Failure Analysis of Billet Caster Tundish Tilter Bolts

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Abstract - A detailed failure analysis was carried out on prematurely failed 60mm diameter bolts of billet caster tundish tilter. The analysis involves visual examination, chemical composition, microstructure, inclusion, bulk hardness, charpy impact toughness, fractography of the failed and new bolt. The result show that the bolts were of 34CrNiMo6 grade with tempered martensitic microstructure, having MnS and alumina inclusions. All the bolts has failed at thread grooves with the river mark on the failed surface indicating fast fracture of the bolts. The bolts were found to be heat treated at a wrong tempering temperature leading to poor impact toughness and hence while tilting; the bots were failed prematurely due to impact load from the jerk. A mix mode of failure with numerus cracks are seen on the fracture surface indicating poor toughness of the bolts conformed by charpy test. It is recommended to correct the heat treatment as per the specification to prevent such premature failures.

***Key Words*: Tundish tilter bolts, wrong tempering temperature, high hardness, poor impact toughness, premature failure**

1. INTRODUCTION

There are many reasons for which bolts and fastener fail such as overloading failure due to excess loading, fatigue failure resulting from presence of large inclusions, dents, corrosion pits, high roughness, high cyclic load, improper alignment, loose connection, corrosion fatigue, embrittlement such as temper martensite embrittlement, temper embrittlement, hydrogen embrittlement, stress corrosion cracking etc. [1-8].

34CrNiMo6 steel is a medium-carbon low-alloy high-strength quenched and tempered steel widely used in various industrial fields. The steels are having excellent fatigue and wear properties in addition to high strength, high toughness and good hardenability [9]. It is also reported that the fasteners being stronger are not necessarily be better as hydrogen can have in the high strength fasteners to give the adverse effect [10].

The specification for 34CrNiMo6 steel is forging or hot rolling in the temperature range of 1100 to 850°C, normalising in the temperature range of 850 to 880°C followed by air cooling, soft annealing in the temperature of 650 to 680°C followed by furnace cooling, hardening in the temperature range of 830-860°C followed by oil quench, tempering in the temperature range of 540 to 660°C followed by air cooling. With the quench and tempered condition for the thickness range of 40 to 100mm diameter, the properties should be minimum of 800MPa yield strength, 1000 to 1200MPa ultimate tensile strength, 11% elongation with 50% reduction in area and notch impact energy of minimum 45Joule [11, 12]. In the present investigation, 60mm diameter 34CrNiMo6 bolts of tundish tilter stand were analyzed to find out the root cause of failure.

2. HISTORY OF FAILURE

The billet caster at SMS-II of JSW Vijayanagar Works, have approximate weight of empty tundish 35ton (Skull 7-10ton), with skull weight of tundish 45ton and in emergency condition tundish weight 70ton. The tundish tilter bolts of 60mm diameter were getting repeated failure in approximate 6 month of service. The bolts experience temperature in the range of 100-150°C in service. In the present case, all the four bolts were failed while tilting leading to fall of material. It is suspected that due to un-balancing of the tilter the accident occurred. A detailed failure analysis has been carried out to investigate the root cause of the bolt failure. Digital image for the visual examination, dimensional measurement, SPECTRO make OES for composition, optical microscopy using an Olympus make opto-digital microscope, Hitachi make scanning electron microscope (SEM), Bulk hardness (Brinell hardness) measurement through an Welspun make Universal hardness tester and Zwick/Roell make impact tester were used for the failure investigation to sort out the root cause of failure of the bolts.

3. CHARACTERIZATION OF FAILED BOLTS

3.1 Visual Examination

Fig. 1 shows digital image of (a) empty tundish, (b) skull from the tundish (c) tundish tilter (d) – (f) bolts on tundish tilter which were being failed. Fig. 2 (a) - (d) shows close view of the bolts with their fracture surface. It can be seen that the bolts are failed at the thread regions where the stress concentration is supposed to be high. The river marks on the fracture surface indicates fast fracture of the bolts [13].

Fig-1: (a) Empty Tundish (b) Skull (c) Tundish Tilter (d)-(f) Tundish Tilter Bolts.

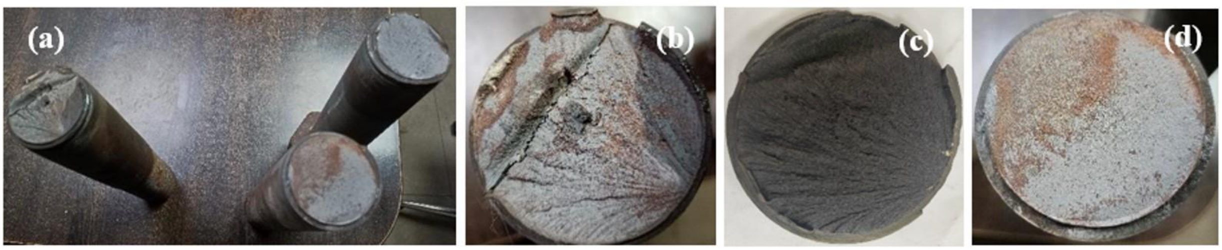

Fig-2: (a) Failed tundish tilter bolts, (b) – (d) fracture surface of the three tundish tilter bolts.

3.2 Chemical Composition

The chemical composition of a typical failed bolt was carried out using SPECTRO make OES as shown in Table-1. The composition matched with the specification of 34CrNiMo6 steel grade. This is a high alloy steel with through hardening characteristics with ultra-high strength range. The steel has 0.017% Al and 0.06 %S, which means it is an Al deoxidized grade that is re-sulfurized to improve the machinability of the bolt. These fasteners maintain strength 1000 to 1300 MPa retaining high toughness and fatigue life. The bolt also gets heated when tundish is filled with molten metal, a high alloy steel withstands temperature preventing the microstructural deterioration in such environment.

Table-1: Chemical composition of the bolts compared with the specification of 34CrNiMo6

Sample	C	Mn	S	P	Si	Al	Cr	Ni	Cu	Nb	V	Ti	Mo	B	Sn
34CrNiMo6	0.30-0.38	0.50-0.58	0.035	0.025	0.10-0.40		1.30-1.70	1.30-1.70	0.40 max				0.15-0.30		
New Bolt	0.352	0.60	0.053	0.045	0.272		1.155	1.455	0.140	0.005	0.015	0.002	0.215	0.0015	0.005
Failed Bolt	0.355	0.61	0.056	0.042	0.276	0.017	1.151	1.450	0.139	0.007	0.015	0.002	0.212	0.0014	0.005

3.3 Inclusion Analysis

The optical microstructure of the steel show inclusion as shown in Fig.3 (a) and (b) obtained from new bolt and failed bolt respectively to evaluate the worst field inclusion ratings as per ASTM E-45 as in Table 2. The inclusion rating in the failed and the newly made bolt is given. The bolt has high level of inclusion, but in service the high level of inclusion has potential to initiate fatigue cracks.

Table-2: Inclusion Analysis –Worst Field Method (ASTM E-45).

Bolts	A-Sulfide Type		B-Alumina Type		C-Silica Type		D-Globular Oxide Type	
	Thin	Thick	Thin	Thick	Thin	Thick	Thin	Thick
New	2.0	-	1.5	-	-	-	1.5	-
Old	3.0	-	1.5	-	-	-	1.5	-

Fig-3: Optical image of the inclusion in new bolt(a) and failed bolt (b).

3.4 Microstructure

The optical microstructure in **Fig. 4** (a) and (b) shows the new bolts at the edge and center region whereas (c) & (d) corresponds to the microstructure of the failed bolts. The microstructure of the new and failed bolts were found to be tempered martensitic in nature. No significant variation in microstructure was seen from the surface to the center of the bolts indicating no surface hardening treatment is made on the bolts.

The SEM microstructure of the new bolt at the edge region at low and high magnification is shown in Fig.5 (a) & (b) and that of the failed bolt in **Fig. 5** (c) & (d) respectively. The core microstructure of the new bolts is shown in Fig. 6(a) & (b) and that of the failed bolts is shown in Fig. 6(c) & (d) respectively. The tempered martensitic structure is seen in the micrographs of both the new and old bolts. However, the martensitic laths found in the microstructure of the new bolts indicating its low temperature tempering.

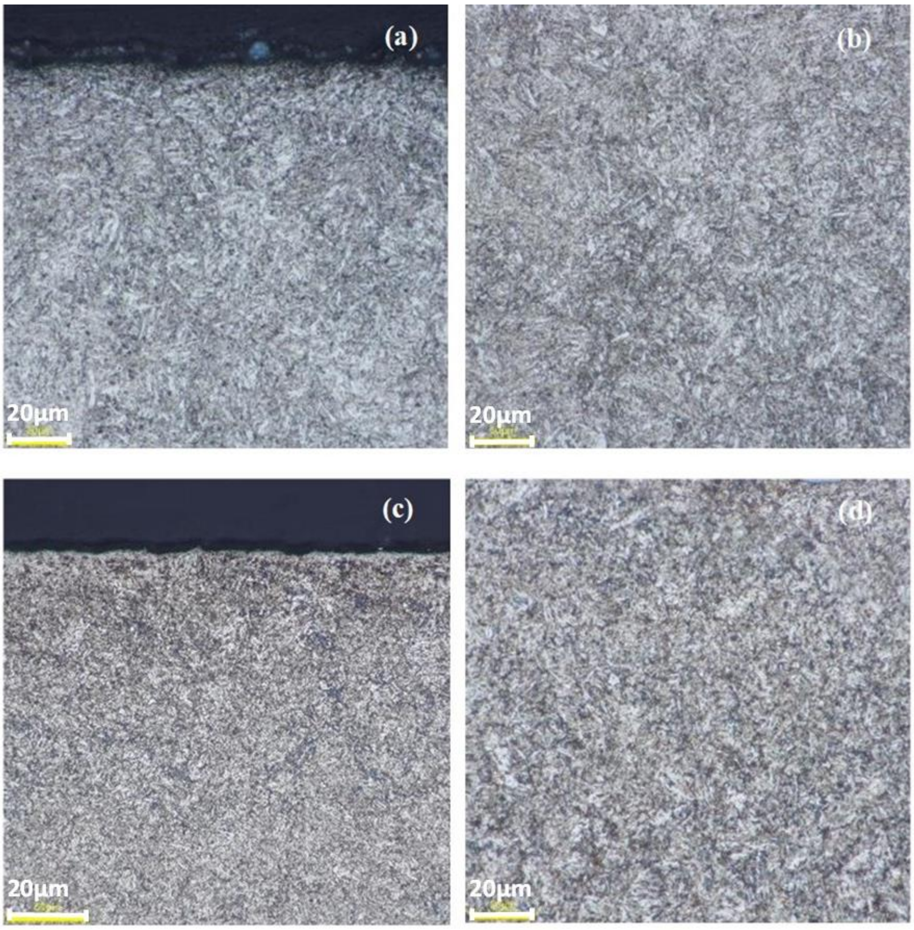

Fig-4: Optical microstructure (a) edge and (b) center of the new bolt with (c) and (d) are their corresponding microstructure of the failed bolt.

Numerous inclusions are seen in the SEM micrograph as shown in Fig. 7(a). The EDS analysis was done on the inclusion 1 and 2 and on the matrix 3 shown in (b) with the spectrum of the EDS in (c). The chemical composition of the inclusions along with the matrix is shown in Table-3, shows that the inclusions as MnS. Such large inclusions and their populations are not desirable for dynamic application of any engineering components. Inclusions are the points of stress concentration regions for fatigue crack initiation, which propagates for final fracture of the engineering components.

Table-3: SEM-EDS of the inclusions (1&2 on inclusions and 3 on the matrix)

Points	O	Na	Mg	Al	Si	P	S	Mn	Cu	Fe
1	0.11	0.25	0.22	0.15	0.13	0.10	32.50	60.35	1.43	4.77
2	0.23	0.28	0.24	0.16	0.15	0.14	32.42	60.27	1.52	4.59
3	0.64	0.73	0.26	0.18	0.52	0.06	0.28	0	1.85	95.47

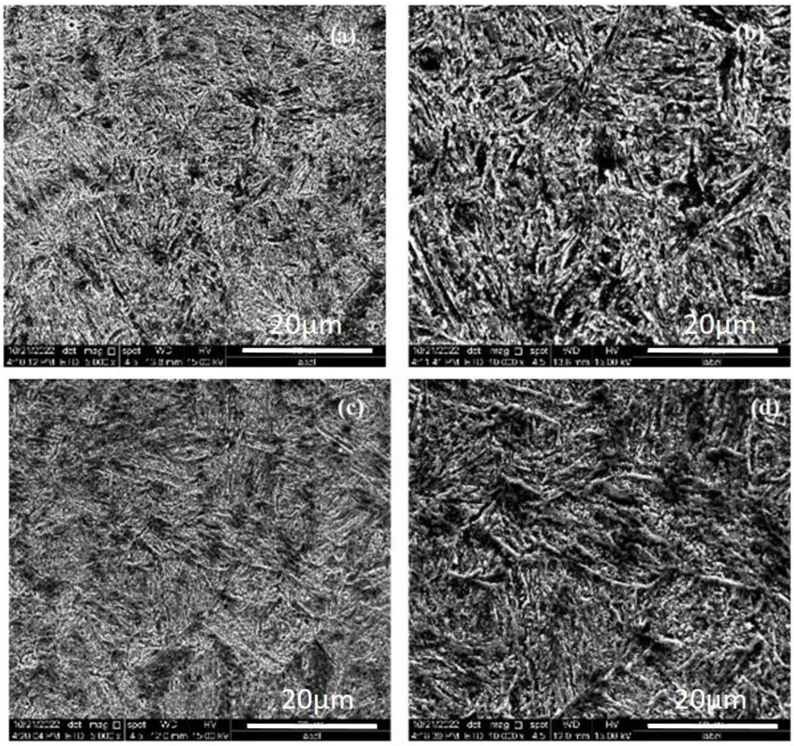

Fig-5: SEM micrograph (a) & (b) low and high magnification of the new bolt at the edge region with (c) & (d) corresponding micrograph of the failed bolt.

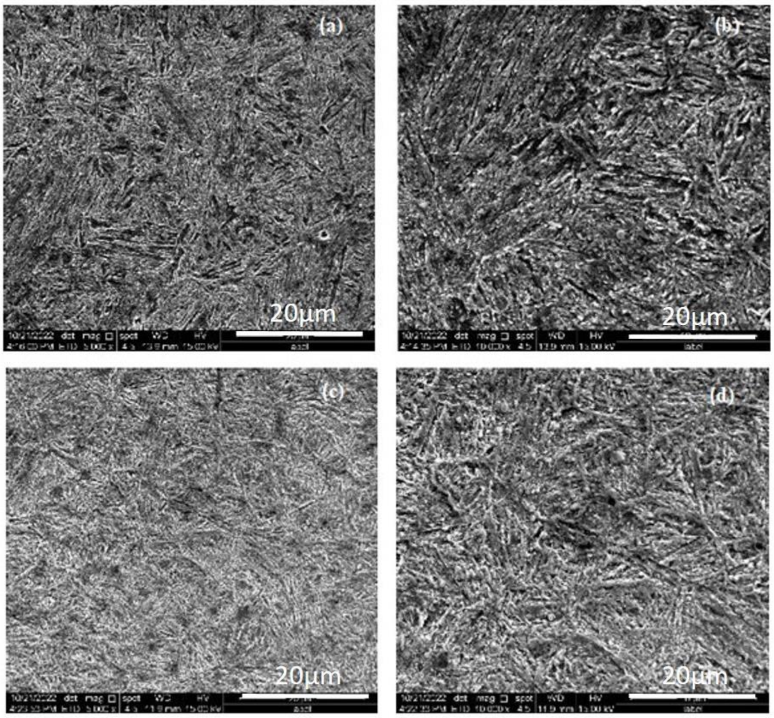

Fig-6: SEM micrograph (a) & (b) low and high magnification of the new bolt at the center region with (c) & (d) corresponding micrographs of the failed bolt.

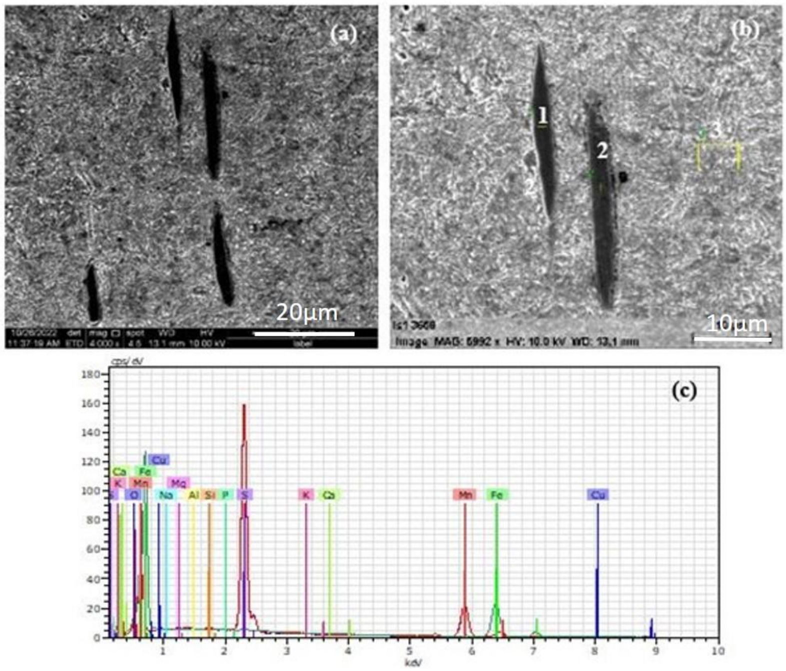

Fig-7: (a) SEM micrograph of inclusions (b) SEM-EDS of the inclusions 1 & 2 with 3 at matrix (c) SEM-EDS spectrum conforming MnS inclusion.

3.5 Bulk Hardness and Impact Toughness

The average bulk hardness (Brinell hardness) was found to be 370 BHN for the failed bolt and 380 BHN for the new bolt. The hardness and impact toughness data with tempering temperature were found from the literature for the 34CrNiMo6 grade and plotted in **Fig. 8.** It can be seen that the hardness for both the new and failed bolts are corresponding to the tempering temperature around 500°C which corresponds to an impact energy of 45Joule. Hence, to conform the exact value of impact toughness standard samples of Charpy impact specimen were made and tested in a Zwick/Roell make impact tester. The results were found to be 19 Joule, corresponding to 425°C tempering temperature. Hence, it is inferred that the low impact energy obtained in the bolts, due to low temperature tempering.

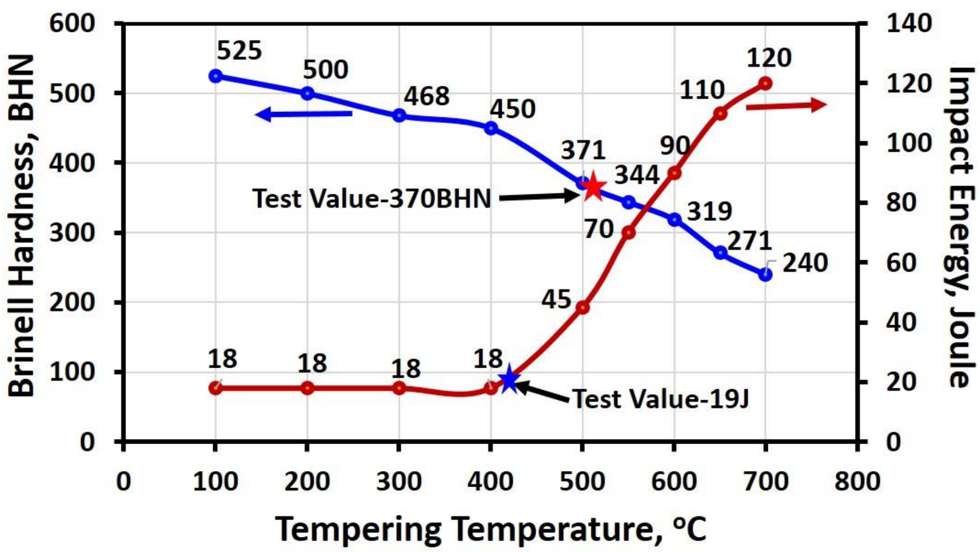

Fig- 8: Bulk hardness and impact energy of the 34NiCrMo6 grade with tested value of failed bolts.

4. FRACTOGRAPHY

SEM Fractograph of the bolt-1 and bolt-2 at various magnifications are shown in **Fig. 9** (a)-(c) and (d)-(f) respectively. The radiating cracks are indicative of fatigue failure of the bolts. The river marks are indicative of low cycle fatigue of the bolts also failure in impact load. The cracks in the samples indicates poor toughness of the steel. The fractography of the failed bolt after impact test is shown in **Fig. 10**. Mixed mode of failure with both cleavages and dimples are seen in the fracture surface of the bolt.

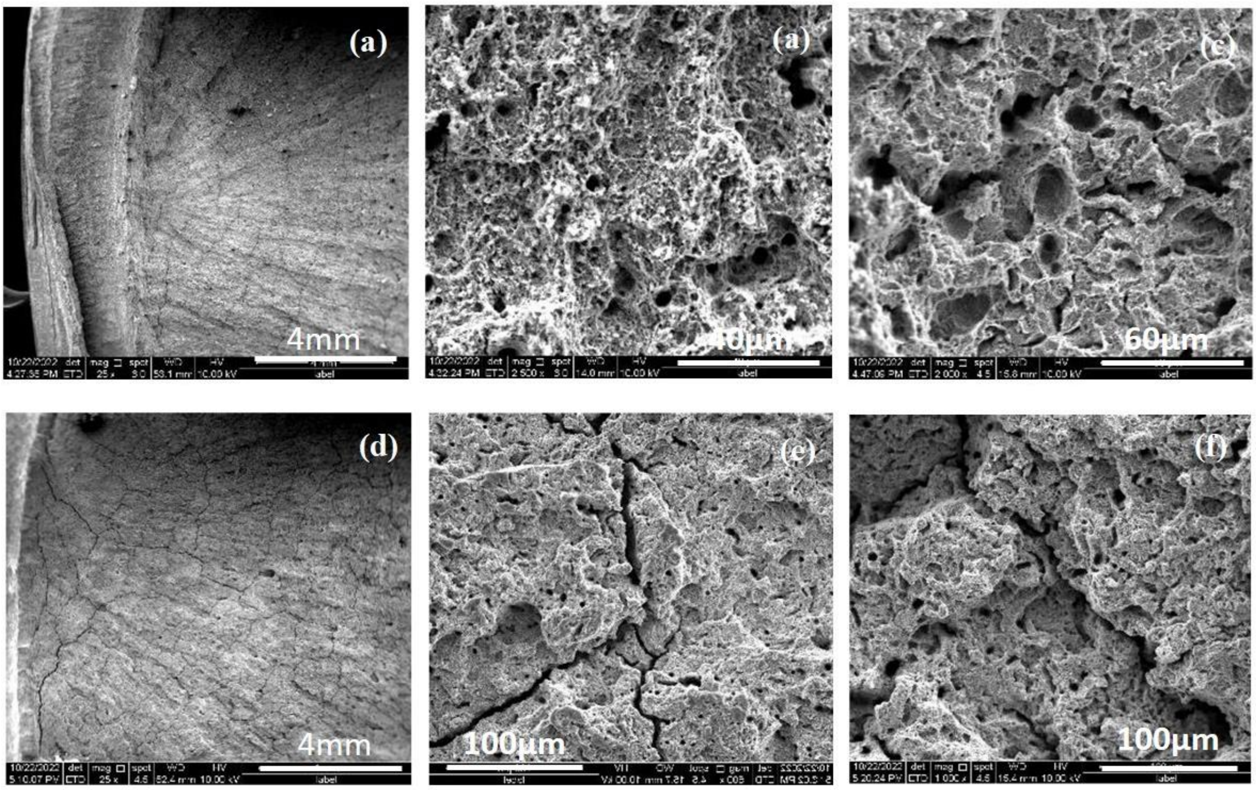

Fig-9: (a)- (c) low to high magnification fractographic image of the bolt-1 with (d)-(f) corresponding micrographs of the bolt-2.

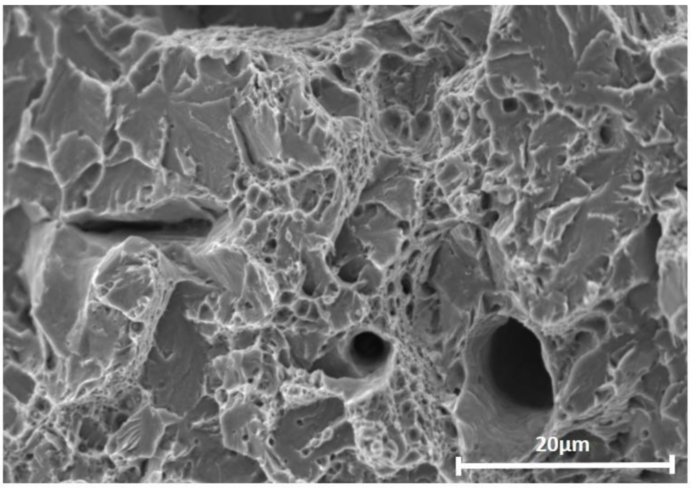

Fig-10: Fractography of the bolt after impact test.

5. CONCLUSION

The root cause of failure is selection of wrong tempering temperature (425°C) instead of following the actual tempering temperature (540-660°C according to specification) leading to poor impact toughness of the bolts. Stress concentrations increased at the thread grooves due to heavy load, due to jerk the bolts failed due to poor impact toughness. The river marks on the fracture surface of the bolts are indicative of fast fracture of the bolts due to the impact load/jerk load.

6. REMEDIAL ACTION

Poor toughness of the bolts (19Joule) due to low temperature tempering is the major cause of failure of the bolts and hence it is suggested to temper the steel as per specification of 540 to 660°C to get very good impact toughness in the range of 70-110Joule or minimum of 45Joule. The material surface hardening can further improve the fatigue life of the bolts. Use of clean steel can give better life of the steel in dynamic loading condition by minimizing the stress concentration from inclusions. As the bolts are experiencing high temperature (100-200°C) there is a chance of loosening of the bolts and hence need to be tightening periodically to avoid fatigue failure of the bolts.

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BIOGRAPHIES

Dr. J N Mohapatra is currently working as a Senior Manager at R&D and SS of JSW Steel Ltd. He is having 19 year of R&D experience with more than 13 years post doctorate experience in the field of NDT, Failure analysis and AHSS. Dr Mohapatra is a recipient of JSPS Postdoctoral Fellow in the year 2010, Young Scientist from MRSI Kolkata in the year 2008, National Young NDT Scientist by ISNT in the year 2013. He has more than 30 SCI Journal publications, 05 non-SCI journal publications and participated and presented his work in several national and international conferences.