Residual stresses and microstructure evolution of alloy 182 after peening

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1. Introduction

Alloy 182 is commonly used as a weld filler metal in welding between nickel-based alloys, low-alloy steels, and austenitic stainless steels in nuclear power plants (NPPs) [1]. It was originally selected for its high corrosion resistance, but after the prolonged operation, it exhibits susceptibility to stress corrosion cracking (SCC) in pressurized water reactor (PWR) [2]. Cracking incidents of alloy 182 welds have been reported in nuclear power plants worldwide. This is one of the critical safety issues for the long-term operation and structural integrity of NPPs. Improving the surface residual stress condition in welded joints is considered as one of various ways to mitigate SCC, and peening can prevent SCC by creating compressive stress on the surface of finished parts and structures. Various peening techniques have been developed, and some of them have been widely used in nuclear power plants in the United States and Japan [3]. In this study, it was intended to evaluate the residual stress conditions and microstructure changes depending on the peening techniques with Alloy 182 weld specimens. Results from this study can be used to understand the effect of peening on the SCC sensitivity.

2. Experimental Method

Alloy 182 was deposited on a stainless steel plate. The chemical composition of the studied Alloy 182 was analyzed: 72.54% Ni, 14.78% Cr, 3.5% Fe, 6.56% Mn, 1.83% Nb, 0.39% Si, 0.026% Ti, and 0.051% C. Three peening techniques were introduced to prepare peened specimens: water jet peening (WJP), underwater laser peening (ULP), and ultrasonic nanocrystal surface modification (UNSM). The specimen surface was heavy grinding (HG) treated before peening. The peening position is located at the center of the specimen (25 mm × 25 mm area) as shown in Fig. 1. Heavy grinding on the surface was followed by peening to simulate the surface finish of actual components in nuclear power plants. To study the effects of over-peening, specimens in which peening was performed 1, 2, 4, and 8 times were prepared. The residual stress was measured using x-ray diffraction (XRD) and a hole-drilling method. The cross-sectional microstructures of the specimens after peening were analyzed using electron backscatter diffraction (EBSD).

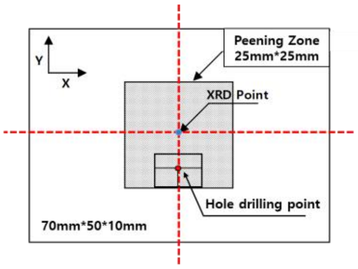

Fig. 1. x-direction: grinding and peening process direction, y-direction: peening step direction.

3. Results

3.1. Residual Stress

Figure 2 shows the residual stress on the specimen surface before and after peening measured by XRD, clearly indicating that compressive residual stress higher than 500 MPa is formed on the surface after peening. The WJP and ULP specimens produced similar compressive residual stress levels after a one-time peening, while in the UNSM specimens, the stress difference in the x and y directions is as significant as before peening. x and y directions imply grinding and peening process direction and peening step direction, respectively. The stress in the y direction is about 1430 MPa, and the stress in the x direction is about 660 MPa.

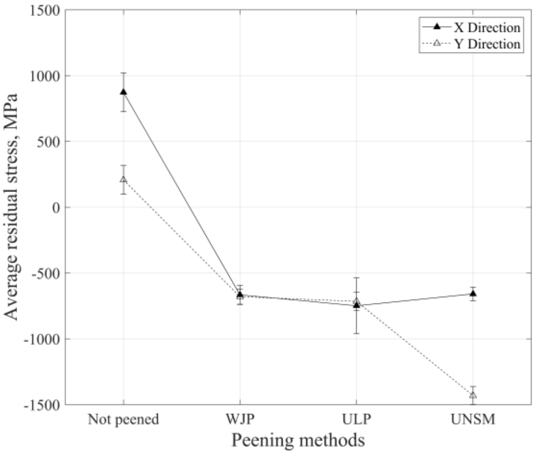

Fig. 2. XRD surface residual stresses of specimens depending on peening methods.

The surface residual stress results for over-peening are shown in Fig. 3, which was also measured by XRD. The ULP and WJP methods showed that the surface compressive residual stress appeared to decrease with the increase of peening times. In the UNSM method, the compressive residual stress increased after 2 times but decreased after 8 times of peening. UNSM peening showed that the residual compressive stress along x direction was always lower than that along y direction regardless of the number of peening, which was maintained only in the UNSM peening.

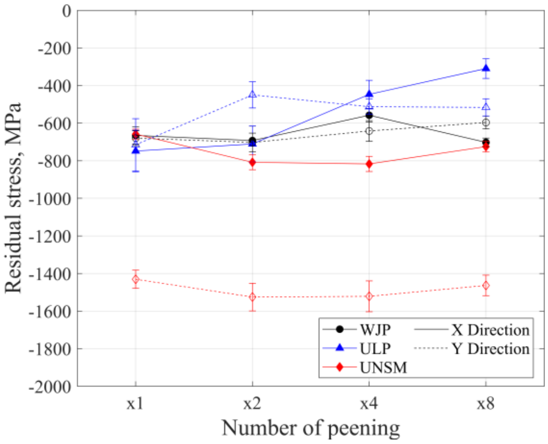

Fig. 3. XRD surface residual stresses of over-peened specimens depending on peening methods.

According to previous work, peening can generate compressive residual stress from the surface to a depth of 1 mm, which helps prevent SCC initiation. Stress depth profiles were measured using the hole-drilling method according to ASTM E837 [4]. The residual stress depth distribution measured by the drilling method is shown in Fig. 4. Heavy grinding yields tensile residual stress to the depth of ~500 μm, which is transformed into the compressive residual stress after peening. The results show that the three peening methods can produce compressive residual stresses to the depth of 1 mm regardless of the number of peening. Based on the results shown in Fig. 4, the compressive residual stresses of the UNSM sample are higher near the surface compared with the WJP and ULP samples. As the depth increases, the compressive residual stress value maintains the near-surface value or gradually decreases. Over-peening seems to have insignificant effect on the stress depth profile.

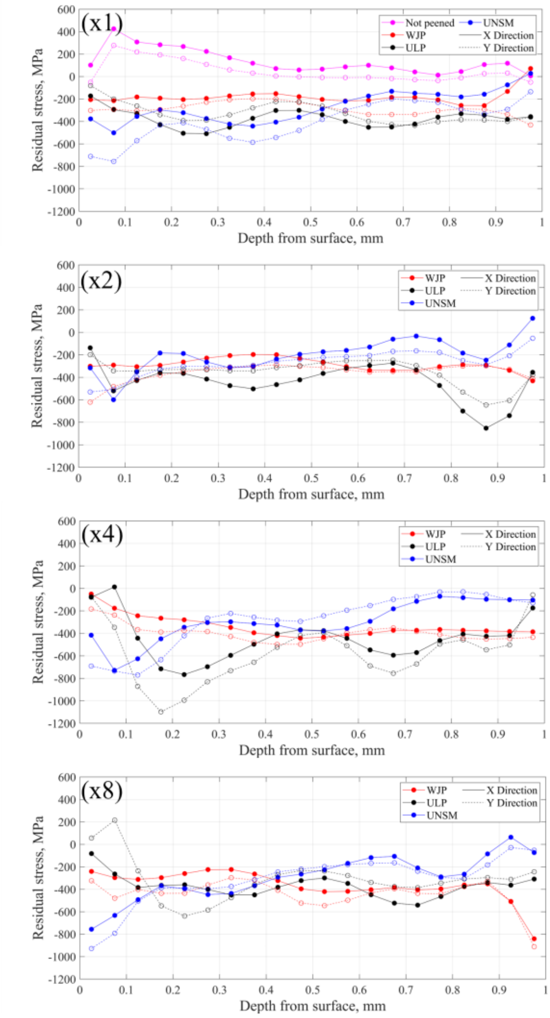

Fig. 4. The hole drilling depth-profiling residual stress results.

3.2. Microstructure

The cross-sectional microstructure of the peened specimen after a single peening is shown in Fig. 5. The Kernel Average Misorientation (KAM) map shows that the UNSM peening method produces the most significant plastic deformation to a depth of ~300 μm during the single peening.

The degree of cold working of UNSM is much larger than that of ULP and WJP. The plastic deformation depth caused by ULP or WJP peening is less than 20~30 μm. As the number of peening increases, it may be possible that plastically deformed layer thickness increases. As shown in Fig. 5, UNSM has almost no microstructure observed in EBSD images near the surface. However, it can be confirmed by Transmission Kikuchi Diffraction (TKD) analysis if nano-scale grains are formed near the surface after peening. TKD analysis on peened specimen surfaces are planned.

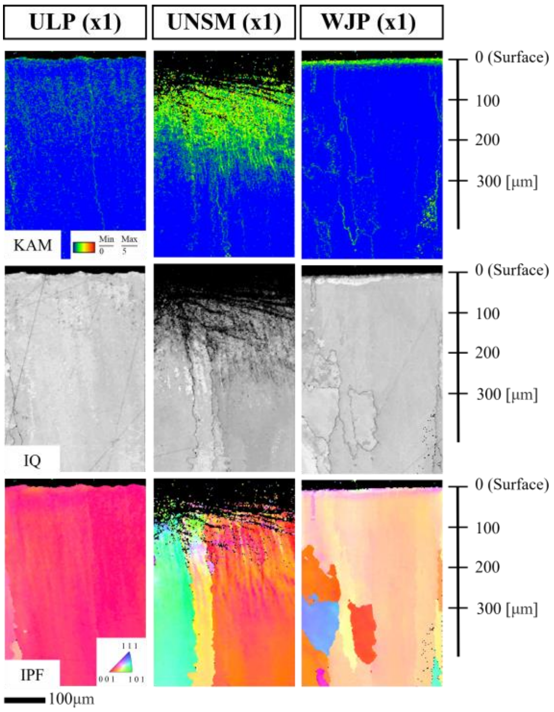

Fig. 5. EBSD microstructure analysis result of single peened specimen.

4. Conclusion

The effects of WJP, ULP and UNSM peening on the microstructures and residual stresses of Alloy 182 was evaluated. The following conclusions were drawn based on the results obtained:

The WJP, ULP, and UNSM can generate compressive residual stress on Alloy 182 to a depth of 1 mm.

In the peened specimens of this study, the WJP and ULP specimens produced similar compressive residual stress levels after one peening, while in the UNSM specimens, the stress difference in the peening process direction and peening step direction was significant, which is the same trend as observed in the specimen before peening.

With the increase of peening times, ULP and WJP specimens showed that the compressive stress value generated on the surface after peening decreased slightly, but the UNSM specimen still maintained the stress level after the single peening or increased slightly.

The UNSM has the most pronounced effect on the microstructure. Based on analysis with the single peening specimens, UNSM specimen showed a plastically deformed layer with a depth of ~300 μm. ULP and WJP specimens showed less than 20~30 μm of the peening affected deformation layer.

Acknowledgment

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