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A Study on the Thermal Characteristics of Epoxy Coating Systems of the Containment Structures

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1. Introduction

The surface of the liner plate in containment is applied with the protective coatings to control corrosion and radioactive contamination levels, and to protect surfaces from wear. So, the protective coatings should be capable of withstanding the high temperature, humidity, pressure, and radioactivity caused at the simulated design basis accident and operating conditions. For this reason, they are classified into the safety related items and produced under the strict quality control.

Emergency situations in nuclear power plants usually arise from physical or chemical causes that are incident in their operations, therefore the great importance for maintaining safety management must be stressed all the more. Especially, aged equipment and improper materials could jeopardize safety systems in power plants, in which proper treatment or (better) prevention in the early stages of emergencies are strongly required [1]. However, information on plant accidents caused by the above factors is very limited.

It is crucially important to understand the characteristics of cured materials through the study of the thermal properties of epoxy resins that might be essential to safety system management in nuclear power plants[2]. Therefore, the present study was conceived in order to examine DBAs in real situations and to investigate the thermal characteristics of the epoxy coatings involved.

2. Test

2.1 Test Materials

The epoxy coating material used in this study was XX-5290, a polyamide-containing di-functional epoxy produced by one of Korean coating manufacturers that supplies coatings for containment liner plates in containment buildings in nuclear power plants. White metal blast-cleaned carbon steel (ASTM A36) plates of 50 x 100 x 3 mm size were employed.

2.2 Sample Preparation

To obtain better adhesion on the steel surface when applying epoxy coatings, the surface preparation work was carried out (SSPC SP10/Near White Metal Blast Cleaning) by steel shot for 2 hours prior to coating application, and then XX-5290 epoxy coating was applied by air spray method. Table 1 shows the coating system applied in this study.

Table 1. Coating Conditions and DFT

Specimen	Front Side (Thickness : μm)	Back Side (Thickness : μm)
1st	Epoxy primer : XX-5290	Epoxy primer : XX-5290
2nd	Epoxy Finish : XX-5290	Epoxy Touch-up : XX-5290
3rd		Epoxy Finish : XX-5290
Total	150~175	225~250

2.3 Irradiation

To investigate the effect of radiation exposure on XX-5290/carbon steel A36 coating system, a test was carried out according to ANSI N5.12. The total accumulated irradiation was 2 x 10^8 rads, and the irradiation rate was 2 x 10^6 rads/h.

2.4 DBA Test

A DBA test was carried out according to ANSI N101.2-1972 and ASTM D3911-1995. The extended duration of the DBA test was 1 million seconds, including added lag time to approach to the normal test condition. The maximum temperature and pressure were 150˚C and 474 kPa, respectively. Figures 1 and 2 show the equipment used and the experimental conditions of design-basis temperature and pressure, respectively.

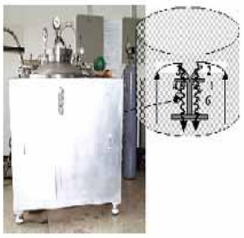

Figure 1. DBA test equipments

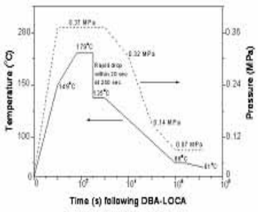

Figure 2. DBA test condition of ANSI N 101.2 and ASTM D3911

2.5 Thermal Analysis

A thermal analysis on the curing reaction of the XX-5290/carbon steel A36 was performed with a Perkin Elmer DSC-6. The cure activation energy was determined by Kissinger equation [3] with different heating rates (2, 5, 10, and 20˚C. min-1). To measure the thermal stability of the same system, thermo-gravimetric analysis was conducted by using DuPont TGA-2950 to determine the thermal stability factors including the temperature of maximum rate of weight loss (Tmax), the initial decomposition temperature (IDT), and the thermal decomposition activation energy (Et). A TGA test was carried out in the temperature range of 30~850˚C and at the heating rate of 10˚C min-1.

Figure 3 depicts the Tg variations of different processing treatments on each test sample of XX-5290/carbon steel A36. Consequently, the test sample that was subject only to the DBA test indicated the largest Tg value in the epoxy coating system. In comparison with that DBA test sample, the irradiated sample without undergoing DBA test showed the smallest Tg value. In the case of the irradiated test sample, there was a significant influence on the structure formation and the maintenance of the network structure. Therefore, the effects of irradiation on epoxy coatings are considered to be an aging factor by free-gasification in the overall coating system. If epoxy coatings are radiation-exposed continuously, this can cause serious damage to the physicochemical properties and thermal resistance of epoxy coatings.

Therefore, when using protective coating materials in nuclear facilities, it is necessary to select radiation-resisting materials. In case of DBA-tested sample, it was subject to adequate pressure and temperature that effected the post-curing of the epoxy resin in the coating system. It was observed that this led to an improvement of overall Tg value. This value, however, excluded the effects of environmental history, that is, of service time and the other external conditions. Accordingly, the combined irradiation/DBA test sample showed a low Tg value compared with the DBA-only sample.

In Figure 4, the TGA thermal analysis results for the XX-5290/carbon steel A 36 epoxy system are shown. Like the preceding Tg results, the experimental sample that was only tested with DBA showed the most excellent thermal stability. This indicates that the start temperature of initial thermal decomposition moved to its right and was slightly increased in the final residue, to 76.6%, comparing the 75.5% attainment for the untreated sample. However, the overall thermal characteristics by TGA before and after treatment were similar. Therefore, irradiation and DBA testing did not significantly affect the thermal decomposition characteristics of the current epoxy system.

However, it was discovered that an irradiated epoxy system exhibits rapid decomposition at approximately 400˚C. This indicates that as the power output of power plants increases, they will be able to predict the cause of the epoxy system's decomposition under increased radiation dosages at elevated temperatures, conditions similar to those of DBAs.

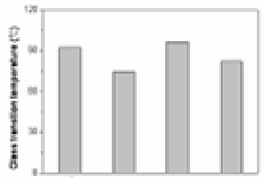

Figure 3. T_g of an XX-5290/carbon steel A 36 epoxy system

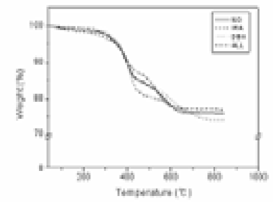

Figure 4. TGA thermograms of 1 xX 10^4 rads/h dose rate

3. Conclusions

The change in thermal characteristics of the test sample after irradiation and DBA testing were examined on the epoxy coating system. In the results, the Tg and the thermal stability of the epoxy coating system were improved compared with the non-treated DBA test sample, because the proper temperature and pressure of the DBA test provided compensatory effects. Those effects could cause post-curing on the epoxy coatings, and the thermal characteristic was improved overall. Therefore, the adhesive strength, one of the typical characteristics of the epoxy/steel interface, was eventually increased.

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