DEVELOPMENT EFFORT ON MITIGATION AND DETECTION OF AGING OF CANISTERS

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Abstract

In order to use the concrete cask system for the storage of spent fuels in Japan, it's necessary to establish method to manage aging effect, especially SCC (Stress Corrosion Cracking). Therefore, the methods are under development to mitigate SCC, to inspect crack, and to monitor confinement of a canister. For the mitigation of SCC, one of following factors should be kept in the certain conditions; residual stress, environment and material. The method has been chosen to make surface residual stress compressive by ZSP (Zirconium Shot Peening) and WJP (Water Jet Peening). At a fabrication factory, ZSP is used because of its economic advantage. At a nuclear power plant, WJP is utilized because its garbage, water is easy to treat at a nuclear power plant. The value of compressive residual stress and the depth of its layer induced by ZSP and WJP have been experimentally confirmed. Pitting corrosion can occur on a metal surface regardless of its conditions. Once pitting corrosion penetrates the compressive residual stress layer, SCC may occur at the tip of pitting corrosion and finally penetrates the canister shell. The pitting corrosion depth on SS Type 316L surfaces has also been measured for 10,000 hours under various conditions, and estimated its growth rate. The estimated depth of pitting corrosion during the storage period is shallower than that of the compressive residual stress layer induced by ZSP and WJP. Additionally, the development of Non-Destructive Testing (NDT) method to inspect cracks in case SCC penetrates the compressive residual stress layer has been succeeding. As the canisters are loaded with spent fuels, the method should be available in radiation environment. Eddy Current Testing (ECT) is chosen from various NDT methods because it is easy to operate ECT automatically and remotely. The magnetized weldment of a canister made of SS Type 316L interferes with inspection of cracks with ECT. It has been succeed in improving ECT method which is able to remove the magnetic noises. This improved ECT method allows detecting cracks by a millimeter unit.

Relating to the method to monitor confinement of a canister, the principle of this method is that it's only necessary to check the temperature difference between top and bottom of the canister in order to monitor the inner gas leakage. The principle has been confirmed experimentally and analytically. As mentioned above, the authors have established the methods to mitigate SCC, to inspect crack, and to monitor confinement of a canister.

1. INTRODUCTION

A metal cask storage system is used for spent fuel dry storage in Japan. In the near future, the introduction of a concrete cask storage system is expected in terms of its economic efficiency, reduction of waste and short delivery period. In addition, it can be used as an alternative way when the metal cask storage system faces some issues, such as undersupply of metal casks. In respect to application of concrete cask in Japan, some studies are conducted by Central Research Institute of Electric Power Industry (CRIEPI) [1]. SCC, the most important issue for concrete cask application in Japan, occurs when three factors exist simultaneously; i.e. tensile stress, sea salt environment and austenitic stainless steel. Since Japan is surrounded by the ocean, the interim storage facility would be built at coastal area. The saline air contacts directly to the canister surface due to the cooling air from seashore. If saline particles in the cooling air adhere to the surface of the canister, it might induce the SCC and lose its containment function in the worst case [2], [3]. Removal of one of the three factors is needed to prevent SCC occurrence. The factor of residual tensile stress can be converted to the compressive stress by Zirconium Shot Peening (ZSP) and Water Jet Peening (WJP), etc. In addition, crack inspection method shall be established to detect appearance of SCC in service condition for preparing such the emergency condition.

2. SCENARIO OF COUNTERMEASURE AGAINST SCC

Three factors, stress, environment and material are necessary to induce SCC that is shown in Fig. 1. If one of the factors is able to eliminate, SCC will not occur. Figure 2 shows SCC countermeasure scenario against SCC on the basis of residual welding stress by Hitachi Zosen.

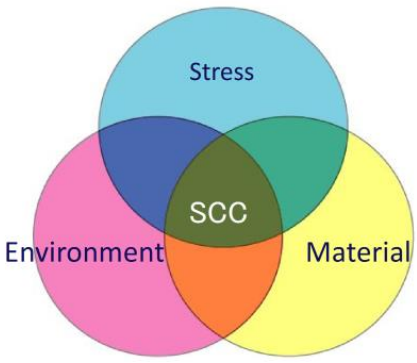

FIG. 1. Three factors for SCC.

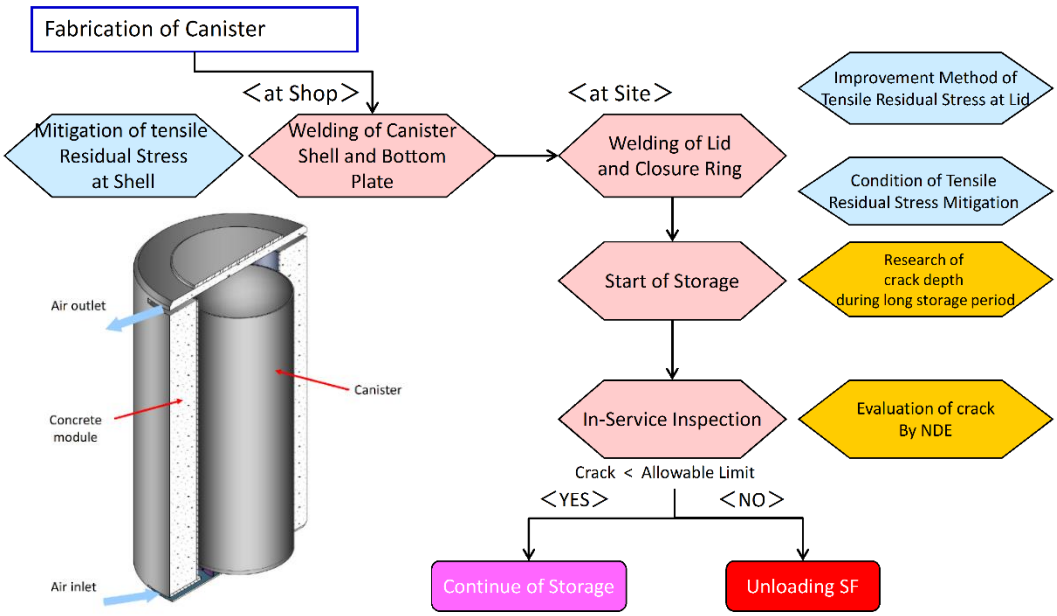

FIG. 2. SCC countermeasure scenario by Hitachi Zosen.

3. IMPROVEMENT METHOD OF TENSILE RESIDUAL STRESS

At first, for the prevention of SCC occurrence, residual stress improvement (tensile to compressive) would be applied during at shop after welding of the canister shell and bottom plate. At this time, a method is required to make surface residual stress compressive by ZSP and WJP. At a fabrication factory, we use ZSP because of its economic advantage. However, ZSP is not available in sites because it discharges a lot of metal pieces. At a nuclear power plant, WJP is utilized because it produces water only and it is easy to treat at the site. The value of compressive residual stress and the depth of its layer induced by ZSP and WJP is obtained by doing an experimental examination. Fig. 3 shows the result of ZSP test on SS Type 316L. Various surface treatments is conducted and the given residual stress is measured. The blue line is the result of only grinding, the red line is that of grinding and buffing, and the green is the result of grinding, buffing and ZSP. The resulting

residual stress is kept compressive until 600 micro meter depth [4]. Figure 4 is the result of applying WJP on SS Type304L test plate. This figure shows compressive residual stress can be applied at 400μm by WJP.

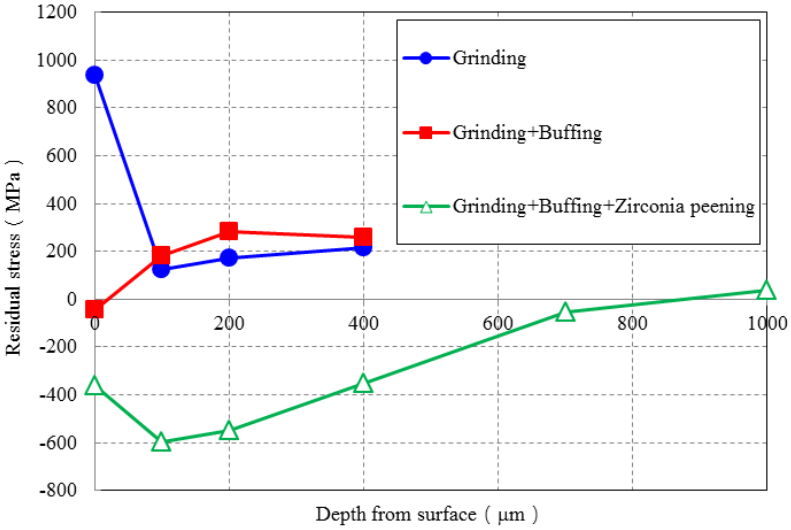

FIG. 3. Effect of ZSP.

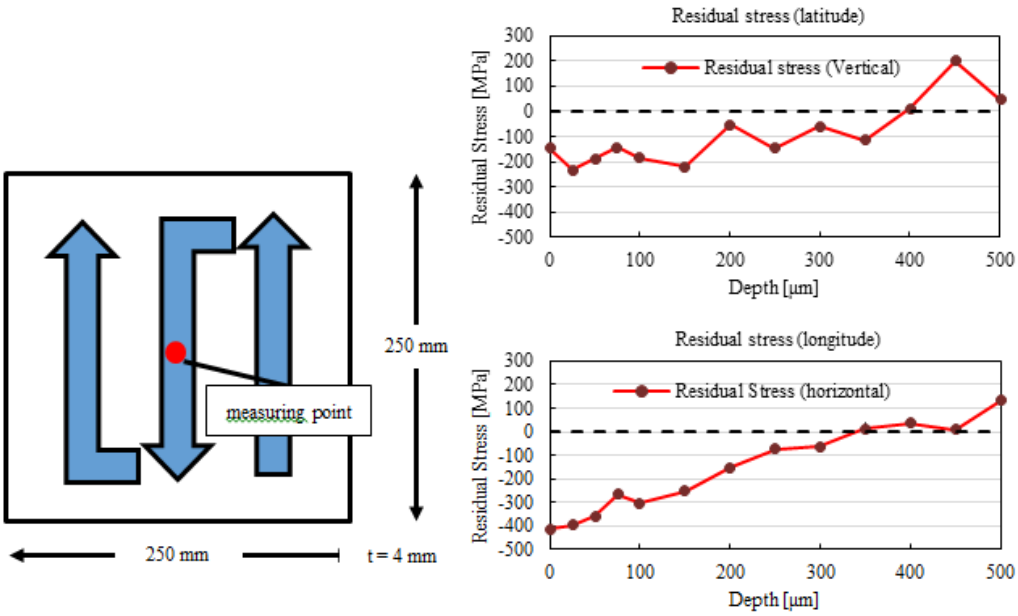

FIG. 4. Effect of WJP.

4. EVALUATION OF AGING EFFECT

In the case of storing concrete modules in the United States, continuous monitoring of canister leakage is not obligated at present, but the evaluation of aging effect during the time of long-term storage is important. Periodic in-service-inspection may be required in Japan because Japan regulatory agency may concern about SCC and it is necessary to find SCC during storage. The surface inspection by visual observation is not easy to

detect SCC occasion visually, so NDT may be required to find SCC. To observe the aging effect, SCC growth is focused. Fig. 5 shows that all steps of SCC growing, SCC can be managed appropriately.

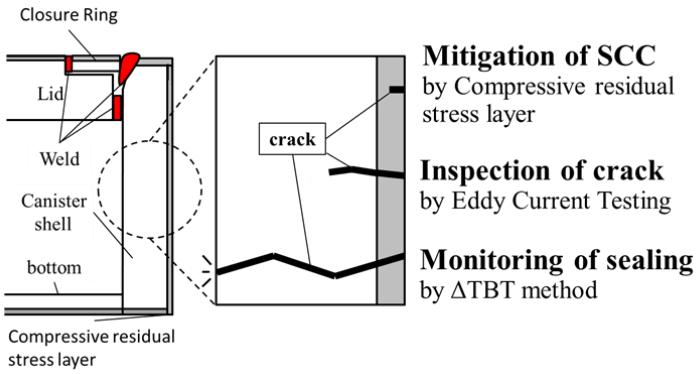

FIG. 5. Schematic view of a canister.

4.1. Pitting corrosion experiment

As is known, regardless of the metal surface conditions, pitting corrosion can occur. It is impossible to deny the possibility of pitting corrosion. Once pitting corrosion penetrates the compressive residual stress layer, SCC can occur and grow at the tip of the pitting corrosion. Therefore, the depth of pitting corrosion is measured experimentally, and its growth rate is estimated. The experimental conditions and results are as shown in the Table 1 and Figs 6 and 8. Considering the decrease of temperature and the corresponding relative humidity (RH) on the canister surface, SCC does not necessary propagate throughout the storage period. SCC can easily initiate if RH exceeds the value for the synthetic sea salt: around 15%. The humid period in which a RH exceed 15% is clarified by an analysis; it is 15,000 hours during a 60 year storage period [5] (Fig. 7). The estimated depth of pitting corrosion at 15,000 hours [6] is just 160 micro meters. These results mean that there is no pitting corrosion risk on the compressive residual stress layer (300~400 μm) for long term-storage period. It emerged that the pitting initially propagated fast, whereupon the propagation rate declined. The result successfully clarified the effectiveness of mitigation of SCC by compressive residual stress layer.

TABLE 1. CONDITIONING OF 10, 000 HOURS PITTING CORROSION EXPERIMENT

Environment	Surface		Material	Position
55oC-35%RH	#600	304 L		Base
			316 L	
	WJP		304 L	Base
				Weld
			316 L	Base
				Weld
	Roller Burnishing		304 L	Base
				Weld
			316 L	Base
				Weld
	ZSP		304 L	Base
				Weld
55oC-30%RH	#600	304 L		Base
			316 L	

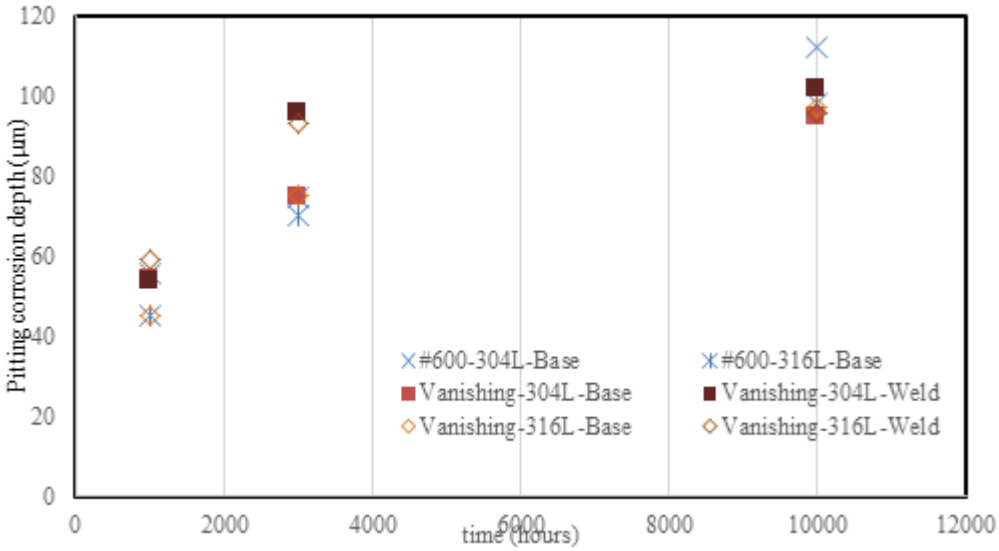

FIG. 6. Result of Pitting Corrosion Experiment.

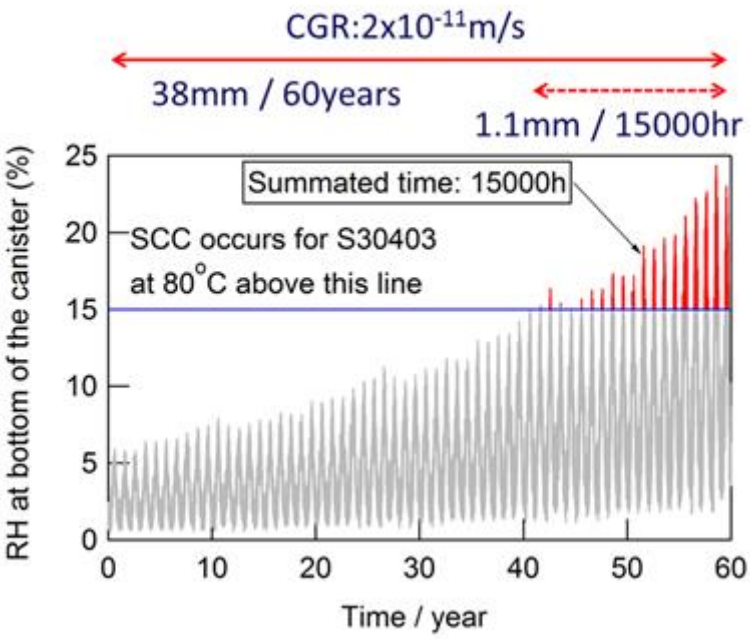

FIG. 7. Crack Growth Test Result.

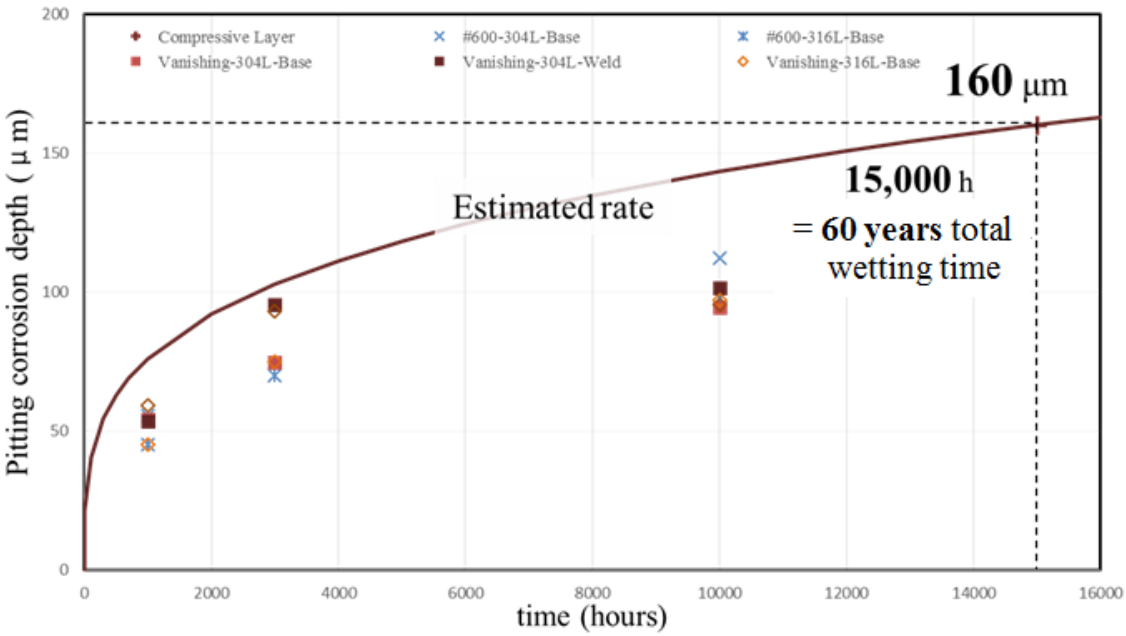

FIG. 8. Pitting Corrosion Growth Rate.

4.2. Eddy Current Testing (ECT)

We develop the NDT method to inspect cracks in case SCC penetrates the compressive residual stress layer. The target depth of cracks is on the order of millimeters.

ECT frequently used at nuclear sites has some advantages over other NDT methods. As the canister loaded with spent fuels make the radiation conditions, NDT should be conducted remotely and automatically. ECT has the potential to be operated remotely but is too sensitive to magnetic noise to detect cracks in magnetic body. In addition, the temperature at the surface of a cask is too high to apply a typical permanent magnet. Therefore, it is necessary to improve the ECT device in order to overcome magnetic noise. The subject can be solved by use the magnet combined a neodymium magnet which can strongly cut down the magnetic noise and a samarium-cobalt magnet which has a high working temperature (Fig. 9).

Figure 10 shows the result of improved ECT. The test piece has no cracks, so there should be no wavelets, but there are too much magnetic noise when using normal ECT device. On the other hand, there is no noise when using improved ECT device.

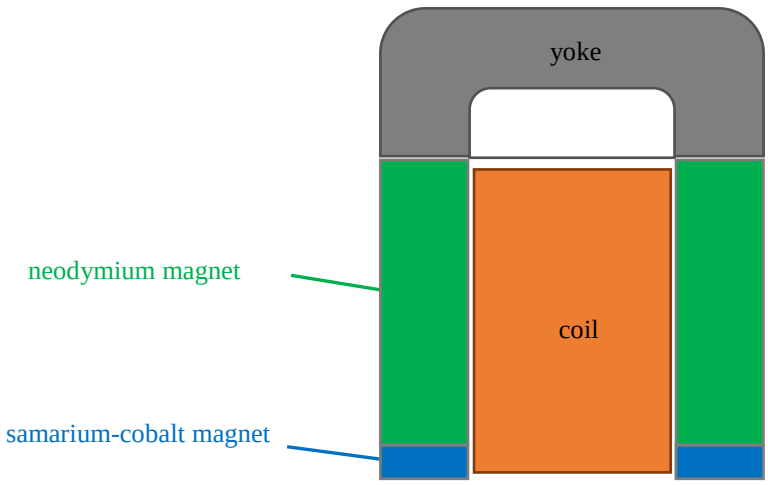

FIG. 9. Combined magnet.

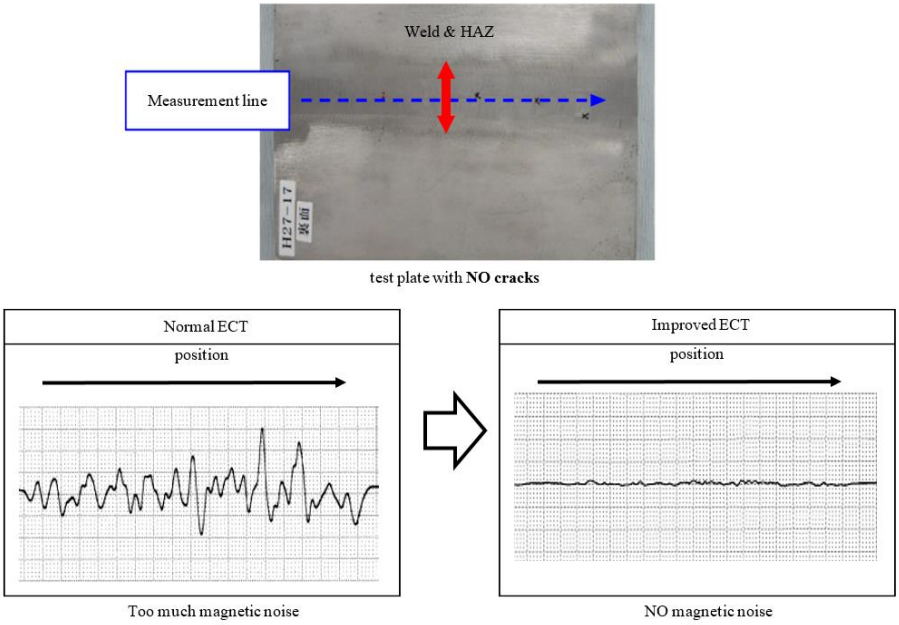

FIG. 10. Improvement of ECT Device (1).

Figure 11 also shows the result of improved ECT. The test piece has 6 cracks, so there should be 6 indications, but there is too much magnetic noise when using normal ECT device. On the other hand, there are 6 clear indications when using improved ECT device.

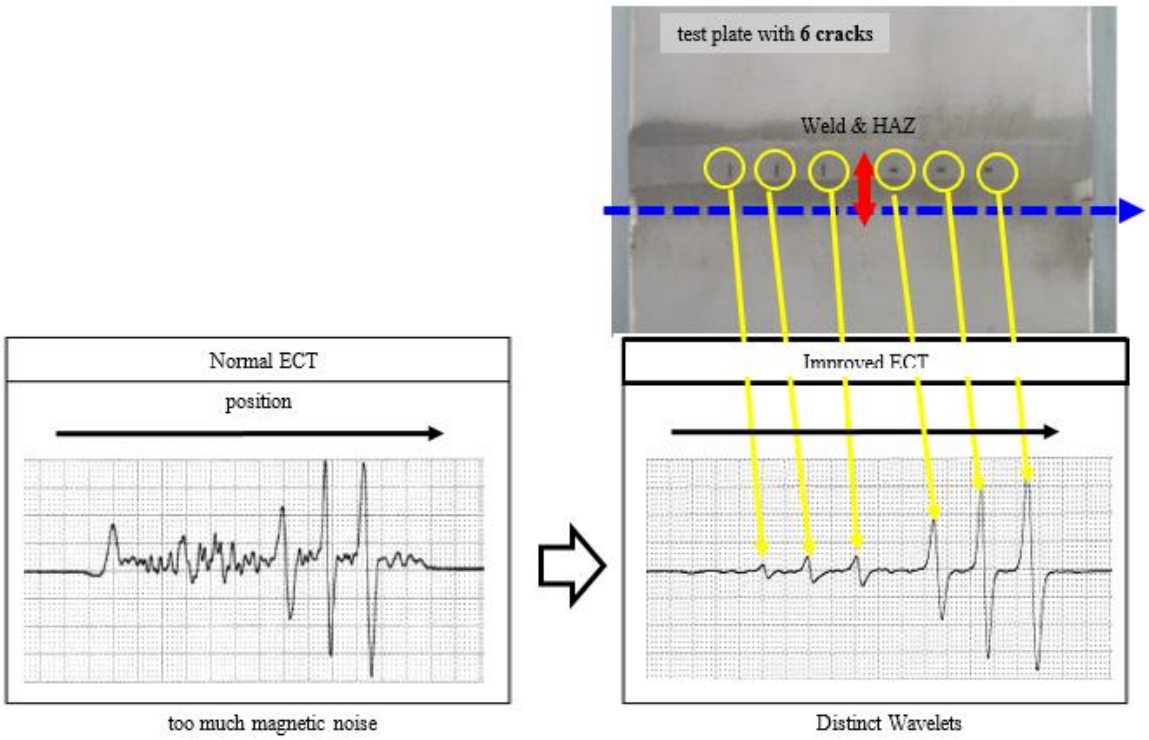

FIG. 11. Improvement of ECT Device (2).

4.3. ΔTBT Method

In the concrete cask storage system, spent fuel is installed and weld-sealed in a canister. The canister is filled with helium gas and its containment shall be maintained and inspected during the storage. The helium gas enhances heat removal from spent fuel. When helium gas leaks, the effect of helium gas convection is weakened in the canister. Then, the temperature on the canister surface changes. By using this principle, the detecting method using information of temperature changes on the canister side surface has been proposed. Figure 12 shows temperature measurement points. The temperature difference ($=T_B-T_T$) was defined as ΔT_{BT}, and ΔT_{BT} rises quickly once the inner gas leaks (Fig. 13) [7].

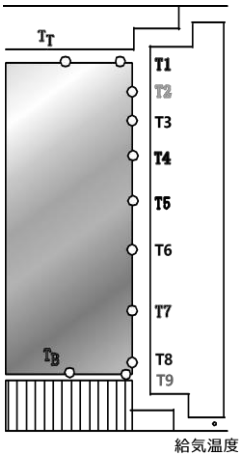

FIG. 12. Temperature measurement points.

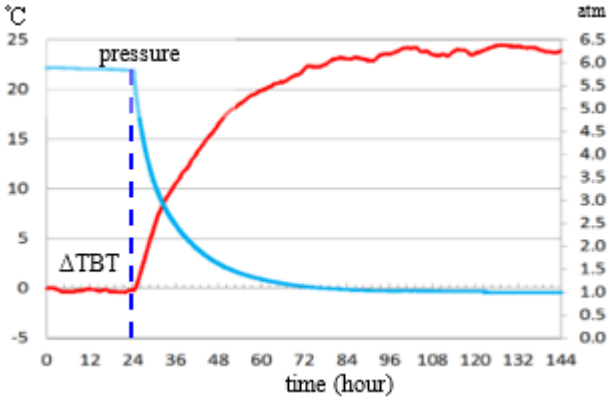

FIG. 13. Relation between ΔT_{BT} and pressure in a cask.

5. CONCLUSIONS

In order to consider a SCC resistant canister for practical use in Japan, following 3 principles for aging management are fully confirmed; Mitigation of SCC, inspection of crack and monitoring of sealing.

The conclusions are as follows:

— Experimentally proved that SCC can be prevented by using ZSP at shop and WJP at the site.
— SCC caused by pitting can be sufficiently prevented.
— ECT method which is able to remove the magnetic noises is improved.
— The principle of ΔTBT method is confirmed experimentally and analytically.

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