Mechanical Strength of Zirconium Alloys with the Nb, Fe, and O Content

Il-Hyun Kim[*a], Hyun-Gil Kim[a], Jeong-Yong Park[a], Byung-kwan Choi[a] ,Yong-Hwan Jeong[a], Sun-Jin Kim[b]
[a]*Nuclear Convergence Technology Division, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea*
[b]*Department of Materials Sci. & Eng. Hanyang University, Haengdang 1-dong, Seongdong-gu, Seoul, Korea*
[*]*Corresponding author: s-weat@hanmail.net*

1. Introduction

Zirconium alloys are being used as fuel cladding and structural components of fuel assembly for nuclear power plants, since these alloys have a good irradiation stability, corrosion resistance as well as mechanical properties. The development of improved zirconium alloys has been extensively carried out in many countries operating nuclear power plants for the last few decades [1-3]. They have reported that the corrosion resistance of zirconium alloys was determined by the alloying element and manufacturing processes. Among the various elements, Nb and Fe are chosen in the advanced claddings, since these two elements increased the corrosion resistance in the irradiation environment. Although Nb and Fe are considered to be important alloying elements in the advanced zirconium alloys, it has a problem that the manufacturing process is limited by increasing the Nb and Fe content in zirconium based alloys. So it is need to find a good formability in the Nb and Fe containing zirconium based alloys. And it is considered that the formability of zirconium based alloys is considerably affected by the O content. This work is studied on the mechanical strength among the Nb, Fe and O contents of the zirconium based alloys. The microhardness test with the Nb, Fe and O contents was performed to evaluate the formability of zirconium alloys.

2. Methods and Results

Table 1 shows the chemical composition of experimental alloys. The Nb content ranged from 1.0 to 2.0 wt% and the Fe content ranged from zero to 0.4 wt% and the O content ranged from 0.07 to 0.15 wt% in the zirconium based alloys.

Table.1: Chemical composition of zirconium based alloys

Alloy	A	B			C			D	E
	O1	**O1**	**O2**	**O3**	**O1**	**O2**	**O3**	**O1**	**O2**
Nb	1.0	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.0
Fe	-	-	-	-	-	-	-	0.2	0.4
O	0.12	0.07	0.12	0.12	0.07	0.12	0.15	0.12	0.12

The experimental alloys with various Nb, Fe and O contents were manufactured as following the general manufacturing process as shown in Table. 2. The alloys were melted in a vacuum environment (3 times), water quenched after β-solution treatment at 1020℃ for 15 min, hot rolled after pre-heating at 640℃ for 15 min, annealed at 570℃ for 3h and then cold rolled of 80%.

Table.2: Manufacturing process of zirconium based alloys

Process flow
Melting: Vacuum arc (3 times)
↓
Beta quenching: Into water (1020℃ x 15min preheat)
↓
Hot rolling: 60% (640℃ x 15min preheat)
↓
Annealing: 570℃ x 3h (vacuum)
↓
Cold rolling: 80%

The microhardness test was performed by using a Knoop-type indenter (Shimadzu, Model HMV-2) to reduce the partial deviation due to microstructural differences, such as grain boundary and precipitates. The hardness for one sample is averaged from the ten times, and applied load is 0.2 N for 10 s.

2.1 Nb effect on microhardness

Fig. 1 shows the microhardness variation with the Nb content from 1.0 to 2.0 wt%, where Fe is not contained and O is maintained as 0.12 wt%. It could be identified that the microhardness increased with increasing the Nb content. As increasing the Nb content of 0.5 wt%, the hardness gradually increased about 7% when compared to the initial point of 1.0 Nb.

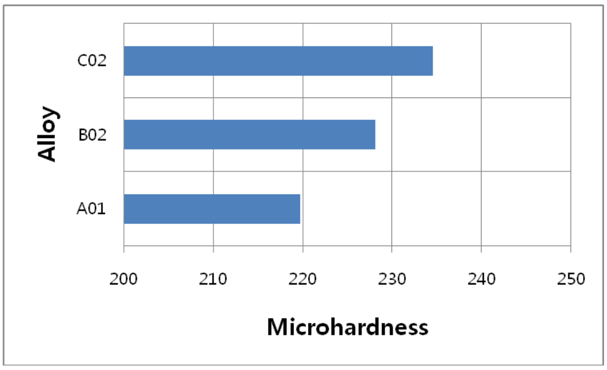

Fig. 1. Variation of microhardness with the Nb content after 80% cold rolling.

Because the solubility of Nb in Zr is 0.6 wt% [4], this trend of hardness increase from 1.0Nb was caused by the precipitate effect from Nb addition. So, it could be anticipated that the precipitation hardening is major effect in this alloy system.

2.2 Fe effect on microhardness

Fig. 2 shows the microhardness variation with the Fe content from zero to 0.4 wt%, where Nb and O are maintained as 2.0 wt% and 0.12 wt%, respectively. By addition of Fe from zero to 0.2 wt%, the hardness increased more than 10 %, however, the hardness similar with the Fe content between 0.2 wt% and 0.4 wt%. Therefore, it is known that the hardness with the Fe content is considerably changed between zero and 0.2 wt% range. The Fe solubility in Zr is about 120 ppm [5]. From this, the hardness increase by the Fe addition in this work is affected by more solution hardening then precipitation hardening.

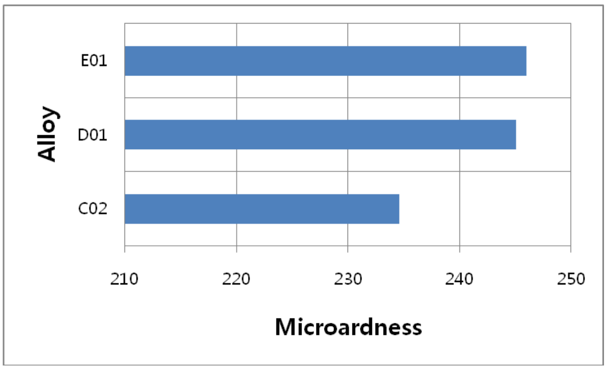

Fig. 2. Variation of microhardness with the Fe content after 80% cold rolling.

2.3 O effect on microhardness

Fig. 3 shows the microhardness variation with the O content from 0.07 to 0.15 wt%, where Fe is not contained and Nb is maintained as 1.5 and 2.0 wt%.

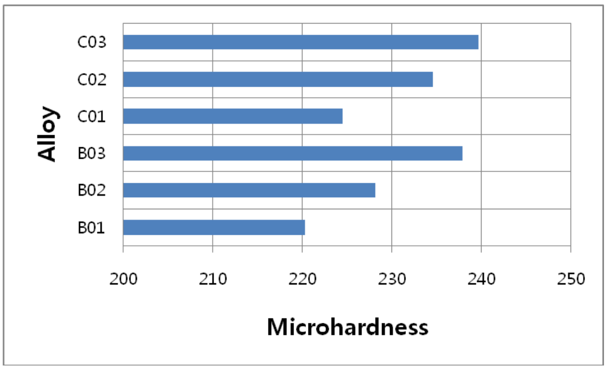

Fig. 3. Variation of microhardness with the O content after 80% cold rolling.

The microhardness gradually increased in amount of 8 % with increasing the O content. Since the oxygen solubility is higher than 8 wt% [6], the hardness increase by O in this work is caused by solution hardening. When compared to the Nb and O effect in hardness, the O content change from 0.07 to 0.15 wt% shows higher variation than the Nb content change from 1.5 to 2.0 wt%.

By increasing the O content about 0.05 wt%, the hardness more changed than by increasing the Fe content of 0.2 wt% and Nb content of 0.5 wt% after comparison among the Figs in this work. So, it is possible that the formability control without the Nb and Fe content change could be possible by controlling the small amount of O in zirconium based alloys.

3. Conclusions

After considering the hardness variation with the Nb, Fe, and O content, the solution hardening is stronger than the precipitation hardening in zirconium based alloy. And the control of O content is higher impact on strength than the control of Nb or Fe content in zirconium based alloys.

REFERENCES

[1] A.V. Nikulina, J. Nucl. Mater. 238 (1996) 205.
[2] R.J. Comstock, G. Schoenberger, G.P. Sabol, ASTM STP 1295 (1996) 710.
[3] Y.H. Jeong, H.G. Kim, T.H. Kim, J. Nucl. Mater. 317 (2003) 1.
[4] C.E. Lundin, R.H. Cox, USAEC Report, GEAP-4089 1, 1962
[5] D. Charquet, R. Hahn, E. Ortlieb, J-P. Gros, J-F. wadier, ASTM STP 1023 (1988) 405.
[6] J.P. Abriata, J. Garces, and R. Versaci, Bull. Alloy phase diagrams, V.7, N2, (1986) 116-124.