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Fracture failure analysis on ultra supercritical turbine bolts

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Abstract: Fracture failure analysis on ultra supercritical turbine bolts was carried out by means of chemical composition analysis, mechenical properties testing, metallographic examination and fracture analysis. The results show that the main reason of the bolts fracture is high temperature stress-rupture, with the fracture morphology being intergranular cracking character. The main fracture is perpendicular to the axial direction of bolt, which indicates that the tensile working stress result in the crack. In addition, another kind of cracks which is 45ºof the axis has been found on the bolt. It indicates that there must be some abnormal torsion stress on the bolt which most possibly be caused during assembling process.

1. Introduction

The research objects in this paper are fractured Inconel alloy783 bolts used on ultra supercritical turbine. Inconel alloy783 is a kind of high temperature alloy with low thermal expansion and crack growth resistant, which was developed for aircraft engine by Special Metals in the USA [1]. With the development of the ultra supercritical turbine, Inconel alloy 783 begin to be used in the bolts installed on the turbine in recent years[2]. Because of the high Al content could induce the precipitation of β phase, the resistance of stress accelerated grain boundary oxidation and the stress rupture properties could be improved[3-6]. The fractured bolts can be separated into two groups. One group contains 2 pieces of M72*6*330mm control value bolts which were installed in horizontal direction. And the other group contains 6 pieces of M90*6*385mm main throttle valve bolts which were installed in a vertical direction. All the bolts had worked over 8 years at 600ºC and been found its failure during overhaul. Chemical composition analysis, mechenical properties testing, metallographic examination and fracture analysis have been done in order to find the failure reason.

2. Experimental and results

2.1 Appearance of the fracture bolts

The photographs of the two kinds of bolts are given in fig.1. It can be seen that the control value bolts are crack from the screw thread position. And the main throttle valve bolts are crack from the rod.

There has no obvious plastic deformation around each fracture.

Figure 1. Fracture macro-profile of the bolts.
(a)(b) control value bolts; (c)-(h) main throttle valve bolts.

2.2 Physical and chemical inspection

The testing results of chemical composition, tensile-strength and hardness of the bolts are separately given from table1 to table3. The tensile tests have been done at room temperature, 600 ºC and 650 ºC according to the real working condition of the bolts. It can be seen that the chemical components and the tensile properties meet the standard and technology agreement of the bolts. The hardness is a little higher than the technology agreement, which may be caused from the long time use of the bolts.

Table 1. Chemical component of the bolts (mass fraction, %).

Element	C	Si	Mn	P	S	Cr
Bolt	0.0096	0.038	0.032	<0.005	0.0004	3.17
GB/T 14992	≤0.03	≤0.50	≤0.50	≤0.015	≤0.005	2.50-3.50
element	Ni	Cu	Ti	Al	B	Fe
Bolt	27.93	0.068	0.20	5.47	0.0063	25.02
GB/T 14992	26.00-30.00	≤0.500	≤0.40	5.00-6.00	0.003-0.012	24.00-27.00

Table 2. Tensile property of the bolts.

	Rm Mpa	Rp0.2, Mpa	A %	Z %	Test temperature ºC
Sample 1	1368	995	22.0	39	25
Sample 2	1362	987	20.0	38	25
Technology agreement	≥1100	≥725	12	20	Room temperature
Sample 3	1160	835	32.0	41.5	600
Sample 4	1160	830	37.0	44.0	600
Technology agreement	≥895	≥620	15.0	25.0	600
Sample 5	1030	780	35.0	40.0	650
Sample 6	1030	780	38.5	44.5	650
Technology agreement	≥895	≥620	15.0	25.0	650

Table3. Hardness of the bolts.

	HRC				
	Sample1	Sample2	Sample3	Sample4	Average value
bolt	41.5	41.3	41.6	41.4	41.5
Technology agreement			27 ~40		

2.3 Microstructure analysis

The normal position structures of the bolts are austenite + β phase as given in fig.2. The structures are homogeneous with no other abnormal structures.

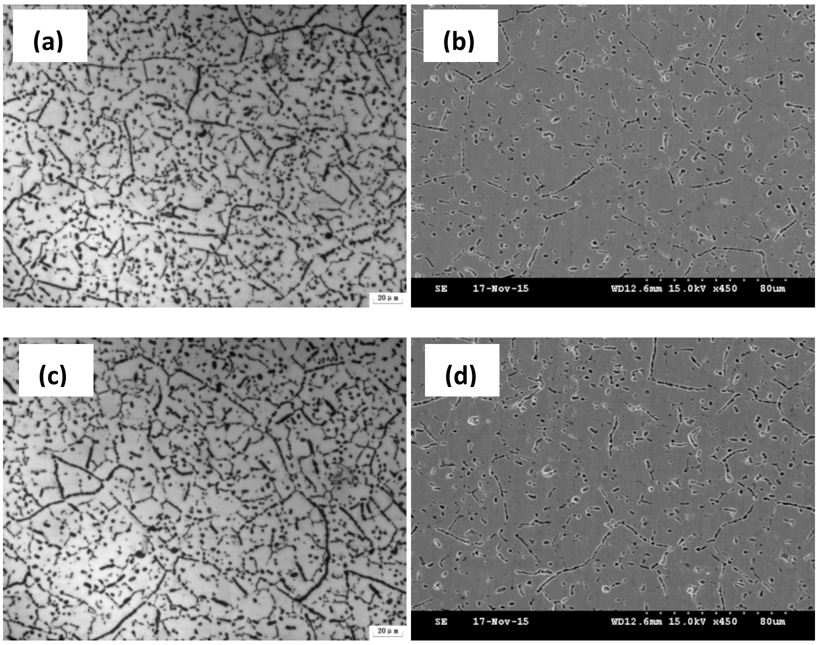

Figure 2. Microstructures of the bolts.
(a)(b) control value bolts; (c)(d) main throttle valve bolts.

2.4 Fracture and crack analysis

It can be seen from fig.3 that the fractures are black because of the severe oxidation at high temperature, which indicate that the bolts have fractured for a long time. The cracks initiated from the inner wall surface according to the radial stripes. The main fractures are perpendicular to the axial direction. Compared with the main throttle value bolts, the fracture surfaces of control value bolts are blunter. It can be speculated that the control value bolts fractured earlier and had been oxidized more severely. The fracture micro-morphology of the bolts is given in fig.4. It is very hard to get rid of the high-temperature oxidation layers. However intergranular fracture can still be seen after derusting treatment. Mean while, some cracks which are not perpendicular to the bolt axial direction have been found near the main fractures as given in fig.5. The cracks are 45º in direction of the bolt axis, with the features being arborization, intergrandular and severe oxidation as shown in fig.6.

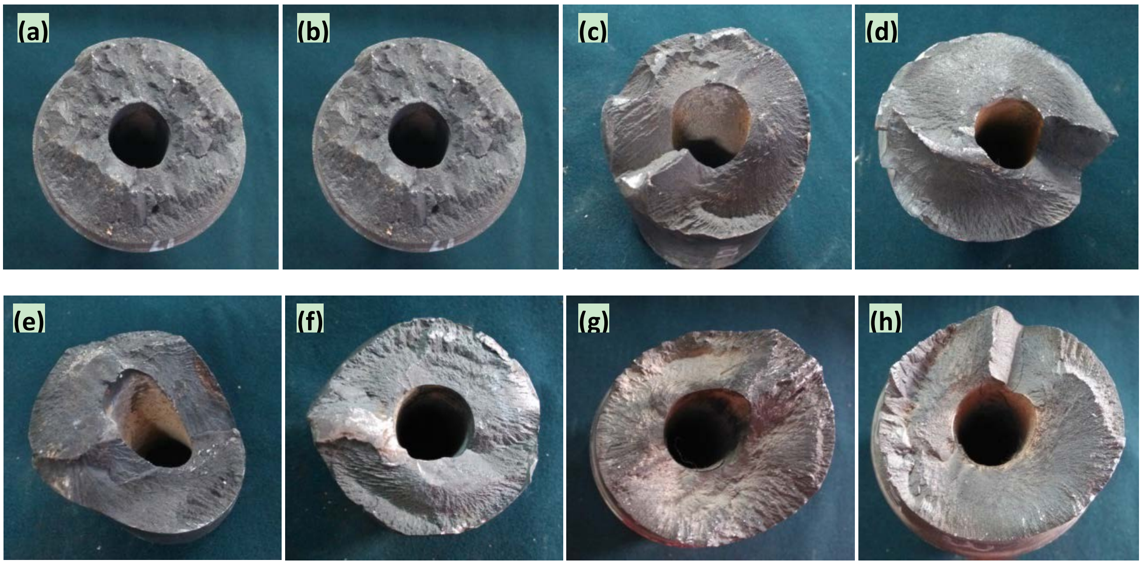

Figure 3. Fracture macro-profiles of the bolts.
(a) (b) control value bolts; (c)-(h) main throttle valve bolts.

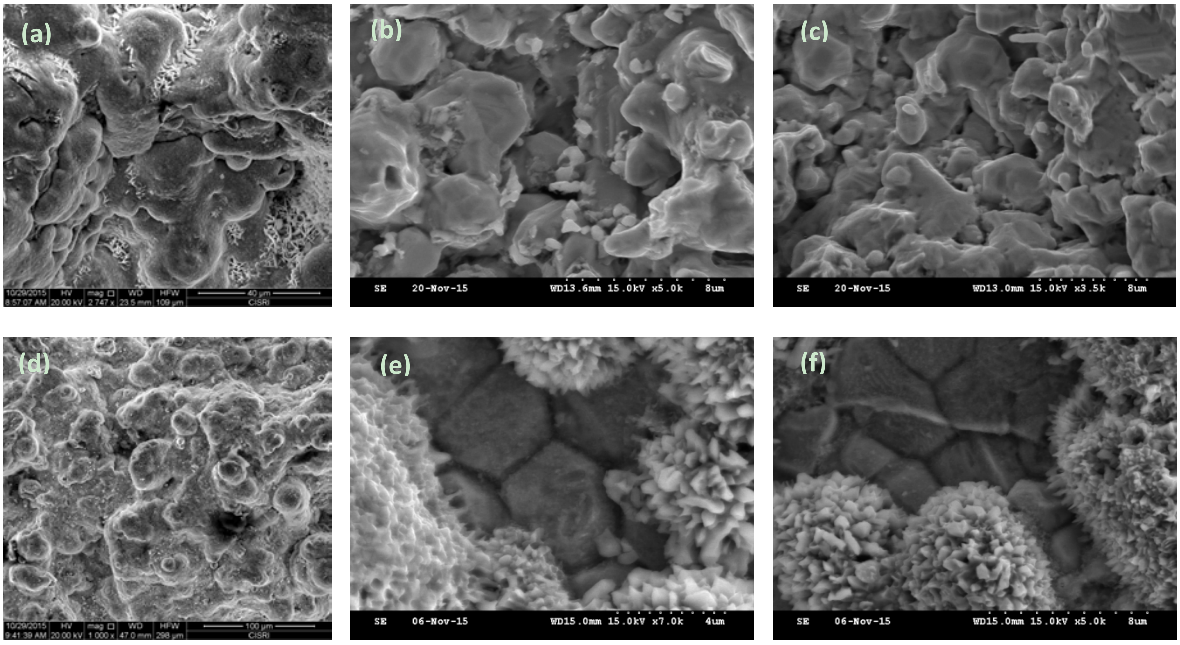

Figure 4. Fracture micro-morphology of the bolts.
(a) control value bolt origin surface; (b)(c) control value bolt derusting surface; (d) main throttle valve bolt origin surface; (e)(f) main throttle valve bolt derusting surface

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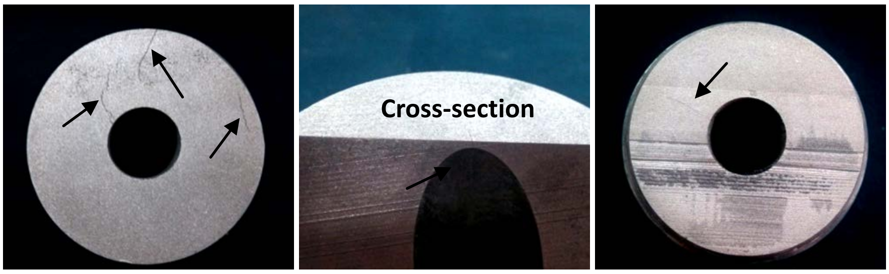

Figure 5. Cracks near the main fracture

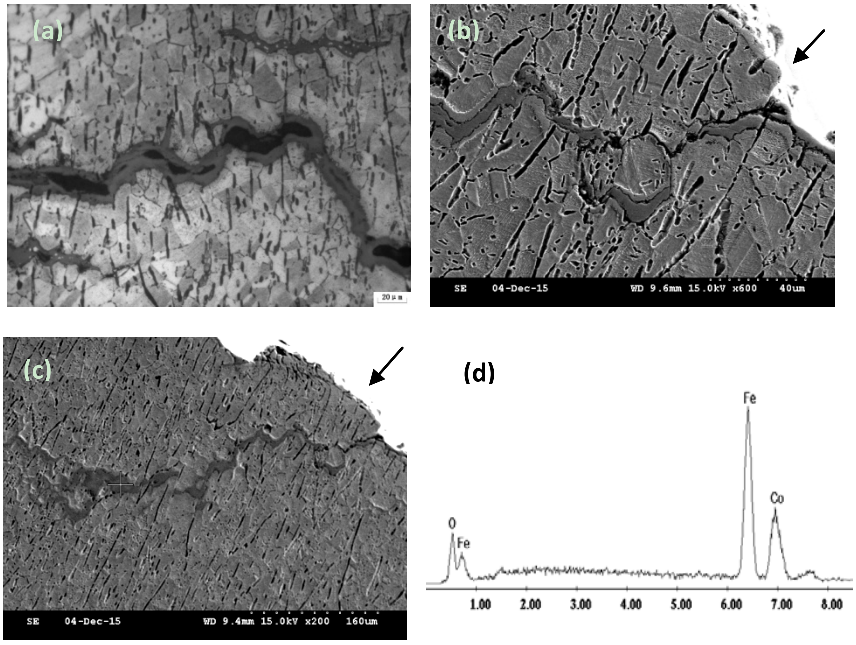

Figure 6. Cracks near the main fracture (where the arrows point are origin fractures).
(a) metallograph of the crack; (b)(c)SEM micrograph; (d) energy spectrum of position marked in (c).

3. Discussion

The fractured bolts have serviced about 8 years at 600 ºC, and the main fractures are severely oxidized, intergranula and has no plastic deformation. The cracks near the fracture are dendritic, intergranular and also have been oxidized severely. All the features indicate that the bolts are high temperature stress-rupture fracture, and the stress accelerated grain boundary oxidative played an important role during the crack growth. Meanwhile, the cracks which are 45º in direction of the axis indicate that there must be some abnormal torsion stress on the bolts. It is known from the user that all the fractured bolts are installed on the same ultra supercritical turbine. And the bolts installed on another turbine at the same time are still used well. It can be deduced that the fractured bolts were improper assembled, which result in higher pretightening stress and abnormal torsion stress. After a long time service at high temperature, the bolts stress-rupture fracture.

4. Conclusions

(1) The testing results of the bolts show that the chemical composition and mechanical properties

meet the technology agreement. And the microstructures are austenite + β phase with no other abnormal structure.

(2) The ultra supercritical turbine bolts are stress-rupture fracture during working at high temperature. The main reason of the fracture is the higher pretightening stress and abnormal torsion stress which were caused by improper assembly.

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