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A High-Speed Tensile Behavior of Bolting Material for Decommissioning Waste Packages

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1. Introduction

Phenomena such as car collisions, dropping of metal container, high-speed machining and high-speed molding can cause deformation or damage due to high-speed impact loads. The behavior of structures and materials subjected to such impact loads is significantly different from that of materials subjected to static loads. Stress waves propagate within structures and those structures can be deformed by high strain rate loadings. And their failure patterns can also be affected. Therefore, the proper design and analysis of these structures are necessary and stress-strain curves obtained from the high-speed tensile tests need to be applied instead of static tensile curves.

The bolts that fasten the main body of a metal container and lid play an important role for the structural integrity of the container in the accident event such as drop impact. It is necessary to apply dynamic tensile curves rather than static tensile curves to the analysis of bolted container. A high-speed tensile test of the material needs to be carried out under high strain rate conditions generally using a Split Hopkinson Pressure Bar (SHPB) or a servo-hydraulic high-speed tensile test machine (Instron VHS or Zwick/Roell).

In this study, high-speed tensile tests were conducted on SNB7 steel [1], selected as a bolting material for wastage package, transportation and disposal containers for decommissioning wastes of nuclear power plant [2], using Instron VHS, a servo-hydraulic high-speed tensile test machine, and the results were reviewed.

2. High-Speed Tensile Tests

A 181.79 mm long rod type tension test specimen was used for a high-speed tensile test as shown in Fig. 1 and ISO standard [3] was applied in this test since ASTM does not have any guidance on this. Table 1 shows the chemical composition of bolting material SNB7 per KS D 3755 [1]. As shown in Fig. 1, a high-speed tensile test specimen is not symmetrical to the left and right sides unlike the conventional tensile test specimen. This is to enable to grip and hold the specimen when the required speed conditions are reached as the specimen starts to drop from the beginning of the test.

High-speed tensile tests were performed at room temperature using Instron VHS-65/80-25 test machine as shown in Fig. 2 and 5 different strain rates were applied; 0.1/sec, 1/sec, 5/sec, 10/sec and 100/sec. Three specimens were tested for each strain rate condition. Strain measurements were made using dual high speed cameras and DIC (Digital Image Correlation) software because it is difficult to apply conventional technologies using extensometers or strain gages in high-speed tests.

Fig. 2 shows the high-speed tensile test rig (maximum impact load of 80 kN) which is located at the Korea Institute of Materials Science (KIMS) at Changwon.

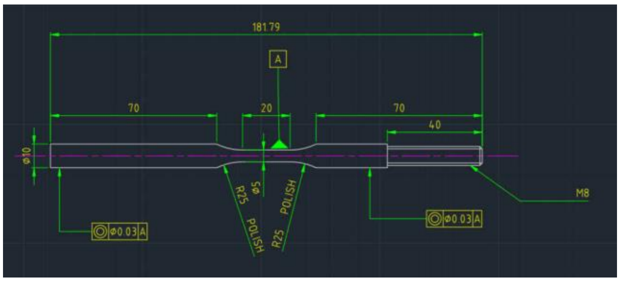

Fig. 1. High-speed tensile test specimen (mm)

Table 1. Chemical compositions of SNB7 steel (wt.%)

	C	Si	Mn	S	P	Cr	Mo
SNB7	0.38-0.48	0.2-0.35	0.75-1.0	0.04	0.04	0.8-1.1	0.15-0.25

Fig. 2. High-speed tensile test facility

Table 2 shows the resultant tensile properties of SNB7 bolting material. Yield stress (YS), ultimate tensile strength (UTS), and rupture elongation are compared with respect to various strain rate conditions including strain rate of 0.002/s which is a typical static tensile loading.

It is reminded that yield stress, ultimate tensile strength, and elongation of SNB7 steel are 881.2MPa, 970.2MPa, and 21.2%, respectively, from the previous static tests [2]. These were obtained from the static tensile test of which strain rate was 0.002/s.

The effect of strain rates is clearly shown in the current high-speed tensile tests as shown in Table 2. Both yield stress and UTS increase as strain rate increases as expected. It can be seen that the elongation also increases as strain rate increases, but these values are smaller than that of the static test result and further investigation would be necessary. One potential reason for this may be that the dynamic tensile test method and procedure is completely different from the static tensile test method and the strain measurement method is different.

Table 2. Comparison of high-speed tensile properties of the SNB7 steel for various strain rate loadings

Strain rate [/s]	Yield Stress (0.2 % offset) (MPa)	UTS (MPa)	Elongation (%)
0.002 (static) [2]	881.2	970.2	21.2
0.1	960.6	1053.6	11.5
1	960.2	1073.1	14.1
5	977.5	1085.9	12.7
10	978.7	1087.2	14.9
100	980.5	1173.2	17.9

Fig. 3 shows the specimens which completed the high-speed tensile tests, and all specimens were broken in the central reduced parallel section and the tests seemed to have been carried out successfully. Fracture elongation, which is one of the material's properties, is difficult to obtain in the SHPB test, but it was obtained well in this test as shown in Fig. 3, because the specimen can be tested until it breaks.

Fig. 4 shows the comparison of engineering stress-strain behaviors of SNB7 steel with respect to various strain rate conditions. It is observed that the high-speed dynamic tensile curves tended to have larger values as strain rate increases and are significantly larger than the static tensile curve. And the UTS reaching time is short compared to that of the static test and the material softens afterwards, resulting in a rapid reduction in stress until rupture elongation. Further testing and analysis are needed on this point.

It is noted that the stress-strain curve for strain rate of 100/s shows somewhat large vibration and noise on the data and this seems mainly due to dynamic loading on equipment and specimen unlike static test. As shown in Fig. 4, one of the data in the test for strain rate 100/s indicates that the data storage has failed.

Fig. 3. Specimens after high-speed tensile tests

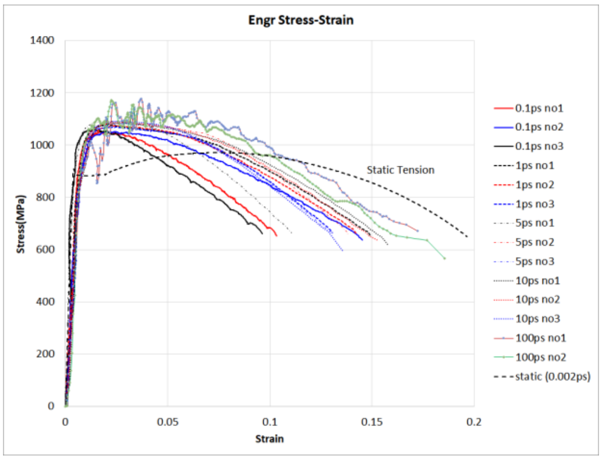

Fig. 4. Stress-strain curves of SNB7 for various strain rates

3. Results and Discussion

For the proper design and analysis of a metallic container for impact loads due to dropping of a container, it is necessary to apply the dynamic stress-strain curves from the high-speed tensile tests rather than using static tensile curves.

In this study, high-speed tensile tests of SNB7 steel, used as bolting material for metallic containers for decommissioning wastes, were performed and the results were reviewed. The high-speed tensile test results of SNB7 steel were compared with the static tensile test result. The dynamic tensile curves showed greater values than the static tensile curve and the yield stress and UTS increased as the strain rate increased.

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