Nuclear Engineering and Technology 50 (2018) 683–689

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Survivability assessment of Viton in safety-related equipment under simulated severe accident environments

Kyungha Ryu [a], Inyoung Song [b], Taehyun Lee [a], Sanghyuk Lee [a], Youngjoong Kim [a], Ji Hyun Kim [b, *]

[a] *Research Division of Environmental and Energy Systems, Department of Nuclear Equipment Safety, Korea Institute of Machinery and Materials, 156, Gajeongbuk-Ro, Yuseong-Gu, Daejeon 34103, Republic of Korea*

[b] *Department of Nuclear Engineering, School of Mechanical, Aerospace, and Nuclear Engineering, Ulsan National Institute of Science and Technology (UNIST), 50 UNIST-gil, Ulsan 44919, Republic of Korea*

ARTICLE INFO

Article history:
Received 20 September 2017
Received in revised form
6 February 2018
Accepted 27 February 2018
Available online 6 April 2018

Keywords:
Equipment Survivability
Severe Accident
Thermal Degradation
Thermal Lag Analysis
Viton

ABSTRACT

To evaluate equipment survivability of the polymer Viton, used in sealing materials, the effects of its thermal degradation were investigated in severe accident (SA) environment in a nuclear power plant. Viton specimens were prepared and thermally degraded at different SA temperature profiles. Changes in mechanical properties at different temperature profiles in different SA states were investigated. The thermal lag analysis was performed at calculated convective heat transfer conditions to predict the exposure temperature of the polymer inside the safety-related equipment. The polymer that was thermally degraded at postaccident states exhibited the highest change in its mechanical properties, such as tensile strength and elongation.

1. Introduction

According to an International Atomic Energy Agency report [1], the probability of occurrence of a severe accident (SA) in a nuclear power plant (NPP) is remarkably low. Nevertheless, the SAs that occurred at Three Mile Island (TMI) and Fukushima Daiichi resulted in substantial social and economic impacts. To prevent and mitigate the effects of an SA, safety-related equipment such as emergency reactor depressurization valves (ERDVs) are installed in NPPs. It is necessary for the safety-related equipment to execute its expected safety function in an SA environment during the required period to ensure the integrity of the containment building, thereby preventing the release of radioactive materials and mitigating the effects of accident [2]. The equipment survivability (ES) of safety-related equipment during the SA environment has been emphasized [3,4]. Based on the reaction between the fuel cladding materials and the coolant in the SA environment, increased temperature, radiation, and pressure can be generated owing to the burning of combustible gases. Safety-related equipment in NPPs must perform its safety functions during normal operation conditions and design basis events. Therefore, technical qualification methods have been established, such as Institute of Electrical and Electronics Engineers (IEEE) standards 323 and 344 [5–7]. However, at present, there are no international standards or regulations about technical qualification methods to assess the survivability of equipment for conditions beyond design basis events, including SA [8]. Moreover, owing to a lack of equipment that can simulate SA environments, ES assessment has not yet been conducted in accordance to specific test types. Therefore, it is not feasible to assess ES for equipment that is planned to be installed in newly constructed NPPs [9].

There are several steps of ES assessment, as illustrated in Fig. 1. The first step defines the safety functions according to the regulations, such as the safety reactor shutdown, mitigation of accident effects, and maintenance of containment integrity. Subsequently, the systems and equipment destined to perform the defined safety functions are selected, and the exposure environments of these systems and equipment are determined. The qualification for such equipment can be achieved by comparing the equipment qualification (EQ) data, experimental results, and degradation temperature of the materials comprising the equipment in an SA environment in an NPP. In the cases in which the assessment

* *Corresponding author.*
E-mail address: kimjh@unist.ac.kr (J.H. Kim).

https://doi.org/10.1016/j.net.2018.02.009
1738-5733/

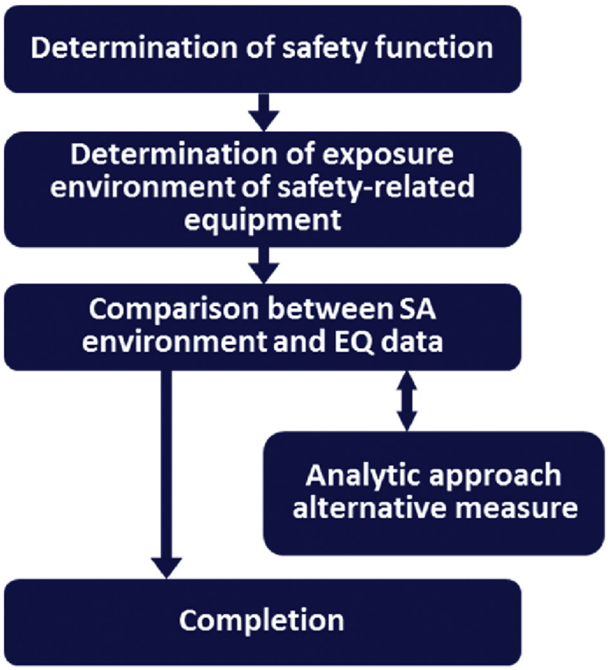

Fig. 1. Assessment procedure of equipment survivability [3].
EQ, equipment qualification; SA, severe accident.

method was based on experimental results, the ES was assessed by performing experiments in the SA environment. In some cases, it is feasible to derive the mitigated environment through thermal lag analysis or alternative measures, such as fire wrap and relocation [10–12]. Some of the equipment that uses polymer components, such as Viton, is likely to fail owing to degradation. In general, polymer materials have been reported to be more easily degraded than metals at high temperatures and pressures and in a radiation environment [13,14]. Therefore, ES assessment of the polymer is important to ensure the safety functions of the safety-related equipment.

In this study, a thermal degradation test was performed to evaluate the degradation effect of the polymer Viton for the temperature profile of SA environments. An electric furnace was used to provide the temperature profile of the SA. To simulate the rapidly elevated temperature in the initial state, a specimen-shifting system was designed using the temperature gradient of the electric furnace. Furthermore, the mechanical properties of the polymer after each SA temperature profile state were obtained using tensile tests.

In this study, a performance test was conducted to verify the simulation environment of the SA for the ES assessment. The performance test was conducted by measuring the temperature distribution of the equipment. Furthermore, tests were performed to evaluate the degradation effect of the temperature profiles at each SA state. In addition, the exposure temperatures of the polymer components inside the equipment during the SA temperature profile were analyzed using thermal lag analysis.

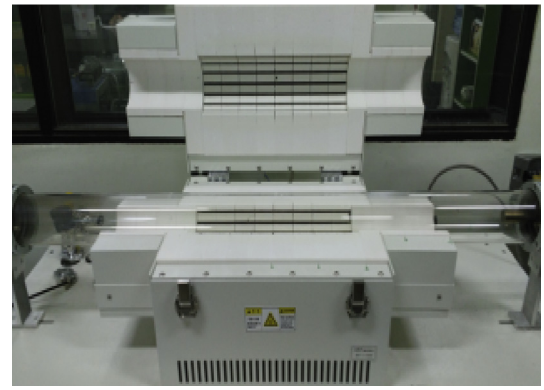

Fig. 3. Photograph of the test equipment using the electric furnace.

2. Materials and methods

2.1. Test equipment

The test equipment consisted of an electric furnace with a specimen-shifting system. Figs. 2 and 3 show typical test equipment. The rapidly heated and cooled regions were simulated by using the shifting system to control the location of the specimen. The shifting system was used to establish the temperature gradient in the tube. Specimen consisted of Viton and a metal housing made of carbon steel for uniform heat transfer to the polymer, as shown in Fig. 4. The dimensions of the metal housing were 25 mm diameter and 110 mm length. The dimensions of the Viton specimen were 5 mm diameter and 80 mm length.

2.2. Test procedure and conditions

For the ES assessment of safety-related equipment, it is important to accurately simulate the SA environment. However, the construction of equipment that can simulate the SA environment is technically challenging because of the unique phenomena associated with SA, such as hydrogen burns. Therefore, ES was assessed by individually evaluating the effects of each environmental factor associated with SAs on the degradation of materials. Based on the actual SA environment, such as the case of hydrogen burns, the elicited temperatures increase rapidly with temporal progression of the accident. This effect varies in accordance with

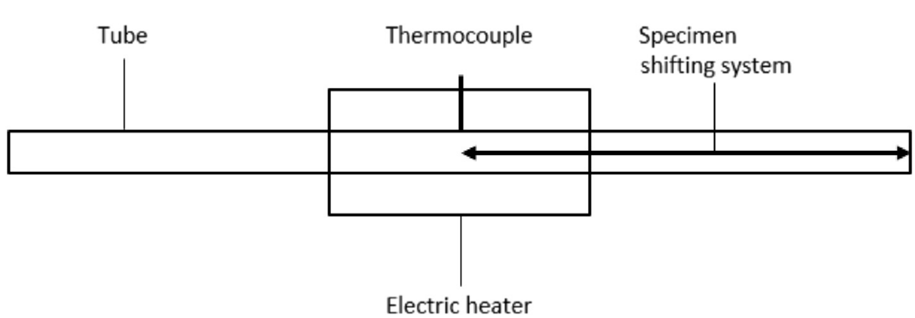

Fig. 2. Schematic illustration of the test equipment.