Journal of Metallurgical and Materials Engineering, Vol.31, No.2, 2020.

The Influence of Hot-working and Solution Annealing on Microstructure and Mechanical Properties of Haynes 188

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1. Introduction

Haynes 188 is one of the most important Cobalt-based superalloys manufactured through hot working processes (hot rolling). Corrosion resistance and service in high temperature are significant attributes of Haynes 188. Solid solution accompanied by precipitation of carbides are the main strength mechanisms. $M_{23}C_6$ and M_6C (M stands for one or more metallic elements) are the main carbides in microstructure, which can precipitate based on annealing conditions.

The range of hot working process of Haynes 188 is limited and it has been reported between 1100-1200 ˚C. Some studies showed that the reduction of thickness (equivalent strain) in hot rolling has important effects on mechanical properties of some Cobalt based alloys. So temperature and strain (reduction of thickness) are major controllable parameters in hot rolling process. Few researches have been done on hot working process of Cobalt base alloys. The study investigates the effects of annealing after hot working.

2. Experimental

The studied alloy was produced using induction melting followed by electroslag remelting (ESR) process. Also ingot was homogenized at 1200 ˚C for 3 hours and water quenched. Table 1 shows the chemical composition of the alloy. As seen, its composition is in the range of AMS 5772 standard.

AMS 5772, Cobalt alloy, corrosion and heat-resistant bars, forgings and rings, 40Co-22Cr-22Ni-14.5W-0.07La, solution heat treated, 2016.

Table 1. Chemical composition of the alloy compared with AMS5772 standard

Alloy/element	**Co**	**Cr**	**Ni**	**W**
AMS 5772[1]	bal	20-24	20-24	13-16
Studied alloy	bal	21.53	22.5	14.51
Alloy/element	**Fe**	**Mn**	**Si**	**C**
AMS 5772[1]	<3	<1.25	<0.5	0.05-0.15
Studied alloy	1.11	0.05	0.33	0.11

The homogenized ingot was divided into two sections and consequently hot rolled at 1150 ˚C with 60 and 85% reduction of thickness. Then the samples were annealed at 1140, 1160 ˚C, 1180 ˚C, and 1200 ˚C for different times, and cooled in water.

Mechanical tests such as Vickers hardness and tensile tests were conducted on the specimens with different hot working and annealing history. In addition, microstructural evaluations were investigated by optical microscopy (OM: Olympus BX51 model) and scanning electron microscopy (SEM: TeScan VEGA3 model). Energy dispersive spectroscopy (EDS) elemental analysis was employed to identify secondary carbide phases.

3. Results and Discussion

Figure 1 shows the microstructure of Haynes 188 alloy before and after hot rolling process. As it shows, after hot rolling cast structure breaks down and turns to structure included dynamic recrystallization grains (DRX) accompanied with some carbide particles.

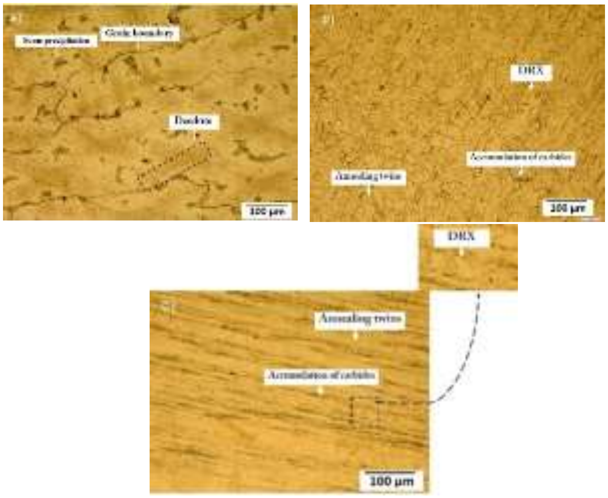

Fig. 1. Optical Microstructure of the haynes 188 alloy at different conditions of a) Homogenized, b) 60% hot rolled, and c) 85% hot rolled

As seen in Figure 1, by increasing reduction of thickness, grain size decreased and volume fraction of secondary carbide phases increased.

As mentioned before, samples were annealed in various temperatures and time. Figure 2 shows quantitative information of the effect of annealing process on microstructure of alloy. In addition, the changing of twin length with annealing process were evaluated through simple manner:

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$$X = \frac{mean\ of\ twin\ length}{mean\ of\ grain\ boundary\ size}$$

where X is the average of change of twin length. Increasing the holding time of 10 to 30 minutes had very ignorable effect on grain size in constant temperature. It is, however, clearer for temperatures below 1180 ˚C. Grain growth observed when the holding time increased from 30 to 60 mintues in all temperatures (with the exception of 1140 ˚C for alloy 60%) by solution of carbides in matrix and grain boundary mobility mechanism.

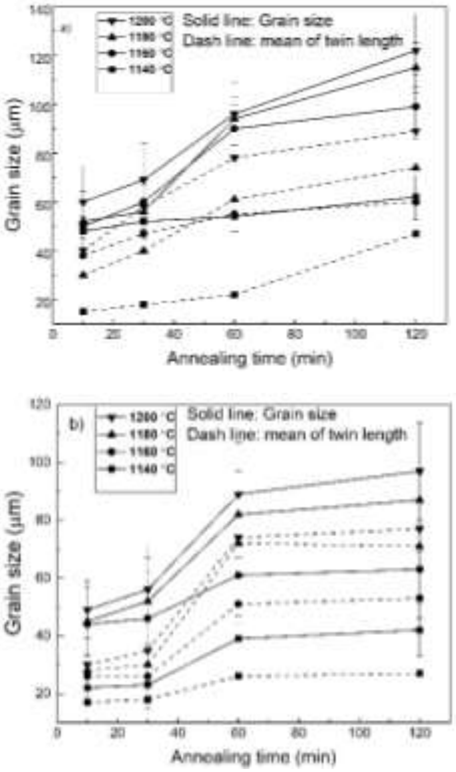

Fig. 2 Change of grain size and twin length by annealing temperature and time for the haynes 188 after hot rolling with thickness reductions of a) 60 % , and b)85%.

Hardness increases by the reduction of thickness simultaneously, because of higher grain refinement and higher fraction of carbides. It's revealed that annealing beyond 30 minutes at 1180 ˚C causes hardness drop by grain growth and solution of carbides mechanism. Figure 3 illustrates as well the tensile properties of alloy. As seen in Figure 3, the strength of the 85% hot rolled specimen was approximately two times higher than the one rolled 60%. Solution annealing had undesirable effects on the strength of the 85% hot rolled specimen but increased the ductility. However, by short time annealing the 60% hot rolled specimen, the ductility increased and the strength maintained constant.

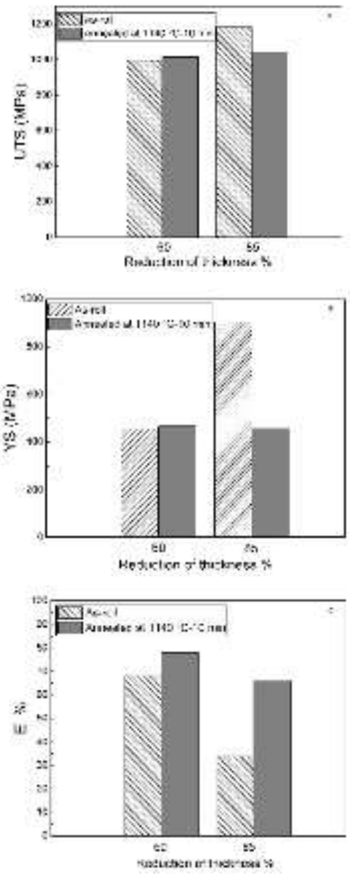

Fig. 3. The results of tensile tests of haynes 188 a) YS, b) UTS, and c) El

5. Conclusion

Reduction of thickness during hot rolling process caused grain refrainment and increased secondary carbide particles. Tungsten rich carbide might be M6C type carbides. The 85% hot rolled specimen had higher level stored energy than the 60% rolled one. Therefore, the grain growth rate was higher for the former one. The best strength and ductility of the Hayness 188 alloy can be obtained by annealing at temperatures below 1160 ˚C.