IOP Conf. Series: Materials Science and Engineering **452** (2018) 022089 doi:10.1088/1757-899X/452/2/022089

# Effect of Heat Treatment Process on Hardness and Corrosion Resistance of GH4169

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**Abstract.** In order to study the effect of the heat treatment process on the microstructure, properties, and especially the corrosion resistance of the nickel-based superalloy GH4169. The three groups of specimens were separately subjected to three types of heat treatment, and the specimens treated in different ways were placed in a simulated seawater solution (6% FeCl3 solution) for 3 days and tested for corrosion rate. It was found that the microstructure of the sample treated at 1050°C was finest and uniform, and the grain size was about 50 μm square. The difference between the hardness values of the samples treated with double aging and 950°C was about 40 HRC, which was higher than 1050°C. The hardness value of the finished sample is high, and the corrosion rate of the sample treated at 1050°C is the lowest.

## 1. Introduction

Ni-base superalloy GH4169 is one of the most widely used superalloys in the aerospace field due to its high strength, ductility, and fatigue life at 650°C [1-3]. GH4169 also hasunique anti-corrosion and even high-temperature corrosion resistance, and has excellent mechanical properties and processing performance. Under certain external conditions, the properties of the alloy itself have an important influence on the corrosion resistance [7]. Song Yiji et al. studied the effect of heat treatment on the microstructure, mechanical properties and corrosion resistance of GH4169 alloy [8]. It was found that the corrosion resistance of alloys treated with only solution treatment was superior. The GH4169 alloy is usually treated with solution and aging before use, so this experiment is expected to study the effect of different heat treatment processes on the microstructure, hardness and corrosion resistance of the alloy.

## 2. Experimental methods and steps

The 3D-printed GH4169 alloy was divided into three groups and placed in an RJX-8-13 box resistance furnace for heat treatment. GH4169 alloy composition table as shown in Table 1. Sample A at 720 °C aging 3h +620 °C aging 3h; sample B for 950 °C solid solution 1h +720 °C aging 3h +620 °C aging 3h; for sample C 1050 °C solid solution 1h720 °C aging 3h +620 °C aging 3h. Sample D was not treated as a blank control. Observations were taken with a CK40M OLYMPUS metallographic microscope and an S-360 scanning electron microscope. Rockwell hardness was measured at 5 randomly selected test points for each sample. The four samples were soaked in simulated seawater (6% FeCl3 solution) for a

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soaking time of 72 h. Measure and record the weight of the sample before and after soaking and observe the corrosion morphology of the sample after soaking for 72 hours.

## 3. Results and Discussion

### *3.1. Effect of Heat Treatment Process on Grain Size*

Comparing Fig. 1(a)(b)(c) with (d), it is found that the heat treated grains are finer than the untreated ones. Comparing Fig. 1(b)(c), it is found that after solid solution and double aging treatment, the grain size of the alloy is smaller at a solution temperature of 1050°C. In addition, it can be found that the grains after only dual aging and 950° C. solid solution plus double aging are elongated. This is because after the solution treatment, the alloy recrystallizes and new equiaxed grains are formed. The 1050°C solid solution grains are finer because the crystallites recrystallize at this temperature but have not yet begun to grow.

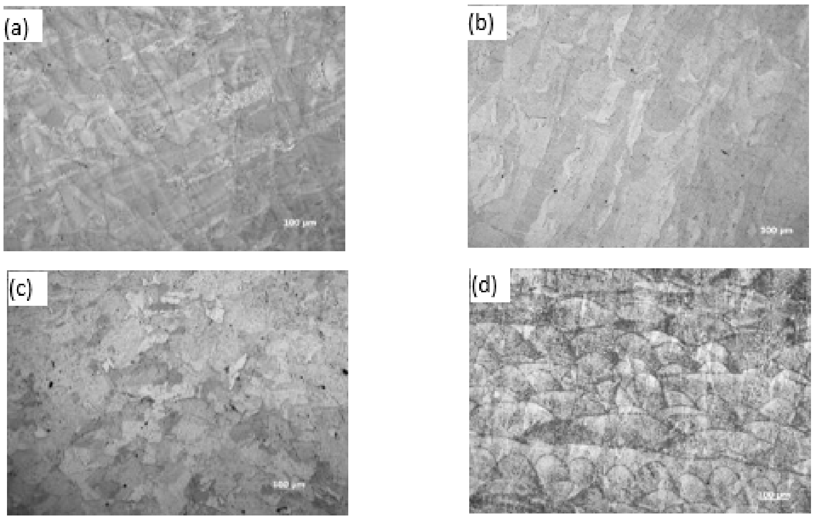


**Fig. 1** The microstructure of the sample after double aging (a),after 950 ℃ + double aging(b) , after 1050 ℃ + double aging(c) ,not heat treated (d).

### *3.2. Effect of Heat Treatment Process on Hardness of Alloy*

As shown in Fig. 2 , the average hardness of the alloy treated with 950°C solid solution for 1h and double aging is 40.3HRC, and the lowest hardness is the alloy sample without heat treatment. Its Rockwell hardness value is 22.4HRC. The Rockwell hardness of the three heat-treated alloy specimens was higher than that of the untreated specimens. This is because the double-aged sample precipitates γ” and γ′ phases. These two phases are the main strengthening phases of the high-temperature Ni-base alloy, so the hardness of the alloy is increased; after the solution treatment and double aging test, The increase in hardness is due to the fact that the alloy not only precipitates the γ” and γ′ phases but also the δ phase precipitates [10, 11]. The precipitation of the δ phase impedes the growth of the grains, and the microstructure has fine and uniform grain hardness. Increase [12].

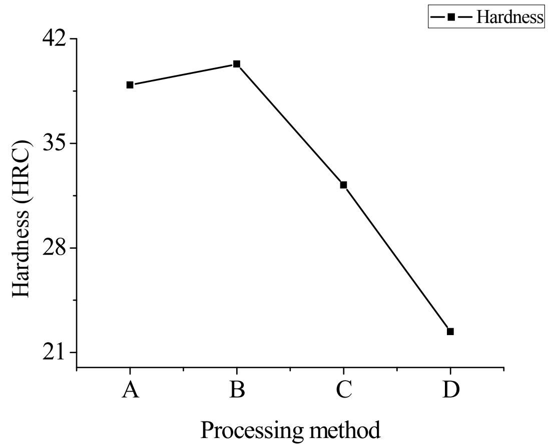


**Fig. 2** After different treatment the average hardness of the sample

### *3.3. Effect of Different Heat Treatment Processes on Corrosion Resistance of Specimen*

After four kinds of differently treated samples were soaked in 6% FeCl3 solution for 72 hours, all four kinds of samples had different degrees of corrosion. After the measurement, the weight loss of each sample is shown in Figure 3, in which the weight loss of the sample after the A, B, and C treatments is only about half of the weight loss of the D treatment sample. The corrosion rate is shown in Figure 4 and the weight loss data. The corrosion rate of the D specimen with the most weight loss was the highest, which was more than double the corrosion rate of other specimens. The corrosion rate of the C specimen was the lowest and the corrosion rate of the A specimen was the same. It was demonstrated that the three heat treatment processes performed have greatly improved the corrosion resistance of the sample.

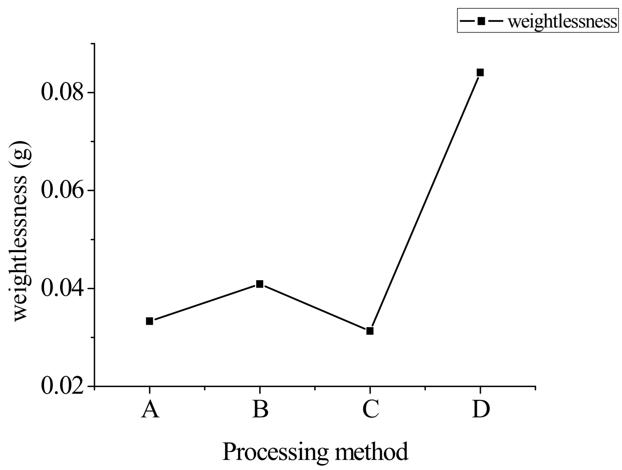


**Fig. 3** The weight loss of four samples treated with different treatments in FeCl3 solution for 72h

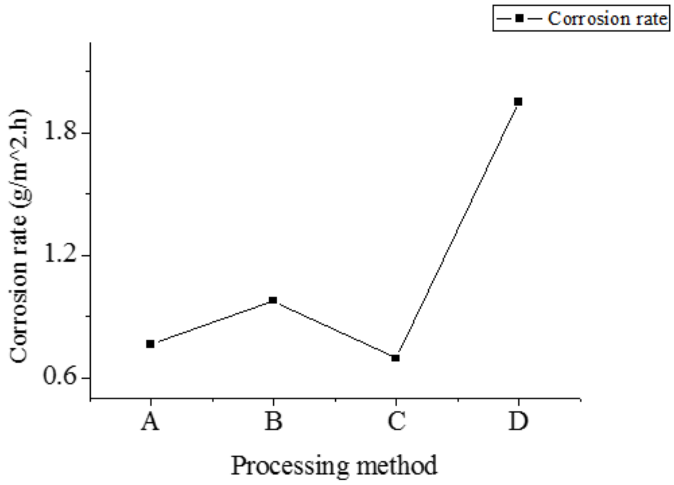


**Fig. 4** Corrosion rates of the differently treated samples in FeCl3 solution

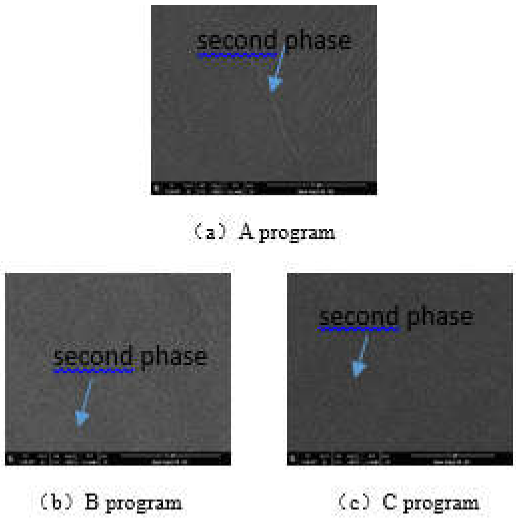


**Fig. 5** SEM images of the samples after heat treatment (a) (b) (c) Figure corresponding to the A, B, C program

The second phase of the heat-treated alloy precipitates at grain boundaries and in the grain, as shown in Fig. 5, which is an electron scanning micrograph of the heat-treated sample. Fig. 5(a)(b)(c) corresponds to A, respectively. In the B and C treatment schemes, the white granular and filamentous precipitates are the second phase precipitated in the alloy. These second phases form an interface with the matrix. In the initial stage of immersion corrosion, the dissolved O^ (2-) enters the matrix. A large number of channels and locations are provided to promote the rapid formation of a thick and dense passive film. Once the surface passivation film is formed, the substrate can be prevented from reacting with the etching solution in the subsequent etching process to protect the substrate. The corrosion rate of the alloy is reduced, and the final weight loss is also reduced.

## 4. Conclusion

(1) Crystal grains become fine due to recrystallization of the heat-treated alloy. The alloy structure treated by the C scheme is the finest and evenest.

(2) After heat treatment of the alloy, a large amount of second phase precipitated, the alloy structure was strengthened, and the hardness of the samples treated with the A, B, and C schemes was improved.

(3) The corrosion rate and weight loss of the unheat-treated specimens were about twice that of the other specimens, and the heat-treated specimens produced a dense protective layer, which greatly improved the corrosion resistance.

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