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A Study of the Affected Layer and Stress Corrosion Crack of Ultra-high-strength Steel (300M) for Aircraft Parts

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ABSTRACT

Mechanical components that support structures in aerospace and power generation industries require high-strength materials. Particularly, in the aerospace industry, aluminum alloys, titanium alloys, and composite materials are increasingly used due to their high maneuverability and durability to withstand low temperature extreme environments; however, ultra-high-strength steel is still used in key components under heavy loads such as landing gears. In this paper, the fault cause analysis and troubleshooting of aircraft parts made of ultra-high-strength steel (300M) broken during normal operation are described. To identify the cause of the defect, a temporary inspection of the same aircraft was performed, and material testing, non-destructive inspection, microstructure examination, and fracture area inspection of the damaged parts were performed. Fracture analysis results showed that a crack in the shape of a branch developed from the tool mark in the direction of the intergranular strain. Based on the results, the cause of fracture was confirmed to be stress corrosion.

Keywords : Stress Corrosion Crack(응력부식균열), Affected Layer(가공변질층), Ultra-high Strength Steel(초고장력강), Fatigue(피로)

1. Introduction

The parts that support structures and the parts that receive large loads in the technical fields such as the aerospace and power generation industries require high-strength materials. In the aerospace industry, in particular, as the required performances such as a wide range, a miniaturization lightening of weight and durability that can withstand the low temperature extreme environment change, steel materials, aluminum alloys, titanium alloys, composite materials are being used.

Ultra-high strength steel is still used for parts

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that receive large loads or require heat resistance, such as landing gear or engines, to ensure flight safety. Aircraft parts utilizing such ultra-high strength steel are widely used for applications requiring strength and toughness, and in particular, landing gear that absorbs shock by supporting the weight of the aircraft ranging from several to hundreds of tons. The ultra-high strength steel(300M), which is mainly used as a part of landing gear, is a material with high fatigue strength as well as high strength and toughness.

In the case of aircraft ultra-high strength steel parts subjected to repeated loads, cracks and stress corrosion can occur due to various variables such as fatigue, corrosive environment, machining. The occurrence of defects can lead to aircraft accidents, which can affect not only personal injury but also loss of aircraft utilization and maintenance costs.

In relation to this, research on stress corrosion cracking behavior and research on affected layers by machining have been advanced, Yoon[1] and others reported that stress fracture and fatigue behavior of alloy steel used for blades for aircraft engines, Lee[2] and others introduced stress corrosion cracking behavior related to the failure of blades used in thermal power plants. Park[3] and others have been studying the effects of surface residual stress (short peening treatment) on the corrosion fatigue crack growth behavior of high-strength steels for suspension systems. Lee[4] and others studied surface residual stress characteristics of austenitic stainless steel by machining and heat treatment. Lee[5] and others studied the properties of the affected layer according to the machining depth during micro-end-milling, and Lee[6] and others studied the fatigue test and evaluation of aircraft landing gear. Nam[7] and others studied the mechanism of fatigue cracking of steel for automotive coil springs using ultra-high strength steel(300M).

However, there is not enough research on the relationship between the affected layer and the stress corrosion cracking for ultra-high strength steel (300M) for aircraft.

In this paper, the cause of the link assembly fracture of aircraft landing gear during operation was analyzed with emphasis on inspections of the affected layer on the machined surface of ultra-high strength steel(300M) and analysis of crack growth on the fracture surface.

We are proceeding with inspections of material components, non-destructive analysis and surface hardness test to confirm the affected layer. The analysis of the fracture surface uses a scanning electron microscope to determine whether stress corrosion cracking will progress. The analysis was performed by adjusting the magnification (17 times, 40 times, 500 times) to increase the reliability of crack analysis.

2. Target of Trouble Shooting

The fractured is a part of the link assembly of the aircraft landing gear. The shape of original part is shown in Fig. 1. Fig. 2 show fracture surfaces. It can be seen that the fracture proceeded diagonally.

Fig. 3 show the operating mechanism of the part and the point where the fracture occurred.

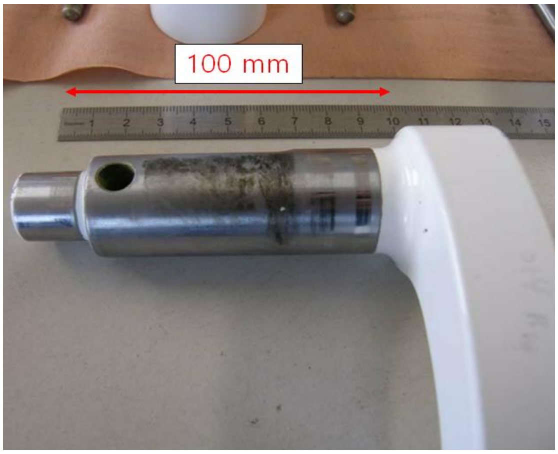


Fig. 1 Shapes of non-fractured part

Fig. 2 Shapes of the fracture surface

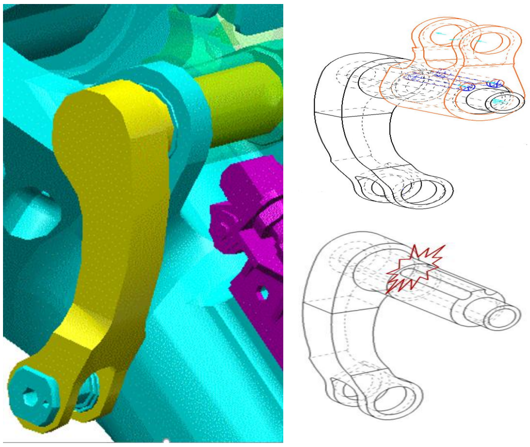
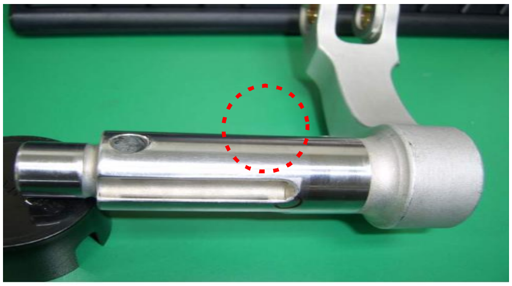


Fig. 3 Working mechanism and fracture point of the part

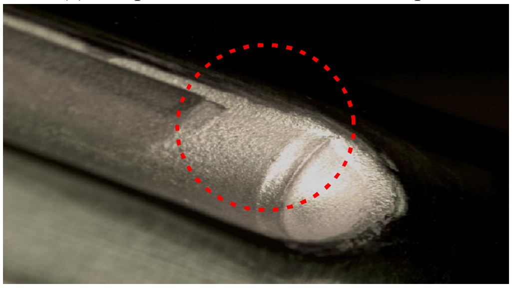
3. Damage Analysis and Consideration

3.1 Visual Inspection

First, a visual inspection of the same type of aircraft was conducted to find the cause of the defect. As a result, the traces presumed to be similar defects are shown in Fig. 4. It is identified at the end of Groove. In particular, Ridge(Tool Mark) was identified on the curved surface of Groove as shown in Fig. 4(b) and (c). Fine cracks were observed around the ridge grooves.



(a) Shape of the similar defected part



(b) View of the defect on groove

(c) View of the defect on groove

Fig. 4 Similar defect of other parts

Table 1 Chemical composition of standard 300M steel substrate and fracture part

(wt%)

	C	Si	Mn	P	S
300M STD	0.400 ~0.450	1.450 ~1.800	0.650 ~0.900	0.010 less	0.010 less
fracture part	0.424	1.620	0.788	0.005	0.003
	Ni	**Cr**	**Mo**	**V**	
300M STD	1.650 ~2.000	0.700 ~0.950	0.350 ~0.500	0.050 ~0.100	
fracture part	1.783	0.755	0.413	0.072	

Table 2 Mechanical properties of standard 300M steel and fracture part

	Tensile Stress (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)	Contraction (%)
300M STD	1930 ~2100	1590 more	7 more	25 more
fracture part	1975	1660	14.2	52.1

3.2 Chemical/Mechanical Component Inspection

As part of the cause analysis, a chemical / mechanical component examination of the damaged area was performed. Table 1 shows the chemical composition specifications of the damaged part (MTL-1201 300M ultra-high tensile low alloy vacuum remelted steel) and spectroscopic analysis (KS D 1651, ASTM E415). The mechanical properties test results are shown in Table 2 and the specifications were met.

3.3 Non-destructive Inspection and Dimensional Inspection

Non-destructive inspection(NDI) was performed on the total quantity of defected products where the ridge edge was identified to check the defects that may exist inside the parts(Fig. 5).

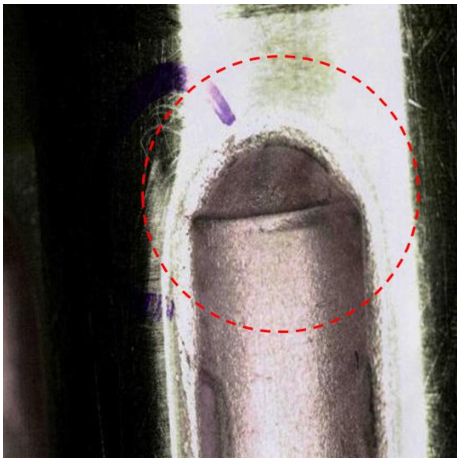
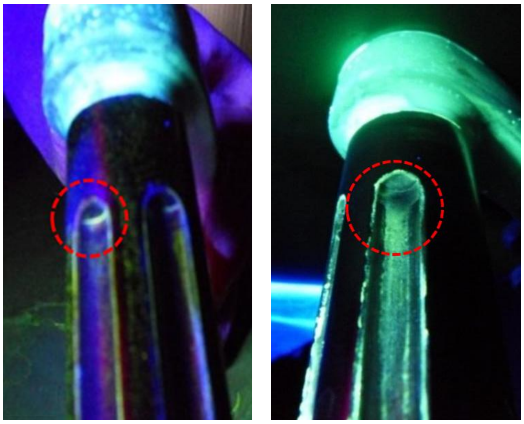


Fig. 5 NDI point of the defected part

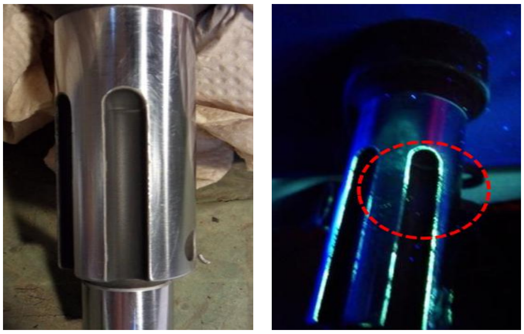


(a) Result of MPI (b) Result of FPI

Fig. 6 NDI for the defected part

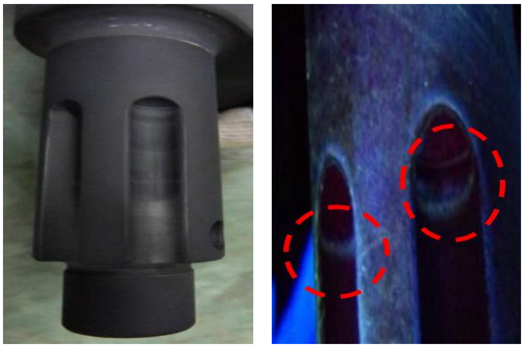
First, magnetic particle inspection(MPI) was performed on the total quantity of defected products for the purpose of surface defect detection. In general, it is possible to check Indication when there is crack or tool mark through MPI. As indicated by Fig. 6(a), in-depth analysis was required by fluorescence penetrate inspection(FPI). FPI was also performed for the total number of defected. Indication did not appear as shown in Fig. 6(b).

Fig. 7(a) shows the part after plating peeling. As a result of performing FPI this part, there was no



(a) Unplated part (b) Result of FPI

Fig. 7 NDI for the unplated part



(a) Nital etched part (b) Result of FPI

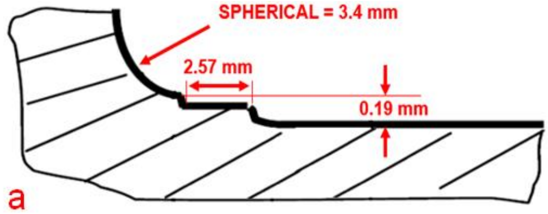
Fig. 8 Nital etched surface of defected part

indication as shown in Fig. 7(b). Through this, it was confirmed that the indication identified in the MPI was not a crack but a tool mark by machining.

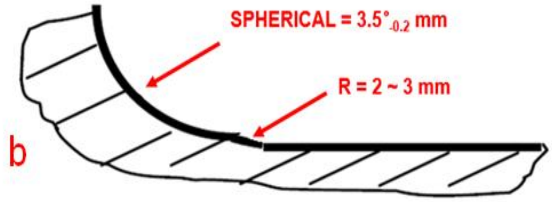
As the tool mark due to the machining was confirmed, in order to check the surface affected layer due to frictional heat during machining, the defected part was subjected to grit blast and nital etching. Through this, the tool mark estimated by friction heat or burn is shown in Fig. 8(a).

As a result of FPI for this part, an abnormal indication that was generated by burn during machining was confirmed in the tool mark on the notch in Fig. 8(b).

In addition, dimensional measurements were performed on the ridges identified in the groove



(a) Defected part(Shape of ridge)



(b) Drawing of the part

Fig. 9 Compare parts and drawing dimensions

curves. As a result of the measurement, a stepped ridge confirmed at the tool mark located at the end of the groove. Fig. 9(a) shows defect(ridge), Fig. 9(b) shows the drawing of Groove.

3.4 Hardness Test

In order to confirm the hardness of the defected, a Rockwell Hardness C test with a load of 150 kg according to the ISO 6508-1 standard was performed to confirm the result value(53 HRC). The test results met the properties of 52 ~ 55 HRC of ultra-high strength steel(300M).

On the other hand, Vickers microhardness test was performed in accordance with the ISO 6507-1 standard to confirm the micro hardness of the tool mark and the affected layer confirmed through the non-destructive test. As shown in Fig. 10, the microhardness was measured by applying 0.2 kgf load to a total of 6 sites(tool mark 5 sites and 1 no indication sites).

In Fig. 11, which is the result of measuring the micro hardness, it was confirmed that there was no significant difference between the hardness value of the tool mark and the no indication.

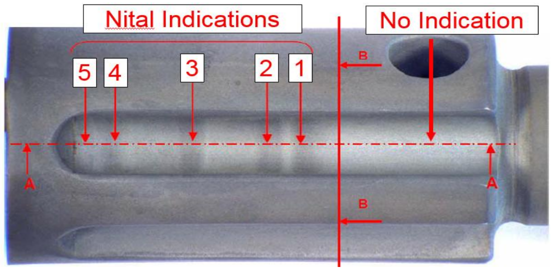


Fig. 10 Microhardness checking area after Nital etching

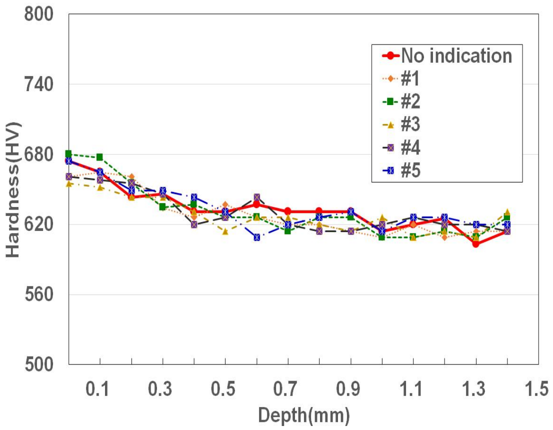
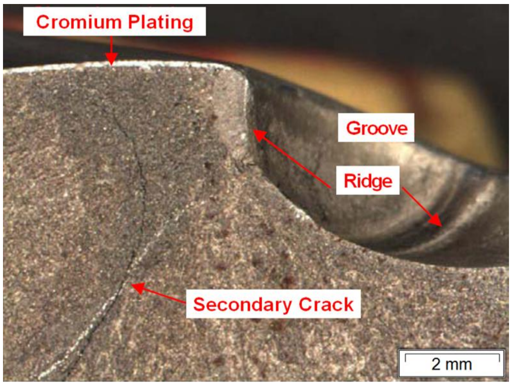


Fig. 11 Microhardness distribution of Indication #1~#5 and No Indiction

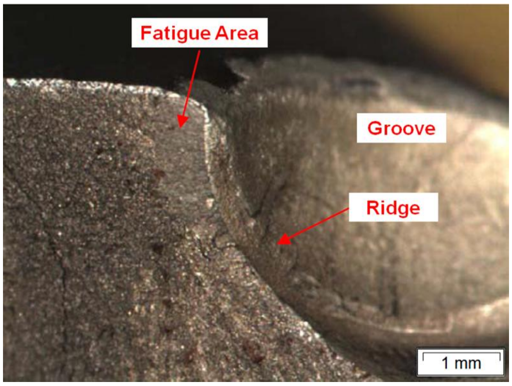
3.5 Fracture Analysis

In Fig. 12(a), which enlarges the fracture surface, it can be confirmed that it is similar to the crack caused by fatigue, and the secondary crack is identified. In Fig. 12(b) and (c), It shows the fatigue fracture in more detail. On the fracture surface, it was confirmed that fatigue progressed to 1.87mm width and 0.65mm depth from the ridge edge of the groove(tool mark) and then to failure.

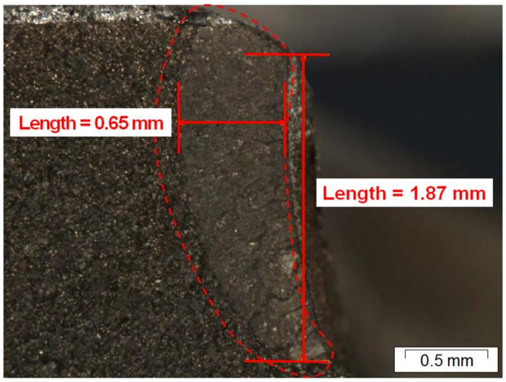
As a result of analyzing the fracture surface as shown in Fig. 13(a) using the scanning electron microscope(SEM), fatigue striation were found in Fig. 13(b). In Fig. 13(c), microsections showed branching with intergranular progressed from the end of the fracture surface. Such observed branching is consistent with stress corrosion cracking initiated from the end of the fatigue propagation.



(a) View of the fracture surface



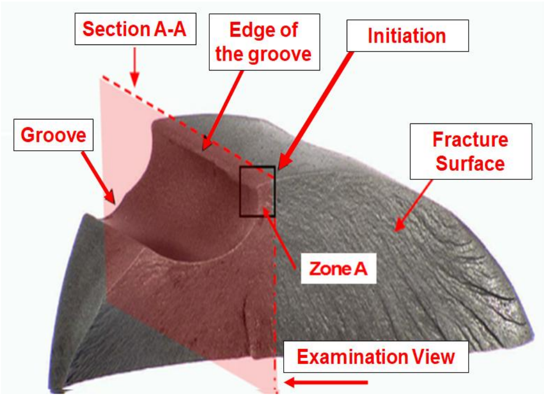
(b) Initiation of fatigue(x17)



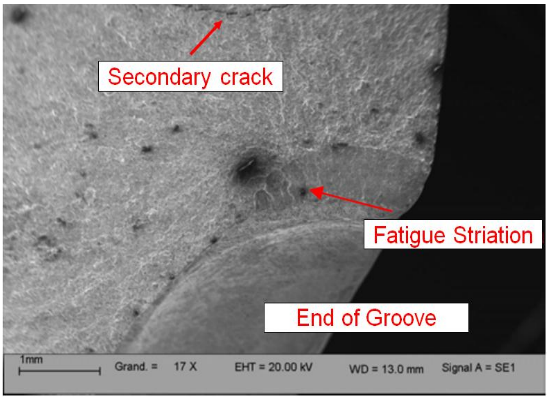
(c) Shape of fatigue area(x40)

Fig. 12 View of the fracture surface

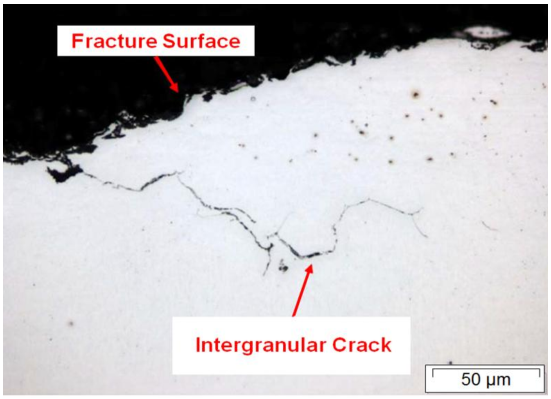
Based on these results, it is estimated that fatigue and initial cracking occurred due to stress concentration



(a) Transverse section of the fracture surface



(b) View of fatigue striation(x17)



(c) View of Intergranular crack(x500)

Fig. 13 Analysis of fracture surface

in the notch generated in the ridge of the tool mark. Thereafter, stress corrosion cracking proceeded to the cracked part, which promotes final failure.

4. Conclusion

The results of the cause analysis of the aircraft part which made of ultra-high-strength steel steel(300M) material are summarized as follows.

1. The affected layer(tool mark) by machining was able to be confirmed, and notch occurred in the ridge(tool mark area) of groove through dimensional inspection and fracture surface analysis.
2. Intergranular cracks in the type of branches, which are characteristic of stress corrosion cracking, were found at the fracture surface.
3. Evidence of fatigue crack propagation initiated from the ridge of the spherical end of the groove and proceeded to a depth of 0.65mm.
4. It was found that the cause of fracture of the link assembly part was stress corrosion cracking caused by the combined action of the notch, the affected layer and the repeated operation loads.

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