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Dynamic Properties and Behaviors of Metallic Materials for Decommissioning Waste Packages

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1. Introduction

The wastage packages for decommissioning wastes of nuclear power plant have been developed [1]. The important load in the design of decommissioning waste packages is the drop impact load and the behavior of metal structures subjected to drop impact load is significantly different from that of materials subjected to static load. Therefore, the proper design and analysis of these structures requires the use of dynamic material properties such as the stress-strain curves obtained from the high-speed tensile tests and the dynamic load-displacement curves obtained from the dynamic shear tests. High-speed tensile tests were conducted on SNB7 steel for wastage package by Kim [2].

In this study, high-speed tensile tests were conducted on carbon steels, SS275 [3] and SPA-H [4], which are used as the metal container body for waste package, and dynamic shear tests were carried out on SNB7 steel [5], which is a bolting material for wastage package [6]. And the test results were compared and reviewed with static material properties.

2. High-Speed Tensile Tests

A high-speed tensile test specimen is shown in Fig. 1 according to ISO standard [7] and the chemical compositions of carbon steels (SS275 and SPA-H) are shown in Table 1. High-speed tensile tests were performed at room temperature using Instron VHS-65/80-25 test machine as shown in Fig. 2 and 6 different strain rates were applied; 0.1/sec, 1/sec, 5/sec, 10/sec, 50/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.

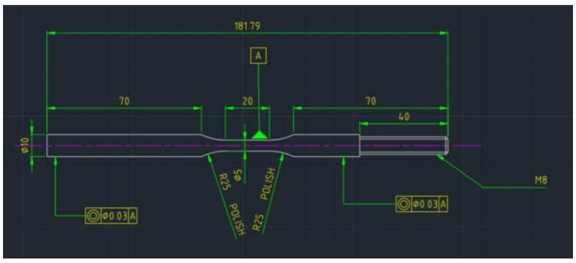

Fig. 1. High-speed tensile test specimen (mm)

Table 1. Chemical compositions of carbon steels (wt.%)

	C	Si	Mn	S	P	Cr	Ni
SS275	0.25	0.5	1.5	0.05	0.05	-	-
SPA-H	0.12	0.25-0.75	0.6	0.035	0.07-0.15	0.3-1.25	0.65

Fig. 2. High-speed tensile test facility

Table 2 shows the resultant tensile properties of SS275 steel. 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.

Table 2. Comparison of high-speed tensile properties of the SS275 steel for various strain rate loadings

Strain rate [/s]	Yield stress (0.2 % offset) (MPa)	UTS (MPa)	Elongation (%)
0.002 (static)	282.6	441.7	37.0
0.1	645.3	691.8	13.5
1	661.0	719.1	15.2
5	665.7	735.6	16.8
10	664.4	734.0	17.1
50	688.7	754.5	18.1
100	727.9	770.4	19.9

Fig. 3 shows the comparison of engineering stress-strain behaviors of SS275 steel with respect to various strain rate conditions. It is observed that the high-speed dynamic tensile curves tended to have larger values of yield stress and UTS as strain rate increases compared to those of the static tensile curve. And for high strain rate tensile test, the UTS is reached at a strain lower than that of the static tensile test and the rupture elongation is significantly smaller than the static test result.

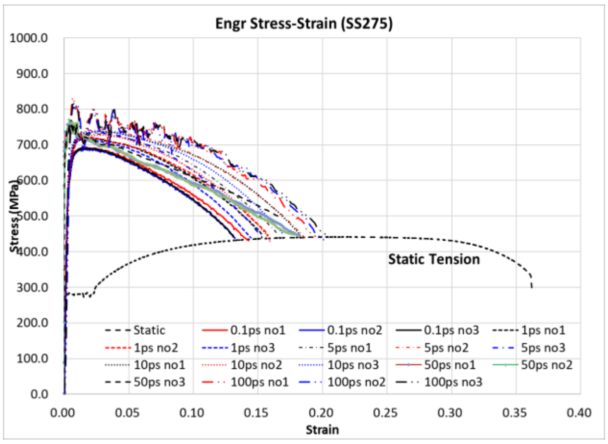

Fig. 3. Stress-strain curves of SS275 for various strain rates

Table 3 shows the comparison of resultant tensile properties of SPA-H steel and Fig. 4 shows the comparison of engineering stress-strain behaviors with respect to various strain rate conditions. As with the results of SS275, the yield stress and UTS values for SPA-H increased in proportion to the high strain rate, but the difference was a little small compared to those of SS275. It is worth noting that the rupture elongation increases as strain rate and these values seem slightly larger than the results of the static case, which are quite different from the case of SS275.

Table 3. Comparison of high-speed tensile properties of the SPA-H steel for various strain rate loadings

Strain rate [/s]	Yield stress (0.2 % offset) (MPa)	UTS (MPa)	Elongation (%)
0.002 (static)	342.1	511.7	34.4
0.1	378.0	528.9	33.9
1	402.0	541.0	33.4
5	418.9	553.5	36.7
10	437.8	567.9	38.4
50	444.5	583.8	38.6
100	463.3	597.2	37.0

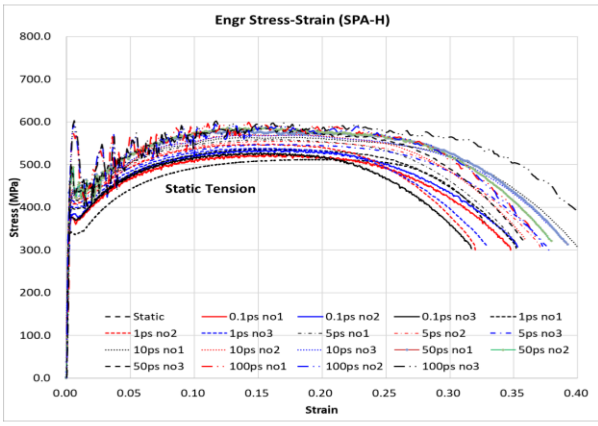

Fig. 4. Stress-strain curves of SPA-H for various strain rates

3. Dynamic Shear Tests

A dynamic shear test using M24 bolt specimen (65 mm long and pitch of 3 mm), the actual size of the SNB7 bolt used in the metal container as shown in the upper right of Fig. 5, was performed by using the drop impact test rig located at KIMS. Fig. 5 shows the test system including a special jig with a bolt specimen mounted inside. The capacity of the test rig is 300 to 3000 J and the load cell is Kistler 9393A. Table 4 shows the chemical composition of the SNB7 material.

Table 4. 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

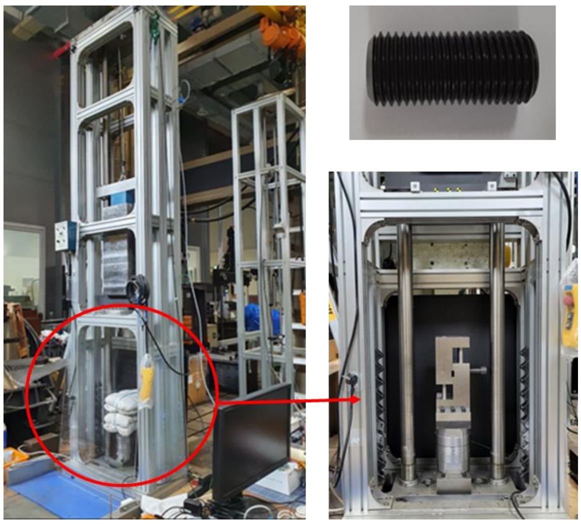
Fig. 5. Drop impact test system (Right : test specimen and jig)

The drop speed of the impactor was measured with the Fastcam Nova S12 high-speed camera. In addition, the drop speed was measured using the Autonics E50S8-5000-6-L-5 rotary encoder and the Autonics BS5-L1M (UL-7-L) photonic sensor, and the dynamic load-displacement diagram of the bolt was obtained.

Two drop speeds of 4.18 m/s and 5.69 m/s were applied and 3 tests were performed at each speed, respectively. Table 5 shows the results of dynamic shear tests and comparisons with static shear test result. Regarding a drop speed of 4.18 m/s, the average maximum shear load is 241.7 kN, and with a drop speed of 5.69 m/s, the average maximum shear load is 278.7 kN, which increases the maximum shear load by 19% and 37%, respectively, from the average maximum shear load of 203.1 kN of the static shear test.

Fig. 6 shows the load-displacement curves of the dynamic shear tests with respective to the two drop speeds (C1 indicates case 1 and C2 indicate case 2) and comparison of the results between the dynamic shear tests and the static shear test.

Table 5. Comparison of maximum shear strength of the SNB7 bolts for various drop speeds

Case	Drop speed (m/s)	Kinetic energy (J)	Max. shear load (kN)
Static shear (Average of 5 tests)	-	-	203.1
Dynamic shear (case 1)	4.2	1867	213.0
	4.2	1867	253.0
	4.15	1823	259.0
Dynamic shear (case 2)	5.68	1867	260.0
	5.7	1880	286.0
	5.7	1880	290.0

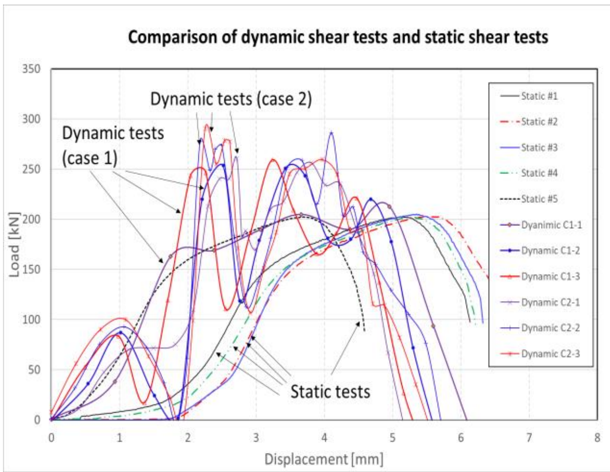

Fig. 6. Load-displacement curves of SNB7 bolt material for various drop speed

4. Results and Discussion

In this study, high-speed tensile tests of carbon steels (SS275 and SPA-H) and dynamic shear tests of SNB7 bolting material, used in metallic containers for decommissioning wastes, were carried out and the results were reviewed by comparison with static test results.

The high-speed tensile test results of carbon steels showed increasing behavior of yield stresses and UTS values as strain rate increases. The rupture elongation of SS275 increases as strain rate but these values are quite smaller than the static rupture elongation. On the other hand, the rupture elongation of SPA-H increases as strain rate and these values are generally larger than the static value. The results of dynamic shear tests indicate that the faster the drop speed, the greater the maximum shear load, and that these values are larger than the maximum static shear load.

From the results of tests on the dynamic properties, it was confirmed that it was appropriate to use dynamic material properties rather than static properties for the analysis of the metal container against the drop impact loads.

Acknowledgement

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