Annealing Effects on Advanced Reduced-Activation Alloy Studied by Positron Annihilation Lifetime Spectroscopy

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1. Introduction

Advanced Reduced-Activation Alloy (ARAA) material was developed in 2001 as a structure used in nuclear fusion reactors [1]. ARAA was mainly by International Thermonuclear Experimental Reactor (ITER), and in addition to, ARAA, Europe (EUROFER97) and Japan (F82H) are used [2]. It is widely used in ITER structure such as the magnet system, the blanket are exposed to high temperatures and for 14 MeV high-energy neutrons and tritium emitted by fusion reactions. The exposed part of the blanket is irradiated by neutrons and may affect another structure. In the case of nuclear structural materials, the point defect and cluster may be deformed, and as a result, the condition of the structure may be degraded and the integrity of the structure may be impaired. Therefore, in the case of the blanket area, it is important to use the part where high temperature plasma is generated should be well endured at high temperatures and that there is not much additional activation produced by neutrons produced by fusion. Therefore, it will be very important to identify the characteristics of the most stable state change of the material as the temperature changes in the process.

2. Materials and Methods

2.1 Positron Annihilation Lifetime Spectroscopy

Positron annihilation lifetime spectroscopy (PALS) was used to analyze the defect of ARAA in this study. The PALS system consists of high voltage power supply (HVPS), fast plastic scintillators, photomultiplier tubes (PMT), constant fraction differential discriminators (CFDD), nanosecond delay, multi-channel analyzer (MCA) and time to amplitude converter (TAC).

A HVPS applies stable high voltage into PMT. The photon energies of 1.27 MeV (start signal) and 0.511 MeV (stop signal) was received by two CFDDs. The generated signal was shifted in the nanosecond delay to optimize the error and stored as MCA through time amplification in the TAC.

The positron source used for PAS was the Na-22 radioactive isotope of 30 μCi as 2.5 μm Ni foil, overlapping like a sandwich on both sides. The 8×8 mm^2 positron source was positioned between the samples. For TMP 2B-RX, TMP 38, TMP 21, TMP 19 positron lifetime spectra were obtained more than 1×10^6 counts during 86,000 seconds, while we collected at least 2×10^6 counts for TMP 22 and TMP 27 samples. The time resolution was about 256 ps in full width at a half maximum (FWHM). The positron lifetime spectra were analyzed by two unfolding modules, *Resolutionfit* and *Positronfit*, in *PALSFit3* [3].

2.2 Samples

ARAA was created by adding 0.01wt% Zr to 9Cr-1.2W based ferritic-martensitic steels. The basic composition of ARAA is described in Table 1. All samples were normalized and rolled for 40 minutes at 1000℃, and each sample was tempered in a different method. Each sample size was 10×10×1 mm^3. Specific sampling methods for ARAA are described in Table 2.

Table 1. Chemical composition of the ARAA steel (wt.%).

Element	Composition (wt%)	Element	Composition (wt%)
C	0.1	V	0.2
Si	0.1	Ta	0.07
Mn	0.45	N	0.01
Cr	9	Ti	0.01
W	1.2	Zr	0.01

Table 2. Sampling processes of ARAA steel.

Sample	Annealing and rolling method
TMP 2B-RX	N+N+25%CR+Tempering
TMP 21	N+N+25%HR@300℃
TMP 22	N+N+25%HR@400℃
TMP 38	N+N+25%HR@500℃
TMP 19	N+N+25%HR@700℃
TMP 27	N+N+25%HR@750℃

N: normalizing: 1000℃/40 minute/air-cooling
HR: hot-rolling
Tempering: 780℃/120 minute/air-cooling

3. Results

τ_1 is a short lifetime and is directly annihilated when positron penetrates from a material, not trapped by defect, which is about 110 ps for pure Fe [4]. τ_2 is a long lifetime, and as long as the penetrated positron is trapped in the defect and the lifetime of the positron is extended, time is considered. For ARAA, τ_1 appears as

>100 ps similar to the published τ_1 using EUROFER97 [5]. τ_2 was observed between 210 ps and 300 ps and 110 ps to 140 ps for mean lifetime. Details for each sample were described in Table 3.

Table 3: τ_1, τ_2, I_1, I_2 and mean lifetime (MLT)

Sample	Lifetime				
	τ_1 (ps)	I_1 (%)	τ_2 (ps)	I_2 (%)	MLT (ps)
TMP 21	88.3	68.4	212	31.6	127
TMP 22	85.3	73.7	219	26.3	120
TMP 38	94.6	83.5	255	16.5	121
TMP 34	90.2	68.2	209	31.8	128
TMP 27	88.4	72.1	224	27.9	126
TMP 2B-RX	87.7	89.2	306	10.8	111

The change according to the temperature applied to hot-rolling was observed as the mean lifetime of PAS. The results were shown in Fig 1. The mean lifetime from 300℃ to 400℃ was drastically decreased. The mean lifetime significantly increased from 500℃ to 700℃, then the lifetime decreased when the temperature was increased further by 50℃. It was also shown to be the lowest mean lifetime when cold-rolling was performed and tempered at 780℃ than temperature treatment was performed at 780℃ in hot-rolling. The results showed a similar response to changes in temperature in the Fe-9Cr steel [6].

Depending on temperature, the change in lifetime appears to be a reaction in the initial microstructure caused by Cr. It is shown to be affected by dislocation and grain structure due to the formation of the extract of Cr [7].

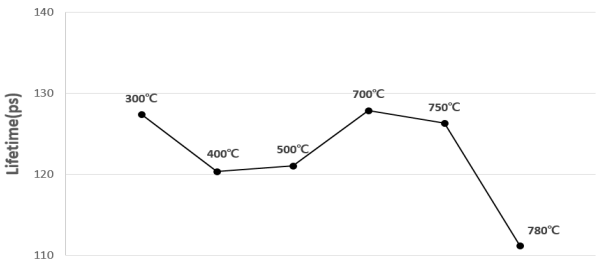

Fig 1. The change according to the temperature applied to hot-rolling was observed as mean lifetime.

3. Conclusions

The change in temperature from 300℃ to 780℃ of ARAA was analyzed for mean lifetime, τ_1, τ_2, I_1, and I_2. The characteristics of ARAA were similar to Fe-9Cr steel because the basic chemical composition of ARAA was Fe-9Cr steel. In other words, the mean lifetime decreased and increased from 300℃ to 700℃, and the mean lifetime decreased from 700℃ and above. Therefore, the defect is found to be recoverable by heat treatment at over 700℃. It is expected that it will be possible to analyze the condition of defects in the material rather than not performing them by performing heat changes the material.

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