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Effect of pulse energy and density on laser peening of Inconel 600 without a protective coating

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1. Introduction

A laser peening process without a surface coating was first developed by Toshiba for application to dissimilar metal welds in BMI nozzles and on J-welds, and on inlet and outlet nozzle inner surfaces of boiling water reactors.[5] According to Toshiba's test results, the induced compressive stress depth from the surface peened by a laser beam exceed 1mm, which is much deeper than that by the other peening methods mentioned above.[6,7] In this study, a laser peening process without protective coating on an Inconel 600 plate is being developed for application to a BMI (bottom mounted instrument) J-weld and nozzle inner wall in a PWR reactor vessel to prevent PWSCC occurring in weld areas during operating nuclear power plants. To obtain the optimum peening conditions, laser peening was performed in water at different peening parameters to obtain the maximum compressive residual stress and depth on the Alloy 600 plate.

2. Methods and Results

2.1 Experimental methods

An Alloy 600 plate having a dimension of 750x500x10t mm^3 was used as a specimen. The specimen was heat treated at 900°C for 2 hrs followed by air cooling before laser peening. An Nd:YAG laser generator, Quantel Laser, Model CFR 400, with a maximum power of 200 mJ/pulse and a wavelength of 532 μm was used. Its maximum reputation rate and laser pulse width are 20 Hz and 8 ns, respectively. The nominal focal length of the focusing lens used in this system was 150 mm. The laser peening conditions used in this study are summarized in Table 1. An area peened by a laser beam at a certain peening process condition was 15x15 mm^2. After laser peening, the residual stress profiles from the specimen surface and the laser peened surfaces were measured and observed using a hole drilling method and SEM, respectively.

2.2 Results and discussion

Fig. 1 shows the appearance of a laser peened specimen and a drawing of the sequence of laser peening for each laser peened area. The size of each peened area was 15x15 mm^2. The residual stress for each peened area

Table 1. Laser peening conditions used in this study

Laser energy (mJ/pulse)	Beam size (Φmm)	Pulse density (pulse/mm^2)	Coverage
60	0.4	49	6.15
		70	8.79
		100	12.6
80	0.4	49	6.15
		70	8.79
		100	12.6
100	0.4	20	2.51
		49	6.15
		70	8.79

was measured using an automatic hole-drilling system, RESTAN MTS3000 made by SINT Technology.

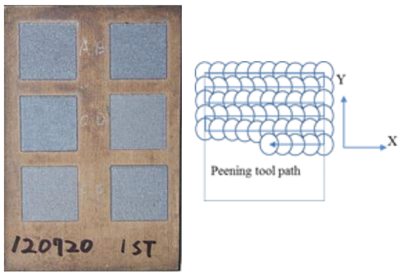
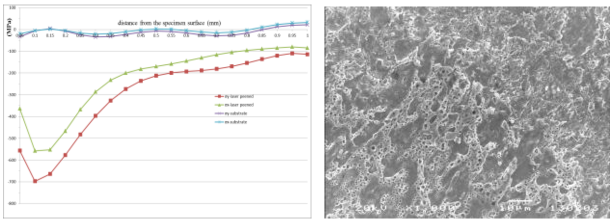


Fig. 1 Appearance of laser peened areas having a size of 15x15 mm^2 at different laser beam powers and the peening tool path.

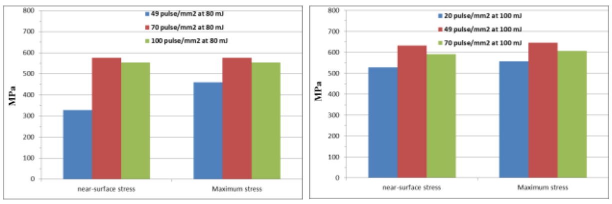
Fig. 2(a) shows an example of a measured residual stress profile from the specimen surfaces peened by a laser beam and unpeened. The specimen was peened at a laser energy of 80 mJ, a beam diameter of 0.4 mm, and a pulse density of 70 pulse/mm^2. As shown in this figure, the compressive residual stress and its depth from that surface induced by laser peening on the Inconel 600 specimen were significantly high and more than 1 mm, respectively, compared with those of the unpeened substrate. After laser peening, the peened surface was observed using SEM, and the results in Fig. 2(b) show that some melting of the specimen surface occurred during the laser peening process. In addition, owing to the pressure exerted on the surface by the plasma created from the irradiation of the laser beam on the specimen, there are signs of a molten metal flow (or splash). This observation indicates that during laser peening without a protective coating, the thermal effect of the laser beam is known to be exerted on the specimen surface, which may result in thermal relaxation of the compressive stress induced by laser peening. However, there is no way to avoid this thermal relaxation without a protective surface coating on the specimen surface. Even without a surface coating, the magnitudes of the compressive stress and its depth are high enough to prevent stress corrosion cracking.



(a) (b)

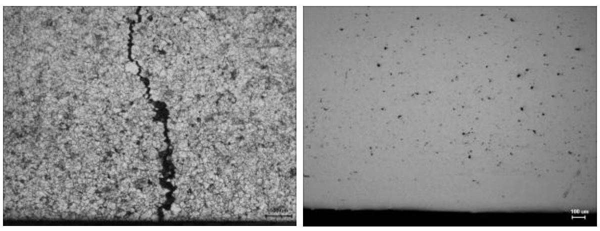
Fig. 2 (a) Stress profiles measured from the specimen surfaces laser-peened and unpeened, and (b) the morphology of the laser-peened surface observed by SEM

In Fig. 3, the experimental results are summarized for all the peening process conditions in this study. As seen in these figures, the highest magnitude of the maximum compressive residual stress was obtained under the peening conditions used in this study at a laser pulse energy of 100 mJ, and a pulse density of 49 pulse/mm^2. Under this condition, the magnitudes of the maximum compressive through thickness and near-surface residual stresses were measured to be 645 MPa and 632 MPa, respectively, using a hole-drilling method.



(a) (b)

Fig. 3. Diagrams showing the magnitudes of maximum compressive residual stresses near the surface and in the through thickness obtained under the laser peening process conditions used in this study.



(a) (b)

Fig. 4. Optical micrographs showing cross-section morphology of specimens after stress corrosion cracking tests. (a) Un-peened specimen and (b) laser-peened specimen.

Fig. 4 shows the OM microstructures of the cross-sectioned surfaces of the stress corrosion cracking test specimens. As shown in Fig. 4(a), stress corrosion cracking occurred in the un-treated specimen in about 2 days after its immersion into the test solution. The crack propagated along grain boundaries, which is a typical cracking mode occurring in Inconel 600 in operating conditions of nuclear power plants. However, no cracking was observed from the laser-peened specimen, as shown in Fig. 4(b) even after its immersion in the test solution for 2 weeks.

3. Conclusions

From a study on laser peening without a protective surface coating, the effect of its process has been proved to be high enough to prevent Inconel 600 material from stress corrosion cracking. The effect of laser peening on susceptibility to stress corrosion cracking of Inconel 600 was confirmed by stress corrosion cracking tests; no stress corrosion cracking was occurred in a laser-peened specimen, while an un-peened specimen failed by cracking in a very short period of testing time.

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