Effects of peening methods on residual stresses and microstructures of alloy 600

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1. Introduction

Alloy 600 is one of widely used nickel alloys in relatively high temperature or severe corrosive environments. In nuclear power plants various components were made of alloy 600, such as reactor head penetrations, various nozzles including hot legs and cold legs, and steam generator tubing. However, stress corrosion cracking (SCC) susceptibility problems appeared after being applied to nuclear power plants. Various studies on SCC of alloy 600 have been conducted. Most of them have been carried out focusing on the growth of SCC. Not many studies have been conducted on the SCC initiation, which is essential for understanding the principle of SCC [1]. SCC is affected by three main parameters: tensile stress, sensitive microstructure, and corrosive environment. One way to mitigate or reduce the SCC susceptibility is replacing alloy 600 with new alloys, which has been implemented in nuclear power plants by using alloy 690. Another way to mitigate the SCC susceptibility is to modify the surface stress condition by applying various techniques. Peening techniques can prevent SCC by generating compressive stress on the surface of finished parts and structures, and various processes have been developed. However, the peening effects on the material properties and SCC behavior has not yet been elucidated. Therefore, more studies are needed on the effects of the peening on the surface residual stress, depth profile of the residual stress, microstructure underneath the peened surface, and SCC behavior.

The main objective of this work is to analyze effects of peening methods on residual stresses and microstructures by using various peened alloy 600 specimens.

2. Experimental Method

Three peening techniques were introduced to prepare peened alloy 600 specimens: water jet peening (WJP), underwater laser peening (ULP), and ultrasonic nanocrystal surface modification (UNSM). Table 1 shows the chemical composition of the Alloy 600. The schematic of the peening specimen is shown in Fig. 1. The peening position is located at the center of the sample (25 mm × 25 mm area). Heavy grinding on the surface was followed by the 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 by using electron backscatter diffraction (EBSD).

Table I: Chemical compositions of alloy 600 specimen.

Element	Ni	Cr	Fe	Mn	Cu	P	C
Amount (wt%)	74.2	16.08	8.99	0.26	0.02	0.1	0.05

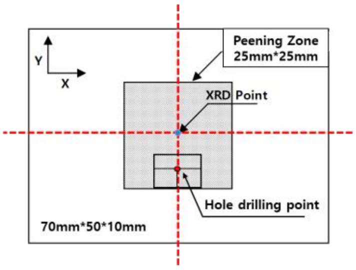

Fig. 1. Schematic of alloy 600 peening specimen surface; x-direction: grinding and peening process direction, y-direction: peening step direction.

3. Results

3.1. Residual Stress

Figure 2 shows the residual stresses on the specimen surfaces before and after peening measured by XRD, clearly indicating compressive residual stresses after peening. UNSM produces the highest compressive residual stress value, while ULP and WJP show similar level of residual stresses. Compared with ULP and UNSM, WJP treatment show the least discrepancy between X and Y directions because the coverage of water jet peening is extensive [2].

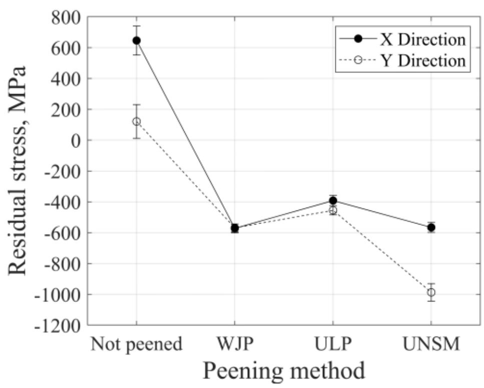

Fig. 2. XRD surface residual stresses of specimens depending on peening methods.

The surface residual stress result for over-peening is shown in Fig. 3, which is also measured by XRD. The ULP and WJP methods show a gradual decrease in the surface compressive residual stress as the number of peening increase. The stress value along the X direction produced by the UNSM method shows no noticeable change with peening times, but the compressive stress along the Y direction gradually increases. Before the peening, the stress along the X direction, which is equivalent to the heavy grinding direction, shows higher value than the Y direction. This tendency is maintained only in the UNSM treatment.

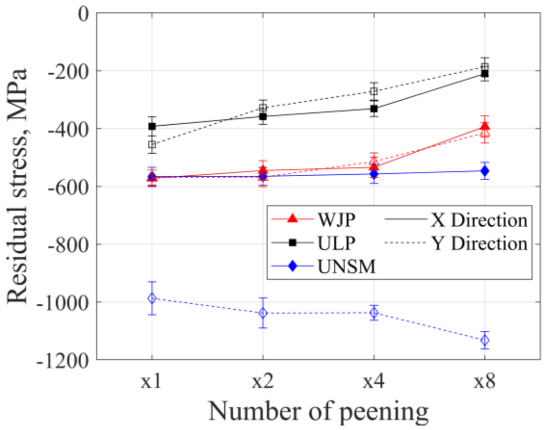

Fig. 3. XRD surface residual stresses of over-peened specimens depending on peening methods.

According to previous work, peening can produce compressive residual stress from the surface to the depth of 1 mm [1]. Hole-drilling stress depth profiles were measured according to ASTM E837 [3]. The depth profiling of residual stresses measured by the hole-drilling method are shown in Fig. 4. The hole-drilling measurement 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(a), which shows the results for the single peening, as the depth increases, the compressive residual stress value gradually decreases. At least for the single peening case, the compressive residual stress values of the ULP method seem to be slightly larger than those of the WJP and UNSM methods over the depth of 1 mm. The 2, 4 and 8 times peening results are shown in Fig. 4(b~d). For 4 and 8 times peening cases, the compressive residual stress values of the ULP method also seem to be slightly larger than those of the WJP and UNSM methods. Over peening seems to have insignificant effect on the stress depth profile.

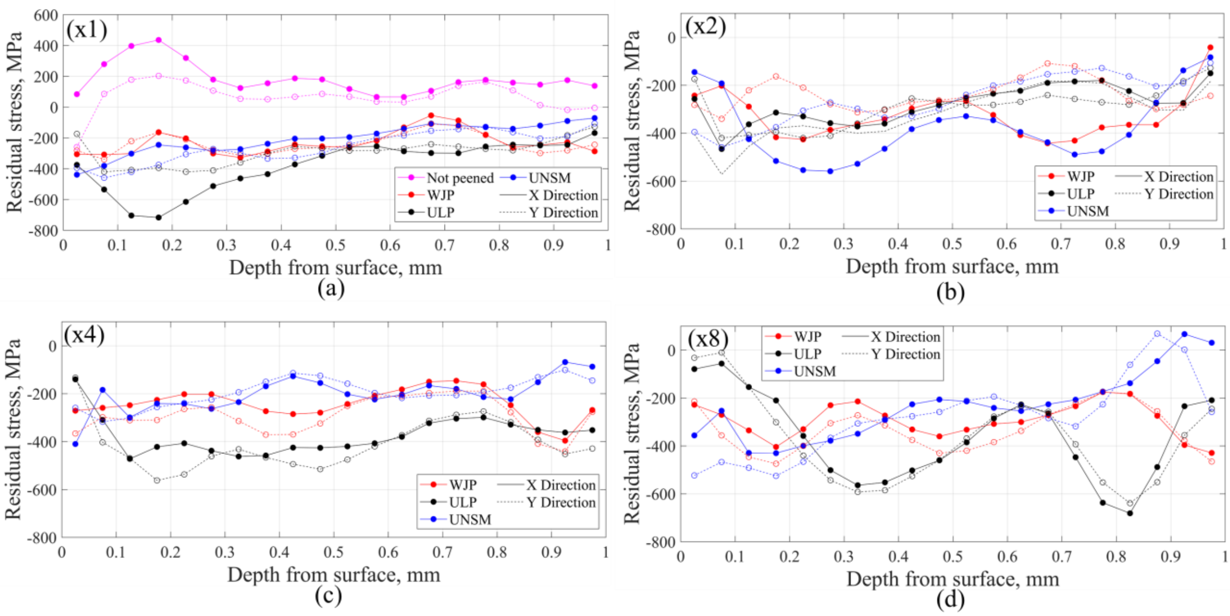

Fig. 4. The hole drilling depth-profiling residual stress results. (a) single peening results, (b) 2-times peening results, (c) 4-times peening results, (d) 8-times peening results.

3.2. Microstructure

The cross-sectional microstructures of 1-time peened specimen is revealed by EBSD as shown in Fig. 5. The kernel average misorientation (KAM) map shows that the UNSM peening method produce the most significant plastic deformation to the depth of about 300 μm. The plastic deformation depth caused by the WJP peening method is only 20~30 μm, which is the smallest among the three peening methods. The depth of the affected layer by ULP is about 200 μm. The image quality (IQ) map shows the dislocation after peening. The relatively high degree of dislocation is observed near the surface. The inverse pole figure (IPF) map reveals the crystal size of the specimen. After UNSM peening, the grain size near the surface is much smaller and almost unidentifiable, and the degree of cold working is much greater than those of ULP and WJP.

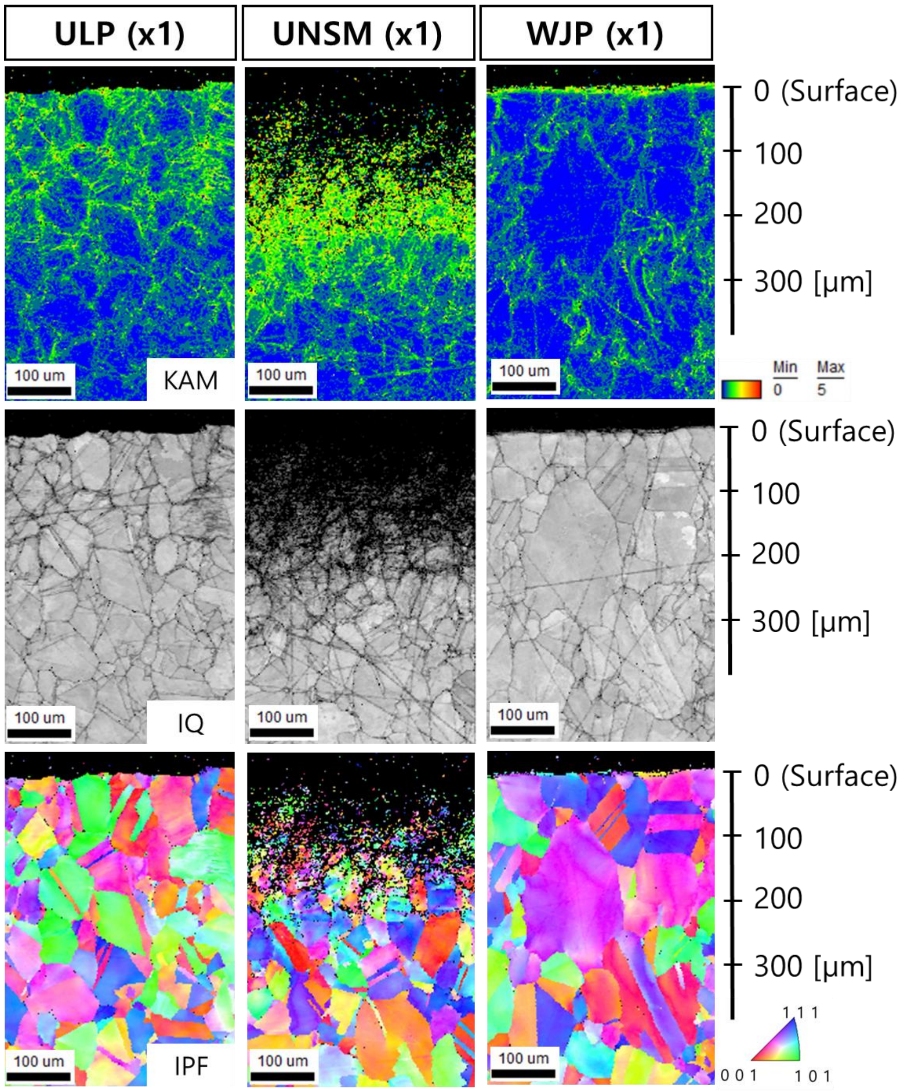

Fig.5. EBSD microstructure analysis result of one-time peened specimen.

The microstructural results for over-peened specimens are shown in Fig. 6. As the times of ULP increase, the depth of the microstructurally affected layer also seem to increase, while UNSM and WJP do not change significantly. Results of UNSM and ULP specimens show that the number of dislocation, KAM level, and the number of small-sized grains increase near the surface.

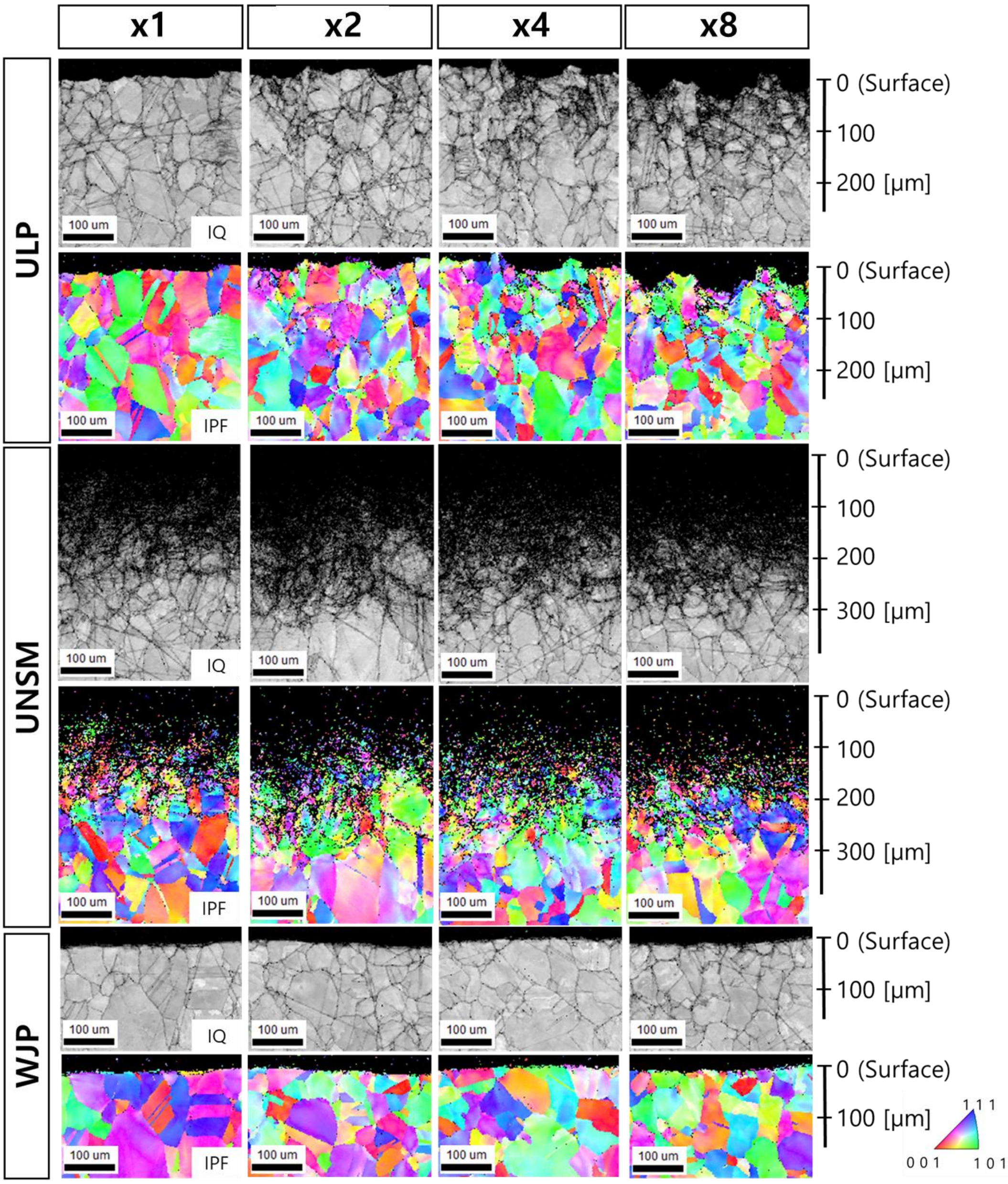

Fig.6. EBSD microstructure analysis result of the over peened specimen.

4. Conclusion

Experimental work was conducted to evaluate the effects of WJP, ULP and UNSM peening on the microstructures and residual stresses of Alloy 600. The following conclusions were drawn based on the results obtained:

- WJP, ULP, and UNSM can generate compressive residual stresses at least to a depth of 1mm on Alloy 600.
- The order of XRD-based compressive stress values generated by different peening methods on Alloy 600 surface is UNSM > WJP > ULP. However, the depth profiles measured by the hole drilling method did not clearly show this trend.
- With the increase in ULP and WJP peening times, the compressive stress value generated on the surface after peening decreases slightly, but UNSM specimen maintains the initial stress level even after over-peening or increases slightly.
- UNSM produce the most significant impact on the microstructure, showing a heavily plastically deformed layer reaching a depth of ~300 μm. Based on KAM map results, ULP shows the affected layer with the depth of ~200 μm, and WJP shows only 20~30 μm of the affected layer.
- As the times of ULP increase, the depth of the microstructurally affected layer also seem to increase, while the depths of affected layers for

UNSM and WJP specimens do not change significantly. The number of dislocations and small-size crystals in the regions near the surface of UNSM and ULP specimens increased significantly.

Acknowledgement

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