Residual stress measurement on air laser peened Inconel 690 using the contour method for chlorine-induced stress corrosion cracking (CISCC) mitigation

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1. Introduction

Several measures have been sought to mitigate Chloride Induced stress corrosion cracking (CISCC), which is a recently developed standing crack at the welds of spent nuclear fuel canister. The three main causes of SCC are as follows: residual stress, corrosion environment, types and conditions of metal materials. Residual stresses among these may occur in material processing such as welding and joining, and have a significant impact on robustness depending on external load conditions.

In this study, laser peening for reducing residual stress was applied as a metal surface improvement technology due to its excellent applicability and low adverse effect. In order to quantitatively analyze the removal of residual stress, the residual stress distribution analysis of the cross-sectional surface, which is the vertical direction of the metal specimen that has been peened, was conducted using contour method (CM) [1].

2. Methods and Results

The test material used in laser peeling was used in the Inconel 690. In this experiment, the air laser peening (ALP) technology was applied, which generates strong shock waves on the surface using high energy laser pulses.

As shown in Figure 1, the metal surface was heated to a high temperature, after then vaporized and ionized to form plasma. The generated shock waves were propagated to the metal through the surface layer, causing plastic deformation in a very short time and compression stress was loaded throughout the surface layer. The conditions of the beam irradiated on the sample surface are as follows: spot size 3^{-10} mm, radiated illumination 1^{-10} GW/cm2, pulse duration range 5^{-25} ns, peak power 109 W [2].

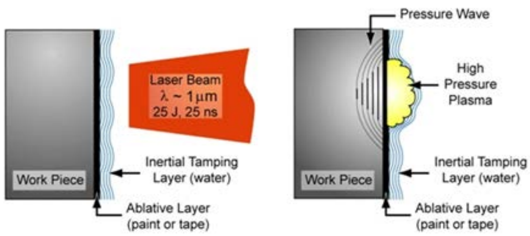

Figure 1. The mechanism of laser peening device [2]

CM technique that can provide a 2D residual stress map that acts on a plane or surface of interest using Bueckner's elastic superposition principle. The basic analysis stage consists of sample cutting, surface measurement, and finally data analysis (FE modeling) through finite element analysis methods. CM measuring equipment was used with the help of the Korea Atomic Energy Research Institute(KAERI).

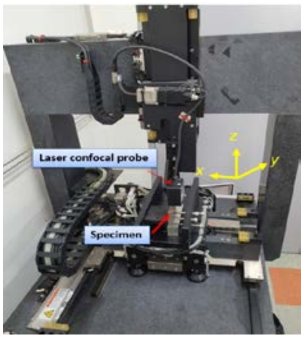

Figure 2. CM measuring equipment by KAERI

Specifically, the central part of the metal specimen is carefully cut within the yield strength using wire electric discharge machine(WEDM). The actual residual stress is analyzed by interpreting the control measurement results of the cut surface with the elastic coefficient of the metal.

The WEDM metal cutting technique is a non-contact technique using electrically charged thin mobile wires. All the cutting processes, which include ionizing and cutting materials with electrical energy, can be carried out in water where the temperature remains constant, minimizing plastic deformation by temperature.

In this experiment, an 100 μm diameter wire was used to cut the Inconel 690 in the direction perpendicular to the weld line (Figure 3).

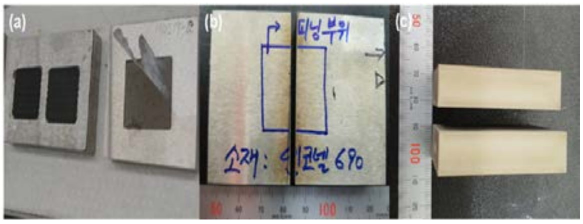

Figure 3. a) Laser peening, b) WEDM cutting, c) A fair of cut surface

The height difference of the cutting surface, which was perpendicular to the direction of the peening, was measured, and Figure 4 shows the distribution of raw data of the mean values of both cut surfaces with contour plot.

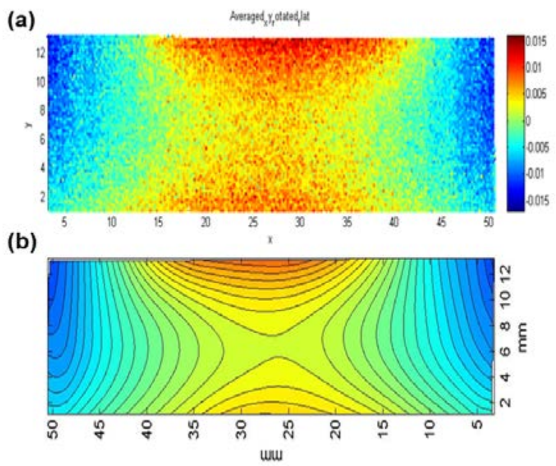

Figure 4. Contour raw data a) averaged point b) smoothed contour

The finite element analysis was performed by using the commercial program ABAQUS, and the material value of the test specimen was applied equally with the young's modulus (elastic coefficient, E=210 GPa) and the poisson's ratio (υ=0.27). After the 3D FE Model Meshing, the residual stress distribution was calculated using the analysis of elastic isotropic material properties.

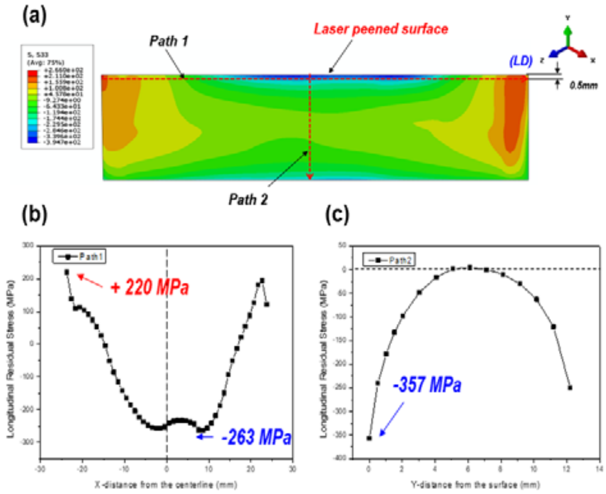

Figure 5. a) Longitudinal residual stress , b) Path 1, c) Path 2

In Figure 5, Path A shows the residual stress in the lateral direction at a location of 0.5 mm above the cutting plane. The negative sign (blue area) means that the compression stress was applied to the peening effect of the metal surface, and the positive sign means the opposite of the tensile residual stress as the part of BKG has not been processed with peening as it gets closer to both ends. In Figure 5 (b), the distribution of residual stress was shown with the vertical direction below the middle part of the specimen in the vertical depth direction. The compression stress of up to 357 MPa on the surface due to the peening effect was observed, and this effect gradually reduced along the depth direction.

3. Conclusions

In this study, Laser peening technique was used to mitigate residual stress, which is the cause of CISCC, and this was confirmed through CM analysis for the Inconel 690 sample. The high residual stress was expected to work in the HAZ (heat affected zone), which was welded in the actual dry storage canister. The results of CM analysis show that the application of the peening technique can be predicted to relieve tensile stress. Hereafter, it is expected that this results will be used as a basic reference information to provide a more reliable residual stress assessment by comparing the results of XRD and Hole Drilling measurements.

REFERENCES

[1] Prime M.B, 'Cross-sectional mapping of residual stresses by measuring the surface contour after a cut', 2001.
[2] KHNP, Planning report on the application of surface stress improvement technique, Jul, 2019.