Development of Portable Ultrasonic Nanocrystal Surface Modification (UNSM) Device for Improving Service Life and Reliability of Welded Joints

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1. Introduction

Welding is very useful technique to join different part and has been used in various industrial application such as in wind turbines, ship, building, etc. The major problem in welded structure is the tensile residual stresses that produced during welding process due to temperature gradient. Heat affected zone (HAZ) where the large tensile residual stress act as accelerant to fatigue crack initiation and susceptible to failure due to stress corrosion cracking (SCC) which shorten the service life of the parts [1].

One of surface treatment technique can be used to improve service life and reliability of welded structure is UNSM (Ultrasonic nanocrystal Surface Modification). UNSM was reported showing a significant mitigation of corrosion and stress corrosion cracking and improvement of fatigue strength for austenite stainless steel, nickel alloy and their dissimilar welded joint for nuclear power plant application. The compressive residual stress and gradient nano or nano twin structure which produced by UNSM treatment are main contributing factor for these improvements.

To simulate those benefits for in-situ application, hence the new system of UNSM was developed. This new system enables the portability of the UNSM which can be used easily for repairs or maintenance of the welded joint

2. Brief Summary of Ultrasonic Nanocrystal Surface Modification (UNSM) Technique

UNSM is one of surface modification technique that utilize static and dynamic load with assistance of an ultrasonic vibration energy to strike the surface with contact stress up to 30 GPa in 10 million strikes per cm^2 or 2.4 million strikes per minute. In UNSM process, a piezoelectric ultrasonic transducer, which serves to amplify the waves traveling through an acoustic booster, was used as shown in Fig 1(a). Tungsten carbide (WC) ball is used to strike the surface during UNSM process. A simplified scheme of UNSM can be seen in Fig 1(b) [2].

During UNSM treatment, Severe Plastic Deformation (SPD) is induced on the surface which modifies the microstructure, affects mechanical properties and induces a high compressive residual stress [2]. Those benefits of UNSM improve the fatigue strength of treated material. It was reported that UNSM treatment mitigate the crack initiation and crack growth 2.6 times and increase the fatigue strength by 38% compared to untreated one as shown in Fig. 2 [3]. As for SCC, Fig.3 shows that UNSM is capable to improve the resistance by mitigating crack initiation and growth by more than 200% in comparison to untreated one [4]. Other effects of UNSM treatment can be seen in Table 1.

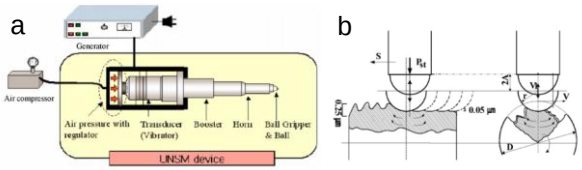

Fig. 1 UNSM Set-up (a) and process schematic (b)

Table 1 Effect of UNSM

Effect of UNSM	Performance Improvement
Deep compressive residual stresses (Greater than 1000MPa into depths of more than 2000 *μm*)	1. LCF, HCF, VHCF Strength 2. Rolling Contact Fatigue Strength 3. Stress Corrosion Cracking Resistance 4. Friction Loss 5. Wear Rate 6. Corrosion Resistance 7. Corrosion Fatigue Strenght
Micro dimples surface and improved surface roughness (Dia. Of area 1-2 μm^2 Depth: sub-micron, nanoscale roughness)	
Increase harness(into depths of more than 1500 *μm*)	
Nanocrystal structure (Grain size of 50-200 nm into depths of 200 *μm*)	

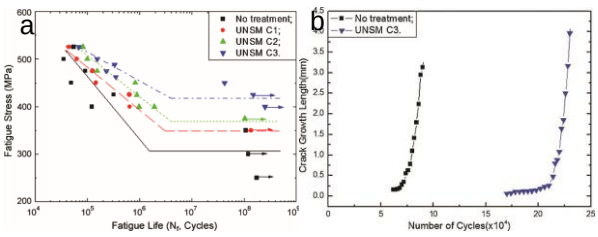

Fig. 2 Effect of UNSM on improvement of fatigue strength (a) and Surface crack initiation and growth delay (b) in SM45C

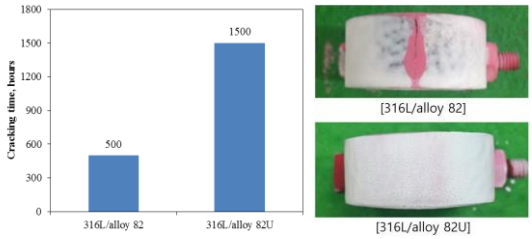

Fig. 3 Effect of UNSM on Stress Corrosion Cracks in SUS316 and Alloy 82 Welds

3. Portable Ultrasonic Nanocrystal Surface Modification (UNSM)

UNSM system has been installed usually in machine tools with CNC controller. This kind of setup is difficult to be used to treat the welded join especially in area which the treatment that only can be performed manually by an operator. Due to that reason, with the portability as the focus, the portable UNSM device was developed. Portable UNSM was designed to simulate the actual UNSM system set-up in terms working principle and offered effects.

Table 2 Ultrasonic Generator Specification

Frequency (kHz)	40	27
Output Power (Watts)	~1800	
Line Voltage	190-235V 50/60Hz, 1Phase	
Weight (kg)	~2.5	~5

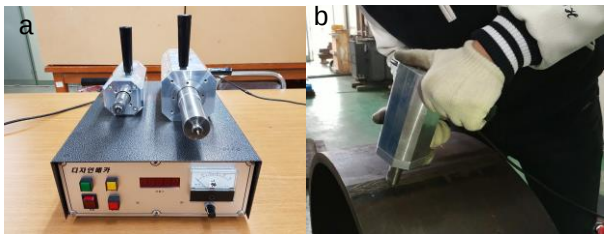

Fig.4 40kHz, 27kHz Portable UNSM Equipment(a), UNSM treatment of tube with 40 kHz Equipment(b)

The set-up of portable UNSM is showed by Fig. 4. The set-up consists of ultrasonic generator and the portable UNSM device unit. The ultrasonic generator and the piezoelectric transducer used in the portable device are same as conventional UNSM system. The specification of the generator is listed in Table 2.

In the development, the initial experiment was performed to assess the influence of portable UNSM application. The experiment was performed by treating the specimens of HAZ of SUS316L which welded with Alloy 52. The evaluation was done by measuring the residual stress using X-ray diffraction (XRD) method and surface roughness using surface profiler. It was found that the tensional residual stress of untreated specimen (+295 MPa) was converted to compressive residual stress using both 40kHz UNSM unit (-502MPa) and 27 kHz UNSM unit (-674 MPa) as shown in Fig. 5(a). Fig 5(b) shows the reduced surface roughness after treated using both (40kHz & 27kHz) UNSM unit compared to untreated one in terms arithmetical average surface roughness (Ra) and mean values of ten peaks of surface roughness (Rz). These initial results are not enough to conclude that portable UNSM device has same effect as the conventional UNSM. Therefore, rigorous validating test is still ongoing.

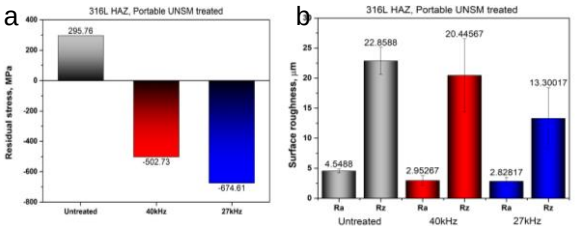

Fig. 5 Comparison of surface residual stress (a) and surface roughness(b) of untreated and Portable UNSM treated SUS316L HAZ

4. Concluding Remark

A Portable UNSM device was developed to be used as post-welding treatment of welded joint. The initial evaluation showed that portable UNSM is capable to change tensional residual stress into compressive residual stress and improve the surface finish and may improve the fatigue strength and SCC resistance of welded joint. This portable UNSM system which could be operated manually by one operator and adapted to welding robot or manipulating system is expected to induce a proper amount of compressive residual stress at any kind of repair welding or maintenance job in aircraft, wind turbine, nuclear power plant, etc.

References

[1] Y. Kim, W. Kim, and J. Kim, Influence of Ultrasonic Nanocrystal Surface Modification on the Corrosion and Stress Corrosion Cracking Behavior of Low Carbon Steel (ASTM A139 Welded Joint in the Simulated District Heating Environment, *Corrosion*, 9312 (2018) 112–122.

[2] A. Amanov, I. S. Cho, Y. S. Pyoun, C. S. Lee, I. G. Park, Micro-dimpled surface by ultrasonic nanocrystal surface modification and its tribological effects, *Wear*, 286–287 (2012) 136–144.

[3] Y. S. Pyoun, I. H. Cho, C. M. Suh, J. Park, J. Rogers, R. Kayumov, R. Murakami, Application of UNSM (Ultrasonic Nanocrystal Surface Modification) Technology for Prolonging the Service life of AISI 1045 Shear Pin in the Flange Yoke Assembly of Stainless Hot Rolling Mill, *Conf Proc 2011: ICSP-11 South Bend*, IN USA, (2011) 171-175.

[4] Y.S.Pyun, A. Amanov, V.K. Vasudevan, S. Mannava, Y. S. Choi, Y. S. Kim, An alternative Surface Stress Improvement Technology for Material Reliability Program-335 (rev.3),PVP 2019-9330 *& Piping Conference*,ASME2019