COMPARISON OF PEENING TECHNIQUES ON 304 AUSTENITIC STAINLESS STEEL

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ABSTRACT

This paper compares a range of peening techniques applied to 8 mm thick 304 austenitic stainless steel test samples. As new peening techniques become established, a range of peening techniques have become available for the engineer. This paper aims to compare two relatively new techniques, laser shock peening (LSP) and ultrasonic impact treatment (UIT), against more conventional shot peening (SP). This work has been carried out in context of mitigation against environmentally assisted cracking, where surface finish, levels of plastic work in addition to depth and magnitude of compressive residual stress are relevant. Residual strain depth profiles have been measured using neutron diffraction and are compared in relation to intensity and depth of compressive residual stress introduced into a 304 austenitic stainless steel sample. Initial results show significant differences in the depth of compressive residual strain for each peening approach.

KEY WORDS

Shot peening, laser shock peening, ultrasonic impact treatment, residual stress, Neutron diffraction.

INTRODUCTION

Peening is broadly used to reduce or eliminate fatigue or stress corrosion cracking (SCC) within industry, with many new techniques being trialled to be competitive with currently used techniques. They are compared in respect to a techniques cost, ease of use, surface finish, levels of plastic work, compressive residual stress intensity and depth of compressive residual stress introduced into a material. Most common peening techniques currently used in industry are shot peening and laser shock peening, both with different advantages and disadvantages.

Shot peening is most commonly used due to its low cost, however; laser peening overshadows SP with a superior surface finish, intensity of surface compressive residual stress and depth of compressive residual stress. There are several new peening techniques, which may also be competitive with currently used techniques. At this stage in the progress of peening techniques available, it seems a comparison of current and new techniques should be made.
One peening technique which has been explored, is ultrasonic impact treatment [1,2]; however there are sparse results on 304 austenitic stainless steel, which is a common engineering stainless steel, used in industry. Ultrasonic impact peening can be seen as a direct impact peening treatment as is shot peening with the difference being that UIT is a thin probe used at ultrasonic frequency to introduce a compressive residual stress into the sample whilst rastering across the surface. There have been a number of research avenues taken in relation to peening and residual stress analysis [3][4], however there seems to be a lack of the *effect* of peening with

respect to *new* techniques compared against currently used ones, and of the effect of these techniques on stainless steels commonly used throughout industrial use. This paper will investigate the residual strain through thickness profiles, measured using neutron diffraction, on 8 mm thick 304 stainless steel test coupons peened with SP, LSP and UIT techniques.

SPECIMEN MANUFACTURE

50 x 50 x 8 mm 304 austenitic stainless steel test samples were cut from an 8 mm thick plate. After cutting, the test samples were stress relieved at 1050°C for 30 minutes in an argon atmosphere, followed by a gas fan quench to prevent sensitisation. SP and LSP were carried out by the Metal Improvement Company. SP was carried out over one face of the test coupon using a peening intensity of 0.010 to 0.0140" A and a 200% coverage. LSP was carried out over the majority of the 50 x 50 mm face leaving a 5 mm border round the edge of the specimen (see figure 1). LSP was carried out using a spot size of 3 x 3 mm, a fluence of 180 J/cm^2 , and a pulse width of 18 ns. UIT was carried out by using a probe tip which impacts the surface at an ultrasonic speed and rasters across the surface at an amplitude of 17, a tool pressure of 22 kg and a raster speed of 150 mm/min with a pin diameter and length 6.3 mm and 35 mm respectively.
After peening each sample was cut into quarters using electro discharge machining, producing four 25x25x8 mm specimens for each condition. This was to provide extra specimens for other measurement techniques at a later date.

NEUTRON DIFFRACTION MEASUREMENTS

Neutron diffraction measurements were carried out on peened coupons using the SALSA diffractometer at ILL in Grenoble, France. The diffraction gauge volume was 20 x 1.2 x 1.2 mm. An extended gauge volume was possible since the 20 mm dimension was parallel to the samples surface, where the stress state was assumed to be constant; this also minimised the diffraction measurement time. Measurements were made using the (311) crystal reflection, with the wavelength of the neutrons being approximately 1.655 Å, this resulted in a diffraction angle (or values of 2θ) that was approximately 91^o.

Measurements of in-plane residual strain were made at the centre of each specimen along a through thickness profile. In the case of the UIT sample, measurements were made of the in plane residual strain component, perpendicular to the probe dragging direction. Measurements were made through the sample surface in step sizes of 0.05 mm for the SP specimen and 0.1 mm fro the LSP and UIT specimen, allowing the near surface profile to be measured in detail. Surface corrections were carried out to avoid measurement of pseudo strains which occur when the gauge volume was partially immersed at the near surface positions. The surface of each sample was accurately determined by monitoring of the integrated peak intensity as the gauge volume was scanned from outside into the sample using step sizes of 0.1 mm or less. A single d_0 value was determined by taking an average of measurements through the thickness of an unpeened specimen. Elastic strains were calculated using this d_0 by the following relation:

$$\varepsilon_{el} = \frac{d - d_0}{d_0} \qquad (1)$$

where ε_{el} is the elastic residual strain, and where d and d_0 are respectively the measured d-spacing and the stress free reference d-spacing for the same set of lattice planes (in this case 311). While a 1 mm measurement gauge volume is relatively large compared to the stress gradient

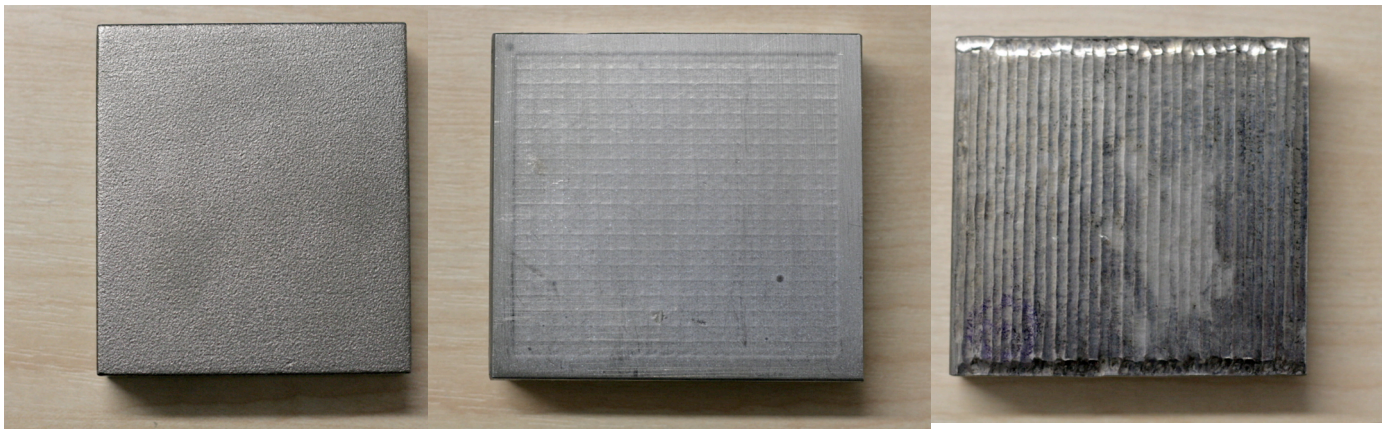
being measured, the near surface spatial resolution is much better than this since measurements are made with partial immersion of the measurement gauge volume. Consequently, measurements made closest to the surface are made with the highest spatial resolution with measurement volume smearing effects being greatest when the measurement gauge volume is fully immersed in the sample.

RESULTS AND DISCUSSION

Figure 2 shows the through thickness (elastic) residual strain profile for each specimen. The figure shows a distinct residual strain depth profile for each peening technique. SP has been used here as a benchmark to gauge the other treatments against. In the near surface region, the peak compressive residual strain is similar for each technique with the UIT showing the highest level of compression at ~2000 με followed by the LSP and SP samples, both with compressive values of ~1500 με. Assuming plane stress conditions and an equibiaxial stress state for each sample this is equivalent to approximately -410 MPa for -1500 με and -550 MPa for -2000 με of residual strain (a Young's Modulus and Poisson's ratio value of 195 GPa and 0.3, respectively). However, it should be noted here that the stress state in the UIT sample is not biaxial, with the residual strain component parallel to the probe dragging direction being significantly lower than the residual strain component perpendicular to the probe dragging direction [5].

It has been widely reported that that SP creates approximately 0.2 to 0.4 mm depth of compressive residual stress into a sample. The results in figure 2 show 0.2 mm depth of compressive residual strain for the SP sample. The LSP and UIT samples both have much larger depths of compressive residual strain surface. The UIT sample has a compressive layer up to ~1.5 mm depth while the LSP sample has a compressive layer up to 3 mm. Consequently both the LSP and UIT samples have a lower stress gradient between maximum compressive residual strain and zero residual strain. The LSP has a much shalower decline in intensity through profile of the sample when compared with the UIT sample. This could be due to a number of factors amongst them being the form of peening itself, shock wave versus direct impact (LSP and UIT respectively). There is a concern about the surface finish of the UIT peened sample as seen in figure 1, The photographs in figure 1 show that the UIT sample has been significantly roughened, with long furrows being deformed into the surface with the UIT probe. This could explain the anisotropy of the stress state observed by the authors [5]. In context of mitigation against corrosion cracking the condition of the surface is important as such cracking would be initiated from the surfaces imperfections. In contrast the surface condition of the SP and LSP samples are far smoother. However, it should be highlighted here that the samples have been provided as part of a preliminary study and further investigations are planned using a 'cross hatching' approach along with a high overlap of each probe raster to limit the anisotropy within the specimen and improve the surface condition.

Further work is also planned to investigate the near surface plastic work profiles between each peening approach as these are factors which are thought to affect the thermal stability of the compressive stress field [6]. In addition, excessive levels of redundant plastic work can also be seen as a form of damage, limiting the resistance of the material to fatigue or stress corrosion cracking. It is anticipated that such plastic work profiles will be determined from diffraction peak broadening or measurement of relative diffraction peak shifts as a measure of the levels of intergranular stress within each sample [7].



Shot Peened (SP)	Laser Peened (LSP)	Ultrasonic impact Peened (UIT)

Figure 1: Images of each peening technique

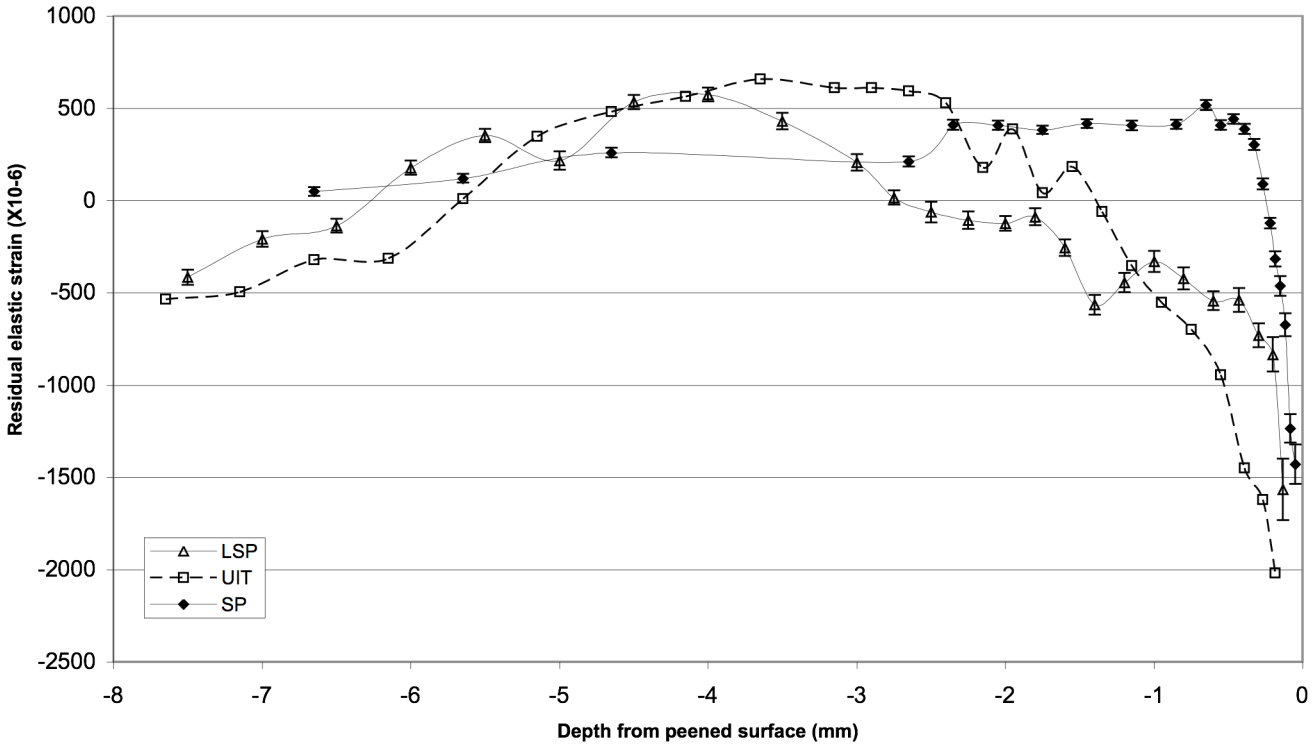


Figure 2: Residual με (microstrain) depth profile from neutron diffraction on SALSA at ILL

CONCLUSION AND IMPLICATIONS

This comparative study shows that a significant magnitude of compressive residual strain (and hence stress) has been introduced into the near surface region of 8 mm thick 304 austenitic stainless steel components. The depth of compression was least for the SP sample at ~0.2 mm and greatest for the LSP sample at 3 mm, the depth of compression for the UIT sample was ~1.5 mm. The magnitude of the peak compressive residual strain was highest for the UIT sample at ~-2000 με followed by the LSP and SP samples at ~-1500 με.

These results suggest that both UIT and LSP processes can provide significant improvements to the depth of compressive stress within 304 austenitic material. However, it is recognised that other factors such as surface finish and levels of redundant plastic work are important in applications for mitigation against environmentally assisted cracking. These factors will be investigated in more detail in future work.

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