FAILURE ANALYSIS-II

Case study of different failures

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Lect./EM

At the end of this lecture the trainees will be able to understand metallurgical and mechanical factors affecting the performance of

Suspension Coil spring

Wheel disc of LHB Coach

Centre Buffer Coupler

Rail

Hot Rolled Cylindrical Spring:

Spring is one of the primary elastic members of the suspension system.

Springs connect the wheel to body elastically and store energy to absorb and smooth out shocks that are received by the wheels from rail irregularity and transmitted to the body.

By doing so, in dynamic loading condition springs may fracture

Material composition:

Material : 52 CrMoV4/52SiCrNi5 as per ISO:683 part-14 or En10089

Element	Percentage	Specification
%C	0.48-0.56	ISO:683 part-14 or En10089
%Mn	0.7-1.10	
%Si	0.40(max)	
%Cu	0.9-1.2	
%Mo	0.15-0.30	
%V	0.1-0.3	
%S	0.025(max)	
%P	0.025(max)	

Process:

- Formation of ends and stamping
- Hot coiling
- Quenching
- Tempering
- Scragging
- End grinding
- Shot peening
- Crack testing
- Phosphating
- Primer
- Pre load testing and load deflection testing.

Causes of failure:

- Raw material defect
- Improper heat treatment
- Surface imperfection
- Corrosion
- Decarburization

LHB Coil Spring

Location of Spring Breakage:

Location of breakage on the suspension spring can be of significance in helping to determine the cause of failure.

- At the transition from inactive coil to first active coil
- At any position on any of the active coils

- Breakage of coil spring at any position on active coils may be due to material defects/fabrication deficiencies
- Breakage at the transition from inactive coil to first coil is due to service related problems.

Fracture Surface:

- Fracture surface is seen to have oriented at approximately 45^0 to the wire axis.
- Fracture may consist of two segments, both at approx. 45^0 to the axis of the coil connected by a short longitudinal step.
- Indicates torsional fatigue failure under cyclic loading.
- Maximum stress occurs at surface for each and every type of loading conditions.
- Hence fatigue properties are sensitive to surface condition.
- Any change in surface condition will greatly alter fatigue properties.

Seam contributing to failure

Factor affecting life of coil Spring.

- Presence of dent/notches at the surface.
- Corrosion.
- Decarburization of the surface.
- Defects/discontinuities within the spring
- Improper microstructure
- Residual stress condition of the surface.
- Rail road irregularities

Points to consider:

- In service, the stress on the inner surface of an active coil is the position of the maximum stress.
- Coil surface itself is vulnerable to imperfection.
- Stress concentration points bring about fatigue crack initiation.
- Concurrent act of wear, corrosion together with stress singularity at the contact zone of the closed ends generally results in fatigue crack.
- Once initial crack is formed, it is the maximum shear stress that forces the crack to propagate along the direction of 45^0 with the spring wire axis.

AN EXAMPLE OF THE INVESTIGATION REPORT

REPORT OF FAILED BOLSTER SPRING

- **EASTERN RAILWAY**

- CHEMICAL & METALLURGICAL LABORATORY
- CARRIAGE & WAGON WORKSHOP/ LILUAH
- ***Sample No:- S/135/16***
-
- TEST CERTIFICATE NO: - F/LLH/LAB/28 dated 08/03/16
- **Material:-** One cut piece of broken Bolster Spring was received from SSE/MR/L-Bay vide letter no MR/LB/L/failure /03/16 dated 02/3/2016 for failure analysis. The failure occurred at HWH division.

REPORT OF FAILED BOLSTER SPRING

- **Particulars:-**

- *Item : -Helical Spring for Bolster Suspension Arrgt. for ICF Bogie*
- **Fig.1:- Broken Helical spring**
- *Coach No:-ER 14401 AB,GS*
- *Train No.:-12345 UP*
- *Date of POH:-18/1/2016*
- *Date of Failure:-29/02/2016*
- *Collected from:-HWH Div.*
- *Material Specification:-Gr.52 Cr_4Mo_2V to IS: 3195-92*
- *Drawing No.:- RDSO's /Sk-84263,Alt.-2*
- *Pl No. :-30984944*

- The component failed within 100 days of POH.

REPORT OF FAILED BOLSTER SPRING

- **Visual Observation** :-
- 2.1. Location Fracture: - Fracture took place at first turn from bottom end.
- 2.2. Nature of Fracture: - Fracture was transverse, progressive in nature & inclined at an angle of 45^{o}

  from the Longitudinal axis of the spring wire indicating tortional fracture. Fatigue covered approx 5% of the cross sectional area

2.3. Other Observations:-

(i) Corrosion pits were present at /near the fracture. It acted as point of Stress Concentration & nucleus of fatigue.

(ii)Stampings particulars: - CM ICF 08 04 80.

PICTURES OF FAILED BOLSTER SPRING : BROKEN PART

Areas showing deep corrosion pits

PICTURES OF FAILED BOLSTER SPRING : BROKEN PART

Arrows indicate the corrosion pits as points of stress concentration and nuclei of fatigue causing failure

REPORT OF FAILED BOLSTER SPRING

3. Mechanical Properties

Test Parameter	*As Specified*	*As Found*	*Inference*
Average Hardness (in BHN):-	**415-460**	**447 BHN**	**Conform**

REPORT OF FAILED BOLSTER SPRING

4.Chemical Composition:

Test Parameter / *Chemical Composition*	*As Specified Gr.52 Cr4Mo2V to IS: 3195'92.*	*As Found*	*Inference*
Carbon %:-	**0.48-0.56**	**0.54**	**Conforms**
Manganese %:-	**0.70-1.10**	**0.70**	**Conforms**
Silicon%	**0.15-0.40**	**0.23**	**Conforms**
Chromium%:-	**0.90-1.20**	**1.00**	**Conforms**
Vanadium%:-	**0.07-0.12**	**0.09**	**Conforms**
Molybdenum%:-	**0.15-0.25**	**0.17**	**Conforms**
Sulphur %:-	**0.03 Max**	**0.014**	**Conforms**
Phosphorous%:-	**0.03 Max**	**0.012**	**Conforms**

REPORT OF FAILED BOLSTER SPRING

- **4. <u>Micro Examination</u>:-**

  Micro Examination of the transverse section revealed tempered martensite structure.

5. <u>Discussion</u>:-

(i) Chemical composition of the spring was Satisfactory to Gr.52 Cr4Mo2V to IS: 3195-92.

(ii) Hardness value was within limit of the specified range as mentioned in IS: 3195-92.

(iii) Corrosion Pits were present at/ near the fracture. It acted as point of Stress Concentration & nucleus of fatigue.

REPORT OF FAILED BOLSTER SPRING

7 Conclusion:-

Corrosion pits at/near the fracture provided location of stress concentration and made the material notch sensitive.

This led to nuclei of fatigue and subsequent failure of the material during service.

8. Remedial Measures:-

Proper care should be taken to avoid formation of stress raisers i.e. corrosion pits on Spring surfaces.

Metallurgical Investigation Report No.10/19

Sub: Detailed Metallurgical & Chemical analysis of cracked wheel.

Ref: Production Engineer/CW/PER/S. Railway's letter no. CW/604/V/OS/LHB,
Dated: 07.02.2019

In reference to above, one broken wheel disc fitted in wheel set along with broken part of this wheel set removed from train no. 22113 at Kochuveli stations in TVC division of Southern Railway, cracked on 09.01.2019, were received for metallurgical investigation. The details of investigation are given as under:

1. M&C Lab Identification:

M&C Lab identification no. allotted to samples are given below:

Sl. No.	M&C Lab Id. No.	Punch marking	Paint marking (Red paint)
1.	10/19	ZB 2014 207 63301 W474 UT UT011010318APS	Train No.-22113 CRLWACCN13119 L1 Wheel ↓ Φ 861.3 mm (White paint)

2. Sample Particulars:

Component/System identify (Coach/Loco/Wagon etc.)	Wheel disc (Coach) Coach No.CRLWACCN13119
Date of failure	09.01.2019
Place/Railway	Kochuveli stations, TVC division, Southern Railway
Location in system if part of assembly	L1 Wheel (B5 Coach)
Drawing no./Specification No.	Specification = IRS R-19/93 part II Rev.4, corrigendum no.1, Drawing no.- LW02103
Sketch of failed component after joining fracture pieces, please attach	----
Function of component in brief	Wheel disc
Manufacturer	M/s Bonatrans India Pvt. Ltd. Aurangabad
Identification marking on the component	ZB 2014 207 63301 W 474 UT
Date of manufacture	2014
Date of fitment	--
Failed in service/assembly/maintenance	Failed in service
Caused derailment/accident	During rolling examination noticed heavy oscillation and unusual sound in B5 coach
Train No. in case of Accident/Engine no.	22113
Nature of stresses/ loading	--
Working environment (temp/humidity etc.)	--
History of repair/maintenance	Docs attached
Document allowing welding repair if any	--
Last NDT testing/result if applicable	--
Attach report of preliminary Investigation	Attached
Expected service life	Approx. 4 years
Condemning criterion	Ø 855 mm (earlier Ø 845mm)

3.Visual Examination:

A broken wheel disc no. ZB 2014 2014 207 63301 W 474 UT fitted in wheel set along with broken part of this wheel having circumferential length of about 520mm was received (**fig. 1 & 2**).Shelling marks, pits, thermal cracks were noticed throughout the tread surface of the wheel disc. Visual examination of fracture piece of wheel disc revealed that crack had initiated in a fatigue manner near to the web zone at a distance of about 90 mm below the tread surface (**fig.3**). Wheel flattening/metal flow, tendency of chipping out of metal and shelling observed on tread surface (**fig.2& 3**). The fracture had initiated in slow fatigue manner having straight length of about 160 mm which had propagated on either side in the web area and later on fracture had propagated on either side of the straight reason and after arrest it progressed upward direction towards the rim in fast fatigue manner and further leading to the separation of rim/tread portion (**fig.3**). Counter part of fractured wheel attached to wheel set was in heavily deformed and bent condition (**fig. 1, 4 &** 5). Crack having length about 80 mm and 650 mm was noticed at the arrest reasons of fast progressive zone (**fig. 4**). Web thickness 15.50 mm observed at fatigue initiation zone. Hitting mark is noticed on wheel rim (**fig. 3**). Wheel flatness of 45 mm length (approx.) noticed above the fracture initiation area. The length of shelling and wheel flatness on the tread located just above the fatigue nucleus on the web.

Wheel rim thickness was found about 30.50mm against 59mm in new wheel which indicates that wheel has wear out about 28.50 mm in service/turning. Metal flow and flatness was also observed at tread surface on broken piece.

Fig.1: Photograph showing fractured wheel set in as received condition.

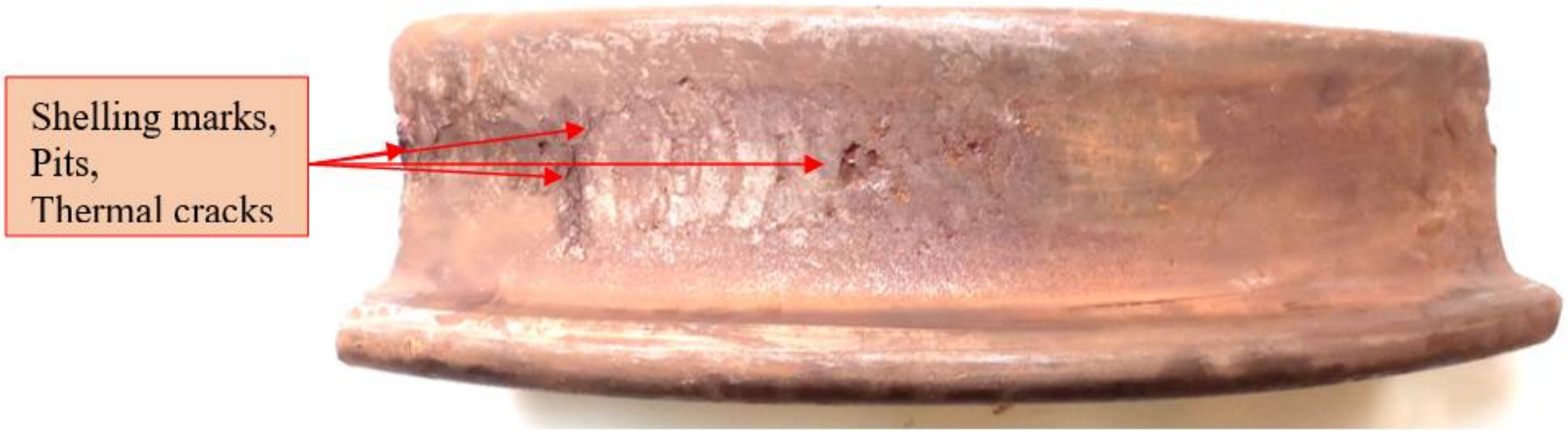


Fig.2: Photograph showing fractured part of wheel in as received condition having shelling marks, pits and thermal cracks on tread surface.

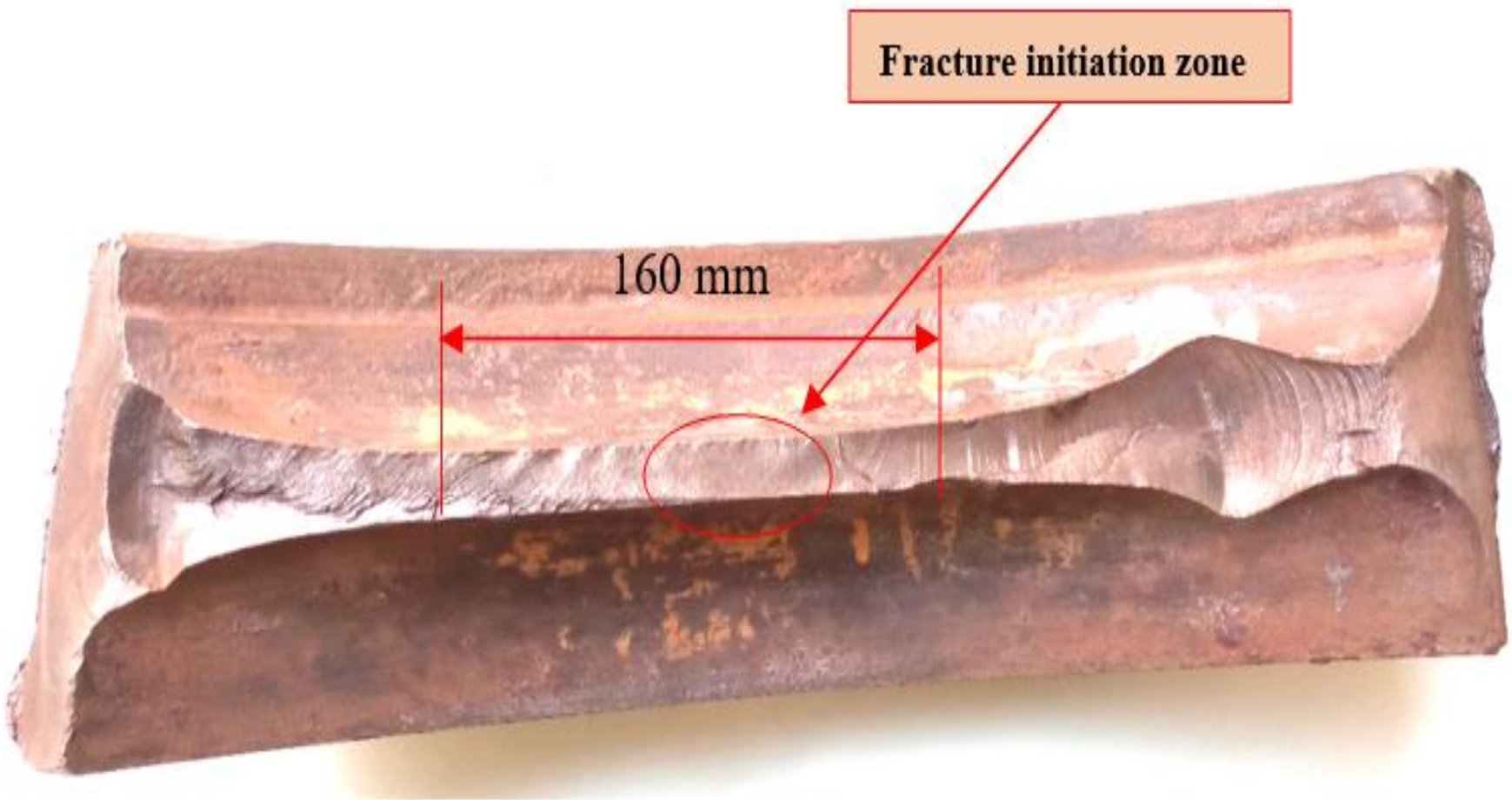


Fig.3: Photograph showing fracture face of the wheel piece.

Fig.4: Photograph showing two numbers of crack in fractured wheel set.

Fig.5: Photograph showing fracture face of the wheel set.

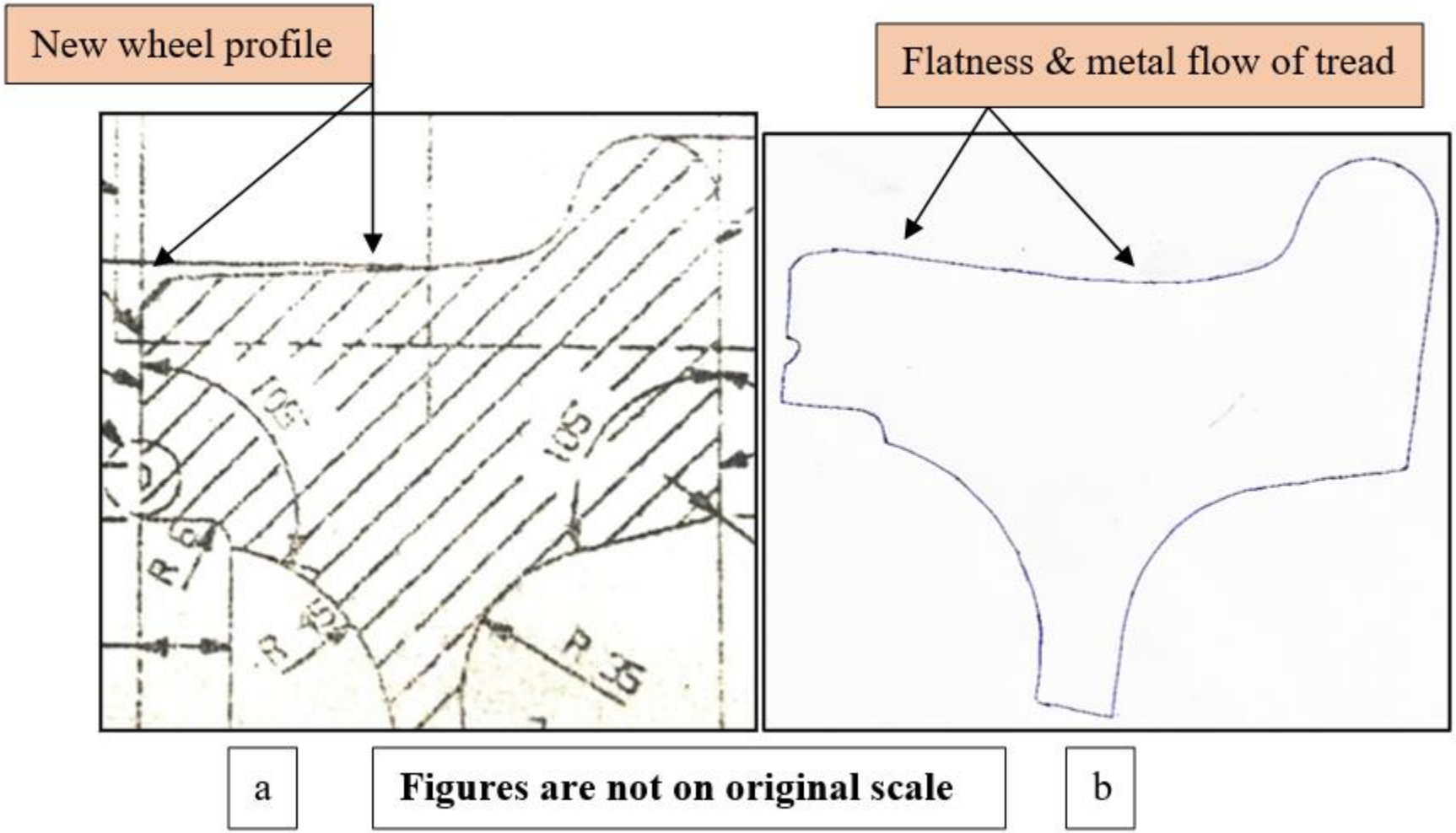


Fig.6: Photograph showing (a) Profile of new wheel. (b) Profile of worn out wheel

4. Chemical Composition:

A piece of each sample was cut and analyzed for the chemistry of the material and the results are given as under:

Element	Observation	Specified as per IRS: R-19/93 Part-II (Rev.4)	
	Sample No. 10/19		
%C	0.512	0.52 Max	
%Mn	0.732	0.60-0.80	
%Si	0.323	0.15-0.40	
%P	0.007	0.03 Max	
%S	0.002	0.03 Max	
%Cr	0.224	0.25 Max	Combined 0.5 max. (Cr + Ni + Mo)
%Ni	0.017	0.25 Max	
%Mo	0.008	0.06 Max	
%Cu	0.017	0.20 Max	
%V	Tr.	0.10 Max	

5. Hardness Test:

Hardness survey was conducted on transverse slice at a depth of about 7 mm (28.5 + 7 = 35.5 mm) from the existing tread surface at three different locations as per IRS R-19/93 Pt.-II (Rev.4) and the results are given as under:

(Depth of Rim wear is about 28.50 mm.)

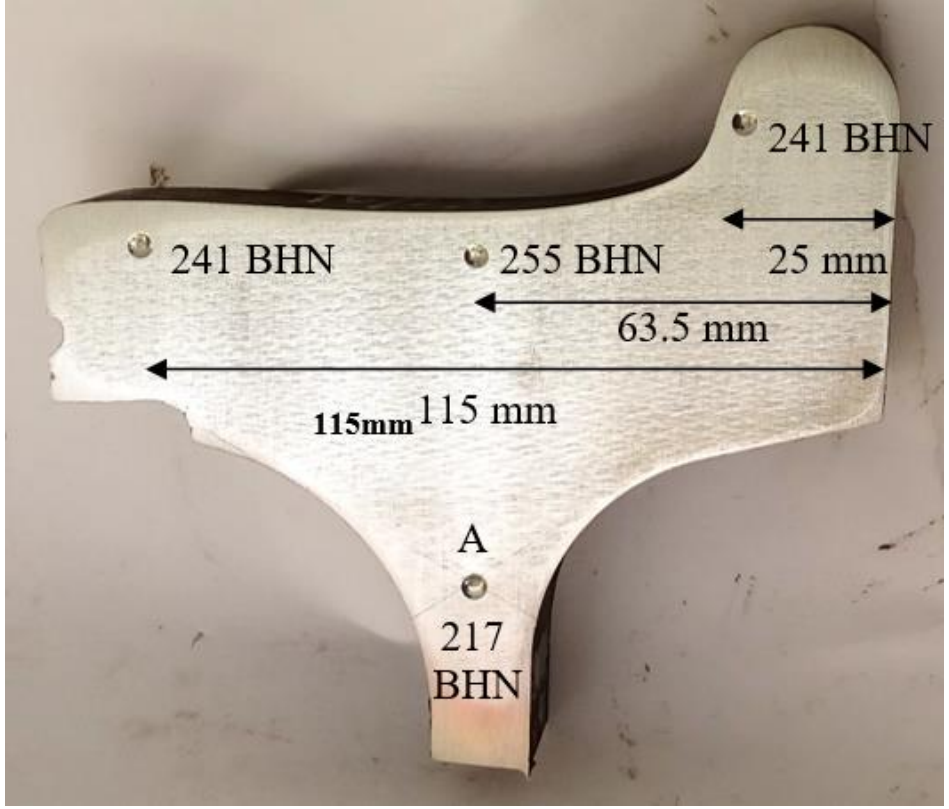


Fig.5: Photograph showing hardness survey on transverse slice of fractured piece as per IRS R-19.

Sample No.	Location	Hardness (BHN) (3000 kg/10 mm/15 secs)		
		25mm	63.5mm	115mm
10/19	Below 7 mm existing tread surface (28.5+7= 35.5 mm w.r.t. new wheel)	241	255	241
	At point 'A'	217		
Specified as per IRS: R-19/93 Pt. II (Rev.4)		241-320 (at Rim) 229 max. at rim-web transition point 'A'		

6. Tensile Test:

Sample No.	Yield Strength (MPa)	UTS (MPa)	%Elongation (GL = 5.65 $\sqrt{S_0}$)
10/19 (Rim) (approximate 28.5+15=43.5 mm below w.r.t. new wheel)	----	812.18	18.39
Specified as per IRS: R-19/93 Pt. II(Rev.4) at 15mm below in new wheel	≥520	820-940	14 Min.
10/19(Web)	Could not be conducted due to sample size		
Specified as per IRS: R-19/93 Pt. II (Rev.4)	Not specified	760 Max.	16 Min.

7. Impact Test :

Sample No.	Impact Strength (Joules) at $+20^0C$
10/19	30.0, 28.0, 28.0 (Avg. =28.67)
Specified as per IRS: R-19/93 Pt. II (Rev.4)	Average Value: 17 Min. Individual Value:12 Min.

8. Micro examination:

Micro pieces were prepared and examined before and after etching.
The results are given as under:

- **Inclusion Rating:**

Sample No.	Sulphide 'A'		Alumina 'B'		Silicate 'C'		Oxide 'D' (Globular Oxide)	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
10/19	1.0	--	--	--	--	--	1.0	--
Max. specified as per IRS: R-19/93 (Pt. II) Rev.4	2.0	1.5	2.0	1.5	2.0	1.5	2.0	1.5
	(B+C+D) max.= 4 for thin & 3 for thick.							

- **Microstructure:**

Sample No.	Location	Observations
10/19	Rim	Pearlite within network of ferrite. Average Grain size is ASTM No. 6. (fig.7)
Specified as per IRS: R-19/93 Pt. II(Rev.4)		Fine pearlite structure with ASTM gain size 6 or finer.

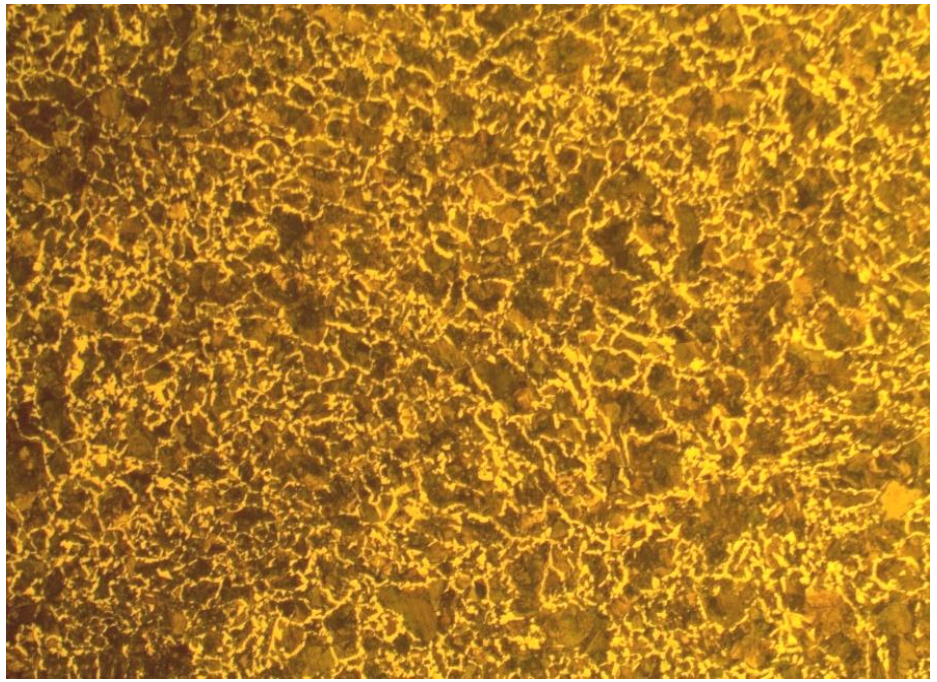


Fig.7: Photograph showing pearlite within network of ferrite in rim adjacent to tensile location.

9. MPT Comments :

- During magnetic particle testing, it was observed that the crack has extended approx. 10 mm one side and 15 mm other side apart from visual cracks.

10. Discussion :

- **Chemical composition** of wheel sample conforms to relevant specification.

- **Hardness** conducted on sample at different location is considered satisfactory.

- **UTS** corresponding to rim are found lower than the specified values. It may be due to downward shifting of location from where the sample has been prepared. Since depth of wear of rim is 28.50 mm, the lowered value of UTS is considered to be satisfactory. Furthermore, % El corresponding to Rim portion is found satisfactory whereas the UTS and % El of web was not evaluated as there was no feasibility for preparation of test piece at this section.

- **U-notch impact strength** is found satisfactory.

- **Inclusion rating level** in the wheel sample is also found satisfactory.

- General **microstructure** prepared from the specified location of rim is satisfactory with average ASTM grain size no.6 or finer. No inherent non- metallic entrapment is noticed.

- It is evident from above that metallurgical properties of failed wheel are satisfactory. Cyclic impact/hammering effect during service due to combined effect of shelling and flat wheel on the tread area above the crack have led to extra stresses in the web. Furthermore, due to wear of rim of about 28.50 mm, the modulus of compressive stresses decreases which is induced by rim quenching at the time of wheel manufacturing. Stresses, owing to cyclic impact, had concentrated on minimum thickness of the web portion and as a result, a crack had initiated in the web portion and further propagated during service, leading to failure of wheel.

11.Conclusion :

- Metallurgical properties of the wheel are considered satisfactory. Failure of wheel is attributable to cyclic impact/hammering effect during service due to combined effect of shelling and flat wheel on the tread area above the crack. Stresses due to cyclic impact had concentrated on minimum thickness of the web portion and as a result, a crack had initiated in the web portion and further propagated in fatigue manner during service.

12. Recommendation :

Design modification of the LHB wheel disc considering anti shelling profile may be looked into.

CENTRAL LABORATORY

West Central Railway

No:-CM/08/ FA-426/2022

Office of the
CMT/CRWS/BPL
Date-10.11.22

DRM(M),BPL

FAILURE INVESTIGATION REPORT

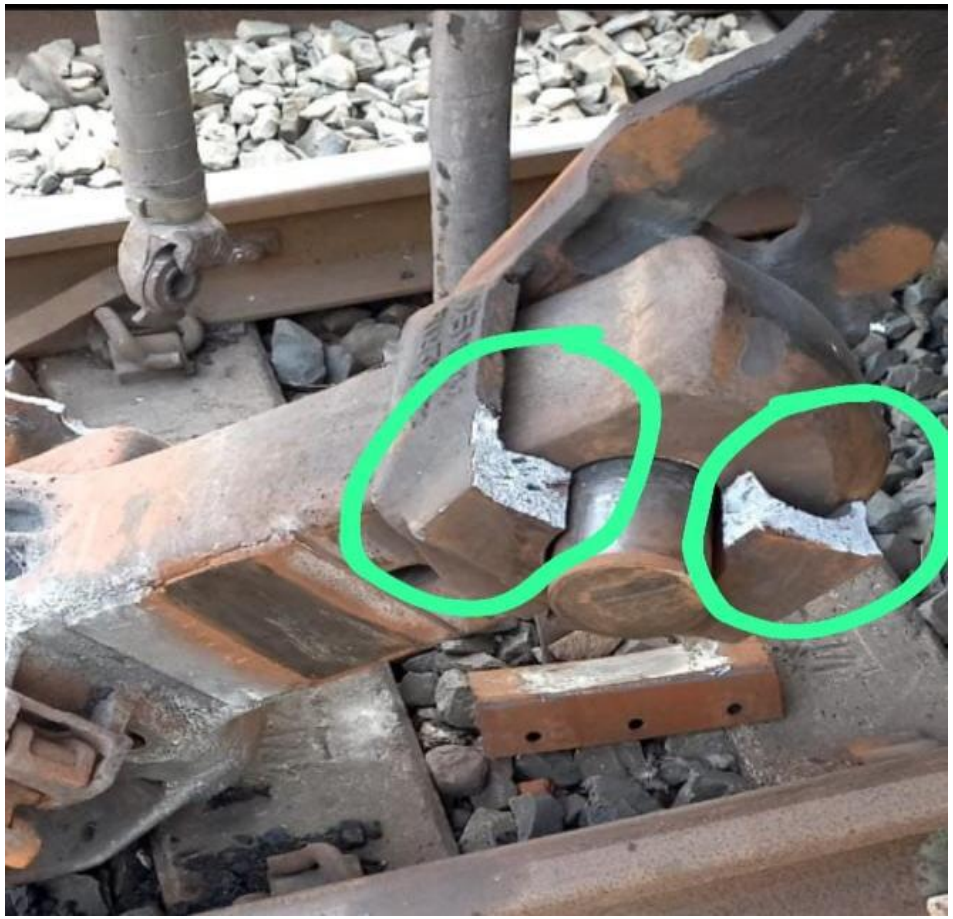
(I)Particulars of the failed component :-(As per letter)

1.	Component name	CBC YOKE
2.	Ref letter no.	BPL/M/211/CW/03 , dt-02.11.2022
3.	Date of sample received	07.11.2022
4.	Wagon No	10089863625/BOXNM1/WR
5.	Lab No.	FA-426
6.	Provided by	DRM(M) BPL
7.	Date of failure	01.11.22
8.	Date of fitment	Not provided
9.	Identification mark/Manufacturer	Yoke-HTEA RIL 11-H7K94 (As seen) Striker casting-RSW/VED 44801 AFU 08/17(As per letter)
10.	Place of Failure	KNW-ET section (BHIRINGI Station)
11.	Drg. No	SK-62724 Alt-25 (Item No-3)
12.	Specification (As per drawing)	AAR M201 Gr-E Steel
13.	Technical requirement	RDSO/LKO STR No 48-BD- 08 or Latest
14.	Date of POH/ ROH/IOH Stn. & date	POH-WRSW-01.05.18 ROH UDL-08.12.21, R/Dt-12/22

(II) HISTORY: CBC Yoke & Striker casting of Wagon No 10089863625/BOXNM1WR 26th from loco got broken and caused train parting of train no **NTPB.** The above incident took place between KNW-ET section (BHIRINGI Station) of bhopal division on date 11.11.2020. The broken components is received for further testing & metallurgical failure investigation.

(III)Visual Examination:- Visual examination revealed breakage of CBC yoke and striker casting. One side strap of yoke broken near yoke pin-hole area. Fractured face shows bright crystalline appearance throughout the surface. Deep crack also observed on opposite side near yoke pin hole. Fractured face of striker casting also found bright crystalline in appearance. Particulars of the manufacturer are visible. Counter part of broken CBC yoke is not received.[Ref fig.a,b &c]

Broken CBC Yoke



Striker Casting

(IV)Chemical Composition:-

(a) CBC Yoke

Elements (%)	Value Obtained (%)	Specified values (%) - As per specification AAR M 201 Gr-E Steel (RDSO/LKO STR No 48-BD-08)
Carbon	**0.363**	0.28-0.33
Manganese	0.841	0.80- 1.10
Silicon	0.523	0.40- 0.60
Sulphur	0.022	0.03Max
phosphorous	0.027	0.03max
Chromium	0.673	0.50-0.80
Nickel	0.553	0.50-0.80
Molybdenum	0.180	0.15-0.25

(b) Striker casting:-

Elements (%)	Value Obtained (%)	Specified values (%) - As per specification AAR M 201 Gr-B Steel (RDSO/LKO STR No 48-BD-08)
Carbon	0.195	0.32 max
Manganese	0.548	0.90 max
Silicon	0.422	0.60 max
Sulphur	0.028	0.03 max
phosphorous	0.024	0.03max

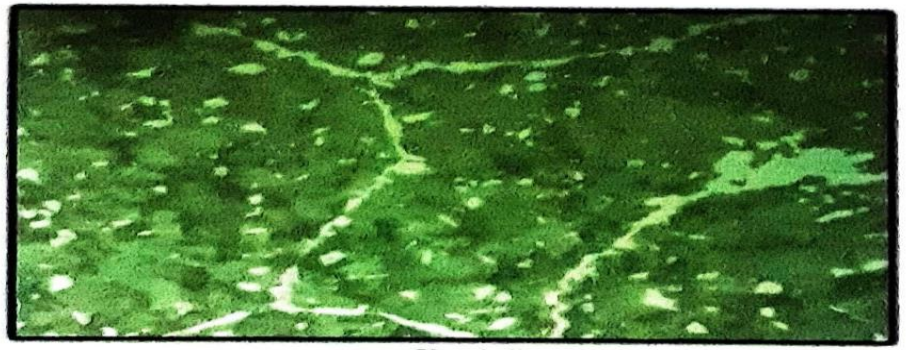
(V)Surface hardness

	Value obtained	Specified as per spec.
a)CBC Yoke	**195/197 BHN**	241 -311 BHN
b) Sriker casting	158/160 BHN	137- 208 BHN

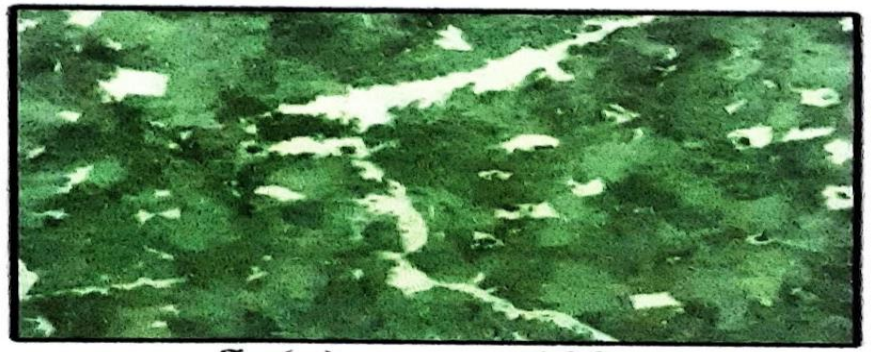
(VI) Non Destructive Test: No crack / blow hole or porosities noticed near fractured area. **(DPT Method)**

(VII)Macro Examination: - Revealed no harmful inclusions.

(VIII)Micro Examination(Yoke):- Matrix revealed coarse grains of ferrite-pearlite instead of uniform distribution of tempered martensite. (fig-d&e)



fig(d) 50X



fig(e) 100x

(IX) Conclusion

(a) (YOKE)

1. The chemical composition of broken yoke material shows carbon content on higher side than as specified however other elements found as per specification.
2. Fractured face of cbc yoke shows crystalline appearance indicated sudden & brittle fracture.
3. Hardness found on lower side indicated improper heat treatment.
4. Micro structure found unsatisfactory as revealed coarse grains of ferrite-pearlite structure instead of uniform distribution of tempered martensite indicated improper heat treatment.

(b) Stiker Casting

1. The chemical composition &hardness found satisfactory.
2. Fractured face found crystalline indicated sudden and brittle fracture.

(X) Probable cause of failure-:-The failure of CBC assembly is attributable to breakage of CBC yoke . Metallurgical properties of yoke like heat treatment, microstructure and hardness are not satisfactory as per specification which adversely affected mechanical properties strength and toughness. Higher side carbon content is also contributory factor inducing brittleness. Breakage of striker casting is consequential damage under service stresses.

(XI) Remedial Measure:-

1. Proper casting practice and adequate heat treatment must be followed to get desired quality during manufacturing.
2. Compliance by manufacturer to Technical Requirements of RDSO/LKO STR No 48-BD- 08 or latest shall be ensured before supply.

CMT 10/11/22

CMS

Sample No:- S/191/16

TEST CERTIFICATE NO :- F/LLH/LAB/28 dated 21/04/16

Material:- One Broken Knuckle received from Sr. DME/ASN /ER vide letter no. MC/115/3 **d**ated 01/4/2016 for failure investigation.

1. Particulars:-

Item: -	*One Broken Knuckle*
Train No:-	*BKTPP/BOBRN/L*
Wagon No.:-	*ECR BOBRN/L 731013/14901*
Date & Place of Failure:-	*In between DUJ and CPLE Station over ASN div on 31/3/2016*
POH;-	*Defaced – 17/01/2013*
ROH:-	*UDL-03/08/2015*
Ret/Dt:-	*01/19*
Reference Specification:-	*Indian Railway Schedule of Technical Requirement No:- 48– BD – 2002 amendment No.2 of January2007, Gr E*
Manufacturing Embossing	*HTEA JM 11 14* *IR 316*

Fig.1:-Broken Knuckle

2.

Visual Observation:-

1. Location of Fracture:- Fracture took place at approx. 200 mm. from the tail end.
2. Nature of Fracture: - Fracture was transverse and coarse crystalline in nature.
3. Other Observations: - Casting defects like shrinkage cavities, & porosities observed throughout the fracture face.

Fig.2:-Fracture Face of broken knuckle showing presence of shrinkage cavities, porosities.

Contd….2

3 **Mechanical Properties:-**

Test Parameter	*As Specified* *48-BD-02, Amnd- Jan 2007*	*As Found*
Average Hardness (in BHN):-	261— 291 BHN	275 BHN

4 **Chemical Composition:-**

Test Parameter *Chemical Composition*	*As Specified* *48-BD-02, Amnd-2007*	*As Found*
Carbon %:-	0.28-0.33	0.30
Manganese %:-	0.80-1.10	0.95
Silicon %:-	0.40-0.60	0.55
Chromium%	0.50-0.80	0.70
Nickel%	0.50-0.60	0.58
Molybdenum%	0.15-0.25	0.17
Sulphur %:-	0.03 max	0.01
Phosphorus %:-	0.03 max	0.02

4. **Micro Examination: -** Micro-Examination of transverse section revealed tempered martensitic structure..

6.Discussion: -(i) Chemical Composition of the material is within specified limit as per 48-BD-02 amnd. 2007.

(ii) Hardness value of the material is within specified limits.

(iii) Casting defects like shrinkage cavities & porosities were present throughout the fracture face. This reduced the effective cross-section & in turns the load bearing capacity of the material and acted as stress concentrator and ultimately caused the failure of the material during service.

7.Conclusion: - Failure is attributed to major casting defects like shrinkage cavities, porosities .

8.Remedial Measures: - Appropriate steps like proper pouring temperature, adequate gating and risering of the mould during casting should be ensured to avoid formation of casting defects like shrinkage , porosities, etc. during manufacturing level..

C h e m i s t & M e t

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DID (0522) 2465310

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1. **RDSO personnel involve in metallurgical investigation:-**

Abhishek Kr. Pandit (M.S/Research)	Sanjay Ranjan (ARO/M&C)	Anoop Singh Dagur (Dy. Dir./M&C)	Rajesh Srivastav (Dir./M&C)	B. L. Bairwa (Exe. Dir./M&C)
Tested & draft report framed by	Draft report prepared by	Draft report reviewed by	Report approved by	Report issued by

□□□□: Metallurgical investigation of fractured AT welded rail piece.

सन्दर्: भ Sr. DEN/Co-ord/NFR/Katihar's letter no. W/411/Misc/W-6, dated: 22.07.2022.

In reference to above, two broken pieces of fractured AT welded rail (counter to each other) were received from NFR/ Katihar for Metallurgical Investigation. Fracture took place at KM 5/6-7, UP line, between NJP - ABFC of NJP - RQJ section on date 16.05.2022 in Northeast Frontier Railway/Katihar division. Details are as under:

2. Particulars of Rail (as furnished)

Railway/Division	N. F. Rly/Katihar
Date of failure	16.05.2022
Section	NJP - RQJ
Line –UP/DN/SL BG/MG/NG/other	UP Line (LHS)
Curvature	----
Location	Km. 5/6-7 UP Line LHS (Chainage Km 5.631)
Traffic density in GTKM/annum	----
Total traffic carried in GMT before failure	252.98 GMT (Welding)
Maximum axle load with type of vehicle	----
Maximum permissible speed	----
Rail Type	60 Kg (880) & Laying 05/2011
Rolling mark of rail	05/2010
Total number of years in service	----
Type of welding	SKV (AT Weld)
Welding Agency	----
Date of welding	19.05.2011
USFD result after execution of weld	----
Last date of USFD testing of Rail/Weld & result	01.05.2022 Rail/Weld through testing and Result good
Last date of USFD testing of Weld & result	04.07.2019, Result Good

3. **Lab. Identification No. & Marking**

Lab. Id. No.	Paint Marking	Sticker Marking	Embossed marking	Approx. Length (cm)	Remarks
76/2022/1	145, GA, KM, UP	----	---	16 cm	counter fracture to each other
76/2022/2	145	----	---	20 cm	

4. **Visual examination**

Two broken AT weld rail pieces (counter to each other) were received for metallurgical investigation (**fig.-1**). One end of both pieces was fracture face and other end of both the pieces was saw cut. Topography of fracture revealed that the fracture had taken place transverse direction, towards HAZ - AT weld region in fast progressive fatigue manner (**figs.- 3 & 5**). Weld protruded fins were noticed at bottom of AT weld, this fin might be acted as stress raiser for fatigue initiation and dimension of fatigue zone is about 34 mm/ 12 mm on major/semi minor axis. The rest of the fracture faces were crystalline in nature (**figs.- 2, 4 & 6**). Metal flow was noticed on the gauge face side of rail table (**fig.-1**). Drill holes were also noticed on the rail table (**fig.-1**).

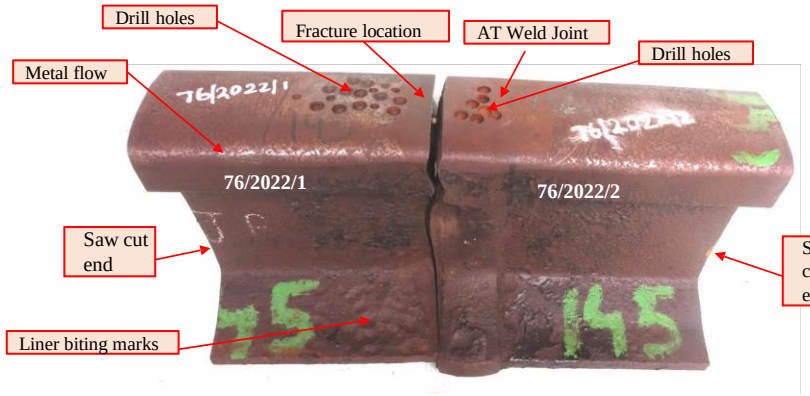


Fig.1 Photograph showing broken pieces of AT welded rail in as received condition from gauge side.

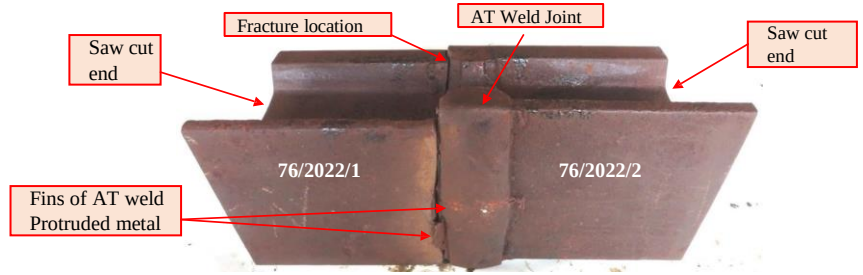


Fig.2: AT weld protruded fin at bottom of AT welded rail.

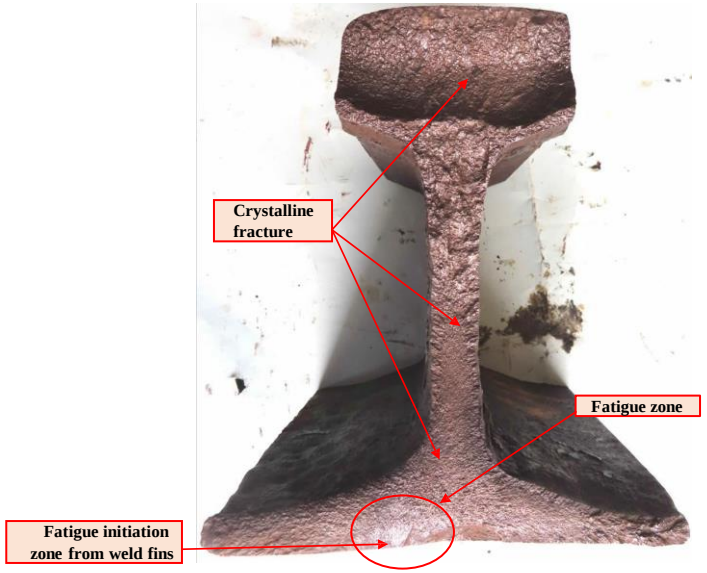


Fig.3: Fracture initiation of fatigue zone and crystalline fracture face of sample no 76/2022/1.

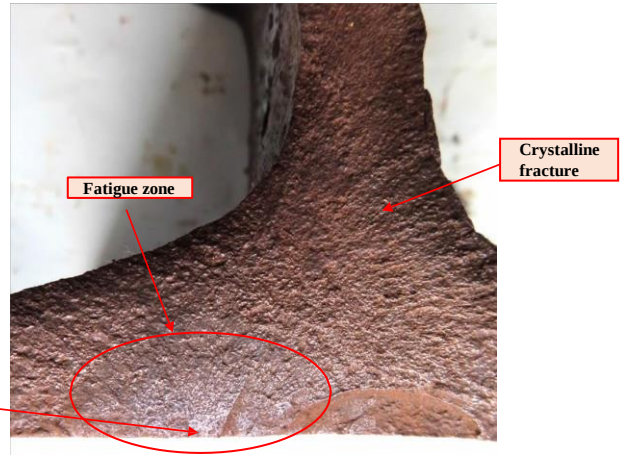


Fig.4: Close view of fracture initiation of fatigue zone and crystalline fracture face of sample no 76/2022/1.

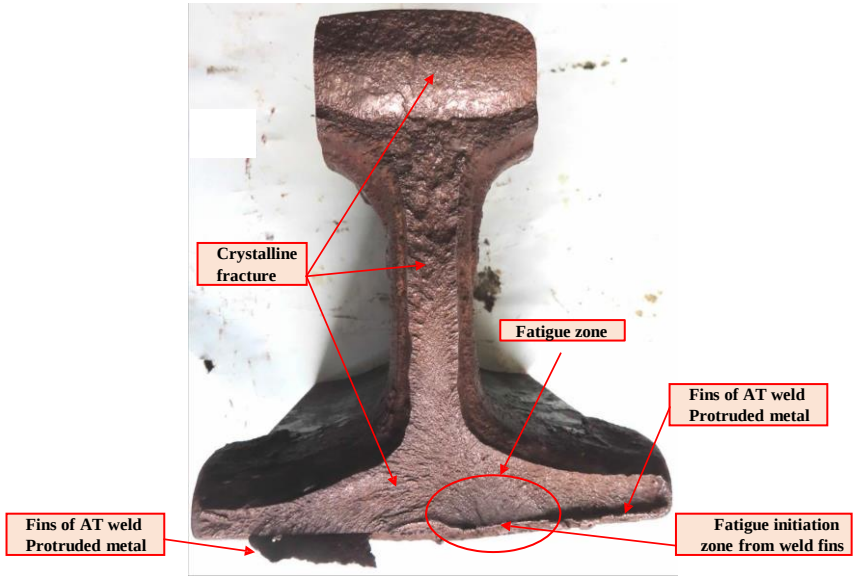


Fig.5: Fracture initiation of fatigue zone and crystalline fracture face of sample no 76/2022/2.

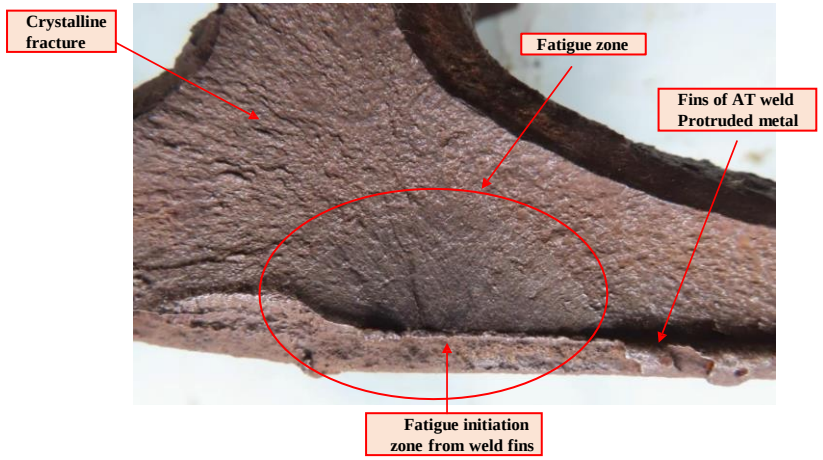


Fig.6: Close view of fracture initiation of fatigue zone and crystalline fracture face of sample no 76/2022/2.

5. Chemical Composition

Sample No.	%C	%Mn	%Si	%S	%P	% V*	%Mo*	%Al	%Cr
76/2022(Rail)	0.71	1.24	0.21	0.030	0.033	--	--	0.0005	--
Specified as per IRS T-12/2009 for 880 grade rail.	0.60-0.80	0.80-1.30	0.10-0.50	0.035 max.	0.035 max.	--	--	0.015 max.	--
76/2022 (Weld)	0.54	0.97	**0.67**	0.026	0.05	<0.0005	**0.07**	0.12	0.025
Specified as per IRS: T-19/1994	0.50-0.70	0.80-1.30	0.50 max	0.05 max	0.05 max	0.10-0.15	0.10-0.25	0.05-0.60	0.2 max
* **Either Mo or V is to be added as grain refiner** * **In case single shot crucible is used, Si% 1.2 max.**									

6. Hardness Test

A longitudinal section of AT weld joint was polished and hardness test conducted at Parent, Heat Affected Zone & Weld. The observations are given below:

Sample No.	Hardness, BHN (3000Kg/10mm/15secs)		
	Weld (BHN)	**HAZ (BHN)**	**Parent Rail (BHN)**
76/2022	**254, 257, 259**	**302, 302, 303**	266, 268, 269
Specified as per IRS T- 12/2009	-----	-----	260 BHN min.
Specified as per IRS T- 19/1994	265 + 20 - 0	± 20 BHN of actual parent hardness	265 BHN Average.

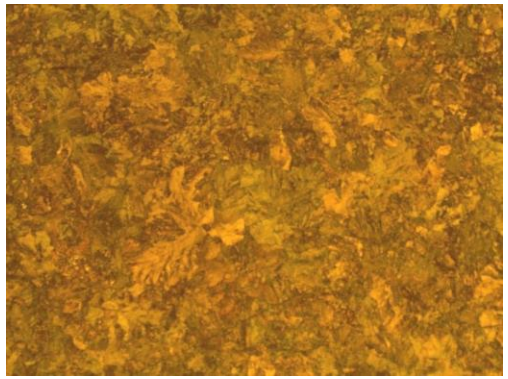
7. Macro-examination

A longitudinal slice of the weld, HAZ and parent rail was etched and macro-examination was conducted. It revealed no inherent abnormality (**fig. 7).**

Fig.7: Photograph showing weld, heat affected zone & parent metal of sample no 76/2022.

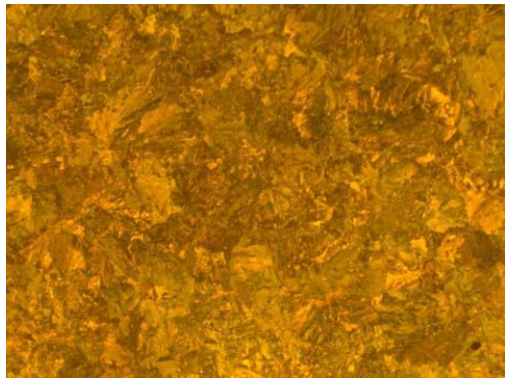
8. Micro-examination

Sample no.	Location	Observations
76/2022	Parent Rail	Revealed pearlite structure with specks of ferrite at places **(fig. 8).**
Specified as per IRS: T-12/2009		The microstructure shall be fully pearlitic with no martensite, bainite or grain boundary cementite.
76/2022	HAZ	Revealed fine pearlite with specks of ferrite at places (**fig. 9**).
Specified as per IRS T-19/1994		The microstructure shall not contain martensite or bainite.
76/2022	Weld	Revealed cast columnar grains of pearlite in broken matrix of ferrite **(fig. 10).**
Specified as per IRS T-19/1994		The microstructure shall not contain martensite or bainite.



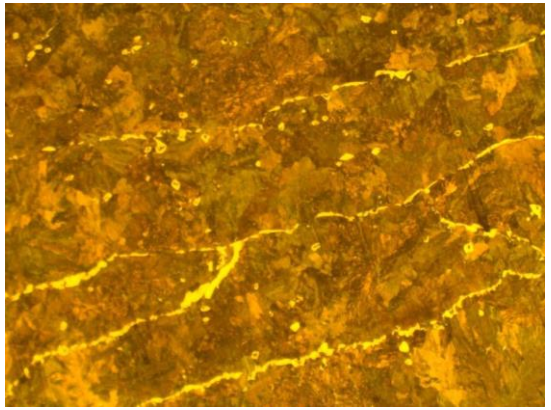
X100

Fig.8: Photomicrograph revealed pearlite with specks of ferrite at places in parent rail.



X100

Fig.9: Photomicrograph revealed fine pearlite with specks of ferrite at places in HAZ.



X100

Fig.10: Photomicrograph revealed cast columnar grains of pearlite in broken matrix of ferrite in weld portion.

9 USFD Comments:

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The sample contains two fractured pieces of AT welded Rail, which are counter of each others. The fractured rail weld pieces have been examined visually fatigue defect of size 34 mm X 12 mm is observed at rail bottom at one side of flange. This defect is not covered in normal rail testing using Ultrasonic Testing equipment (SRT/DRT) as per Manual for Ultrasonic Testing of rails & welds, Revised 2012.

Since this defect is a service defect hence, it was not available at the time of welding and this defect may be incipient in nature at the time of last subsequent periodic AT weld testing (i.e. 04.07.2019) and due to small size at the time of last periodic AT weld testing,

this defect may not be detectable at last periodic AT weld testing as per procedures laid down in chapter 8 of Manual for Ultrasonic Testing of rails & welds, Revised 2012.

10. Discussion

Chemical composition of parent rail conforms to the relevant specification. **Chemical composition** of ATW conforms to the relevant specification except high Si% - 0.67% against specified 0.50% max. (If single shot crucible was used, Si% is 1.20% max.) and low Mo% - 0.07 against specified 0.10 -0.25.

Hardness of rail is found to be satisfactory as per relevant specification and hardness of HAZ found higher than specified limit & AT weld found lower than specified limit as per relevant specification.

Macro-examination test revealed no abnormality in AT weld.

Microstructure of weld zone revealed cast columnar grains of pearlite in broken matrix of ferrite, microstructure of heat affected zone revealed fine pearlite with specks of ferrite at places & microstructure of parent rail revealed pearlite structure with specks of ferrite at places and considered satisfactory to the relevant specification.

It is evident from above that the metallurgy of rail conforms to the relevant specification and AT weld does not conform to the relevant specification in terms of chemical composition i.e. high Si% - 0.67% against specified 0.50% max. (If single shot crucible was used, specified Si% is 1.20% max., chemical composition conformed to the relevant specification), low Mo% - 0.07 against specified 0.10-0.25% and low V% - < 0.0005% against specified 0.1 – 0.15%, low hardness of AT weld & high hardness of HAZ. Microstructure of weld zone revealed cast columnar grains of pearlite in broken matrix of ferrite, microstructure of heat affected zone revealed fine pearlite with specks of ferrite at places & microstructure of parent rail revealed pearlite structure with specks of ferrite at places. The AT Weld had broken transversally from HAZ - AT weld region in fast progressive fatigue manner, weld protruded fins were noticed at bottom of AT weld, this fin might be acted as stress raiser for fatigue initiation.

11. Conclusion

Metallurgy of rail conforms to the relevant specification and AT weld does not conform to the relevant specification in terms of chemical composition i.e. high Si% - 0.67% against specified 0.50% max. (If single shot crucible was used, specified Si% is 1.20% max., chemical composition conformed to the relevant specification), low Mo% - 0.07 against specified 0.10-0.25% and low V% - < 0.0005% against specified 0.1 – 0.15%, low hardness of AT weld & high hardness of HAZ. Microstructure of weld zone revealed cast columnar grains of pearlite in broken matrix of ferrite, microstructure of heat affected zone revealed fine pearlite with specks of ferrite at places & microstructure of parent rail revealed pearlite structure with specks of ferrite at places. Due to high hardness of HAZ, low hardness of AT weld and chemically deficient material of AT weld, AT weld might be brittle in nature. Due to weld protruded fins at bottom of AT weld, might be acted as stress raiser for fatigue initiation leads to fracture of AT welded rail in fast progressive fatigue manner at HAZ - AT weld region. Breakage of AT-weld transversally across the weld-HAZ region in fast progressive fatigue manner is attributable to combined effect of chemically deficient material, high hardness of HAZ, low hardness of AT weld and weld protruded fins in service.

Above conclusions have been made based upon metallurgical investigation of available sample and data only.

12. Recommendation

i. AT Welding execution practice may be ensured as per manual.

ii. Specified time shall be given for mould opening to avoid high hardness of HAZ.

iii. Portion material may be ensured as per manual.

iv. Rail steel is notch sensitive. Any fins/notch like formation may be avoided.

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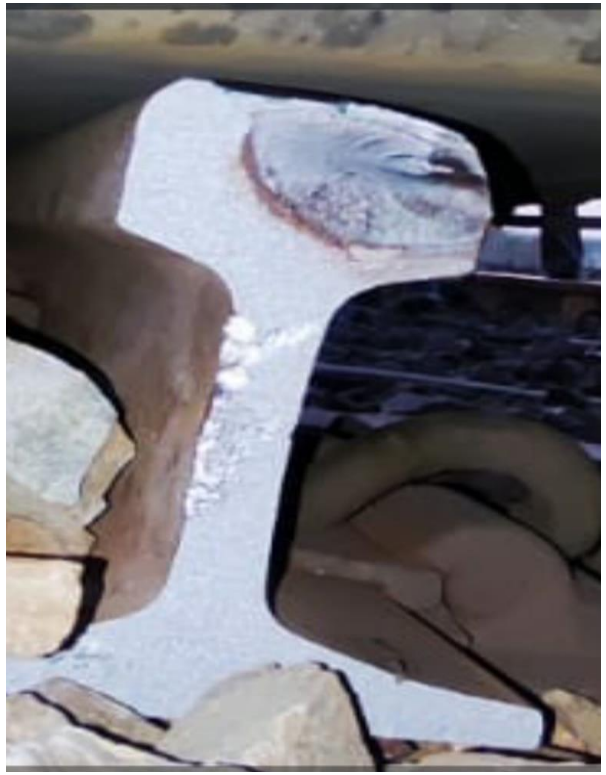
1. Sr. DEN/Co-ord/KIR/NFR ……. **(By Regd. Post)**
DRM (Work) Office, Northeast Frontier Railway, Katihar – 854 105

2. ED/Track-I/RDSO

Derailment of SuryaNagari Exp.(12480)

Date of failure	:	02.01.2023
Place	:	Between section Rajkaiwas and Bomadara
Division	:	JU(Jodhpur)
Rly	:	NWR
Subject	:	Rail fracture

Rail Failure



Transverse Fissure/Hydrogen embrittlement

- Resembles a kidney in shape in the rail head.
- Mainly hydrogen accumulation causes this defect.
- Originates from nucleus/crystalline centre located inside rail.
- Subsurface defect formed around 10-20 mm below rail head surface.
- Propagates outward at right angle to the length of rail.
- Smooth, bright/dark round/oval surface.
- Growth is slow until it reaches up to 25%, then rapid.
- Defect may be introduced during manufacturing of rail or when poor welding is done in rails.
- Can be detected by 70^0 transducer during UST of rail.

Hydrogen embrittlement

- As little as 0.0001 wt. percent of hydrogen can cause cracking in steel.
- Hydrogen is present in steel as monoatomic hydrogen due to dissociation of molecular hydrogen.
- Because it is very small interstitial atom, it can diffuse very rapidly at temperature above room temperature.
- As hydrogen diffuses into voids, microcracks high pressure is developed.
- No single fracture mode that is characteristic of hydrogen embrittlement
- Most prevalent in high strength material.

Thank You!