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Metallurgical Investigation of Tie Rod used for lifting Ferro-Alloy during Steel Making: A Safety Issues

Souvik Das*, **Kaushal Kishore and Manashi Adhikary**

Tata Steel Limited, Jamshedpur, India

***Corresponding author:** Dr. Souvik Das, Sr Manager, BIS and Documentation, Scientific Services, Technology and New Materials Business Division, Tata Steel Limited, Jamshedpur – 831007, India, Tel: +91-8092084714; Email: souvik.das@tatasteel.com

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Abstract

In steel making industry, bottom dispenser buckets are widely used to carry ferro-alloys, lime or other materials from one place to other or one height to other. In one of the steel making shops, such bottom dispenser buckets are used for lifting ferro-alloys which is charged further to ladle furnace. One of the ferro alloy buckets with carrying capacity up to 3 Ton failed while being lifted and crash against sidewalls of the cage and an observation platform. Fortunately, no one was reported injured due to the incident. Upon observing the failure, it was revealed that the bucket fell due to fracture of its tie rod while lifting ferro-alloys. Visual observation reveals thermal cracks and significant thining which indicates enourmous amount of deformation that the bracket underwent prior to failure. Fractography of the fracture surface of the bracket showed dimples and these dimples have predominantly graphite nodule within them. It suggests ductile mode of failure probably due to exposure to high temperature for prolonged duration that activated sufficient slip systems to cause plastic deformation before fracture. Chemistry of the failed tie rod complied with the specification of AISI 431 Martensitic stainless steel. And the bracket was made up of SG iron. Micrograph of the failed bracket showed substantial bursting of the graphite nodules. These are typically observed when SG iron are subjected to very high temperature for prolonged time. It is evident that such detoriation occurred during service as graphite nodules were observed without any bursting in unused / new bracket. SEM micrograph revealed creep voids predominantly at grain boundary triple points. Precipitation of chromium carbide was observed along grain boundaries as confirmed by EDS analysis. The above analysis reveals that tie rod and bracket failed in creep mode due to exposure to excessive (unusually high) flame for prolonged duration.

Keywords: Tie Rod; Dimples; Graphite Nodules; Temperature; Creep Mode

Introduction

In steel making shops, Ferro alloys are added during steelmaking to achieve certain desired properties in the final product. These ferro-alloys are fed to the steel in the ladle refining furnace via a conveyor which is at a suitable height. The ferro-alloys are generally lifted to this height using bottom dispenser buckets. In bottom dispenser buckets (BDBs), the bottom portion has a hole at its center which is closed by an umbrella shaped disc. This disc is connected to a tie rod which passes through a pipe attached at the center of the bucket which in turn acts as pathway for the movement of this tie rod. The tie rod is then fixed to a plate with C-hook to form a lifting arrangement [1]. The photograph of the BDB and its representative drawing is shown in Figure 1. These buckets rest on a frame and the tie rod-umbrella assembly is pushed downwards which in turn releases the material through the opening at the bottom. The movement of buckets from filling station to lifting station is done using fork lifts with modified boom. These buckets carry loads up to 3 tons. As the bucket is lifted with the help of tie rod, the entire load is carried by the tie rod while lifting the filled bucket. These buckets are lifted to the heights as high as 20-25 meters and thus become a safety hazard if any of the tie rods fail while it is being lifted.

Experimental Procedure and Results

Failed sample was collected from the drawing mill for investigations. The sample was cleaned with acetone to remove dirt for visual examination prior to metallographic sample preparation. Transverse and longitudinal specimens were made from the breakage location of each failed samples for conducting light optical microscopic examination. These samples were individually mounted in conductive mounting and polished by conventional metallographic techniques for scratch free surface. The polished samples were etched in 3% nital solution (3 mL HNO3 in 97 mL ethyl alcohol), and both un-etched and etched samples were examined in a light microscope to observe microstructural constituents optical (Leica DMRX) and stereo micrography (Leica DMC4500). Scanning electron microscopy image was performed with a (ZEISS FEG-SEM)). The hardness was determined by Vickers hardness testing machine (EMCO Duravision 20).

Results

Visual observation

Failure occurred after approximately 1 month of service life which is much below is its expected service life of at least 6 months. Tie rod thinned down substantially as shown in the Figure 1. Bracket also suffered substantial deformation prior to fracture.

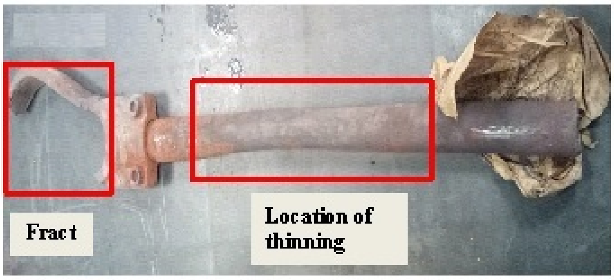

Figure. 1a shows the overall view of the failed tie rod and the bracket.

Measurement of thickness was carried out along its length. It revealed a minimum thickness of 56.5 mm at the location of thinning. At locations away from thinning, thickness was measured to be 69.62 mm. The length of the tie rod is around 1880 mm and it get increased up-to 2145 i.e 12.35% elongation was observed in the failed region. The original diameter was 65 mm and diameter at the necked region was 56.5 mm thus there is around 13% reduction in diameter. One sample was taken from the region where no necking was observed and no thinning was observed at that location. Tie rods are often exposed to flame of the LD vessel along with the tensile stress. This situation is sufficient to cause creep mode of deformation. However, this needs to be validated with microstructural analysis. Figure 2 (a) shows the overall view of the failed tie rod along its length.

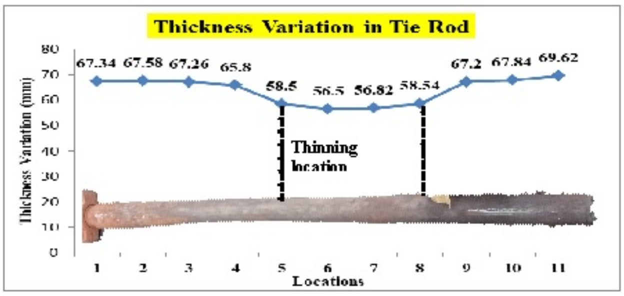

Figure. 1b: Visual images of the failed tie rod

Failed bracket is shown in Figure 1(c). Thermal cracks are observed. New bracket is shown in Figure 1 (d). It was referred for non-destructive analysis. Comparing this with the failed one suggests the enourmous amount of deformation that the bracket underwent prior to the failure.

Figure.1: Visual images of the (c) failed bracket, (d) new bracket

SEM fractography of bracket

Fracture surface of the bracket showed dimples as shown in Figures 2a and 2b. These dimples have predominantly graphite nodule within them. It suggests ductile mode of failure which is rare for cast iron and it is due to exposure to high temperature for prolonged duration that activated sufficient slip systems to cause plastic deformation before fracture.

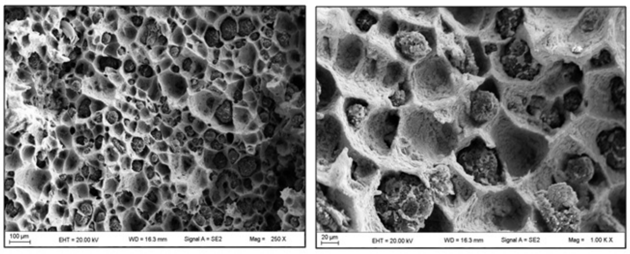

Figure. 2: SEM Fractography of the failed bracket: (a) 250x, (b) 1000x

Chemical analysis

Sample id.	C	Mn	S	P	Si	Cr	Ni	Mo	V	Cu	Nb	Mg	Ti
Bracket	2.87	0.38	0.017	0.018	0.50	0.021	0.006	-	0.012	0.012	-	0.048	0.038
Tie rod	0.152	0.750	0.015	0.030	0.410	15.300	1.460	0.208	0.070	0.159	0.016	0.000	-
AISI 431 Stainless steel	0.20 Max	1.00 Max	0.03 Max	0.04 Max	1.00 Max	15-17	1.25-2.50	-	-	-	-	-	-

Table 1: Chemical Analysis (Wt.%)

Chemical analysis of samples was carried out using x-ray fluorescence (XRF) spectroscopy except C and S (Table 1). The carbon (C) and (S) contents were analyzed by combustion infrared technique. Chemistry of the failed tie rod complied with the specification of AISI 431 Martensitic stainless steel. No deviation in the chemistry was observed as per drawing. Bracket was made up of SG iron. Mg was added for speroidization of graphite.

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Microstructure analysis

Micrograph of the failed bracket showed substantial bursting of the graphite nodules (Figures 3a-3d). These are typically observed when SG iron is subjected to very high temperature for prolonged time. It is evident that such detoriation occurred in the failed bracket during service as graphite nodules were observed without any bursting in unused / new bracket (Figure 3e and 3f).

Failed Bracket:

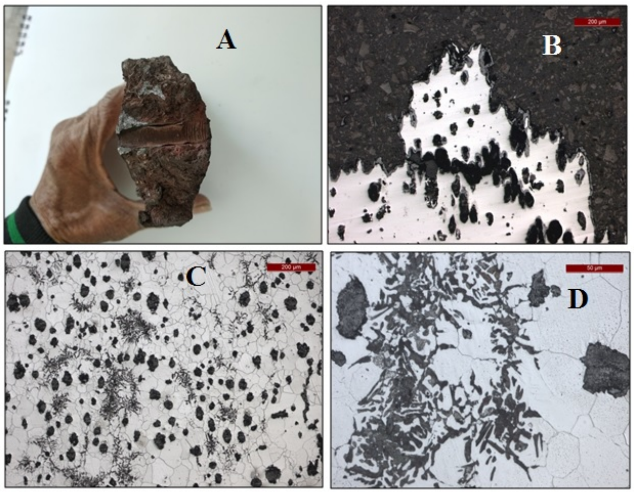

Figure. 3: (a) Location of micro-sample preparation, (b) un-etched micrograph showing fracture contour, (c) etched micrograph-100x, (d) etched micrograph-500x

New Bracket:

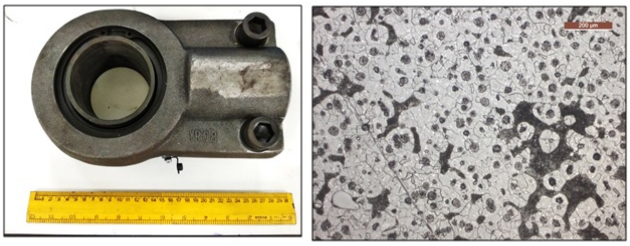

Figure. 3: (e) location of microstructural analysis in new bracket through in-situ metallography, **(f)** replica micrograph of the new bracket-100x

Scanning electron microscopy analysis

EDS analysis was carried out on the globular particles found in microstructure in the necked region. The EDS analysis in the globular particles showed iron carbides at grain boundary and along that at 5000 X magnification few creep voids were observed at grain boundary triple points as shown in Figure 4 and Table 2. Hardness profile was measured along the length of the tie rod (Table 3). An increase in hardness was observed near thinned region. This is probably due to microstructural deterioration due to precipitation of carbides at elevated temperature.

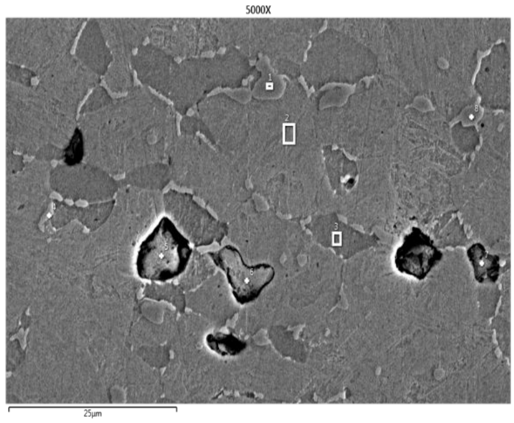

Figure. 4: SEM micrograph of the failed tie rod in thinning location

Spectrum Label	1	2	3	4	5	6	7	8
C	9.55	3.42	3.81	13.33	5.45	6.46	7.1	16.79
O					1.34		1.98	
Si		0.5	0.52		0.69		0.57	
S	0.5						0.4	
Cr	54.39	14.37	16.11	17.1	15.64	13.87	16.28	53.92
Mn		1.03			0.97	0.98	2.89	
Fe	35.56	79.37	79.57	68.35	74.94	77.66	69.52	27.85
Ni		1.31		1.22	0.97	1.02	1.26	

Table 2: EDS analysis (Wt.%)

Hardness Profile:

Hardness profile was measured along the length of the tie rod. An increase in hardness was observed near thinned region. This is probably due to microstructural deterioration due to precipitation of carbides at elevated temperature.

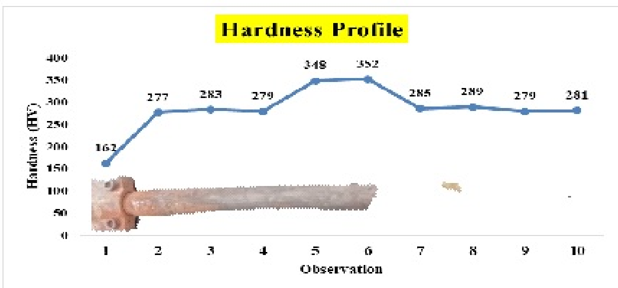

Figure. 5: Hardness Profile of the failed tie rod

Sample ID	Avg. Hardness
4243-19-Bracket	161.67 (HBW)
4243-19-Near thinned region	350-360 (HV10)
4243-19- Away from thinned region	277-289 (HV-10)
As per Drawing	265-295 HV

Table 3: Hardness profile of different location of failed sample

Steady state creep rate

The steady state creep behavior has been investigated by evaluating the creep rate.

Initial Length=1880 mm

Final Length=2145 mm

Change in Length=265 mm=0.265 m

Time of failure=3 months=3*30*24*6 0*60 seconds

Assuming Steady state creep rate (έ)=d€/dt=Change in length/ time=0.265/ (3*30*24*60*60)=3.4 × 10-8 m/s.

Generally, for creep resistant steel the steady state creep rate should be 10-11 m/s; 3 order lowers than that of the present used material.

Discussion

The tie rod of the vessel skirt lifting failed. The tie rod was found thinned at hot working zone of its total length. The working temperature was 650°C-700°C. The thinning of tie rod under tensile stress and temperature may be due to high temperature deformation called Creep [2]. Tie rod was made up of AISI 431 martensitic stainless steel, which is as per the specification. Both the new and failed brackets were made up of SG iron. Substantial thinning and elongation of the tie rod and bracket was observed. Both suffered from microstructural deterioration. In contrast to the nodular graphite in the new bracket, failed bracket had burst-out graphites [3-5].

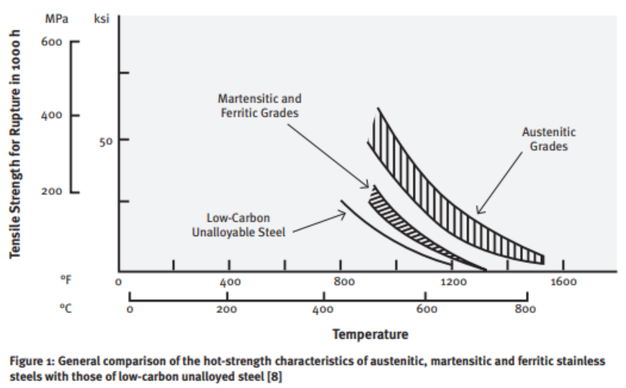

Figure 6: Tensile Strength for Rupture in 1000h

Likewise, extensive grain boundary precipitation of chromium carbides was observed in failed tie rod. These are characteristics of creep. Furthermore, creep voids were also observed in the tie rod. The steady state creep rate was calculated for the working hours of tie rod and found to be 3 orders lower than general creep resistant steel [6,7]. For better creep performance as shown in the Figure 6, certain austenitic grades have substantially higher tensile strength for rupture in 1000 h at all temperatures between 800°C-1200°C compared to ferritic or martensitic grades (existing). Thus, there exists a scope of improved creep resistant material.

Creep Resistance Steel	Operating Temp (Deg.C)	Creep rate (m/s)	Tensile Strength (Mpa)@RT	Strength @650 Deg. Temp (MPa)
9Cr1Mo(QT)	550-650	10-Sep	>600	140
X10CrMoVNb9(QT)	650	10-Sep	>600	170
NiCr20TiAl	>650	10-Oct	600	190
GX30CrSi7 (austenic matrix)	800-900	10-Nov	600	200
GX35NiCrSi2521 (austenic matrix)	>850	10-Nov	650	200
AISI 446 (Ferritic Stainless)	>750	10-Oct	500	150
AISI 431 (Martensitic Stainless)	>750	10-Oct	>850	250

Table 4: Creep Resistance Steel

As shown in the Table 4, although the present grade, i.e., ASIS 431 has a creep rate of 10-10 m/s which makes it quite resistant to creep, there are grades like GX30CrSi7 and GX35NiCrSi2521 which are having an order of magnitude lower creep rate and can improve the service life. As shown in Table 4, these grades can be used at much higher operating temperatures compared to the existing one [8]. Thus, all effort should be made to replace the existing grade with one of these grades of austenitic stainless steels.

Conclusion

Tie rod and bracket got elongated and thinned and failed in creep mode possibly due to exposure to excessive (unusually high) flame for prolonged duration.

Recommendations

For tie rod purpose, grades like GX30CrSi7 and GX35NiCrSi2521 can be used.

Possibility of providing a ceramic insulation layer of around 500 μm should be explored.

Closer monitoring of the operating parameters is needed to minimize excessive splashing/ exposure to flame.

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