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A Study on the Kinetic Energy of Pendulum Impact Test considering the Weight of Arms

Sung-Uk Lee [a*], Jae-Yong Kim [a], Hong-Ryoul Oh [a], Kyung-Ho Yoon [a], Hyo-Chan Kim [a], and Dong-Hak Kook [a]
[a]*NFSR Division, Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yusung-gu, Daejeon, South Korea*
[*]*Corresponding author: leesunguk@kaeri.re.kr*

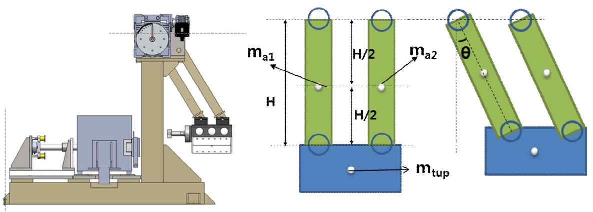
1. Introduction

As the amount of Spent Nuclear Fuel (SNF) in KOREA domestic spent fuel pool increases dramatically, the storage capability of the SNF is expected to saturate during the 2020s [1]. The SNFs in the pool must be transferred to the designated wet or dry spent fuel storage facility. In the issues of the SNF treatment, handling and transport of the SNF have been considered as an important factors. Various experimental evaluations on the soundness of mechanical behavior during SNF management are necessary. Among the various component of the SNF, the spacer grid (SG) is the main structure for securing the fuel rods from an external impact. A typical test method for evaluating the soundness of SG is a pendulum type impact test. In the fuel design of the Westinghouse, the strength of SG is determined by the impact load after buckling under successive impacts of increasing kinetic energy [2]. Kim and Yoon [3] proposed a dynamic impact analysis method for a 7x7 SG pendulum impact test.

It is important to accurately calculate the amount of kinetic energy because the strength and deformation of SG are different depending on the applied kinetic energy. In this study, we present a kinetic energy applicable to pendulum impact test using heavy arms. The modified equation was verified by simulation of the pendulum behavior of the actual device. In order to validate the modified kinetic energy, the experimental and simulation results for the simplified unit grid impact test were analyzed.

2. Kinetic energy of pendulum impact test

2.1 Pendulum impact test



(a) (b)

Fig. 1. Pendulum impact test (a) Real model and (b) Simplified model

Fig. 1(a) shows the design of the impact test. The impact tester consists of five main parts: pendulum arm, hammer, base structure, specimen mounting part, and measurement sensors. In order to derive the kinetic energy, the model is simplified as shown in Fig. 1(b).

2.2 Modified equation of kinetic energy

Conventionally, the kinetic energy of the pendulum impact test was induced without considering the weight of the arm as shown in Eq. (1).

$$T = m_h \cdot H \cdot (1-\cos\theta)\, g \qquad (1)$$

Where m_h, H, Θ, and g are the weigh of hammer, length of arm, impact angle, and gravitational acceleration, respectively.

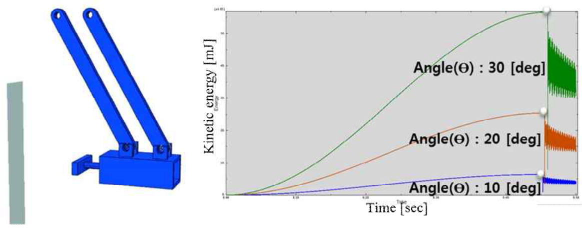
Table I : Weight of parts for pendulum impact test

Component	1st Arm	2nd Arm	Hammer
Weight [kg]	10.51	10.45	38.97

However, when the sum of the weight of the arms exceeds half of the hammer weight, this assumption is not appropriate. Therefore, a modified energy equation taking the weight of arm into account was derived. The derived equation is Eq. (2). The left term of Eq. (2) is the energy generated by the weight of hammer as in Eq. (1) and the right term is the energy value calculated by the weight of arms.

$$T' = m_h \cdot H \cdot (1-\cos\theta)\, g + (m_{a1} + m_{a2}) \frac{H}{2} (1-\cos\theta)\, g \qquad (2)$$

Where m_{a1} and m_{a2} are weight of 1st arm and 2nd arm, respectively.



(a) (b)

Fig. 2. Simulation of pendulum behavior (a) FE model and (b) kinetic energy

The simulation on the pendulum motion due to gravity was carried out using a FE model with the same specification as the actual equipment to verify the modified equation. Theoretically calculated kinetic energy and energy obtained by FE simulation are summarized in table II.

Table II : Kinetic energy according to impact angle

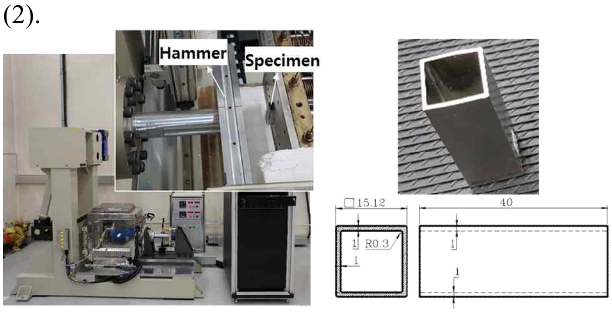
Impact angle [deg]	Analytical value though Eq. (1) [J]	Analytical value though Eq. (2) [J]	FE results [J]
10	5.05(1)	6.41(1.27)	6.41
20	20.06(1)	25.45(1.27)	25.45
30	44.56(1)	56.54(1.27)	56.53

The kinetic energy in consideration the arm weight increases by 27% compared with the case where the weight of arms is not considered. The values of modified equation shows almost the same result as the simulation results.

3. Impact test for unit structure

3.1 Experiment of impact test

In order to validate the effect of correcting of the kinetic energy, an impact test of 1x1 unit structure was carried out. The experimental setup is shown in Fig. 3(a). The hammer of pendulum impact test impacts on a unit structure made by AISI304. Figure 3(b) illustrates the shape and dimensions of the 1x1 unit structure. Three experiments were conducted on the same specimen to ensure reproducibility. When the impact angle (ϴ) is 15 degrees, the impact energies are 10.5 J and 14.38 J respectively according to the Eq. (1) and Eq. (2).



(a) (b)

Fig. 3. Photographs of pendulum impact test, (a) Apparatus and (b) Specimen (1x1 unit structure)

3.2 Results of impact test

We performed FE analysis with the two impact energies. Commercial code, ABAQUS/explicit was used to carry out the impact simulation with the mechanical properties of AISI304 stainless steel. Figure 4 (a) shows the cross-sectional shape of the experimental samples. The average of deformed height of the specimens is 14.84mm. Impact FE simulation was carried out using the kinetic energies when considering the weight of the arm and the kinetic energies when not considering the weight. The simulation results are shown in Fig. 4(b) and 4(c). The result considering the arm weight was similar to the experimental result. When kinetic energy without considering the weight of arm was used, the simulation result expressed smaller deformation than the actual one.

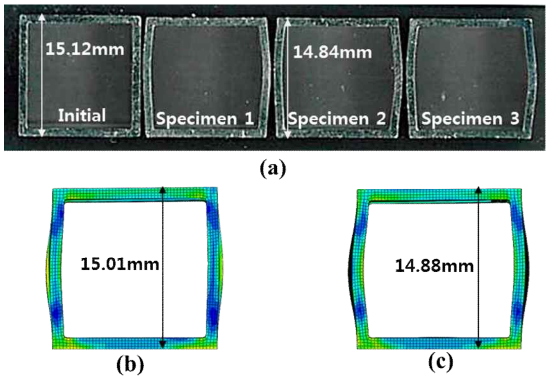


Fig. 4. Impact test of 1x1 unit grid (a) Experimental results, (b) FEM result (KE : 10.50 J), and (c) FEM result (KE : 14.38J)

4. Conclusions

We present a modified kinetic energy on the pendulum impact test. The heavy arm weight at the impact test is hard to ignore during kinetic energy calculation. The kinetic energy considering weight of arm shows about 27% difference. In order to prove the analytic model, a simulation for free drop of the pendulum impact test was carried out. Comparison with the FE results shows that the modified kinetic equation bring about improved accuracy. The simulation results for 1x1 unit structure calculated with the modified kinetic energy show the same deformation behavior compared with the impact experiment of the 1x1 unit structure.

ACKNOWLEDGEMENTS

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