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EFFECT OF COMPOUND JACKETING ROLLING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SUPERALLOY GH4720Li

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Abstract

In this paper, a compound jacketed rolling technique for superalloy GH4720Li is experimentally investigated. The results show that microstructure of GH4720Li is susceptible to hot working parameters. When rolling temperature is about 1130ºC, a fine-grained microstructure, excellent mechanical properties and high yield strength can be obtained. In addition, the rolling temperature can be controlled effectively, friction force between ingot and roller can be reduced, surface cracking induced by rolling can be avoided, and uniform microstructure can be obtained using compound jacketing. When accumulative strain of rolling is greater than 65%, the coarse columnar dendritic microstructure can be refined completely and grain size of ASTM 8 obtained. After heat treatment, GH4720Li bars exhibit excellent mechanical properties.

Introduction

GH4720Li is a high strength and difficult-to-deform superalloy with excellent mechanical, corrosion resistant and oxidation resistant properties. It is now widely used in aircraft and land-based turbine discs. In practice, the temperature required for a long-term use of GH4720Li is below 700 °C. The weight percent of Al+Ti is as high as 7.5%, and the amount of γ' strengthening phase is as high as 40%. GH4720Li has a high strength, but low ductility at elevated temperatures due to its high alloying content. It is crucial to get a fine-grained microstructure so as to gain excellent mechanical properties for GH4720Li.

At present, the breakdown of GH4720Li is mainly by press forging, a combination of press forging and radial forging, extrusion and / or compound jacketed rolling. Among them, cogging by compound jacketing rolling is the most effective processing route because of its characteristic high efficiency and procedure simplification. Compound jacketing rolling technology employs aluminum silicate fiber to wrap the ingot, and then an overlayer of seamless steel tubing to avoid surface cracking induced by rolling. In this paper, a compound jacketed rolling technique for superalloy GH4720Li is experimentally investigated.

Experiment

GH4720Li alloy is made by vacuum induction melting followed by vacuum arc remelting. Chemical composition of the alloy investigated is listed in Table I. The 406 mm diameter ingot is homogenized at 1180ºC for 30 hours and then machined to 180mm in diameter and 700mm in height cylindrical specimens.

Table I Chemical compositions of GH4720Li investigated

Element	C	S	P	Cr	W	Mo	Al	Ti	Co	B	Zr	Ni
wt%	0.01	0.001	0.004	16.0	1.17	2.86	2.32	4.82	14.08	0.01	0.02	Bal.

After heating at 1130ºC for 6 hours, the ingot is compound jacketing (Figure 1) rolled by 420 rolling mill and the rolling rate is about 0.7m/s. Finally, the ingot is rolled to 90mm diameter bars.

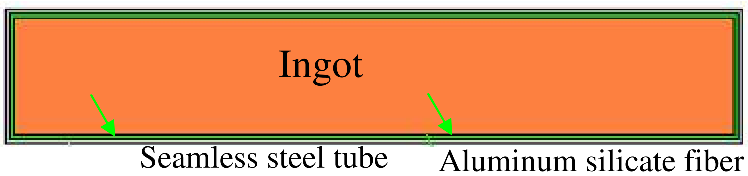


Figure 1. Illustration of compound jacketing for ingot

An etchant of 80mlHCl, 7mlHNO_3 and 13mlHF was used for microscopic inspection of the bars. Microstructural evolution was observed by LEICA MEF4A optical microscope (OM) and JSM - 6480LV scanning electron microscopy (SEM).

Results and Discussion

Microstructure of ingot

The longitudinal macrostructure of GH4720Li ingot illustrated in Figure 2 is composed of three parts; surface fine grained zone, middle columnar crystal zone and central equi-axed crystal zone. Because the weight percent of Al+Ti is as high as 7.5%, Ti is prone to segregate to the interdendritic area and $\gamma+\gamma'$ eutectic increases. In that uniformity of microstructure depends on homogenization of elements, GH4720Li superalloy must be held at high temperature for homogenization before rolling so as to mitigate segregation of elements and increase ductility of the alloy.

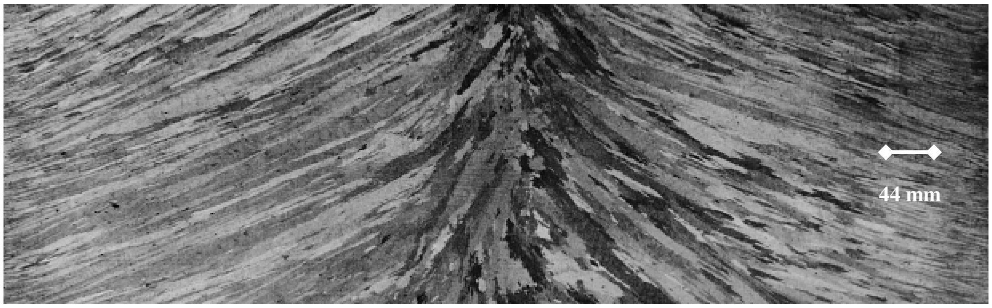


Figure 2. The longitudinal microstructure of GH4720Li ingot

Figure 3 shows that the as-cast dendritic structure of GH4720Li alloy. The white region is dendritic trunk, and the black region is interdendritic area. The microstructure of GH4720Li ingot investigated by LEICA MEF4A scanning electron microscopy(SEM) demonstrated in Figure 3(c) shows that a large number of different size γ′ phase precipitate in dendritic and interdendritic areas. The size of γ′ particles distribution range from several microns to several hundred microns. Additionally, few sunflower shaped γ+γ′ eutectic precipitates were observed in interdendritic area. The eutectic is commonly surrounded by finer γ′ particles and becomes the crack origin during forging. So the structure must be eliminated before forging.

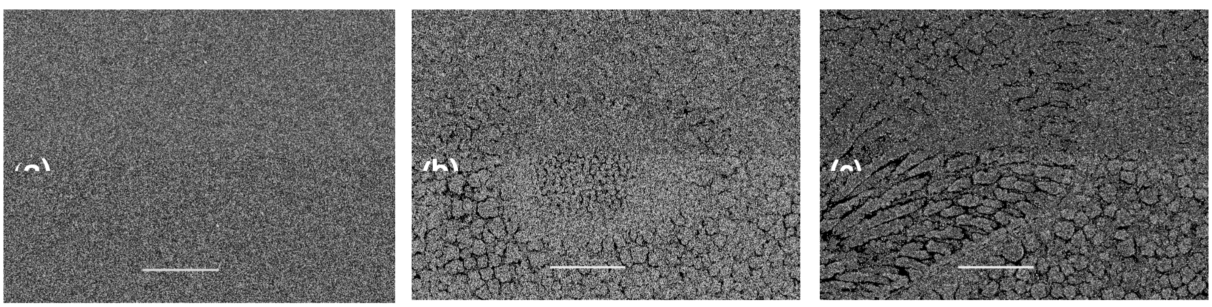


Figure 3. The as-cast structure of GH4720Li alloy

The homogenization of chemistry and structure can be obtained by heating at high temperature. This can also increase the ductility of alloy. The microstructure of GH4720Li alloy after homogenization heat treatment demonstrated in Figure 4 shows that γ′ particles and γ+γ′ eutectic have dissolved into γ matrix. Only few carbide, carbonitride and boride are observed.

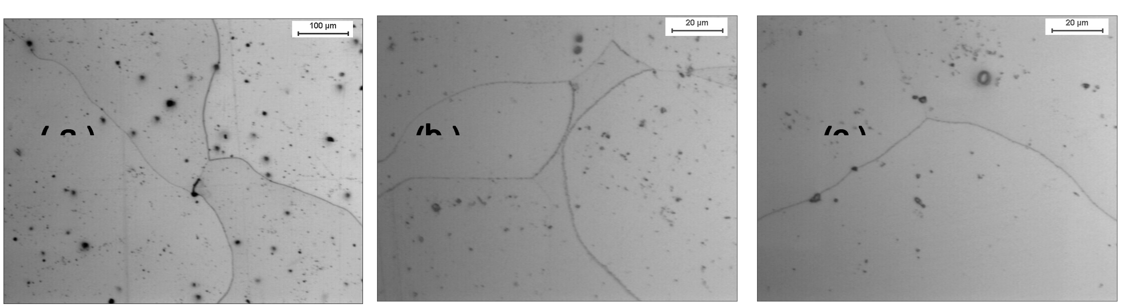


Figure 4. Microstructure of GH4720Li ingot after homogenization

Microstructure evolution of GH4720Li

With the increase of alloying elements, the high temperature strength and dynamic recrystallization temperature of an alloy tends to increase and its melting point tends to decrease. This results in a narrower hot working window and the resistance to deformation increases rapidly.

The transverse macrostructure and microstructure of rolled GH4720Li bars are illustrated in Figure 5 and Figure 6 respectively. It can be seen that the macrostructure of top and bottom of the bar showed in Figure 5(a) and Figure (b) respectively is homogeneous. The coarse dendritic structure is fully refined after compound jacketing rolling for GH4720Li ingot. The size of primary γ′ is about 0.46μm.

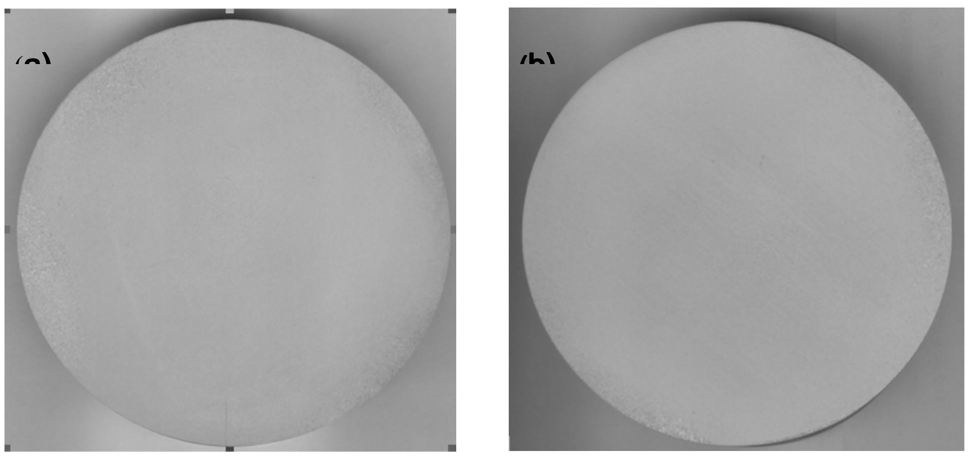


Figure 5. Transverse macrostructure of GH4720Li 90 mm rolled bars

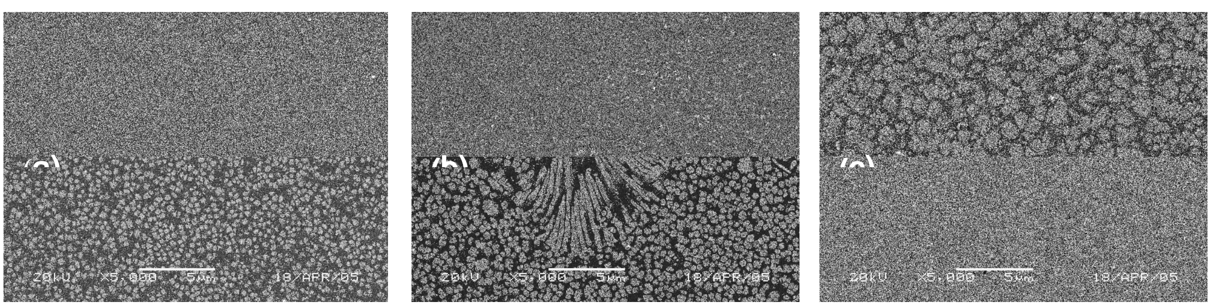


Figure 6. Microstructure of GH4720Li rolled bars

The different morphologies of γ′ particle shown in Figure 6 include spherical shape, dendritic shape, fan and irregular shape. Fan-type secondary γ′ consists of a number of parallel rod γ′ which end at a grain boundary. Because the grain boundary is a disordered and high energy region and energy required during precipitation is low, phase transformation commonly occurs at grain boundary. Therefore, fan-type γ′ is inclined to nucleate at grain boundary, and it grows toward adjacent grain as shown in Figure 7.

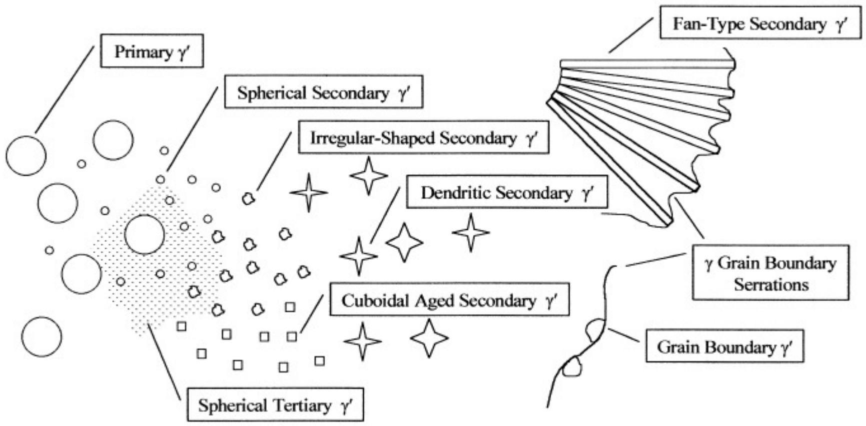
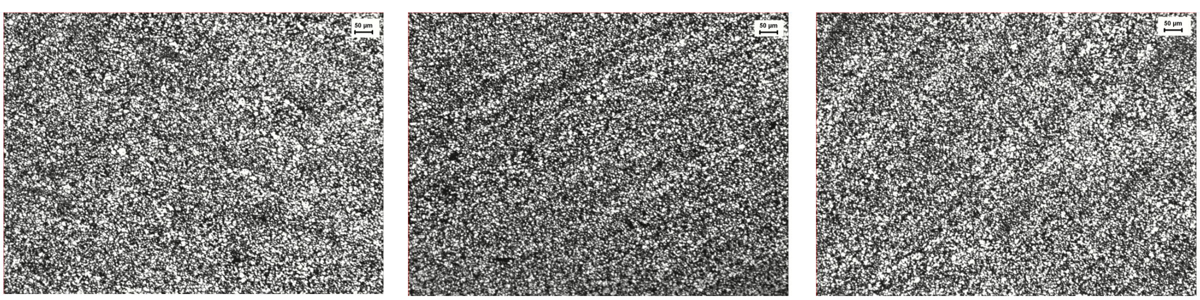


Figure 7. Illustration of different morphology of γ′

Microstructure of heat treatment of GH4720Li alloy

Heat treatment is crucial to the microstructure of alloy. The rolled GH4720Li alloy contains a large number of γ′ particles, so the alloy has the high temperature strength, but low hot ductility. The size, amount and shape of γ′ can be adjusted by heat treatment. Figure 8 and Figure 9 illustrates the microstructures of GH4720Li after heat treatment by 1090°C/4 hours/oil quench + 650°C/24 hours/air cooling +760°C/16 hours/air cooling. It can be seen that fan-type and dendritic γ′ are put into solution and some γ′ precipitate forming a zigzag grain boundary. The average grain size is about ASTM8 and average size of γ′ is about 0.60μm.



(a) Center area (b)1/2 area (c) border area

Figure 8. Microstructure of GH4720Li after heat treatment

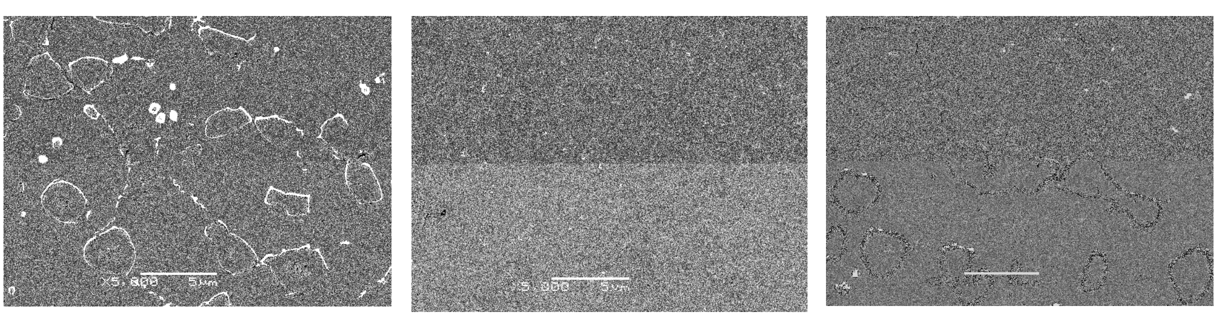


Figure 9. Morphology of γ′ after heat treatment

The solvus temperature of γ′ phase is about 1159ºC calculated by THERMO - CALC software. Therefore, GH4720Li alloy mainly consists of matrix, primary γ′, few carbide and boride after solution treatment. And secondary γ′ and tertiary γ′ can precipitate during the aging treatment. This further improves the elevated strength and ductility of GH4720Li alloy.

Mechanical properties of GH4720Li

As indicated in Figure 10, it is important to gain a size distribution of γ′ to get excellent mechanical properties by proper heat treatment. It shows that GH4720Li alloy has high strength and excellent ductility below 750ºC. At 800ºC, the tensile ductility drops in a similar manner to other precipitation strengthened nickel base alloys.

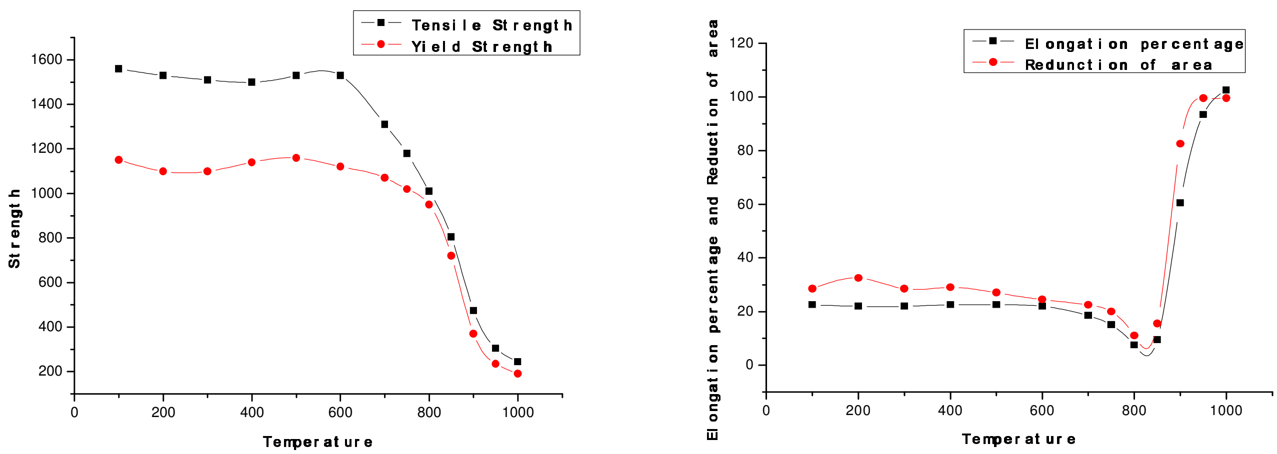


Figure 10. Mechanical properties of GH4720Li alloy

Conclusion

(1) The coarse dendritic structure of GH4720Li ingot can be fully refined and an average grain size of ASTM 8 can be obtained by compound jacketing rolling technique.

(2) The size of γ′ can be further refined and the hot ductility increases after hot rolling plus heat treatment.

(3) The size, amount, shape and distribution of γ′ can be optimized by heat treatment such that mechanical properties can be obtained to meet service requirements.

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