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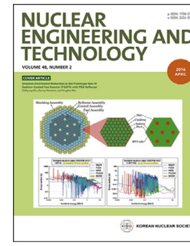

Original Article

Assessment of Mass Fraction and Melting Temperature for the Application of Limestone Concrete and Siliceous Concrete to Nuclear Reactor Basemat Considering Molten Core–Concrete Interaction

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ABSTRACT

Severe accident scenarios in nuclear reactors, such as nuclear meltdown, reveal that an extremely hot molten core may fall into the nuclear reactor cavity and seriously affect the safety of the nuclear containment vessel due to the chain reaction caused by the reaction between the molten core and concrete. This paper reports on research focused on the type and amount of vapor produced during the reaction between a high-temperature molten core and concrete, as well as on the erosion rate of concrete and the heat transfer characteristics at its vicinity. This study identifies the mass fraction and melting temperature as the most influential properties of concrete necessary for a safety analysis conducted in relation to the thermal interaction between the molten core and the basemat concrete. The types of concrete that are actually used in nuclear reactor cavities were investigated. The H_2O content in concrete required for the computation of the relative amount of gases generated by the chemical reaction of the vapor, the quantity of CO_2 necessary for computing the cooling speed of the molten core, and the melting temperature of concrete are evaluated experimentally for the molten core–concrete interaction analysis.

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1. Introduction

In case of damage to the nuclear reactor vessel in a severe accident, a reaction may occur between the high-temperature molten core and the concrete of the cavity basemat at the base of the containment vessel. Such reactions will lead to erosion and produce inflammable gas (H_2), inert gases, and fission products, which will result in an increase of the pressure inside the containment vessel, affecting its safety. Among the major factors that influence the reaction between the molten core and concrete, the types and relative amounts of gases generated by the chemical reaction between the molten substances, concrete, and vapor, together with the melting speed of the cavity basemat, are very important when determining the thickness and area of the cavity basemat and for designing the containment vessel.

In the 1990s, the Argonne National Laboratory in Lemont, IL, USA carried out experimental and analytical research on molten core–concrete interaction (MCCI) by pouring water on the top of the molten core, using MACE test equipment [1]. The MACE experiment led to the presumption of the existence of cooling mechanisms for molten material, such as bulk cooling, water ingression, melt eruption, and crust failure. This presumption stressed the necessity of gathering additional experimental data to provide a more reliable basis for understanding each of these cooling mechanisms, solving the cooling problem of the molten core welling out of the reactor by means of experimental models, and settling the uncertainty problems related to MCCI.

However, despite the need for experimental data to provide a reliable basis, most of the research related to MCCI to date has been performed in the fields of nuclear power and mechanics, where concrete is assumed simply as a unique object the properties of which are applied in a model for the analysis. Moreover, the past experimental approaches for MCCI focused primarily on the molten matters with regard to the phenomena provoked by the contact between concrete and the molten core, such as melt eruption, water ingression, crust failure, and long term two-dimensional MCCI [2]. However, most of the input variables in the models used to date in MCCI analysis, including those characterizing the physical properties of concrete, are not clearly identified in the absence of criteria. In addition, one cannot deny the absence of clarity in the documents and data based on which the physical properties of concrete were derived.

If MCCI analysis is performed using the CORCON-Mod3 model [3,4], it can be verified that the physical properties of concrete, such as its density and melting point, differ with respect to the type of aggregate among the factors governing the characteristics of concrete. However, it is difficult to find a model reflecting the experimental evaluation results of the physical properties of concrete according to the changes in its materials that can be used for a realistic MCCI test and analysis. The current absence of models incorporating the physical properties of concrete mixed with materials produced in Korea should be noted.

This study proposes accurate data gathering and analysis methods for characterizing the physical properties and behavior of concrete at high temperatures seen in severe accidents. To this end, limestone concrete was examined, as well as the mixed composition concrete used in Units 3 and 4 of the ShinKori nuclear power plant.

2. Mix compositions and fabrication of specimens

The properties intended for investigation in this study are mass fraction and melting temperature. To that end, two mix compositions have been considered: one involving siliceous aggregate (the most utilized aggregate in the construction of nuclear power plants) and the other involving limestone aggregate (currently discussed for application to nuclear reactor cavities); the corresponding results have been compared with those of previous research.

2.1. *Mix compositions*

In order to conduct the experimental evaluation and comparative analysis of the properties of concrete with regard to MCCI, tests were performed on the two mix compositions. These two mix compositions are identical except for the aggregates so as to assess the effect of the gravels and sand on the mass fraction and melting temperature of concrete. In particular, the concrete was fabricated to have identical types and quantities of cement, fly ash, and water. Here, SS indicates the mix with siliceous coarse aggregate and siliceous fine aggregate, and LL indicates the mix with limestone coarse aggregate and limestone fine aggregate.

2.2. *Fabrication of specimens*

All the specimens are fabricated as ϕ 100 × 200 mm^2 cylinders to comply with the standard American Society for Testing and Materials (ASTM) C 39. The tests were performed on the specimens after 91 days of curing, according to the standard curing method for nuclear power plant concrete. The concrete density is measured on the ϕ 100 × 200 mm^2 cylindrical specimens. The composition and melting temperature were evaluated using pulverized samples obtained from the specimens.

2.3. *Fabrication of pulverized samples and sampling method*

The general standard method for the chemical analysis of concrete (ASTM C 1084) recommends that only the cement paste without aggregates is considered [5]. Apart from ASTM C 1084, there is no specification or standard related to the testing of pulverized concrete samples, including the aggregates, as this approach is rarely adopted. Accordingly, reliability of sampling is enhanced by complying with the International Organization for Standardization (ISO) and Korean Standards (KS) standards for the fabrication and sampling processes of samples.

Sampling and sample preparation are performed using the following procedure in compliance with the international ISO 3082 [6] and Korean KS E 3605 [7] standards: The first sampling process is done after the first pulverization of the ϕ

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