calculated on absolute wear measured in track. In case of RCF, the axis shows head check crack depth rate, calculated out of measured crack depth detected in track.

9.0 Indian Railway Scenario:

On Indian Railway R 260 grade rails of IRS 52 Kg and UIC 60 Kg section are widely used. Though on KK line of East Coast head hardened rails were used which gave satisfactory performance and after completion of their life they have been replaced by R 260 grade rails. Bhilai steel plant has planned to install facilities to produce head hardened rails in new rolling mill being set up with universal rolling mill which will produce 130 m rails. In the mean time, to improve performance of rails various kinds of micro-alloyed rails have been developed which are described as under:

10.0 Development of Micro-alloyed Rails on Indian Railways:

In order to meet the special requirements and environmental degradation following micro-alloyed rails have been developed.

(i) Fracture Resistant Niobium Rails:

Heat No.	C	Mn	Si	S	P	Nb	Al	UTS (MPa)	YS (MPa)	YS/ UTS	% EL	Hardness (BHN)
18854	0.64	1.09	0.02	0.019	0.026	0.055	0.005	923			14.64	269
18860	0.63	1.04	0.013	0.015	0.018	0.049	0.004	903			13.47	269
18865	0.64	1.05	0.016	0.013	0.023	0.062	0.004	925			15.2	
18852	0.66	1.09	0.019	0.022	0.029	0.048	0.005	915	562	0.61	14.4	262
18851	0.63	1.06	0.028	0.021	0.027	0.051	0.005	931	542	0.58	13.47	269
18850	0.64	1.04	0.022	0.023	0.023	0.052	0.006	896	548	0.61	13.33	262
18223	0.69	1.02	0.02	0.023	0.021	0.054	0.008	930	574	0.61	13.2	262
18226	0.69	1.06	0.019	0.021	0.022	0.056	0.008	944			13.33	
18858	0.64	1.06	0.017	0.015	0.021	0.063	0.005	905	540	0.6	14.93	262
18856	0.66	1.11	0.02	0.02	0.027	0.058	0.005	929			14.53	277
18863	0.63	1.03	0.017	0.011	0.025	0.062	0.009	922	552	0.6	13.2	262
Mean	**0.65**	**1.059**	**0.0192**	**0.0185**	**0.024**	**0.055**	**0.006**	**920.27**	**558**	**0.6**	**13.97**	**266**

Rail Fracture is one of the major problem faced on Indian Railway as it not only results service interruptions and traffic detentions but it is also a safety hazard as it may lead to derailment. In order to reduce incidents of sudden rail fractures i.e. transverse fractures without any apparent origin and impede flaw growth, fracture resistant Niobium rails have been developed in association with SAIL in year 2002 and laid in track in Kharagpur division of South Eastern Railway for field trial where they performed satisfactorily since then. The role of Niobium has been found to consistently provide fine pearlitic grain structure which increases both strength and toughness of ferrite microstructure, precipitation hardening and retardation of recrystalisation which plays a key role in thermo-mechanical rolling. The properties of Niobium rails produced in Bhilai Steel Plant in Year 2002 are as under:

Table 4 : Showing Chemical Composition and mechanical properties of Niobium Rail

One heat comprises of liquid steel weighing around 150 MT. The mean value fracture toughness of 3 heats of Niobium rails tested in RDCIS/Ranchi is 44 $MPam^{1/2}$ against mean fracture toughness value of R 260 grade C-Mn rail of 39 $MPam^{1/2}$ for year 2009-10.

(ii) **Wear Resistant Vanadium Rails**:

Vanadium rails were developed in association with SAIL to enhance wear resistance and provide higher Ys/UTS ration for fulfilling requirement of higher yield strength as in high temperature variations zones (zone-IV) with temperature variation upto 76^0C, the rails are subject to higher tensile stresses. Addition of Vanadium improves wear resistance as it is a strong carbide forming element and impart hardenabilty. It dissolves ferrite to some extent and imparts strength and toughness. Due to refinement of microstructure it also improves fracture toughness. Five heats of Vanadium rails were produced and rolled into UIC 60 Kg rail section and laid in Chakradharpur Division of South Eastern Railway for conducting field trials. So far these rails have performed satisfactorily and there has been no incident of rail fracture and no defect has been detected by regular ultrasonic testing. The chemical composition and mechanical properties of Vanadium rails produced in BSP are as under:

Table 5: Showing chemical composition and mechanical properties of Vanadium rails

Heat No.	C %	Mn %	Si %	S %	P %	V%	Al %	UTS (MPa)	YS (MPa)	YS/ UTS	El%	Hardness BHN
27671	0.64	1.06	0.21	0.01	0.013	0.067	<0.010	966			11.87	282
27677	0.61	1.1	0.18	0.021	0.017	0.084	<0.010	969			12.27	285
27679	0.62	1.1	0.19	0.03	0.022	0.081	<0.010	980	643	0.67	10.67	285
27680	0.62	1.07	0.18	0.028	0.019	0.079	<0.010	982	662	0.67	10.67	285
27949	0.62	1.05	0.22	0.027	0.017	0.077	<0.010	978			12.93	282
Mean	**0.622**	**1.076**	**0.196**	**0.0232**	**0.018**	**0.078**	**<0.010**	**975**	**652.5**	**0.67**	**11.68**	**283.8**

(iii) **High Strength Chrome –Vanadium (Cr-V) 110 UTS Rails**:

In order to cater for need of high axle load and to reduce wear and enhance service life of rails, high strength and wear resistant Chrome- Vanadium rail have been developed by in association SAIL. Chromium in combination with Vanadium imparts strength and hardenability required for 110 UTS rails which have minimum UTS of 1080 MPa, YS of 560 MPa and hardness of 320 BHN as per IRT T-12 2009. These rails have been included in Indian Railway Standard Specification of Flat Bottom Rails (IRS T-12-2009). The chemical composition and mechanical properties of the same are as under:

Table 6: Showing Chemical Composition and Mechanical Properties of 110 UTS rails (as per IRS T-12 2009)

C	Mn %	Si %	S %	P %	Cr %	V %	Nb %	Al %	UTS (Mpa)	YS (MPa)	El%	Hardness BHN
0.6-0.8	1.0-1.5	0.2-0.7	0.025 max.	0.025 max	0.6-1.1	0.3 max	0.3 max	0.01 max	1080	560	9 min.	320-340

Table 7: Showing Chemical Composition and Mechanical Properties of Experimental Heat Produced in BSP

Heat No	C %	Mn %	Si %		P %	Cr %	V %	Nb %	Al %	UTS (Mpa)	YS (MPa)	YS /UTS	El%	Hardness BHN
63456	0.66	1.39	0.26		0.023	0.68	0.12	0.022	0.005	1157	779	0.67	10.32	282

11.0 Development of Corrosion Resistant Rails:

Indian Railway faces major problem of corrosion especially at liner seat in coastal areas as well as hinterland. The problem of corrosion is aggravated due to droppings of human waste from toilets of passenger trains. In order to mitigate the problem of corrosion it was decided to improve rail metallurgy to improve its corrosion resistance. In this attempt two corrosion resistant rail chemistries have been developed. Corrosion resistant Copper – Molybdenum (Cu-Mo) rail chemistry was developed in association with RDSCI, Ranch (R&D Wing of Steel Authority of India Limited) and Bhilai Steel Plant. Another rail chemistry i.e. Nickel- Chromium- Copper (Ni-Cr-Cu) was developed in collaboration with IIT/Kanpur with SAIL as industrial partner as a part of Technology Mission of Railway Safety. The corrosion resistant attribute of these rails are on account of fact that they produced fine rust layer which inhibits ingress of moisture and chloride ions forming a protective layer. These rails chemistries are discussed as under:

(i) Corrosion Resistant Copper- Molybdenum (Cu-Mo) Rails:

Corrosion resistant Copper – Molybdenum rail were developed in association with RDCIS/ Ranchi to mitigate the problem of corrosion faced in Indian Railways in 2002 and put in track for initial field trial in June 2003. Subsequently 900 MT of these rails were rolled in November 2003 and put in track in coastal region of South Central and East Coast Railway. They were also put in track in approaches of major cities where the passenger trains approach in early morning hours when utilisation and dropping of toilets are at its peak. As mentioned above the corrosion resistant property of these rails is attributed to formation of fine rust which inhibits ingress of moisture and chloride ions thus preventing further corrosion. In the field trial corrosion resistant Cu-Mo rails were laid side by side and the rust formed in them was collected and analysed. The amount of rust collected from normal 880 grade rails was twice that of Cu-Mo rails. The rust obtained from plain Carbon – manganese (C-Mn) rail was of flaky granulometric constitution whereas rust from Cu-Mo rails was fine and powdery, thus revealing the compact and adherent nature of the corrosion product of micro-alloyed rails. The performance of these rails has been found satisfactory. Further 1,000 MT of these rails will be laid in track for extensive field trial before their mass production . The chemical composition and mechanical properties of properties of these rails are shown in table 8 below.

Table 8: Chemical Composition and Mechanical Properties of Cu-Mo rails

Heat No.	%C	Mn %	%P	%S	%Si	%Cu	%Mo	%Al	UTS (MPa)	YS (MPa)	%EL	Hardness (BHN)
80914	0.67	1.15	0.024	0.029	0.22	0.34	0.20	<0.010	1127	869	10.40	302
80983	0.66	1.17	0.031	0.028	0.30	0.29	0.18	<0.010	1121	815	10.93	302
80978	0.67	1.13	0.020	0.017	0.28	0.30	0.18	<0.010	1131	892	10.13	302
80972	0.64	1.13	0.028	0.017	0.23	0.30	0.17	<0.010	1101	791	11.60	285
80975	0.64	1.14	0.027	0.018	0.23	0.30	0.17	<0.010	1097	749	12.53	302
80984	0.66	1.15	0.030	0.021	0.30	0.28	0.17	<0.010	1143	860	11.07	285
80981	0.66	1.14	0.029	0.023	0.30	0.28	0.17	<0.010	1114	843	10.80	309
Mean	**0.66**	**1.14**	**0.03**	**0.02**	**0.27**	**0.30**	**0.18**	**<0.010**	**1119.1**	**831.3**	**11.1**	**298.1**

The fracture toughness and fatigue value of heat no. 41808 of the lot produced earlier was 49.67 MPa $m^{1/2}$ and 305 MPa respectively.

It can be seen from the above that these rails not only have very good corrosion resistant properties but they have excellent mechanical properties.

(ii) Corrosion Resistant Ni-Cr-Cu Rails:

Owing to high cost of molybdenum and necessity to develop even better corrosion resistant rails, research project for its development was undertaken as a part of Technology Mission for Railway safety (TMRS) with Indian Institute of Technology, Kanpur (IIT/Kanpur). In this project five rail chemistries were tried and their corrosion resistant properties were evaluated in laboratory conditions. The rail chemistry which gave best corrosion resistant properties and gave satisfactory mechanical properties was selected. The rails of this chemistry were rolled and tested in laboratory conditions. On confirmation of its superior characteristics, 550 MT of these rails were rolled in Bhilai steel plant and supplied to South Central Railway and East Coast Railway where they have been laid in track in April-May 2008. So far their performance has been in accordance with expectations. Further, out of 10,000 MT ordered for extensive field trail 7,835 MT rails have been rolled and supplied to South Eastern Railway, South Central Railway, Southern Railway and Western Railway for laying in track for extensive field trial. The Chemical composition and mechanical properties of these rails are shown in table 9 below.

Table 9: Chemical Composition and Mechanical Properties of Ni-Cr-Cu Rails

Heat No.	%C	% Mn	%P	%S	%Si	%Ni	%Cr	% Cu	%Mo	UTS (MPa)	YS (MPa)	%EL	Hardness (BHN)
88373	0.67	1.09	0.015	0.015	0.19	0.34	0.52	0.37	0.015	1009	582	12.40	311
88366	0.67	1.10	0.022	0.015	0.20	0.31	0.57	0.34	0.015	1042	635	13.33	313
88371	0.67	1.10	0.014	0.009	0.21	0.35	0.58	0.38	0.015	1028	607	12.80	315
88369	0.66	1.07	0.014	0.015	0.20	0.36	0.55	0.35	0.015	1010	601	12.40	311
88377	0.67	1.12	0.018	0.020	0.22	0.32	0.53	0.35	0.015	1016	707	12.00	302
88368	0.68	1.09	0.020	0.019	0.20	0.32	0.55	0.35	0.015	1013	691	12.40	302
88310	0.67	1.06	0.013	0.011	0.26	0.32	0.59	0.36	0.015	1044	744	13.60	302
88308	0.68	1.08	0.017	0.014	0.26	0.32	0.61	0.32	0.015	1056	537	12.53	321
88305	0.67	1.08	0.018	0.017	0.22	0.34	0.61	0.33	0.015	1039	699	13.33	302
90245	0.66	1.14	0.018	0.025	0.23	0.33	0.62	0.32	0.015	1040	691	12.40	305
90262	0.66	1.09	0.023	0.022	0.20	0.33	0.55	0.34	0.015	1032	652	12.27	321
90258	0.67	1.10	0.210	0.022	0.23	0.33	0.60	0.35	0.015	1025	659	12.40	314
90255	0.66	1.13	0.190	0.016	0.22	0.34	0.61	0.33	0.015	1032	678	12.40	331
90239	0.66	1.13	0.020	0.026	0.21	0.35	0.60	0.39	0.015	1035	659	12.00	308
90234	0.67	1.12	0.025	0.015	0.17	0.33	0.61	0.38	0.015	1034	691	12.13	311
90250	0.66	1.13	0.021	0.018	0.23	0.34	0.62	0.37	0.015	1049	693	10.67	311
90242	0.65	1.12	0.022	0.017	0.19	0.36	0.61	0.39	0.015	1046	717	12.00	317
90248	0.65	1.11	0.022	0.014	0.19	0.38	0.61	0.37	0.015	1056	700	12.13	305
90252	0.67	1.14	0.025	0.021	0.21	0.33	0.62	0.38	0.015	1049	687	11.87	314
Mean	**0.67**	**1.11**	**0.04**	**0.02**	**0.21**	**0.34**	**0.59**	**0.36**	**0.02**	**1034.4**	**664.7**	**12.37**	**311.37**

Heat No.	U.T.S.	YS	YS/UTS Ratio	El%	Hardness	Fracture Toughness	Fatigue strength
	(MPa)	(MPa)			(BHN)	(MPa√m)	(MPa)
80135							

It is evident from the above that these rails not only have superior corrosion resistant properties but have excellent mechanical properties. The comparative chemical and mechanical properties of these rails are as under.

Table 10 : Comparison of Chemical Composition of Micro-alloyed Rails

Table 11: Comparison of Mechanical Properties of Micro-alloyed Rails

Rail Type							
C-Mn Rails	937.75	536.27	0.57	12.15	271.18	39.91	306
NCC Rails	1034.5	664.74	0.64	12.37	311.37	35.55	310
Cu-Mo Rails	1119.1	831.3	0.74	11.1	298.1	49.69	305
Nb Rails	920.3	558	0.6	13.97	266	44	315
V Rails	975	652	0.67	11.62	284	43	350

12.0 Conclusion

To meet the challenges of growing Indian Economy, Indian Railways being backbone of its transportation system are required to carry increased traffic both goods and passenger on almost the same track infrastructure as growth of infrastructure i.e. railway lines have not kept pace with increase in traffic. As a result, demand of the increased traffic has been met by increase in axle load and increase in length and number of trains on same railway lines. Rails being in direct contact with wheels of rolling stock have to suffer degradation and failures due to increase in axle load and traffic volume requiring frequent renewals. To overcome higher stresses due to increased axle load moving at higher speed higher rail section i.e. 68 Kg (RE 136) suitably modified to Indian conditions has been included in IRS T-12 / 2009. Bhilai Steel Plant has also developed facilities for its rolling.

In order to optimize utilization of rails for increase service life and reduce degradation due to wear and rolling contact fatigue INNOTRACK report D4.1.5GL has recommended use of heat treated (Head Hardened) rails in curves. On Indian Railways though initial trials of head hardened rails on heavy axle load routes were successful but they could not be inducted in mass scale due to the fact that these rails are not produced in the country and these have to be imported. With the induction of new rolling mill with head hardening facility, head hardened rails can be produced in the country in Bhilai Steel Plant and their use can be planned along with proper rail grinding strategy to improve service life, reduced rail degradation and reduce service interruptions on account of rail failures and frequent renewals.

Corrosion resistant Cu-Mo and Ni-Cr-Cu rails which have been developed for corrosion prone area have shown excellent mechanical properties. These rails in addition to corrosion prone area can be used on heavy axle load routes where these rails will not only prevent corrosion but also give increased service life as their service life is expected to be more on account of their superior hardness and toughness. Wear resistant Vanadium rail is also another alternative whereas Niobium rails with improved ductility and toughness can be inducted to reduce rail fractures on Indian Railways after extensive field trial.

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(v) Shri R K Srivastava SE/Track/Inspection/RDSO for collecting valuable data.

14.0 References:

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