Statistical Assessment of Charpy Data Agreement Between Two Heating Methods

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1. Introduction

Surveillance tests to evaluate the irradiation embrittlement of reactor pressure vessels are carried out in accordance with the NSSC Notice No. 2017-20 "Code for Surveillance Tests of Reactor Pressure Vessels in Korea" [1]. One of the main contents is to measure and estimate the change of Charpy impact properties after neutron irradiation of reactor vessel materials during lifetime. This mandatory regulation is basically the same as the contents of the US federal regulation code 10CFR50 as well as the Codes and Standards of ASME and ASTM while the domestic code refers to KS (Korean Standard) test methods.

Although the KS standard method for Charpy testing defines essentially the same as international standards such as ASTM and ISO, there may be some inconsistencies from certain reasons such as industrial demands and renewal cycle of technical standards. In domestic industry, Charpy impact tests have mostly been conducted at room temperature or in the lower temperature range. Only surveillance tests in nuclear industry requires Charpy tests at higher temperatures above 100°C since the high fluence of neutron irradiation can shift the brittle transition range to high temperature region.

According to ASTM E23 [2], the international standard test method for Charpy impact tests, either a liquid bath or a furnace can be used to heat the specimens as long as the temperature control can be maintained within the corresponding test temperature ± 1°C. On the other hand, KS B0810 [3], domestic Charpy impact test method, stipulates to maintain the test temperature ± 2°C using a liquid bath at high temperatures up to 200°C. Either a liquid bath or a furnace can be used in the same manner as ASTM E23 at the other temperature ranges.

The current investigation was performed to determine if the difference in heating media could produce a biased result in the Charpy aborbed energy data at high temperature. Standard Charpy specimens made of a typical RPV steel were tested in two different testing labs and the test data were analyzed by using statistical tools. The results may be used to improve the credibility of surveillance tests and to revise the domestic test standard method.

2. Experiments and Analysis Methods

2.1 Test Material and Specimen Preparation

The test material is a commercial RPV steel, SA533-B1 pate, which shows homogeneous mechanical properties. The chemical composition is listed in Table 1. Standard Charpy V-notch specimens were machined from a single layer between 1/4T and 1/2T. The specimen orientation is L-T.

Table 1. Chemical composition (wt.%)

Element	C	Mn	P	S	Si	Ni	Mo	Cu	V
(wt.%)	0.21	1.45	0.010	0.005	0.21	0.57	0.48	0.05	< 0.005

2.2 High Temperature Charpy Impact Tests

Charpy impact tests were carried out according to the standard procedures of ASTM E23 and KS B0810. Two different heating media were used to control the test temperature, 120°C. The first one is a liquid bath using a high temperature silicone oil and the second one is an air heating furnace. The oil heating tests were carried out by an experienced technician in a mechanical test lab. The air heating tests were carried out by using an automated loading system in the IMEF hot cell.

Moreover, the amount of temperature change during test period may also be a concern of different heating media. Thermocouple is welded to a Charpy specimen and temperature changes were measured during test period at the ambient temperature after heating up to 120°C through two different media.

2.3 Statistical Analysis of Sample Means by T-test

Statistical tools are used to compare the mean values measured from two different sampling groups. The purpose of the analysis is to determine if the measured difference in mean values is statically acceptable within a single data population. Since the mean and standard deviation of the real data population are generally not known, the Student's T-test is used for the sampling means and variances. When the variances of two populations are neither known nor equal, the following equation can be used for the T-test measure [4]:

$$T' = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{s_1^2/n_1 + s_2^2/n_2}}$$

where, $\bar{x}_1, \bar{x}_2$ are the measured means, s_1, s_2 the variances, and n_1, n_2 are the sizes of two sampling groups.

The above T′ values follow the Student's t-distribution with the degree of freedom expressed by the following equation.

$$\upsilon = \frac{\left(s_1^2/n_1 + s_2^2/n_2\right)^2}{\frac{\left(s_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(s_2^2/n_2\right)^2}{n_2 - 1}}$$

3. Results and Discussion

3.1 Charpy Impact Test Data

Fig. 1 and Table 2 show the test results. Standard deviations of the oil bath testing are about 2 times bigger than the air furnace testing. However, the average means of two sets of data are well matched to each other within 1% difference. It is noted that the standard calibration procedure of Charpy test machine requires error range less than ± 5% of the expected value at a high energy level.

A thin layer of heating oil covers the specimen surface and it may a little affect the contact between specimen and the test machine. Even though the difference was very small, test results of air furnace heating seemed more stable and conservative as well.

Fig.2 shows the temperature changes of Charpy specimens during test period after heating by different media, oil and air. In both cases, the amount of temperature change during 5 seconds was less than 1°C, almost negligible.

3.2 Statistical assessment by using t-test

Statistical data analysis tools of Microsoft Excel® was used to evaluate the test data of two groups. The student's t-test result gives the two-sided p-value of 0.36 by assuming the variances of real two populations are different. The p-value is much bigger than a significance level of 0.05. Therefore, the small difference in two average means does not have a statistically significant meaning. If assumed the variances of two populations are the same, the p-value would be 0.41 and give the same statistical meaning.

4. Conclusions

A comparative test study was carried out by using two different heating methods to resolve a probable issue from an inconsistency in Charpy impact test procedures between domestic KS B0810 standard and ASTM E23 standard. The test results showed that the expected Charpy impact energy values are practically and statistically equivalent to each other while the dry heating data are more stable and slightly more conservative as well.

REFERENCES

[1] NSSC Notice No. 2017-20 "Code for Surveillance Tests of Reactor Pressure Vessels in Korea" (2017)
[2] ASTM E23, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials" (2018)
[3] KS B 0810 "Impact Test Methods for Metallic Materials", (2003, re-approved in 2018)
[4] "Probability & Statistics for Engineering & Scientists", 9th Edition, Pearson Publisher (2011)

Table 2.Comparative Charpy Test Data at 120°C

	Oil Bath Heating	Furnace Heating
Absorbed Energy Measured Values (J)	204, 205, 213, 218, 219, 214, 221, 227, 221, 215, 215, 217, 223, 213, 205	217, 214, 213, 210, 213, 216, 206, 217, 212, 216
Average Mean (J)	215.4	213.3
Standard Deviation (J)	6.69	3.25

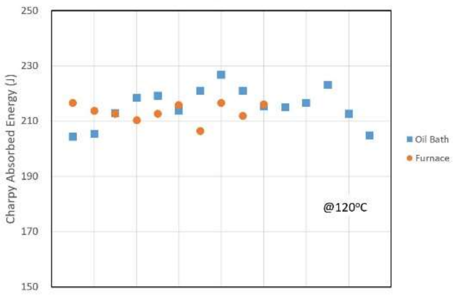

Fig. 1. Charpy test results by using different heating methods (oil bath and air furnace at 120°C)

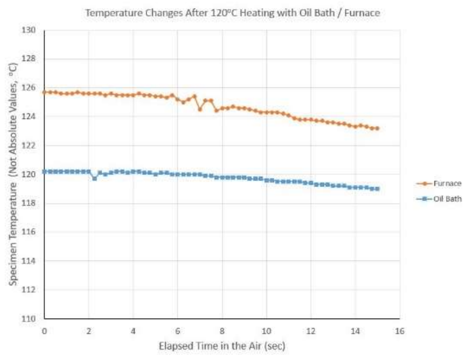

Fig. 2. Temperature changes of Charpy specimens during test period after heating by different media