Effects of aging and thread rolling process sequence on tensile-tensile fatigue of GH4169 alloy bolt

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Abstract. GH4169 superalloy has excellent corrosion resistance, high temperature strength, good machinability and high temperature stability.Therefore, GH4169 was widely used in the manufacturing field of aviation equipment components. In this paper, GH4169 was used as the research material to analyze the effects of aging treatment and thread rolling process sequence on metallographic structure, thread morphology, tension-tension fatigue life and fracture morphology. The results showed that the manufacturing process of aging treatment before thread rolling process can reduce the grain size of the material and have good thread morphology, and its tension-tension fatigue life is higher than that of aging treatment after thread rolling process. And there were obvious differences in fracture morphology.

Keywords: Aviation bolt; GH4169；aging treatment; rolling thread; tensile fatigue.

1. Introduction

High temperature alloy bolts are widely used in the fastening field of hot end components in the aerospace industry. Due to its extreme service environment, new requirements have been put forward for fatigue performance. GH4169 belonging to the category of Fe Ni Cr based high-temperature alloys, its service temperature up to 800℃. The Cr and Co elements added to the material can form a strengthening phase during heat treatment, exhibiting excellent high-temperature mechanical properties. Although breakthrough progress has been made in material properties in China, there are still many exploratory works in optimizing bolt machining processes that have not been carried out, which limits the further improvement of fatigue performance of high-temperature alloy fastening bolts [1].

Lieyong Pei et al [2] studied the effect of aging treatment and rolling process sequence on the tensile mechanical properties of GH738, and found that the tensile performance of the rolling process sequence after aging was 1117 MPa, significantly improving the tensile performance of typical bolt samples. In order to improve the microstructure defects of R26 high-temperature alloy bolts, Chen Shun et al. designed different heat treatment processes to improve the microstructure of the material. The research results showed that the heat treatment process of intermediate treatment and composite aging treatment precipitated small and dispersed second phases, improving the material properties. Xiaojun Sun et al[3] believe that although heat treatment has a significant impact on the grain size of GH4141, forming a matching process specification through appropriate heat treatment and bolt processing technology is an effective way to improve the service performance of bolts.

This article takes typical bolts of high-temperature alloy GH4169 as the research object, investigates the effects of aging heat treatment and rolling sequence on the tensile fatigue performance of bolts, and investigates the effects of microstructure, material hardness, and residual stress.

2. Test method

The test material specification is a solid solution GH4169 high-temperature alloy rod with a diameter of 5.5mm, and the material composition is shown in Table 1. The specification of the tensile fatigue test bolt is M5 × 36. Using the GPS50 high-frequency testing machine, a typical bolt fatigue test was conducted by setting the high load 25.21 kN/low load parameter to 10% of the high load (2.521 kN) according to GJB715.29-1990. After the experiment was completed, the fracture morphology was observed using scanning electron microscopy (SEM, NOVA NANOSEM 430). According to the research ideas of GH4169 alloy bolt heat treatment (1120 ℃ solid solution, 900 ℃ aging for 4 hours) and rolling sequence, two sets of schemes will be designed for comparative testing. Plan one is to roll the wire after aging; Option 2 is aging after rolling, and the rest of the process flow is the same. The specific test plan is shown in Table 2. Cut and embed bolt specimens using wire cutting. After being corroded by a mixed solution of hydrochloric acid and ferric chloride, observe the thread morphology and metallographic features using an optical microscope (Leica DMi8).

(a)

(b)

(a) Fatigue testing machine (b) GH4169 alloy bolt physical object

Fig.1 Fatigue test and physical bolt

Table 1. Chemical composition of GH4169(w.%)

Cr	Ni	Mo	Nb	Al	Ti	Mn	Fe
18.44	53.04	3.02	4.88	0.32	0.90	0.18	Bal

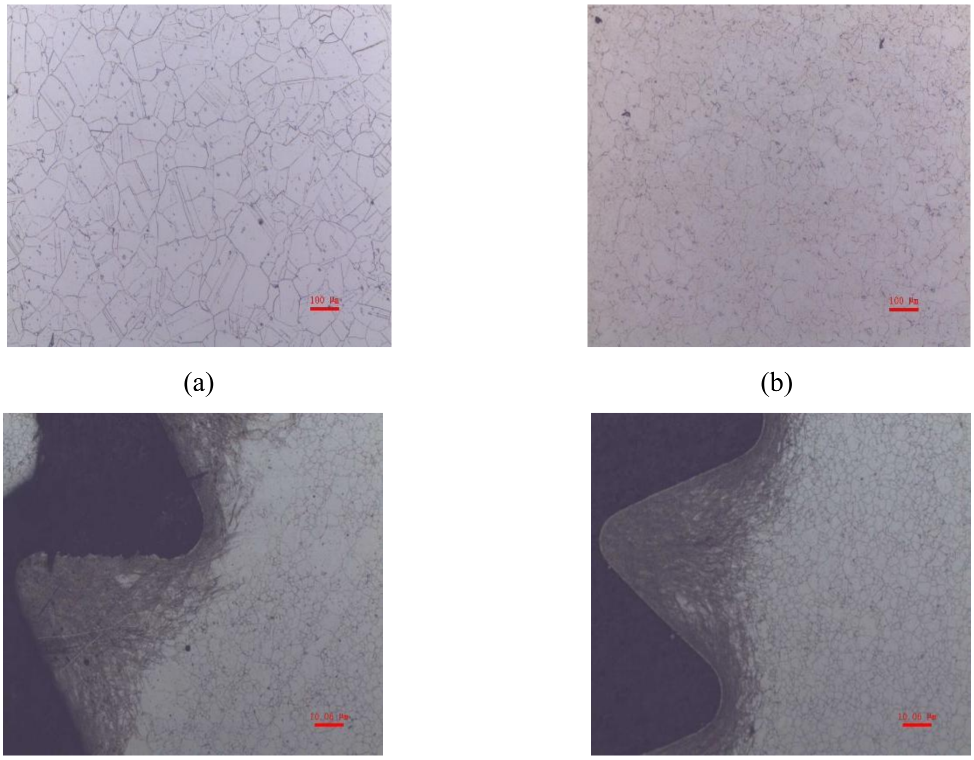
Table 2 .Experimental scheme

Scheme	Bolt processing process
Scheme1 Scheme2	Cutting-heading-turning-grinding-rolling-aging- rolling R-finished product Cutting- heading-turning-grinding-aging-wire rolling-rolling R-finished product

3. Result analysis

3.1 Thread metallographic and morphological analysis

GH4169 is a precipitation hardening nickel based high-temperature alloy, which dissolves the γ 'phase and some carbides in the alloy matrix through solid solution, and then undergoes aging treatment to precipitate the strengthening phase γ. The appropriate distribution of carbides is obtained, which meets the requirements of tensile and fatigue properties of bolts in service [4]. The black particle carbides in Fig.2 (a) are dissolved in the alloy material matrix, playing a solid solution strengthening effect and improving the mechanical properties of high-temperature alloys. Meanwhile, analyzing the metallographic characteristics of GH4169 high-temperature alloy threads before and after rolling, it can be concluded that the grain size and morphology of the thread metallographic structure aged after rolling in Scheme 1 are relatively small and uniform. The reason for this result is that thread rolling processing, as the final step, is accompanied by significant material deformation and removal during thread formation, further refining the grain size of GH4169 high-temperature alloy. Secondly, it can be observed from the thread morphology formed by the aging process of Scheme 1 (Fig.2(c)) and Scheme 2 (Fig.2(d)) that the thread produced by Scheme 1 has folding damage defects, while the thread contour produced by Scheme 2 is relatively smooth and the thread morphology is relatively good.



(a) (b) (c) (d)

(a) Scheme 1 Thread Metallography (b) Scheme 2 Thread Metallography

(c) Scheme 1 Thread Morphology (d) Scheme 2 Thread Morphology

Fig.2 metallographic and thread morphology of bolts

3.2 Fatigue performance analysis

Fig.3 shows a comparison of the tensile tensile fatigue life at room temperature for two different schemes. As shown in the figure, the average tensile fatigue life of bolt specimens processed in Scheme 1 and Scheme 2 is 155000 and 171000 times, respectively. Compared with Scheme 1, Scheme 2 has increased the fatigue life of the rolled wire by 11% after aging. It can be seen that the fatigue life of scheme 2 is higher than that of scheme 1. At the same time, combining the grain size and thread morphology characteristics of the material, it is believed that aging treatment will form some stable precipitation strengthening phases in the alloy, such as γ 'and γ' phases, which can improve the strength of bolt specimens [5,6]. Secondly, the work hardening effect formed by these strengthening phases after wire rolling further improves the strengthening effect of bolts. Relevant literature [3,7] also confirms that the grain refinement effect formed during wire rolling and the introduction of residual compressive stress are important factors in improving the fatigue performance of bolts.

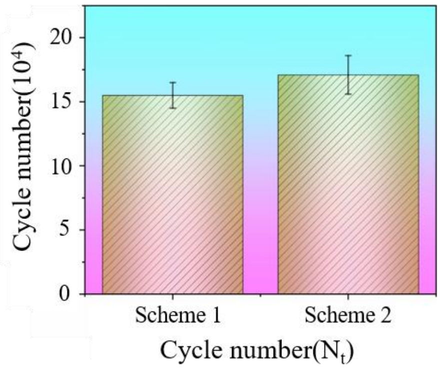
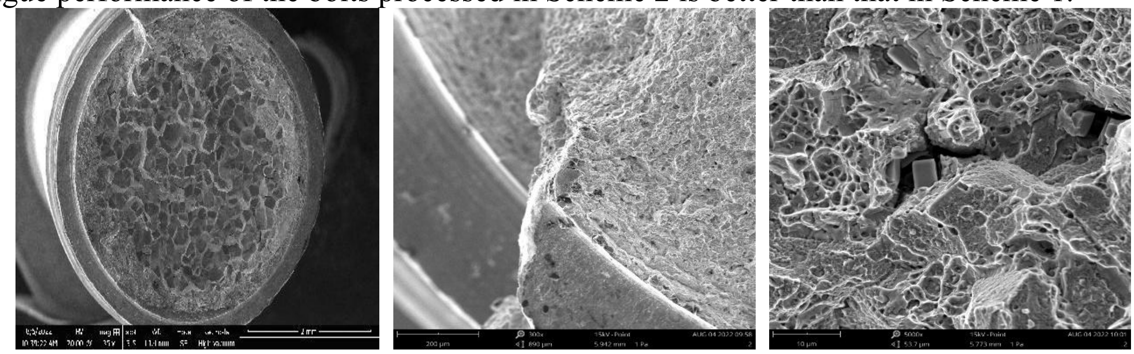


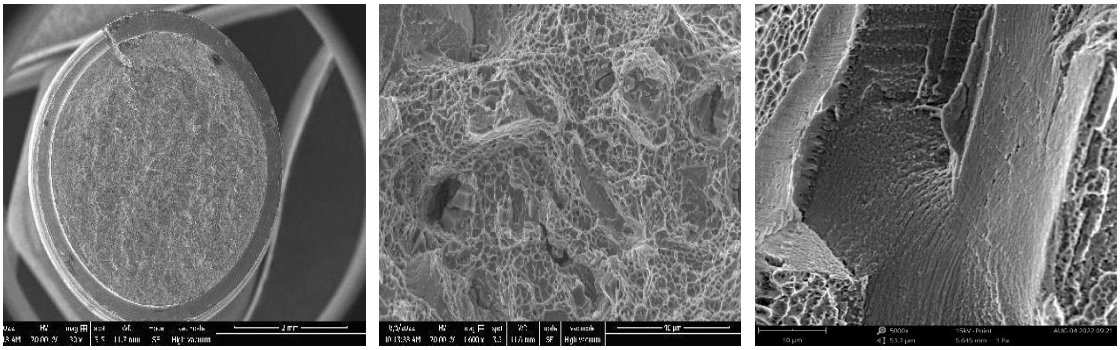
Fig. 3 Comparison of tensile fatigue life

3.3 Fatigue fracture analysis

Fig.4 shows the electron microscopy images of the fatigue fracture morphology characteristics of two schemes. The fatigue fracture surfaces of the two schemes exhibit significant characteristics in the fiber zone, radiation zone, and shear lip zone. The shear lip area is relatively smooth, but after generating a crack source at the stress concentration location, it continues to propagate inward. Fig. 4 (a) shows the fatigue fracture morphology of Scheme 1. The morphology of the fracture surface is significantly different from the former, and large-sized dimples can be observed. The strengthening phase and carbides inside the dimples are not completely dissolved in the matrix, which accelerates the intergranular brittle fracture of the bolt and the formation of large-sized cracks. Fig.4 (b) shows the fatigue fracture morphology of Scheme 2. It can be seen that under high and low frequency stretching, small-sized equiaxed tensile dimples are formed inside the fracture surface. Meanwhile, flat cleavage steps can also be observed in the dimple area, indicating that the material has been subjected to significant tensile stress. Reference [8] suggests that the interface bonding force between the strengthening phase and the matrix in the high-temperature alloy matrix decreases, leading to the grain boundary strength of the material sample and causing intergranular fracture. Due to the aging treatment after wire rolling in scheme one, the deformation strengthening and residual compressive stress formed during the wire rolling process are both subjected to grain growth and residual compressive stress release during the aging treatment at 900 ℃ for 4 hours, which has a negative impact on the fatigue performance of the bolt [9]. Therefore, the overall fatigue performance of the bolts processed in Scheme 2 is better than that in Scheme 1.



(a)



(b)

(a) Scheme 1 (b) Scheme 2

Fig. 4 Bolt fracture morphology

4. Summary

The following conclusions have been drawn through research:

(1) The grain size of the bolt sample of high-temperature alloy GH4169 treated with aging followed by wire rolling (Scheme 2) is smaller than that of the bolt sample treated with wire rolling followed by aging (Scheme 1), and the thread contour is relatively smooth and the thread shape is relatively good;

(2) The tensile fatigue lives of Scheme 1 and Scheme 2 are 155000 and 171000, respectively. Compared with Scheme 1, the fatigue life of the rolled wire after aging in Scheme 2 has increased by 11%;

(3) There is a significant difference in the fatigue fracture morphology characteristics between the two schemes. Scheme 1 forms a larger size of ductile dimples, while Scheme 2 forms obvious cleavage steps.

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