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STUDY ON PREVENTION OF STRESS CORROSION CRACKING OF THE CANISTER FOR TRANSPORT AND STORAGE

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ABSTRACT

In the long-term operation of austenitic stainless steel canister, the possibility of stress corrosion cracking (SCC) by chloride, are beginning to be pointed out ［1］［2］［3］.

As measures to prevent this SCC, there are ways to convert compression stress from tensile stress represented by the welding part. Here, it is clarified that zirconia peening process or ball burnishing process can prevent SCC by using laser welding specimens of SUS304L or SUS316L stainless steel. Compressive stress layer where the ball burnishing or zirconia peening methods were applied is about 800μm and 1500μm respectively. Those depths were almost the same as the depths of hardness change. On the other hand, depths that metallurgical structures change by work hardening were 60 percent of those.

To evaluate the stability of the compressive residual stress layer which is granted by peening or the like, we measured the residual stress change with adding tensile loading by X ray diffraction method. The compressive residual stress was kept compression state until base metal yield.

SCC tests were carried out with boiling aqueous magnesium chloride solution in order to evaluate the processed surface performance. SCC was observed in the as welded specimen and grinded specimen. But, compressed materials by zirconia peening or burnishing did not show any SCC.

In long-term use, effect of pitting corrosion was also a big concern. But, the predicted maximum pitting depth on 60 years design life is shallower than that of compressive stress layers obtained by burnishing or zirconia peening. So, long time SCC prevention by these methods can be expected.

INTRODUCTION

Hitachi Zosen Corporation has more than 30 years’ experience of manufacturing casks and canisters used for transportation or storage of spent nuclear fuel. Those are used in Japan, United States and some other countries. In particular, austenitic stainless steel canisters which are installed into the concrete cask for interim storage of spent nuclear fuel have been manufactured since late 1990s. The number of delivered canister has already more than 500.

In Japan, Concrete cask system are being to recognized that have the merits of small amount waste generation and good economic efficiency ,comparing to metal cask system . Then, some studies of concrete cask suitable for Japan have started by Central Research Institute of Electric Power Industry (CREIPI) [1] [4].

In Japan, it is considered that the location of the interim storage facility will become near the shoreline because the transport of spent fuel is carried by ship. In addition, the interim storage by the concrete cask is based on the natural air cooling system. So, the austenitic stainless steel canister surface has some possibility of sea salt particles adhesion carried from the sea. It may be a cause of chloride SCC.

Then, it is a big concern to establish the design and manufacturing technology that does not lose its sealing function. Apart from the CRIEPI's study, we also conducted a study of manufacturing technology of canister for concrete cask.

In this paper, several test results by using laser welding stainless steel specimens of 304L or 316L those are burnished or zirconia peened, were reported. The test results of residual stress distribution, compressive residual stress stability, hardness distribution, microstructure observation clarified that long-term SCC prevention can be achieved by burnishing or zirconia peening.

TEST ITEMS

Welding method and test materials

SUS 304L and SUS316L stainless steel are selected for test materials because they are the candidate materials of canister. Welding residual stress is considered to the main cause of SCC. Here, laser welding method was chosen for the test welding method because it generates minimum residual stress and makes minimum deformation. Laser welding stainless steel specimens of 12.7mm thickness were prepared.

Surface processing method

As processing methods for giving the compression residual stress to the weld, ball burnishing method or zirconia peening method were selected. Zirconia peening is a peening method of blowing zirconia ball shown in Fig.1 by high-speed air. Since zirconia ball have big bulk density, high hardness and excellent toughness, zirconia peening can give a deep compressive residual stress layer. Ball burnishing method (Figure 2) is intended to making plastic deformation by pressing a hard rolling ball at the tip of the head.

In this method, by varying process pressure, process quality is changed. The fatigue improvement by compressive stress, and high speed material surface smoothing are the well-known applications. Here, in order to evaluate their ability, two levels of process pressure (soft and hard mode) were evaluated. On stainless steel canister fabrication, machining, grinding and buffing processes are essential processes. So, the effects of those processes on SCC were also evaluated.

Figure 1. Zirconia ball

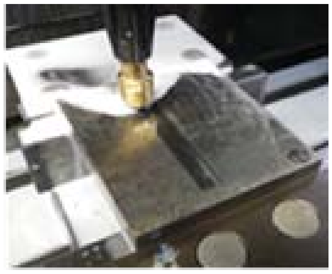

Figure 2. Ball burnishing method

EVALUATION OF COMPRESSIVE STRESS LAYER BY ZIRCONIA PEENING (SUS304L)

Residual stress distribution

Surface appearances of specimens subjected to various process are shown in Fig.3.
Figure 4 shows residual stress distribution in the thickness direction measured by X-ray diffraction method. The residual stress becomes tensile to 400μm depth in the grinder treatment. By additional buffing, the stress of surface 100μm depth area has decreased. Further zirconia peening changes the surface stress state into compression. The compression depth is reach to 800μm.

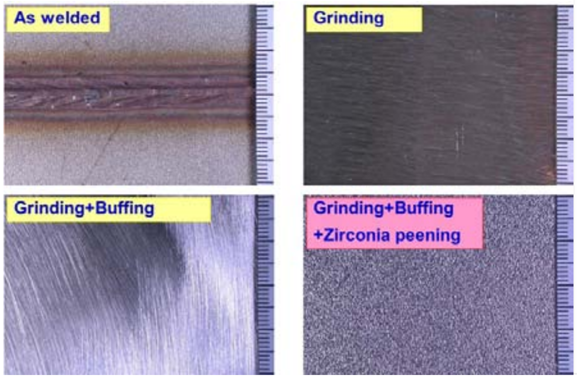

Figure 3. Surface appearance
in the thickness direction

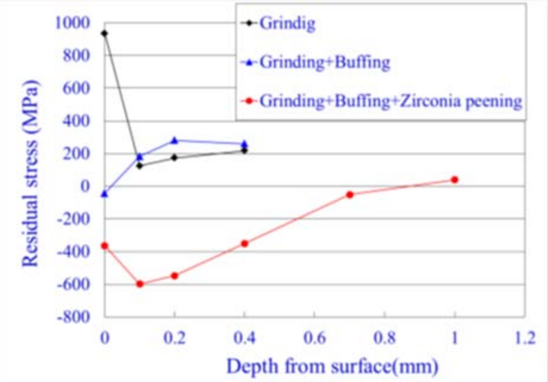

Figure 4. Residual stress distribution
of processed material

Hardness distribution

Measured hardness distributions in the thickness direction are shown in fig.5. Hardest surface is obtained by zirconia peening, and those of grinding process or buffed ones are followed. Hardness change depth by zirconia peening is approximately 1 mm, which is about the same as the depth of the compressive stress exists.

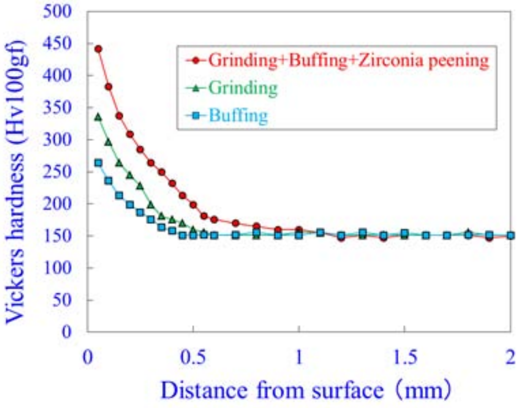

Figure5. Hardness distribution change by applied process

Metallographic observation

Cross-section micrograph of the material surface portion subjected buffing (a), grinding (b), zirconia peening (c) are showed in Fig.6. Work hardened area determined by metallurgical observation is the upper side of red dotted line. In this area, acicular structures are observed in the crystal grains. The depth of metallurgical change are 100 μ m, 200 μ m and 500 μ m respectively, and that was 60% of the region where hardness and residual stress changes.

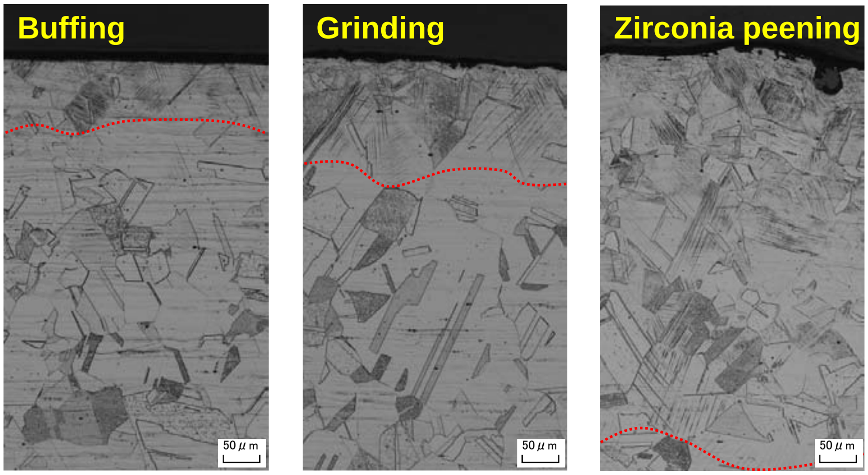

Figure6. Morphological changes of the crystal grains

Stability of the compressive stress layer

The importance of compression method for preventing SCC is deeply depended on the stability of the compressive residual stress layer under loading condition. Figure 7 shows the test condition of stress change under loading .The stress change of compression area is measured by X ray diffraction method. Compressive residual stress was kept compression state until 243MPa that coincide with 0.2% proof stress. Since the design stress is sufficiently smaller than 0.2% proof stress, the compressive stress state does not change during the life time of the canister.
Then, it can be confirmed that compression method is effective for SCC prevention.

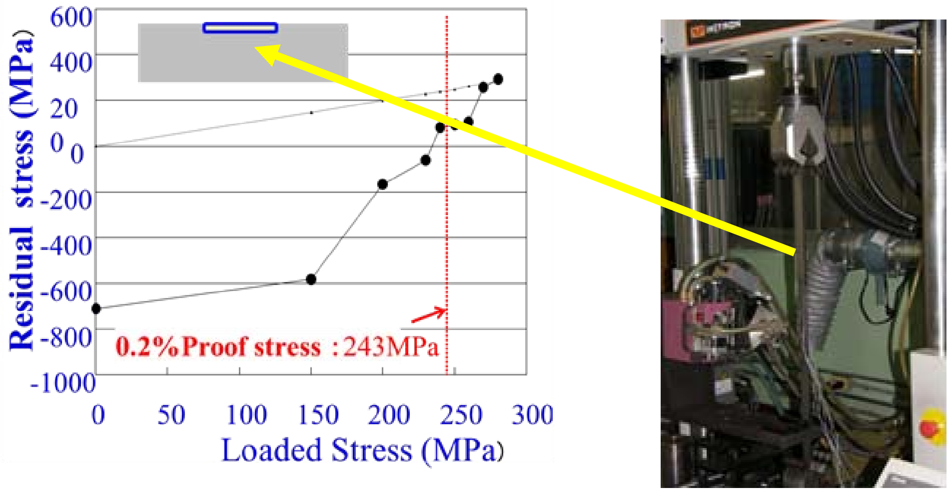

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Figure 7. Loading test of compressed material

SCC test

Specimens subjected to various surface treatments were evaluated by the SCC test method (JISG0576) using 42% boiling magnesium chloride aqueous solution. Fig.8 shows the visualized cracks by penetrant test of SSC test specimens. Since the tensile residual stress is strong in weld line direction, SCC is generated in the direction perpendicular to the weld line in as-welded specimens. Those cracks existed in 30mm area from weld line.   In grinded specimen, SCC occurs in the whole surface area of specimen. In buffed specimen, SCC occurs near the center area because relatively small compression stress is applied on whole the surface. In zirconia peened specimen, SCC did not occur at all. From these, it was found that zirconia peening is very effective method for preventing SCC.

Figure 8. Visualized cracks of SSC test specimens

EVALUATION OF COMPRESSIVE STRESS LAYER BY BURNISHING (SUS316L)

Residual stress distribution

Residual stress distribution in the thickness direction measured by X-ray diffraction was shown in Fig.9. The surface of the base material, compressive stress depth is about 300μm. Grinding process generates tensile residual stress whose depth of 1000μm. The compressive stress depth is 1800μm by hard burnishing, and that of by soft burnishing is 1200μm, depended on the loaded pressures. Those depths are deeper than that of zirconia peening.

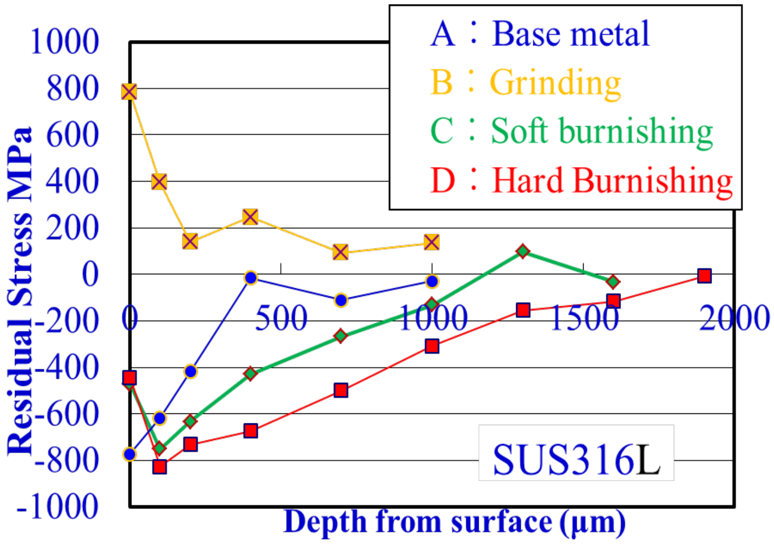


Figure 9. Residual stress distribution in the thickness direction

Metallographic observation

Cross-sectional micrographs of base material (a), soft burnished surface portion (b), and hard burnished surface portion (c) are shown in Fig.10. Morphological changes of the crystal grains are observed in the surface side divided from the black curve, were subjected to large hard working. Measured compressive stress layer depth is 300μm, 500μm, and 700μm, respectively. The depth of metallurgical change observed in the burnished specimen is about 40% of compression depth.

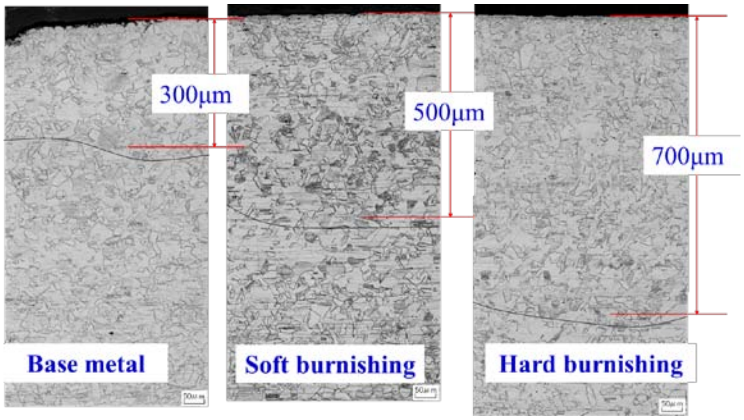
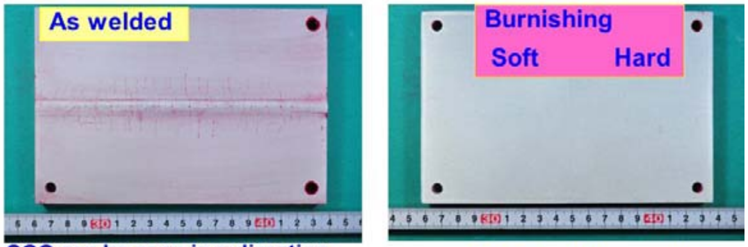


Figure 10. Morphological changes of the crystal grains

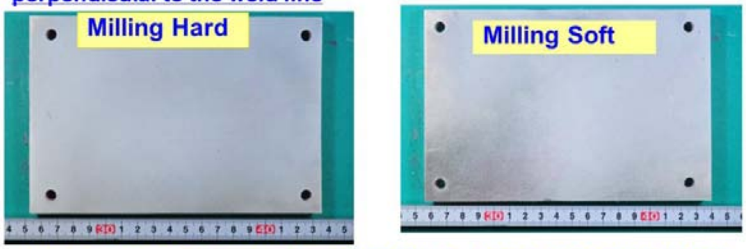
SCC test results

The effects of machining or burnishing by using 316L specimens were evaluated by SCC test (JIG 0576). The visualized SCC pictures by using penetrant test are shown in Fig.11. Strong tensile stress remains in the welded specimen (a) to the welding direction. The SCC of about 20mm is occurred in the direction perpendicular to the weld line. In the burnished material (b), SCC could not see regardless to the process pressure. By visual observation, any SCC could not find in the both hard milling specimen (c) with fast feed rate and soft milling specimen (d) with small feed rate. However, some micro sizes SCC were detected by microscopic observation. From these result, we can find that the burnishing method is very effective one in preventing SCC.



SCC can be seen in a direction perpendicular to the weld line

SCC is not observed



Milling surface has tensile residual stress, but the SCC instruction pattern is not confirmed

Figure11. The effects of machining or burnishing on SCC (SUS316L)

EVALUATION OF LONG-TERM CORROSION RESISTANCE BY PITTING

Preparation of the specimen

Grinded or zirconia peened specimens were prepared for SUS304L stainless steel. Grinded or zirconia peened and burnished specimens were prepared for SUS316L stainless steel.

Test conditions

The 5μL of artificial seawater dropped on the 100×100 sized specimens and it is dried in φ3mm area. The salt condensation is about 14g/m2. The dropped portions are weld material, weld boundary, and heat affected zone (5mm from the weld boundary) and base metal. 10 portions were tested in each position. Tests environment was 50 ℃ and 35% relative humidity. The pitting depth measurement by microscope was done at 100h, 300h, 1000h and 3000h.

Maximum pit depth

The relationship between the test time and the maximum pit depth of the processed SUS316L specimens are shown in Figure 12. Pitting depth of the grinder treated material is slightly deeper than the others at a longer time side, but we recognize that differences by the surface treatment or the tested position are negligible.

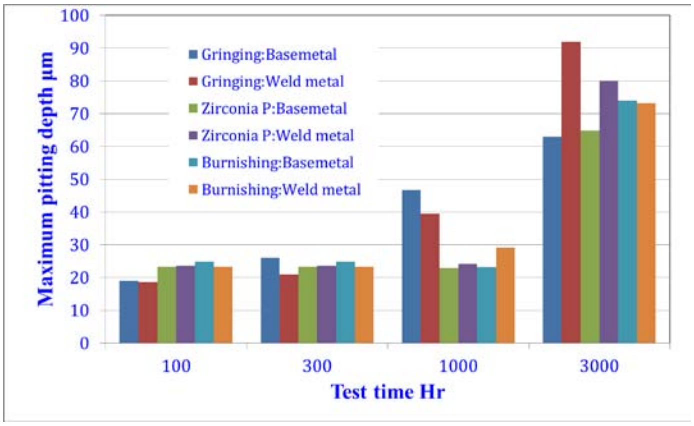
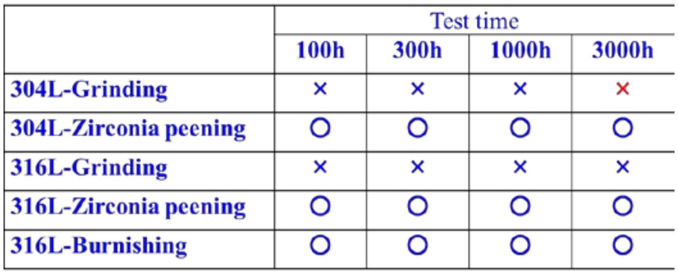


Figure 12. Measured maximum pitting growth

SCC in pitting test body

Table 1 shows the presence or absence of SCC initiation seen in pitting test body. SCC occurs at 100hr on the grinder treated material both 304L and 316L. On the other hand, at 3000hr, SCC was not observed on the burnished material or zirconia peened material. These results confirm good SCC prevention ability of burnishing or zirconia peening.

Table 1. Presence or absence of SCC initiation in pitting test body



	Test time			
	100h	300h	1000h	3000h
304L-Grinding	×	×	×	×
304L-Zirconia peening	○	○	○	○
316L-Grinding	×	×	×	×
316L-Zirconia peening	○	○	○	○
316L-Burnishing	○	○	○	○

Estimation of 60 years pitting growth

I will present an estimation of pitting growth during 60 years in Table 2, under the following two assumptions.

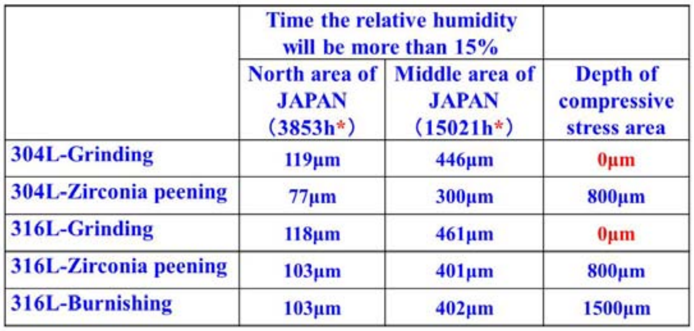
1) It is assumed that the pitting grew linearly based on the maximum pit depth of the foregoing 3000h data.

2) Time of exposure to corrosive environments is the time that relative humidity becomes more than 15% [1]

Table2 shows the estimated 60 years pitting depth at center columns, and the compression stress depth obtained in the processes at the right columns.

It is considered that pitting originated SCC does not occur during 60 years because the maximum pit depth of the material subjected to burnishing or zirconia peening, is less than that of compression.

Table 2. Comparison between estimated maximum pitting depths and available compressive stress depth



	Time the relative humidity will be more than 15%		
	North area of JAPAN (3853h*)	Middle area of JAPAN (15021h*)	Depth of compressive stress area
304L-Grinding	119µm	446µm	0µm
304L-Zirconia peening	77µm	300µm	800µm
316L-Grinding	118µm	461µm	0µm
316L-Zirconia peening	103µm	401µm	800µm
316L-Burnishing	103µm	402µm	1500µm

CONCLUSIONS

The main conclusions are as follows

1) Zirconia peening and burnishing method are very effective methods for preventing SCC.
2) The compressive residual stresses remain compression state until base metal yield.
3) Zirconia peening or burnishing can give deep compressive residual stress layer of 800 μ m and 1500 μ m.
4) Pitting originated SCC does not occur during 60 years because the maximum pit depth of the material subjected to burnishing or zirconia peening, is less than that of compression.
5) The depth of hardness change region is substantially the same as the depth of the compressive residual stress, but the depth of metallurgical change observed is about 60% of their depth.
6) Effects of surface finishing methods for pitting corrosion were not so big.
7) As grinder treatment generates very large tensile residual stress, the grinded area needs post processing to prevent SCC.
8) We were able to obtain manufacturing technologies that are useful to avoid SCC.

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