Microstructure and Mechanical Properties of Solution Heat-Treated Alloy 617 ODS Alloy

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1. Introduction

Future nuclear energy systems raise challenges for materials that can be operated safely in the severe environments, due to the requirement for higher efficiency and longer operation duration. Alloy 617 is a solution hardened Ni-based Superalloy containing Cr, Co, Mo, and Fe, and is among the best candidate materials for the key components of VHTR (Very High Temperature Reactor) system [1-3]. As an alternative, Oxide Dispersion Strengthened (ODS) Ni-based superalloys, are known to possess superior high temperature mechanical properties and long-term high temperature microstructural stability due to the nano sized oxide dispersoids, which effectively hinder the dislocation motion at high temperature. This study is focused on the fabrication and characterization of nano-sized oxide dispersion strengthened alloy 617. The influences of alloy composition and processing variables such as the content of Y_2O_3, hot extrusion ratio, and hydrogen reduction on the microstructure and mechanical properties were studied.

2. Methods and Results

2.1 Experiments

Four alloy specimens were prepared. Alloy specimen 1 was processed from Alloy 617 prealloyed powder with 0.6 wt.% yttria (Y_2O_3) powder by mechanical alloying in a ball mill. Before extrusion, the powders were degassed at 500 ℃ for 2 hr. The extrusion process was conducted at 1100 ℃ for 2hr, and the extrusion ratio was 6.25:1. Alloy specimen 2 was subjected to hydrogen reduction before degassing. The alloy specimen 3 was fabricated with an extrusion area reduction ratio of 9:1. Alloy specimen 4 was fabricated by the same procedures as the sample 1, but contained 0.45 wt.% yttria. All the samples were solution heat treated at 1100 ℃, 1150 ℃, 1200 ℃, 1250 ℃ and 1300 ℃ for 2 h followed by air cooling. The chemical compositions of Alloy 617 ODS specimen is shown in Table 1.

Table 1. Chemical composition of Alloy 617 ODS alloy - wt.%

Ni	Cr	Co	Mo	Fe
Bal.	22	12.5	9	1.5
Al	**Ti**	**C**	**B**	**Y_2O_3**
1	0.4	0.1	0.004	0.6

2.2 Results and discussion

Each specimen was solution treated at 1100, 1150, 1200, 1250 and 1300℃ for 2 h to optimize solution heat treatment condition.

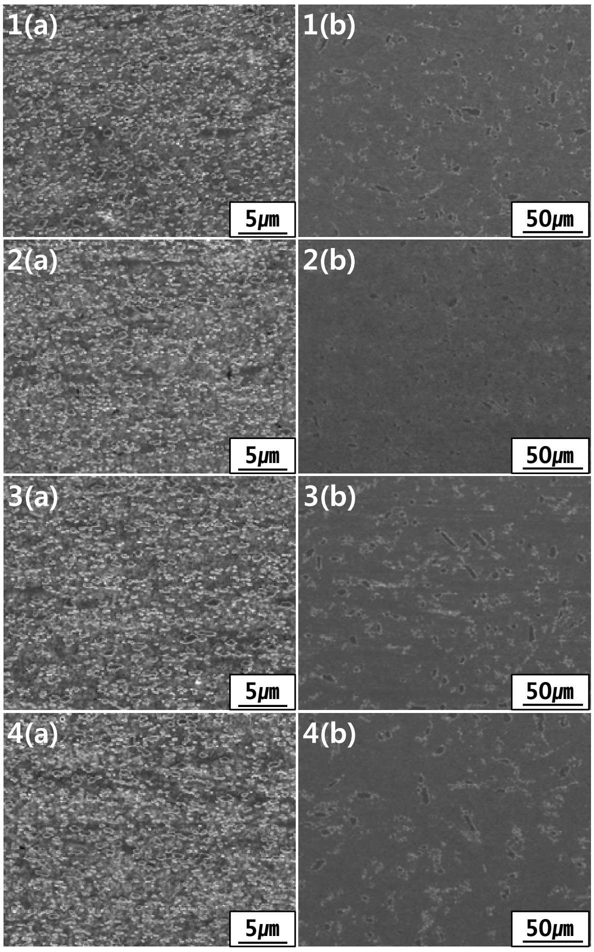
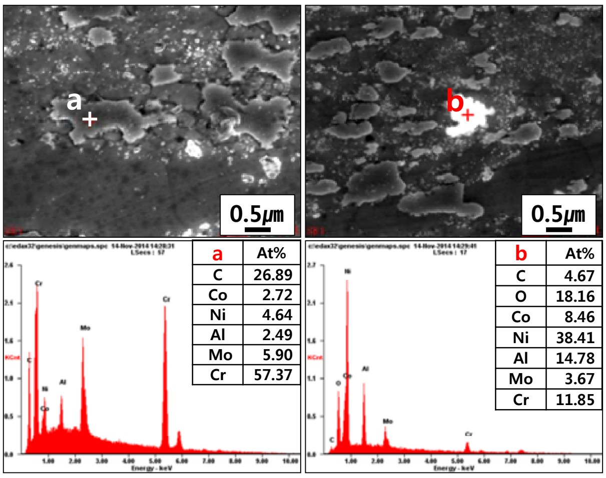


Fig. 1. SEM micrographs of alloy 617 ODS (a) as-extruded specimen before annealing and (b) solution annealed at 1250℃/2 h.

The microstructure of the as-extruded specimen and solution treated at 1250 ℃ for 2 h are shown in Fig. 1. In as-extruded condition (Fig. 1a), a lot of precipitates of $M_{23}C_6$ are shown, and the precipitates of Cr_6C are also observed locally. Such precipitates disappeared gradually with increasing the temperature of solution heat treatment. When solution heat treated at 1250℃ for 2 h (Fig. 1b), a good portion of precipitates seem dissolved with in the matrix. The size and number density of precipitates slightly reduced. At 1300℃, over 1250℃, grain growth is happening and lamellar structure carbides are formed along the grain boundaries. Shown in Fig. 2 are chemical compositions of precipitates found in specimen 1. Dark precipitates are $M_{23}C_6$-type carbides (fig.2a) and bright precipitates are Al-base oxides (fig.2b). The carbides reduce at 1250℃ for 2hr (Fig. 1b), but grain size and the kind of precipitates do not appear much changed.



a	At%
C	26.89
Co	2.72
Ni	4.64
Al	2.49
Mo	5.90
Cr	57.37

b	At%
C	4.67
O	18.16
Co	8.46
Ni	38.41
Al	14.78
Mo	3.67
Cr	11.85

Fig. 2. SEM/EDS analyses results for the specimen 1 ; solution heat treated at 1250℃ for 2 h (a) $M_{23}C_6$ and (b) Al-base oxide.

Tensile test results of as-extruded specimens at RT, 700℃, 900℃ and 950℃ are presented in Fig. 3. All the specimens exhibit similar values of yield strengths at all test temperatures: the yield strength at RT are ~1800 MPa but decrease linearly with increasing the test temperature, showing ~280 MPa at 950℃. The attractive high temperature strengths of ODS superalloys are primarily due to the presence of uniformly dispersed fine oxide particles. These oxide particles produce a dispersion strengthening effect by acting as barriers to dislocation motion [4].

All the samples exhibit negligible ductility, ~3%, at RT. Ductility of all the samples was increased with increasing temperature, peaking at 900℃ and was decreased again at 950℃. At temperatures higher than 900℃, the ductility increases in the order of the specimen 4, 3, 1 and 2. Higher ductility of the specimen 4 and 3 could be attributed to the lower yttria content and less pores, respectively. The H2 specimen was expected to show a good ductility due to its lower oxygen contents, but exhibited lowest ductility at 900℃ and above, which suggests that hydrogen reduction was not effective enough for the oxygen content control.

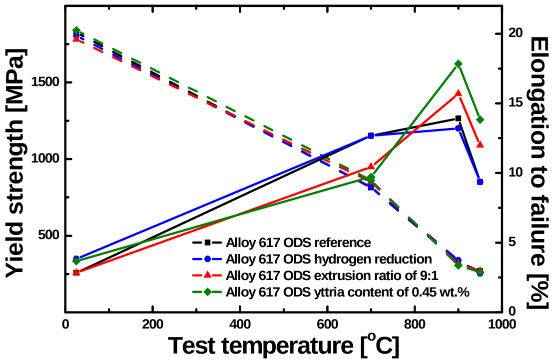


Fig. 3. Tensile test results of Alloy 617 ODS alloys at RT, 700℃, 900℃ and 950℃.

3. Conclusions

From the analyses of microstructure of solution heat treated Alloy 617 ODS alloy specimens, a proper solid solution heat treatment temperature to reduce carbides is 1250℃. The major phases present in the alloy 617 ODS were found to be $M_{23}C_6$ and Al-O. Lowering yttria content to 0.45 wt.% and increasing extrusion ratio are found to be effective to enhance the tensile properties of ODS alloys.

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