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RAPID PUBLICATION

Effect of Specimen Size on Toughness Evaluation by Charpy Test

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Herein we present an experimental investigation on the toughness evaluation method for the samples of copper and aluminum, which are generally employed as electronic equipment parts, through the miniaturized version of the Charpy impact test. Overall, the resulting high reproducibility of the absorbed energy values informed by the miniaturized Charpy impact test can be witnessed; moreover, it is possible to compare the values given by the Japanese industrial standard (JIS) Charpy impact test to those given by the miniaturized Charpy impact test and correction factors were calculated accordingly. [doi:10.2320/matertrans.MH201806]

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1. Introduction

With the continuous advancement in technology and engineering, machinery downsizing has become possible. If on one hand, the downsizing strategy might translate to a decreased consumption of resources, on the other hand it might also bring serious environmental issues. Another aspect to be considered along with the miniaturization of mechanical parts is the increasing demand for evaluation methods to obtain local mechanical properties of such materials.

The art evaluation method for toughness of materials, the Charpy impact test, is commonly applied for many mechanical tests such as rupture, hardness, tensile, and fatigue tests. According to the Japanese industrial standard (JIS), the dimension of a test piece is regulated as 10 mm of width × 10 mm of thickness × 55 mm of length. However, it is difficult to use such standards to evaluate miniaturized mechanical parts.

Corwin *et al.*[1]) have reported that the size effect of the ductile-brittle transition temperature (DBTT) of a Fe–Cr–Mo–V–W alloy, can be better reduced if volume normalization is performed instead of area normalization when comparing full-size and sub-size Charpy impact tests. Yamamoto *et al.*[2]) investigated the DBTT of a Fe–Cr–Mo–V alloy which had been used for about ten years as the internal casting of a turbine, and by using a miniaturized Charpy impact test they obtained a smaller value than when performing the conventional Charpy impact test.

Kimura *et al.*[3]) developed a miniaturized Charpy impact test machine, by employing a small punch method, to evaluate the toughness of extra small specimens. Under neutron irradiation environment, the usefulness of such a technique has been already proved.[4]) Kurishita *et al.*[5]) reported that the small punch method was useful in determining the upper-shelf energy and DBTT of ferritic steels for both full-size and miniaturized specimens. Lyu *et al.*[6]) reported the evaluation of local toughness of a heat affected zone of a welded material. Furthermore, Misawa *et al.*[7]) carried out the ductile-brittle transition evaluation of laser welded steel metals by means of impact tests, and it was shown that there is a correlation between the data obtained using JIS-sized specimens and the miniaturized ones.

Moreover, there are many reports about the embrittlement of steel alloys as discussed above. Conversely, non-ferrous materials, which do not undergo embrittlement at low-temperatures, are rarely reported till date. The present work aims to fill this gap. Herein we performed the Charpy impact test on miniaturized and JIS-sized specimens of materials with high ductility, C1020 and A1050, and the relation of both the data are then clarified.

2. Experimental Procedure

Oxygen-free copper (JIS C1020) and pure aluminum (JIS A1050) samples, which had been hot-extruded and annealed, were used. Table 1 shows typical values of physical and mechanical properties of these materials. Test samples were cut from annealed materials by using an electric discharge machining method in order not to change microstructures and mechanical properties.

A Charpy impact test (conventional test) was performed according to the JIS Z 2242 standard. The dimensions of the test piece used on the conventional test are noted as 10 mm^2 of area × 55 mm long. The dimension of the V-shape notch was 45 degrees, 2 mm in depth, and 0.25 mm in root radius. The lifting angle during the test was 148 degrees. An

Table 1 Typical values of physical and mechanical properties of C1020 and A1050.

	C1020	A1050
Thermal conductivity [W/mK]	391	231
Electric resistivity [10^{-3} μΩm]	17.1	28.1
Tensile strength [MPa]	240	75
Elongation [%]	48	39

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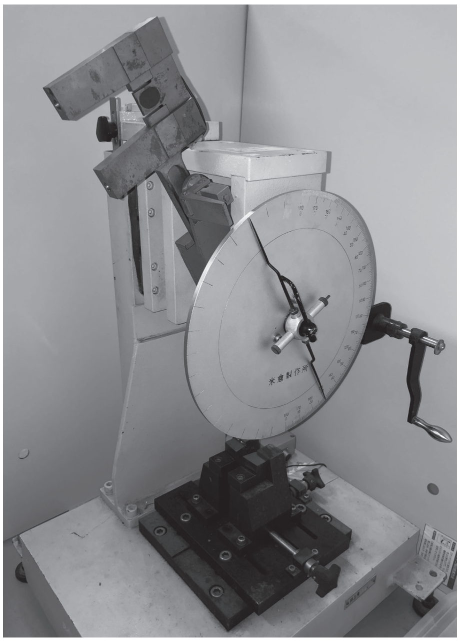

Fig. 1 Miniaturized Charpy impact test apparatus used.

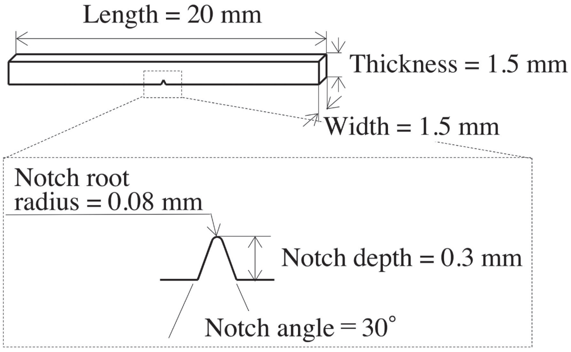

Fig. 2 Schematic of the miniaturized Charpy impact test specimen.

apparatus made by Yonekura Seisakusho whose hammer was 9.408 N in weight, 230 mm in length, and 12.5 mm in width, was used for the miniaturized Charpy impact test (or simply, miniaturized test). Figure 1 displays the appearance of the miniaturized testing machine. The dimension of the test piece for the miniaturized test was $1.5\,mm^2 \times 20\,mm$ long, and the dimension of the V-shape notch was 30 degrees, 0.3 mm in depth, and 0.08 mm in root radius. V-shape notches for both test specimens were formed using an electric discharge machine. Five pieces underwent both conventional and miniaturized tests. Scanning electron microscopy (SEM) was employed to observe the fracture surfaces, employing a JEOL JSM-6400VS microscope.

3. Results and Discussions

Figure 2 displays the miniaturized test samples of C1020 and A1050. Both samples, which have high ductility, did not completely rupture during the miniaturized and conventional tests. Table 2 shows the absorbed energy values obtained for C1020 and A1050 for both conventional and miniaturized tests. For the A1050 samples, which revealed results with higher deviations than the ones obtained for the C1020 samples, the coefficient of variation for the absorbed energy values was 6.8%. Meanwhile, a lower value for the conventional tests was obtained, i.e., 0.23%. Thus, these results support the fact that it is possible to apply the miniaturized Charpy impact test as a toughness evaluation method for extremely small parts.

Figure 3 shows the SEM images for the fracture surfaces of both C1020 and A1050 specimens obtained after the Charpy impact tests. Table 2 shows the "unit absorbed energy" values, which were calculated by the fractured area measured from the SEM images shown in Fig. 3. The calculated unit absorbed energy values of C1020 for conventional and miniaturized tests were $8.31\,MJ/m^2$ and $0.544\,MJ/m^2$, respectively. For the A1050 samples, the results were $2.95\,MJ/m^2$ and $0.351\,MJ/m^2$ for the conventional and miniaturized tests, respectively. Due to the correspondence of the results, we suggest that the evaluation of the unit absorbed energy values obtained from the miniaturized tests can be applied using the correcting factors (Table 3).

The morphology of both fracture surfaces for the A1050 samples look similar despite a large difference in strength, which represents the unit absorbed energy values. In the case of C1020, the morphology of fracture surfaces obtained during conventional tests, look similar to the results of A1050. Conversely, fine wavy unevenness is observed on the fracture surfaces resulted from the miniaturized tests for the C1020 samples. These results suggest an existing relation between the unit absorbed energy values and morphology of the fracture surfaces. However, the reason for the discrepancies observed is unclear.

Table 3 Unit absorbed energy values of C1020 and A1050 samples for both miniaturized and conventional Charpy impact tests [MJ/m^2].

	Miniaturized specimen	JIS-sized specimen	Correction factor
C1020	0.544	8.31	15.3
A1050	0.351	2.95	8.40

Table 2 Absorbed energy values of C1020 and A1050 specimens for both Charpy impact tests.

	C1020		A1050	
	Miniaturized specimen	JIS-sized specimen	Miniaturized specimen	JIS-sized specimen
Average [J]	0.479	143	0.283	58.9
Deviation [J]	0.017	0.894	0.019	0.134
CV value [%]	3.6	0.63	6.8	0.23

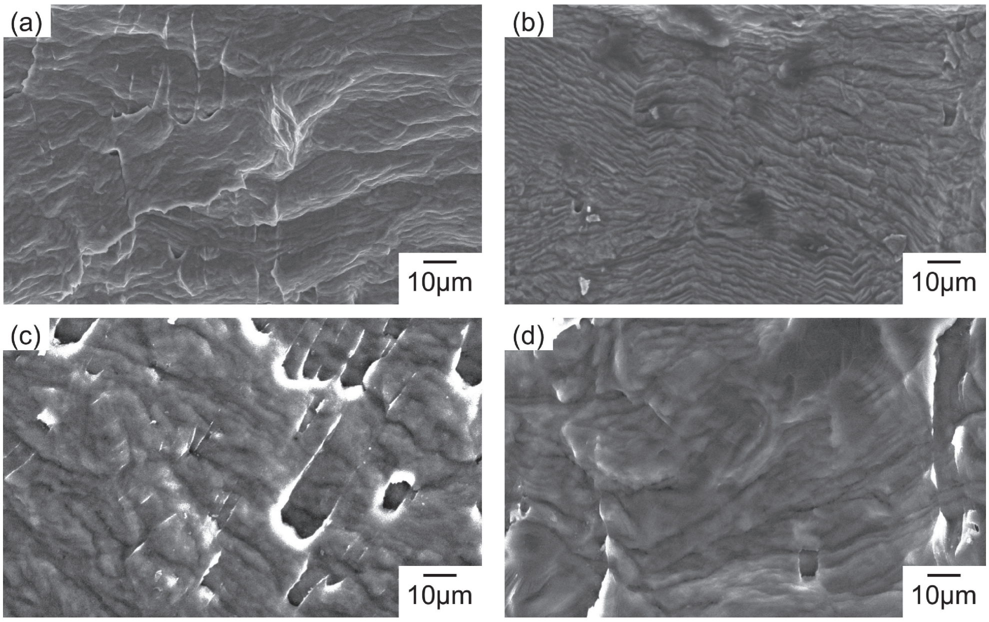

Fig. 3 Scanning electron micrographs of the fracture surfaces obtained by conventional and miniaturized impact tests for both C1020 and A1050 samples: (a) JIS-sized specimen of C1020, (b) Miniaturized specimen of C1020, (c) JIS-sized specimen of A1050, and (d) Miniaturized specimen of A1050.

4. Conclusion

In the present study, the impact of the specimen size (conventional and miniaturized) with regard to Charpy impact tests employed for toughness evaluation was investigated for high ductility in materials, in terms of C1020 and A1050 samples. The relation of the data obtained for conventional impact tests, following the JIS, and the miniaturized version is clarified. It is suggested that the evaluation of unit absorbed energy values by using a miniaturized test could be applied using correcting factors.

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