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Establishment on the Design Stress Intensity of KJRR fuel using a Tensile Test

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1. Introduction

Investigating the material properties of KJRR fuel is crucial because it becomes the basis of the stress design criteria of the fuel. During the cladding fabrication process, i.e. hot and cold rolling processes and inspection test, several heat treatments and hardening processes are applied to the cladding, which possibly causing the mechanical properties to change from the raw material. Given that the material properties of the cladding are no longer identical to those of the original material, the design stress intensity values described in the ASME code [1] cannot directly utilize. Thus, it is necessary to measure the yield strength (YS) and ultimate tensile strength (UTS) of the cladding so as to determine the design stress intensity value, using the method described in the mandatory appendix 2 of the ASME code section II.

2. Methods and Results

The tensile tests of the cladding (Al6061) and structural materials (Al6061-T6) used for the KJRR fuel assembly were planned and conducted. For the tensile test of the sheet-type test specimen, the tests are carried out in accordance with the ASTM E8 [2]. In order to consider the uncertainty of the data, i.e. for the probability level with a certain confidence level, a sufficient number of test results are required.

2.1 Specimen preparation

As a tensile test specimen, a subsized specimen of 6 mm wide in accordance with ASTM is adopted. The cladding specimens were manufactured using the same process of the fuel plate fabrication, except the process of the U-7Mo powder treatment.

2.2 Test condition

Considering the maximum temperature of the cladding and structural components in the KJRR operational states, a test matrix for the tensile test is designed. The mechanical properties are measured at five different temperature points for the cladding material: room temp., 100ºC, 150ºC, 200ºC and 250ºC. Also used are four temperature points for the structural material: room temp., 100ºC, 150ºC and 200ºC.

Because the thickness of the fuel plate is very thin, a specific jig for the tensile specimen, as shown in Fig. 1, is designed to apply a tensile load on the specimen without slipping during the loading process.

Fig. 1 Tensile test setup

2.3 Test results

Fig. 2 shows the YS and UTS of cladding material (Al6061) with temperatures. The measured data and two-sided tolerance limits with a 90% probability and a 95% confidence level are plotted together in the graph. The YS and UTS values for Al6061 at room temperature are 200.2 MPa and 225.0 MPa, respectively, which are reduced by 30 ~ 40% from those of the raw material, Al6061-T6. During several heat treatment processes of hot rolling and blister test, the cladding alloy is exposed to elevated temperature for a period of time sufficient to undergo a solution heat treatment and annealing, leading to grain boundary precipitation. The mechanical properties of the strength and hardness are reduced during the annealing process, which render the strength of the cladding material lower than that of Al6061-T6. After the cold work, the cladding alloys are strain-hardened. Up to the temperature of 150ºC, the strengths of the cladding do not significantly decrease due to the dislocations generated from the cold work, but after 150ºC, they begin to decline.

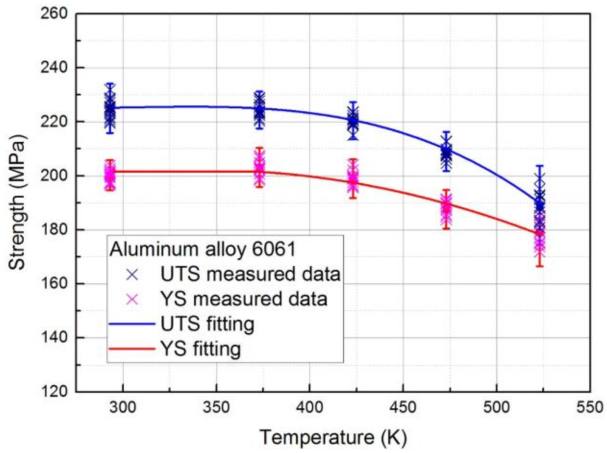

Fig. 2 Yield ad ultimate tensile strength of cladding material (Al6061)

Fig. 3 shows the YS and UTS of the structural material (Al6061-T6) with temperatures. It is shown that the YS and UTS decrease monotonically with the temperature. The YS and UTS at room temperature are 318.0 MPa and 339.0 MPa, respectively, satisfying the specification values of the ASME code Section II, with YS equal to 240 MPa and a UTS value of 290 MPa at room temperature.

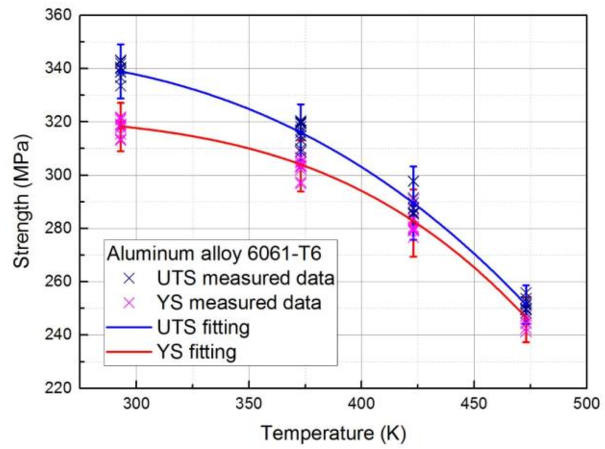

Fig. 3 Yield ad ultimate tensile strength of structural material (Al6061-T6)

The S_m values of the cladding (Al6061) and structural (Al6061-T6) materials computed from the test results are illustrated in Fig. 4. The lower-bound values of S_m are determined considering the one-sided tolerance limits of a 95% probability and a 95% confidence level. The S_m values of Al6061 at 200ºC are found to be 69.7 MPa for the best estimate and 67.3 MPa for the lower-bound. The S_m values of Al6061-T6 at 100ºC computed from the test results are 105.3MPa for the best estimate and 101.8 MPa for the lower-bound. For Al6061-T6, the S_m values with respect to the temperature are listed in ASME Section II. The S_m values for Al6061-T6, plate of sheet type (SB209) in the ASME code, are 96.5 MPa at room temperature, 96.3 MPa at 100ºC, 90.9 MPa at 125ºC and 77.3 MPa at 150ºC. It is thus confirmed that the calculated S_m values from the tensile test are higher than those in the ASME code.

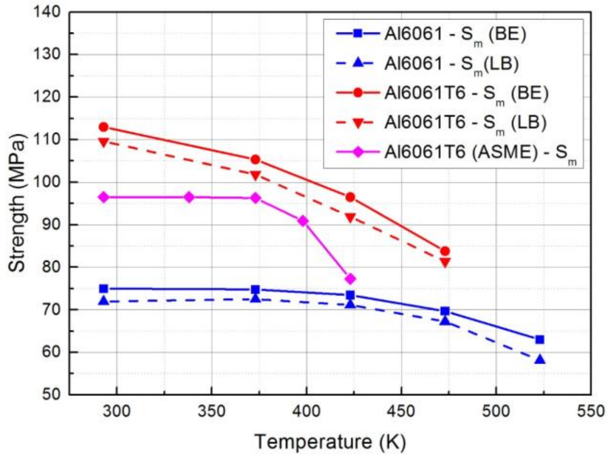

Fig. 4 Design stress intensity values of aluminum alloy 6061 and 6061-T6 with the temperature

3. Conclusions

In this paper the mechanical properties, yield and ultimate tensile strengths, of the KJRR fuel plates are measured by means of tensile tests. The mechanical properties of the cladding (Al6061) are reduced by 30~40% compared to those of the raw material during the fabrication process. The strength of the cladding do not significantly decrease until it reaches 150ºC, but, over 150ºC, it begins to decrease due to recrystallization. The design stress intensities of the KJRR fuel assembly are presented by considering the uncertainties of the measured data. A comparison of the test results of Al6061-T6 with those of the ASME code reveals that the calculated design stress intensity values for the KJRR fuel are thought to be valid and the test results are reasonable.

REFERENCES

[1] American Society for Testing and Materials, 2011. ASTM E8 / E8M-11, Standard Test Methods for Tension Testing of Metallic Materials, ASTM International.

[2] The American Society of Mechanical Engineers, 2004. ASME Boiler and Pressure Vessel Code, Section II Materials, New York, NY 10016-5990.