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Development of New Generation Rails for Railway Application

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Abstract— *The present work is an endeavour to develop rail steel with strength, ductility, corrosion resistance and fracture toughness properties superior to 90 UTS rails. It has been statistically established by Indian Railways that erstwhile 72 UTS rails (C-0.40-0.60 wt%) are less prone to sudden failure as compared to present 90 UTS rails (C-0.60-0.80 wt%). 72 UTS rails are associated with good fracture toughness and elongation properties. However, reduction in carbon level is associated with reduction in strength. Eight laboratory heats with carbon ranging from 0.40 to 0.55 wt% were made with addition of various alloying elements like Cr, V, Nb, Ni, Cu in different combinations to achieve desired properties. Alloying elements were selected on the merit of their strengthening and corrosion resistance properties. Results have shown improvement in tensile, hardness, fracture toughness and corrosion resistance properties.*

1. INTRODUCTION

Modern railway systems are subject to intense use, with fast trains and large axle loads. There are many criteria which determine the suitability of steel for rail track applications. The primary requirement is structural integrity, which can be compromised by a variety of fatigue mechanisms, by a lack of resistance to brittle failure, by localised plasticity and by excessive wear. All of these depend on interactions between engineering parameters, material properties and the environment. The track material must obviously be capable of being manufactured into rails with a high standard of straightness and flatness in order to avoid surface and internal defects which may cause failure Indian railway is carrying 20.32 t axle load on most of the BG routes and it is planning to universalize 25t axle load for BG routes with higher speed and dedicated freight corridors. Our rails are also applied to use in coastal/ corrosion prone areas. There is the problem of discharge of human excrement onto the rails, which exerts severe corrosive attack. So property requisites for a modern-day rail are good resistance to fracture, adequate high cycle fatigue resistance to counter in-service problems like shelling (Incidentally, shelling is a fatigue-type of failure associated with initiation and propagation of sub-surface cracks culminating in spalling of rail pieces from the running surface of a rail head), must exhibit low fatigue crack growth rates, must have excellent wear resistance must possess sufficient resistance and must show corrosion resistance. It's a user dream to get a rail with all properties together. In an endeavor to achieve the same current project was undertaken with useful inputs from RDSO. RDSO records of fracture shows that 70 % of total failure occurred either at weld joints or heat affected zone while 30 % fractures were reported away from joints. Survey also shows the frequency of occurrence of sudden failure was more in 90 UTS rails than that of 72 UTS rails. 72 UTS rails being low carbon hypoeutectoid grade shown great fracture resistance but poor tensile properties. In order to increase its tensile properties 72 UTS rail was alloyed with various combinations of alloying elements and properties were investigated. Report includes detailed laboratory experiments, results and investigations along with rolling of a selected grade at BSP.

2. CURRENT TECHNOLOGICAL TRENDS

. Indian railway is carrying 20.32 t axle load on most of the BG routes and it is planning to universalize 22.82t axle load for BG routes and Construct dedicated freight corridors fit for 32.5 t axle loads. Feeder route required for connecting existing route to DFC are to be for minimum 25t axle load. So there is need to improve in metallurgy of rail to carry 32.5 t axle load which in terms of having property greater resistance against rail wear caused by wheel interaction as well as longer life (GMT). Bhilai Steel Plant is the sole supplier of rails to Indian railways. Its two sections under C-Mn rail category in R 52 & R 60 Kg are capable to withstand a maximum axle load of 29.12 & 33.79 t respectively. Increasing cross section weight to 68 Kg can increase the load bearing capacity to 38.1 t. The axle load has always shown an increasing trend over the years. Days are not far when when BSP will be asked to design rails for 40t axle load bearing capacity. The worldwide trend also depicts the same story. In USA rails are mainly used for carrying ores and goods. The axle requirement for their rails is more than 30t.

In order to address all of above glaring issues, RDCIS in recent times in close association with BSP and RDSO has embarked on a mission to develop new grades of special rail steels to cater to the diverse requirements/ applications of Indian Railways. As a result, three new categories of rails have been developed over the recent years and few are in laboratory scale.

- Microalloyed pearlitic rails with low alloying additions of Nb or V, high YS/UTS ratio and excellent resistance to in-service plastic flow and deformation. BSP has also taken initiative to develop 110 UTS rails by alloying with Cr-V-Nb.
- Marine-weathering pearlitic rails with low alloying additions of Cu & Mo and with corrosion resistance derived from the development of a protective, adherent rust layer for during heavy-haul service in coastal/ corrosion-prone environments. RDSO, IIT Kanpur, RDCIS & BSP jointly developed a new class of corrosion resistant rail by alloying Nickel-Chromium-Copper. Both rails have shown excellent weather resistant properties and are commercially produced and laid at coastal regions of Indian Railway.
- Corrosion resistant high strength rail (Cr – Cu) to sustain stringent operating conditions. New alloy design is being worked out at RDCIS laboratory to propose a rail under this category.

3. EXPERIMENTAL

Several alloys have been made to achieve following mechanical properties.

UTS : 880-1000 N/mm^2

% El : 13-15

YS : 560 (Min.) N/mm^2

Hardness : 300 BHN

Fracture Toughness -20^{o}C: >35 MPa√m

Experimental heats were made at Melting and Solidification lab of RDCIS. Heats were made in air induction furnace of 50 Kg capacity. Two ingots in dimensions110x100x350 mm were casted from each heat. Casted heats were allowed to air cooled and stripped at room temperature. About 25 mm from top is sliced to remove the defects associated with pipe. Achieved chemistries of all heats are mentioned in Table 1.

Table 1: Chemistry of different heats

Grade	YS. MPa	UTS, MPa	% El	Fracture toughness, MPa√m	CVN, J	Hardness, BHN	Corr. Res. Index
HTCR 1A	825.5	1101.0	14.90	37.68,37.85	5.0	283.0	1.260
HTCR 1B	824.0	1141.0	12.80	33.01,32.71	3.0	298.0	1.220
HTCR 1C	653.5	1033	15.8	35.11, 36.87	6.0	301.5	
HTCR 2A	753.5	1038.5	11.8	35.40, 37.92	7.5	287.0	1.590
HTCR 3A	560	870.5	17.5	40.69,39.75	9.3	252.0	

4. RESULTS AND DISCUSSION

Mechanical testing samples of all grades were carried out. Tensile test was carried out at RDCIS and BSP while all other tests were carried out at RDCIS only. Test result is compiled in Table 2.

- HTCR 1 & 2 grades have YS, UTS & % El values more than the required values. However % El for HTCR2 is slightly less (11.2%).
- 283, 298, 287 & 252 BHN hardness was achieved in HTCR 1A ,1B, 2A & 3A grades respectively which are higher than the required value of 280 BHN except for 3A.
- Fracture toughness of all grades except 1B was found higher than 90 UTS rail. It was expected also as lower carbon concentration leads to higher fracture toughness.
- It was inferred with the test results that higher Cr concentration in 1A & 1B was responsible for increasing the UTS above 1100 MPa. Higher strength and hardness was also achieved in 2A with lower elongation. 3A could not match with the required values hence was discarded from consideration. It had happened due to very low carbon (0.44%) and absence of strong strengthening element. It can be compared with 1A in which carbon concentration was kept at 0.42% and UTS of 1100 could be achieved. It was possible due to presence of Cr. The response of other elements like V, Nb & Si could not be ignored. They have definitely improved the mechanical properties. 1A, 1B, 1C were added almost equivalent amount of V, Nb & Si to see the effect of C & Cr on mechanical properties.
- Grade 2A was derived from similar grade being rolled in BSP popularly known as NCC rail. Ni, Cr & Cu concentration in experimental grade 2A was kept similar to NCC grade but Carbon was reduced in a view to increase fracture toughness. Small amount of Nb was also added to compensate the strength loss due to reduction in carbon concentration. All values except elongation were found as per requirement. %El was found slightly lower (11.8%).
- It has been reported in literature that higher amount of Cr leads to lower value of fracture toughness. It has also been noticed that Arcellor Mittal has limited the use of Cr to 0.5 % in their rail steel due to this effect only.
- Based on literature and results found, grade 1C was made by reducing Cr concentration to 0.4 % keeping carbon to 0.49 %. As expected YS & UTS value came down but remained within the specified limit. Highest hardness out of five grades (301 BHN) was achieved with a fracture toughness value of 37 MPa√m.

Table 2: Mechanical properties

Type	C	Mn	Si	S	P	Cr	V	Nb	Ni	Cu	Mo
HTC R1A	0.42	1.30	0.63	0.02	0.029	0.84	0.113	0.023	-	-	-
HTC R 1B	0.56	1.31	0.24	0.019	0.032	0.63	0.114	0.018	-	-	-
HTC R 1C	0.49	1.56	0.66	0.028	0.028	0.40	0.11	0.021	-	-	-
HTC R 2A	0.49	1.41	0.45	0.023	0.030	0.69	-	0.022	0.33	0.35	-
HTC R 3A	0.44	1.41	0.60	0.019	0.023	-	-	-	-	0.32	0.20

One grade out of 5 made at laboratory scale was selected for plant scale production. HTCR 2A grade was having best combination of properties. Protocol for its plant scale production was made. One heat as per decided chemistry shown in was made in sms II and continuous casted into 24 nos of blooms. 4 Nos of blooms were selected for rolling in Rail & Structural Mill, BSP and properties were investigated.

5. CONCLUSION

- Grades alloyed with Cr were found to have maximum tensile strength but lower fracture toughness and corrosion properties.
- Lowering carbon concentration of Cu-Mo rail resulted in maximum value of fracture toughness with lower tensile strength values. It has seriously affected the microstructure and shifted to fully bainitic which is not desirable.
- Based on the results and findings it can be concluded that tensile and a fracture toughness property of rail steel is inversely related and a compromise between two should be aimed at.
- Grade 1C & 2A have shown best property among all grades and should be considered for further development.
- Plant scale production of grade 2A has established that high strength with high elongation is achievable Acknowledgements

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