Specific Heat Capacity of Alloy 690 for Simulating Neutron Irradiation

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1. Introduction

The KAERI(Korea Atomic Energy Research Institute) is developing new type of nuclear reactor, so called “SMART”(System Integrated Modular Advanced Reactor)[1] which has many features of small power and system integrated modular type. Alloy 690 was selected as the candidate material for the heat exchanger tube of the steam generator of SMART[2]. The SMART R&D is now facing the stage of engineering verification and approval of standard design to apply to DEMO reactors. Therefore, the material performance under the relevant environment is required to be evaluated. The important material performance issues are mechanical properties i.e. (fracture toughness, tensile and hardness) and thermal properties i.e. (thermal diffusivity, specific heat capacity and thermal conductivity) for which the engineering database is necessary to design a steam generator. However, the neutron post irradiation characteristics of the alloy 690 are barely known. As a result, PIE(Post Irradiation Examination) of thermal properties are planed and performed successfully. But specific heat capacity measurement is not performed because of not having proper test system for irradiated materials. Therefore in order to verify the effect of neutron irradiation for alloy 690, simulation method is adopted. In general, high energy neutron bombardment in material bring about lattice defects i.e. void, pore and dislocation. Dominant factor to impact to heat capacity is mainly dislocation in material. Therefore, simulation of neutron irradiation is devised by material rolling method in order to make artificial dislocation in alloy 690 as same effect of neutron irradiation. After preparing test specimens, heat capacity measurements are performed and results are compared with rolled materials and un-rolled materials to verify the effect of neutron irradiation simulation. Main interest of simulation is that heat capacity value is changed by neutron irradiation

2. Experimental

2.1 Rolling specimens preparation

Selected material for neutron irradiation simulation is heat A type which were supplied by “FAULENBACH SCHMIEDETECHNIK GmbH” in Germany. According to CMTR (Certified Material Test Report), chemical compositions are shown in table 1.

Table 1 Chemical Composition of Alloy 690, %

Nickel	60.70
Chromium	28.97
Iron	9.13
Carbon	0.02
Silicon	0.28
Manganese	0.21
Sulfur	< 0.002
Copper	0.01

Materials are fabricated in rectangular shape and the size of specimen is 10(W) x 2.75(t) x 30(L) mm. The rolling machine is “Yoshida Kinen Korea” which have rolling capacity of 30 ton, maximum permitted specimen thickness of 1 ㎝. The material rolling rate ((original thickness - rolled thickness) / original thickness) is about 20 % so that the resultant rolled specimen size is 11.17(W) x 2.19(t) x 36(L) mm. Comprehensive material rolling process are shown fig 1.

Fig 1. Rolling specimen preparation process

2.2 Test specimens preparation

Owing to DSC(differential scanning calorimeter) specimen crucible size limitation, test specimen of DSC are machined to small size in 6 mm and weight in 150 mg below. Final fabricated test specimen for DSC are shown in Fig 2.

Fig 2. Machined specimen for DSC

2.3 Specific heat capacity measurement

Tests were carry out on temperature range from room temperature, 50, 100, 150, 200, 250, 300, and to 350 ℃ for each specimen. Total specimens are consist of 3 un-roll and 3 rolled specimens . The test was performed by KRIS (Korea Reseach Institute of Standards and Science) in order to enhance reliability. Test standard methods are KS M 3049 and ASTM E 1269 . The used test equipments are DSC 404C : Netzsch for temperature range 50-350 ℃ and DSC Pyris 1 : Perkin Elmer for room temperature.

3. Results

3.1. Measurement results

Below table show the measurement results performed by KRIS. Three Rolled and three un-rolled specimens are measured for each relevant test temperature and processed in statistical manner to get average and standard deviation. The Fig 3 Show pictorial results of specific heat capacity measurements.

Table 2 Specific heat capacity measured value

J/kg ℃

	Rolling					Un-rolling				
온 도	No 1	No 2	No 3	Aver	Std	No 1	No 2	No 3	Aver	Std
25.5	470.9	464.5	466.0	467.1	3.35	454.8	457.0	440.8	450.8	8.79
57.4	453.2	502.8	444.2	466.7	31.56	462.5	458.0	472.2	464.2	7.26
106.2	467.0	529.7	455.5	484.1	39.94	471.0	474.0	480.5	475.1	4.86
155.3	472.6	541.8	459.9	491.4	44.08	481.0	475.9	491.7	482.8	8.06
205.2	486.9	559.3	464.4	503.5	49.59	493.2	492.5	503.0	496.2	5.87
254.9	494.1	564.9	476.0	511.7	46.98	500.0	497.2	505.2	500.8	4.06
305.2	502.9	572.2	478.6	517.9	48.57	505.8	504.9	515.1	508.6	5.65
355.5	506.9	576.5	487.9	523.8	46.65	511.7	513.5	522.6	515.9	5.84

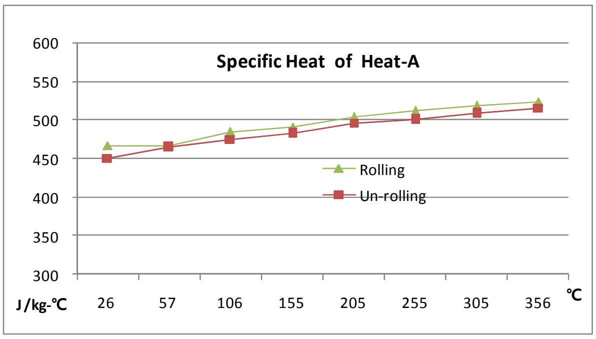

Fig 3 Specific heat capacity for rolled and un-rolled specimen

3.2 T-test of mean value

In order to evaluate effect of neutron irradiation, t-tests are performed by null hypothesis that mean value of two population is same. Those test conditions are expressed in statistical form.

$$H_0: \mu_1 - \mu_2 = 0$$
$$H_1: \mu_1 - \mu_2 \neq 0$$

Confidence level of test set up 95% so that significance level is 5%. This mean that type-1 error is α=0.05. T-test are carry out using MS Exell application in assumption of different variance two population. Table 3. And table 4 show the t-test results for examples. Except for room temperature , t-statistical are within t-critical value so that null hypothesis is accepted. We can conclude that specific heat capacity mean value of two population are same in confidence level 95 %.

Table 3 t-test of two population for 100 ℃

	Var 1	Var 2
Mean	484.1	475.17
Variance	1595	23.583
No of measurements	3	3
Hypothesis for mean difference	0	
Degree of fredom	2	
t statistics	0.383	
P(T<=t) one-side test	0.369	
t critical value one-side test	4.303	
P(T<=t) two-side test	0.738	
t critical value two-side test	6.205	

Table 4 t-test of two population for 150 ℃

	Var 1	Var 2
Mean	491.4	482.87
Variance	1943	65.023
No of measurements	3	3
Hypothesis for mean difference	0	
Degree of fredom	2	
t statistics	0.331	
P(T<=t) one-side test	0.386	
t critical value one-side test	4.303	
P(T<=t) two-side test	0.772	
t critical value two-side test	6.205	

4. Conclusion

To obtain the effect of specific heat capacity change caused by neutron irradiation, the method to simulate neutron irradiation using material rolling is adopt. The difference of mean value of specific heat capacity for rolled and un-rolled material are not change in 95% confidence level for all temperature range except room temperature.

REFERENCES

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