Structural evaluation of Fission Molybdenum target at drop accident

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1. Introduction

The Fission Molybdenum (FM) target is loaded in the Ki-Jang Research Reactor (KJRR) and subsequently unloaded to produce the FM after a week of an irradiation. The movements of the FM target are strictly limited to keep it under a certain water level in the pool to preclude the possibility of excessive radiation doses for workers. During manipulation and transport, the FM target may accidently drop to pools due to the failure of handling tool or operator's mistake.

The FM target drop accident due to an erroneous handling or failure of equipment or components could be considered in the safety analysis for the KJRR, as well as a drop accident of fuel assembly is selected as postulated initiating events in the nuclear reactor design [1][2].The safety requirement of the FM target drop accident is to prevent mechanical damage of the FM target, and it shall be confirmed that the fission gas release into the environment does not occur.

The mechanical damage or impact force in the drop accident is mainly affected by the drop velocity at the moment of impact. Because the drop velocity of the FM target is an important factor in evaluating intact state of the FM target after the drop accident, it is necessary to derive an accurate drop velocity.

In this study, the impact behavior of the FM target is evaluated through experimental testing and structural analysis to confirm that the FM target remains intact after the drop accident, ensuring no release of fission gas products within the reactor building.

2. Description of FM target and FM target holder

The FM target is a flat plate composed of the FM target meat and the surrounding cladding as shown in Fig. 1. The FM target meat is made of fine UAl_x particles dispersed in the aluminum matrix. The material of the cladding is aluminum alloy 6061. When the FM target is loaded into the reactor core, and transferred to the service pool after irradiation, the FM target is inserted into the FM target holder and transferred as shown in Fig. 1. The material of the FM target holder is aluminum alloy 6061-T6 for its high strength and good performance in the reactor core.

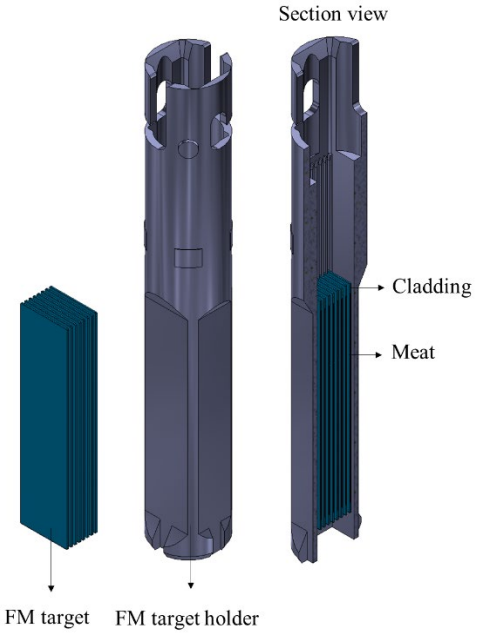


Fig. 1. FM target and FM target holder

3. Drop velocity measurement test

A drop velocity measurement test of a plate-type fuel assembly was investigated [3]. In this study, the drop velocity measurement test of the FM target was conducted using the same experimental setup in above reference. In a water environment, the falling velocity does not increase infinitely even if the drop height increases owing to drag forces. A falling object falling in a fluid will accelerate until the gravitational force is balanced by the resistance force, which includes buoyancy and drag. The falling velocity can be calculated using the following equation (1).

$$v(t) = A[\tanh(Bt)] \quad (1)$$

where, $A = \sqrt{\frac{g(m-\rho V)}{\frac{1}{2}\rho A C_d}}$, $B = \frac{\sqrt{(m-\rho V)g\frac{1}{2}\rho A C_d}}{m+m_a}$, v is the velocity, m is the mass, m_a is the added mass, ρ is the density of water, C_d is the drag coefficient, V is the volume, A is the projected area, and g is the acceleration of gravity.

When the equilibrium state is reached, the falling object will reach its maximum kinetic energy, and consequently its highest velocity, known as the terminal velocity. In a steady state, the falling velocity becomes the terminal velocity, which is written as the following equation (2).

$$V_{terminal} = \sqrt{\frac{g(m-\rho V)}{\frac{1}{2}\rho A C_d}} \quad (2)$$

In the drop velocity measurement test, dummy FM target and FM target holder are used for the test specimens in order to avoid disposal difficulty of the test specimen itself as well as radioactive test water possibly contaminated by radioactive materials. Fig. 2 shows the test facility for the drop velocity measurement test. The test specimens are vertically dropped along a guide line installed inside the water tank. The drop behaviors of the test specimens are photographed using a high-speed camera.



Fig. 2. Test facility for the drop velocity measurement test

For the test conditions, 0.425 m, 0.925 m, 1.425 m, 1.925 m, 2.425 m and 2.925 m are chosen as the drop heights. For the repeatability and reproducibility of the test results, the drop tests are repeated more than twenty times at each drop height. Fig. 3 shows the measured data points and empirical formula for the drop velocity. When the drag coefficient and added mass become 1.4 and 0.1 kg, respectively, the empirical formula falls into reasonable expectation with a high accuracy. The terminal velocity of the FM target is expected to be 2.5 m/s from the empirical formula.

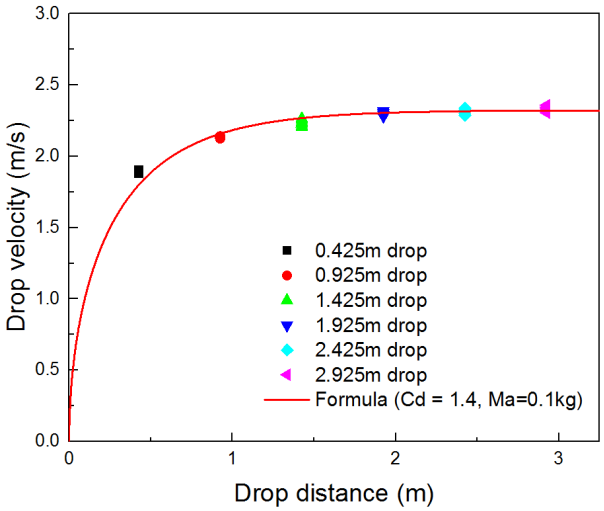


Fig. 3. Drop velocity measurement test results in water and curve fitting

4. Structural impact analysis

Before conducting the structural integrity assessment of the FM target, design limit and drop scenario were established based on a conservative approach. To ensure against mechanical failure and radioactive material leakage of the FM target during the drop accident, elongation values of the aluminum alloy [5] are adopted as the fracture strain. The design limit for the fracture strain of the FM target cladding is 0.078 mm/mm (7.8%). The most conservative scenario among the various FM target drop scenarios in the KIRR was selected. In this scenario, the FM target holder loaded with the FM targets was assumed to fall from maximum lift height to reactor pool bottom, corresponding drop to a drop height of 7.8 m. As described in section 3, the terminal velocity at this drop height is expected to reach 2.5 m/s. Therefore, the structural impact analysis was conducted using a drop velocity 2.5 m/s. Commercial software, ANSYS LS-DYNA, is used [4]. Fig. 4 shows the finite element model employed for the analysis. The aluminum material properties were defined based on the stress-strain curve obtained from tensile test [5], while Cowper-Symonds model was adopted to account for strain-rate effects. The remaining materials were defined using elastic material properties. To describe contact behaviors between the FM target and FM target holder, and between the FM target holder and pool bottom, surface to surface contact conditions are applied to each component.

As a results of the evaluation, Fig. 5 shows the Y-direction displacement distribution of the FM target and FM target holder before and during the impact with the pool bottom. During the impact event, localized bending of the FM target is observed, resulting from contact between the FM target and the FM target holder.

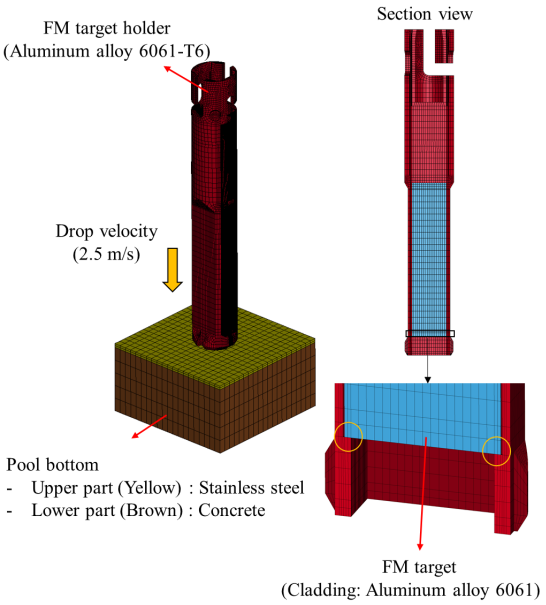


Fig. 4. Finite element model of the FM target and FM target holder

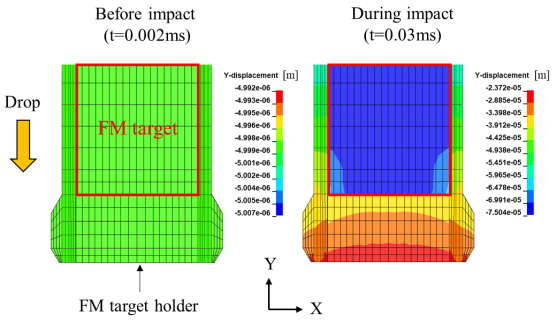


Fig. 5. Y-direction displacement distribution before and during impact to pool bottom

Fig. 6 (a) shows the stress distribution history. As the impact initiates, stress concentrates at the contact point between the FM target cladding and the FM target holder, subsequently propagating throughout the structure and dissipating over time. Fig. 6 (b) shows the maximum stress history of the FM target cladding, indicating that the stress in the FM target cladding during a drop accident originates primarily from the contact between the FM target and the FM target holder. Fig. 7 shows the elastic and plastic strain results of the FM target cladding. The elastic strain increases with contact duration and then decreases, while the plastic strain accumulates progressively up to approximately 0.0029 mm/mm (0.29%) before ceasing to increase further. This value is significantly lower than the design limit of 0.078 (7.8%). Table 1 summarizes the maximum total strain of the FM target cladding calculated during the analysis. The maximum total strain, representing the sum of elastic and plastic strains, is computed to be 0.00765 (0.765%). Consequently, it can be concluded that the FM target cladding remains intact during a drop accident, with no failure occurring, thereby preventing the release of radioactive materials to the external environment.

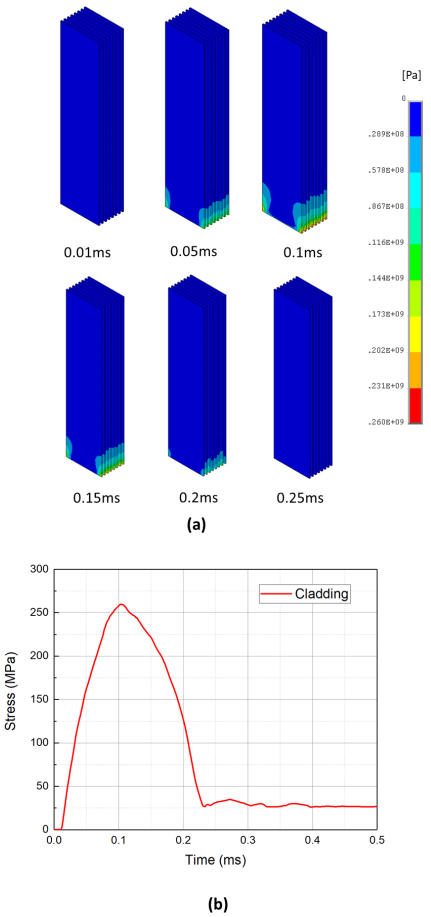


Fig. 6 (a) Stress distribution history and (b) stress intensity history of FM target cladding

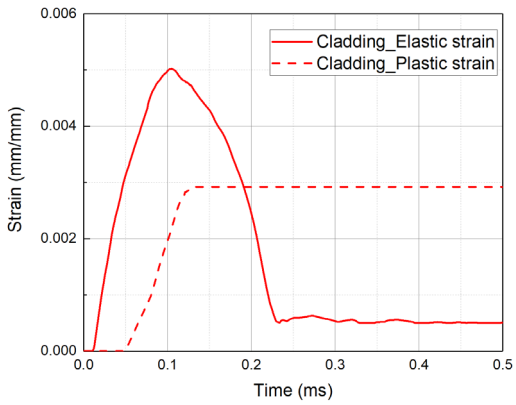


Fig. 7 Strain history of FM target cladding

Table 1. Total strain of the FM target cladding

Material	Maximum total strain (elastic + plastic) [mm/mm]		
	Value	Limit	State
FM target cladding	0.765%	7.8 %	Intact

5. Conclusion

In this document, the prevention of radioactive material release in the FM target at drop accident was investigated through the drop velocity measurement test and structural impact analysis.

The drop behaviors of falling FM target in water are examined through the drop test in the water tank. By varying the drop distances, each drop velocity is measured using images from the high speed camera. With the experimental data points, empirical drop formula is obtained. Using the empirical drop formula, any drop velocity associated with the drop distance can be achievable.

The FM target drop accident scenarios expected to occur in the KJRR pools are defined in advance. In the viewpoint of impact force exhibited on the FM target, conservative one of vertical drop is considered.

For the conservative case that is the direct impact to the pool bottom, the total strain of the FM target was lower than the design limit, leading to the conclusion that the FM target remains intact, and the fission gas release can be precluded.

ACKNOWLEDGEMENT

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