Evaluation of spherical conditioned cut wire in comparison to cast steel shot peening media applied to Inconel 718

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Introduction and objectives

Shot peening is a well-established manufacturing process primarily used to enhance the fatigue life of critical components across a number of industries. In order to reduce process costs and remain competitive, industries are looking for alternative and enhanced shot peening media types to improve upon their current selection.

It has been suggested that spherical conditioned cut wire (SCCW) steel shot peening media may be a beneficial alternative to cast steel media. Previous studies have concluded that SCCW media demonstrates improved life and thus presents an opportunity to lower process costs due to the reduced frequency of media replacement required [1-3]. These benefits may be dependent on the target material systems used. In order to evaluate the impact of replacing cast steel with SCCW media for a target Ni-based alloy system, testing and characterisation were undertaken. Surface roughness, residual stress evaluation, material microstructure and fatigue life were all analysed as part of the study. In addition, media life (also referred to as media durability) testing was completed to determine if the SCCW media does indeed provide improved life compared to the cast steel media for this particular target material system.

Methodology

The target material selected for the study was a Ni-based alloy, Inconel 718 (IN718). Specimens were fabricated in two types; flat plates (for surface roughness, residual stress and microstructural analysis) and threaded axial specimens (for fatigue testing). The cast steel media selected for the study was ASR110 compliant to AMS2431/1 [4]. The SCCW media selected was AWCR14 compliant to AMS2431/3 [5], which was determined to be an equivalent SCCW alternative to ASR110 using AMS2430 [6].

The shot peening process for both media was performed with a peening intensity of 7A ± 0.5A µinches, a coverage level of 100% and with the same applied settings for media impingement angle, nozzle type and offset using a Progressive Surface computer controlled shot peening machine. For surface roughness analysis, pre- and post-peen R_a measurements were taken using a Taylor Hobson Stylus Profilometer, and post-peen S_a using a Bruker NPFlex machine. A Stresstech G3R X-ray diffraction (XRD) machine was used to measure all residual stress profiles, which were generated using an incremental electro-polishing technique to a depth of 240 µm. Microstructural analysis was performed using Electron Backscatter Diffraction (EBSD), which was used to assess grain misorientation and slip band presence. In order to identify any differences in fatigue life resulting from the use of the different media, strain-controlled fatigue testing (R=0, 0.5%/s strain ramps, 1 second maximum and minimum dwell times) was performed up to 10k cycles at a temperature of 400°C. Beyond 10k cycles, load-controlled testing was continued at 10Hz using the maximum and minimum stress values established at 5k cycles in strain-controlled mode.

To assess media life, media durability testing was performed using an Ervin tester. This machine propels a sample of media at a hardened plate a number of times (each occasion is defined as a 'cycle') via a centrifugal wheel, in order to assess media breakdown over time to provide a measure of durability. Testing was performed on two 100g samples of media per media type, and was interrupted at 500-cycle intervals to remove under-sized media and replace with an equivalent mass of new media. The steady state loss rate of the media was used to compare the

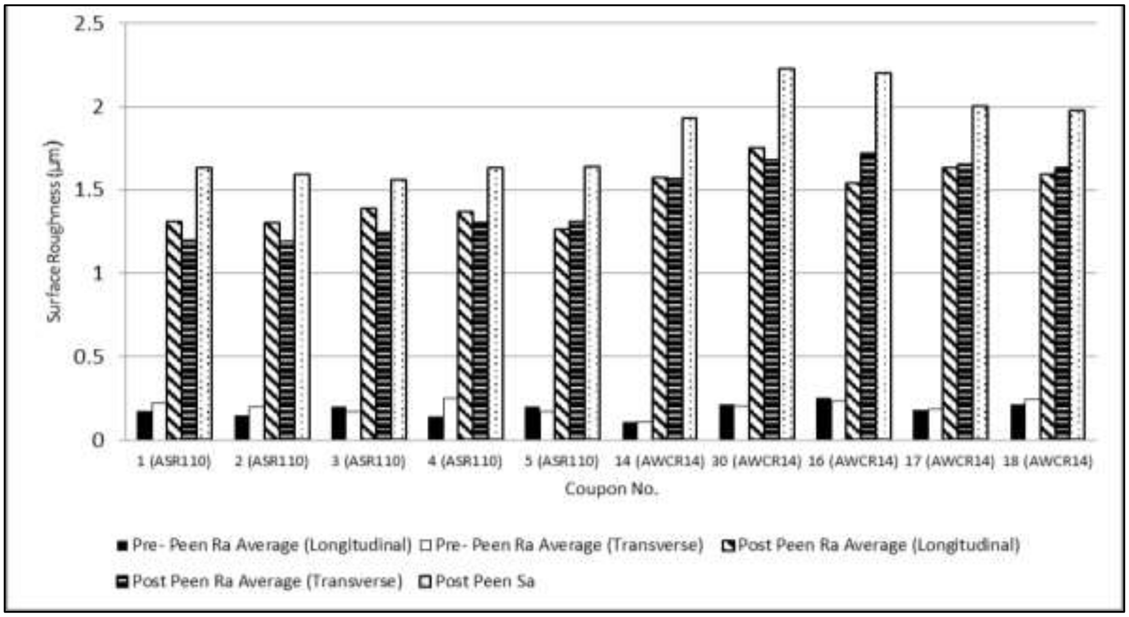

Figure 1 - Comparison of surface roughness results for IN718 specimens peened with ASR110 & AWCR14

Table 1 – Collated results of surface characteristics of peened sample surfaces and media characteristics for ASR110 and AWCR14 (NM – not measured, NA – not applicable)

	As Machined	ASR110	AWCR14
Av. Post Peen Longitudinal Ra (µm)	0.18	1.33	1.62
Av. Post Peen Transverse Ra (µm)	0.20	1.23	1.65
Av. Sa (µm)	NM	1.61	2.07
Av. hardness (HRC)	NM	42.0	54.4
Av. media particle size (mm)	NA	0.38	0.40
Media particle size standard deviation (µm)	NA	32.3	12.5
Av. media density (g/ml)	NA	7.68	7.79

relative durability of the different media types. In order to determine media characteristics, hardness testing was performed in accordance with requirements for new media in AMS2431/1 [4] and AMS2431/3 [5]. Particle size analysis was performed using a Morphologi G3 Particle Size Analysis Machine. Finally, media density analysis was also completed using a multi-pycnometer.

Results and analysis

The surface roughness results presented in Figure 1 and Table 1 show that peening using AWCR14 media produces higher (by 20-35%) average R_a and S_a values compared with peening using ASR110 media. AWCR14 surfaces also exhibit a greater standard deviation in S_a compared to cast media (0.14 µm vs. 0.03 µm).

Analysis of the circularity (where a perfect circle has a circularity value of 1) of the media was also completed for each type. It was found that the ASR110 media exhibited an average circularity value of 0.97 compared to 0.87 for the AWCR14. This reduced circularity of the AWCR14 media is consistent with the observed increase in surface roughness for these media. Media hardness assessment (Table 1) showed that the AWCR14 media also exhibited higher hardness compared to ASR110 (average 54.4HRC versus 42.0HRC). This may also contribute to the relative increase in roughness values for plates peened with AWCR14. The higher media hardness and lower circularity are most likely attributed to the conditioning manufacturing method of SCCW. Huyton (2014) suggested that the difference in component surface roughness results between cast steel and conditioned cut wire media is also attributable to the size distribution of the media within a type [7]. Particle size analysis (Table 1) showed that the ASR110 media diameter was smaller than that for the AWCR14 media, and that the standard deviation (size variation) was higher than that for AWCR14, which may result in a rougher surface according to Huyton's observations.

The XRD results presented in Figure 2 suggest that there are only slight differences in the compressive residual stresses induced by shot peening of each media type. Compared to ASR110, the AWCR14 media appears to promote marginally higher compressive residual stresses at the sample surface (-800 MPa versus -650 MPa), and overall slightly deeper penetration of compressive stresses (160 μm versus 130 μm).
Figure 3 shows an example of grain misorientation maps of the nearest 300 μm to the sample surface, colour coded according to misorientation angular range. The average misorientation angular ranges are quantified in Figure 4, showing that ASR110 and AWCR14 exhibit a similar proportion of highly misoriented (>7.5°) grains, but AWCR14 exhibits a greater proportion of moderately misoriented (1-7.5°) grains. The degree of misorientation in a surface can be related to the degree of cold work performed on the material [8], therefore suggesting that the material peened with AWCR14 media is the more heavily cold worked of the two.

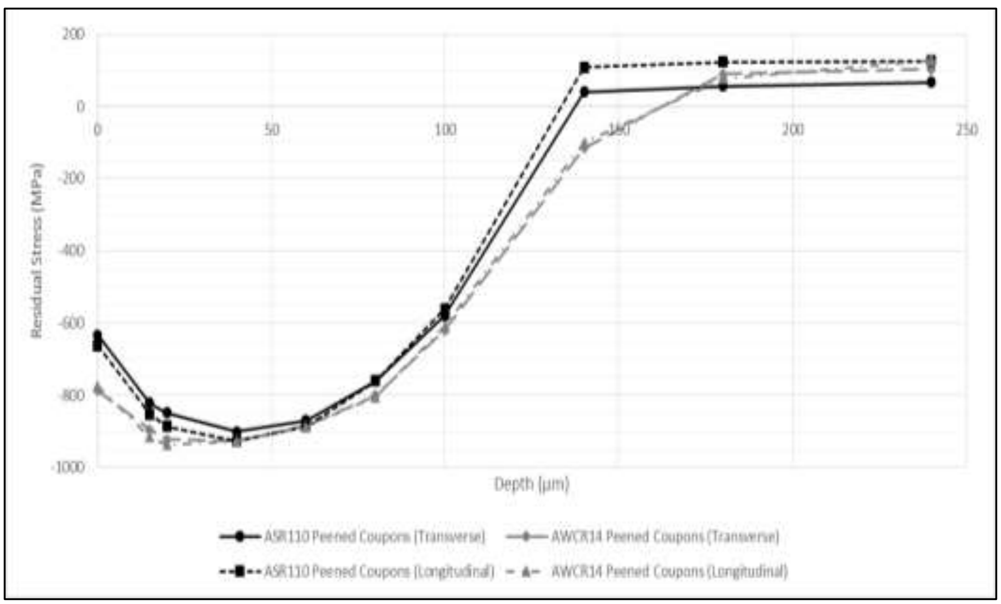

Figure 2 - Averaged residual stress profiles for IN718 Peened with ASR110 & AWCR14

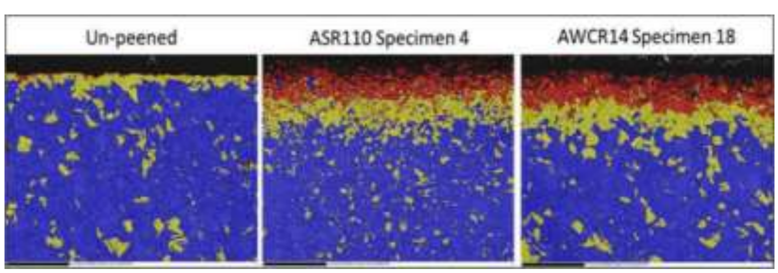

Figure 3 - Grain misorientation maps for un-peened and peened specimens

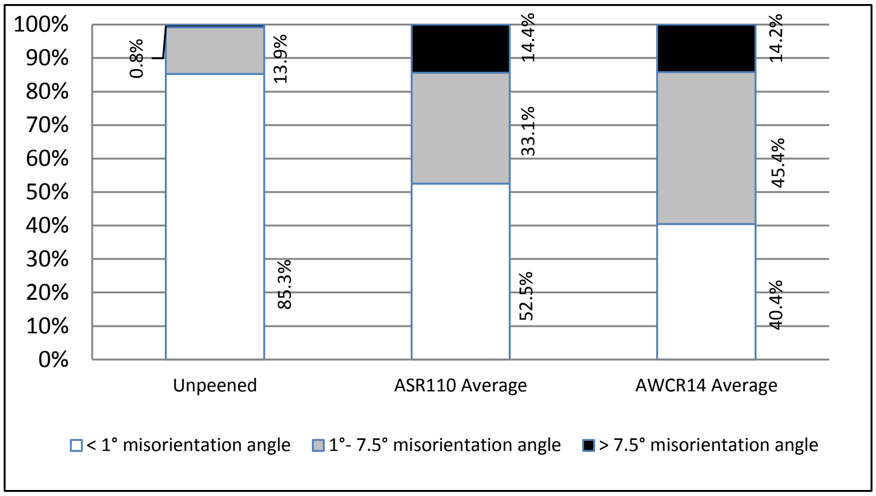

Figure 4 - Grain misorientation percentages for un-peened and peened specimens

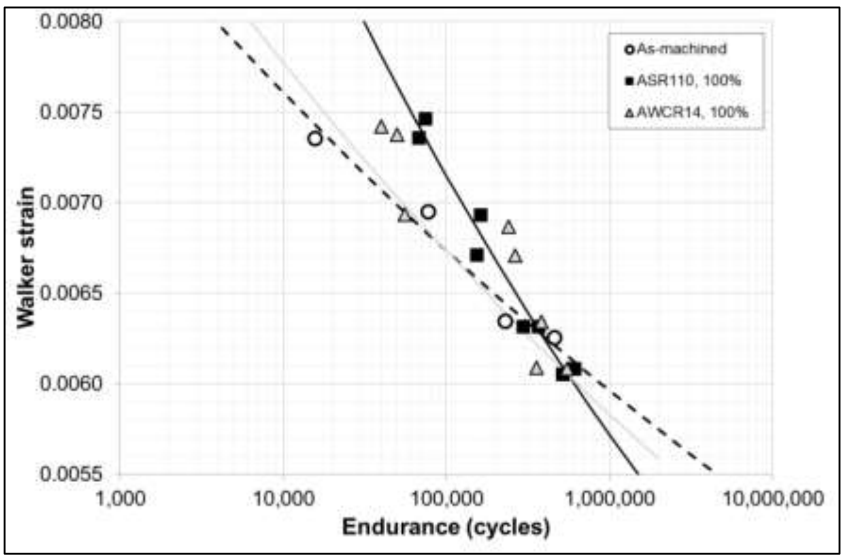

Figure 5 - Fatigue test results for un-peened and peened specimens

Fatigue results from test specimens peened with each media type are shown in Figure 5. At low strains (<0.65%) no clear difference was visible between the fatigue lives for the two media types. This group of peened specimens all initiated failure from sub-surface locations and so the similar lives demonstrate the similarity in near-surface residual stress profiles and bulk material characteristics for the two sets of specimens. At higher strains (>0.65%) the number of cycles to failure becomes more dependent on the condition of the surface. Peened specimens outperform as-machined specimens, but the differences between ASR110 and AWCR14 results are again minor. Further testing is required to more clearly define any potential differences in fatigue life induced by the media types.

Figure 6 considers mass loss of media subject to Ervin testing. Conventional Ervin test procedures quote the number of cycles for 100% of the original media load to be replaced (100g in this case). However, it was considered that using a measure of steady state loss rate (stabilised gradient of the mass loss curves), provides a more accurate representation of a continuous production process. As such, durability testing results (Figure 6) showed that ASR110 media exhibited lower loss rates than ACWR14 media in steady state conditions (indicated by the shallower gradient

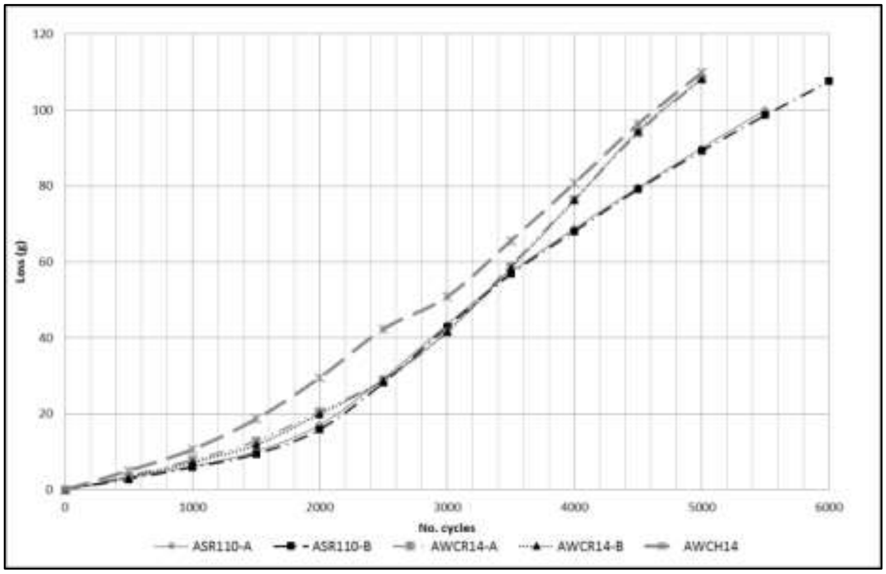

Figure 6 - Durability test results for ASR110, AWCR14 & AWCH14 media

beyond approximately 2,500 cycles in Figure 6), which contradicts findings of previous studies [1-3].

In order to understand this unexpected result, data from media hardness testing, media size analysis and media density measurement were considered (Table 1). The average hardness of both media types was found to be outside of the acceptable range for new regular hardness media (45.0 - 52.0 HRC) [4, 5]. The AWCR14 media (average hardness of 54.4 HRC) was found to be very close to the range for high hardness media (55.0 – 62.0 HRC) [9]. To understand the performance of higher hardness media a durability test on AWCH14 media was performed (see Figure 6) and was found to stabilise to a similar loss gradient to the AWCR14 data, suggesting that media hardness may be influential in durability characteristics. AWCR14 was measured to be approximately 1.4% denser than ASR110 (Table 1), but this difference appears small and does not translate into a significant difference in impact velocity required to achieve a target intensity if a simple kinetic energy calculation is performed. However, such calculations do not consider the fundamentally different processing routes by which these media were manufactured and levels of inherent cold work present in a cut wire media compared to cast media. Further assessment of media microstructure appears necessary.

Conclusions

It has been shown that in comparison to ASR110 media, the AWCR14 media appeared to display detrimental characteristics in terms of surface roughness and near-surface cold work, but these did not appear to adversely affect fatigue performance for the conditions tested. Both media resulted in increased fatigue life compared to the as machined condition in surface-initiating strain regimes. For the media tested, the AWCR14 media did not exhibit the anticipated improvement in durability compared to ASR110, which was reasoned in terms of differences in key media parameters (media hardness, density and size).

References

[1] Gillespie, R. (1993). Shot peening media - its effect on process consistency and resultant improvement in fatigue characteristics. International Conference for Shot Peening 5, (pp. 81-90). Cleveland, Ohio USA.
[2] Gillespie, R., & Gloerfeld, H. (1990). An investigation of durability and breakdown characteristics of shot peening media. International Conference for Shot Peening 4, (p. 27).
[3] Hatano, A., & Namiki, K. (1992). Application of hard shot peening to automotive transmission gears. Paper No. 920760. Society of Automotive Engineers.
[4] SAE AMS 2431/1 Rev E. (2010). Society of Automotive Engineers.

[5] SAE AMS 2430/3 Rev D. (2007). Society of Automotive Engineers.
[6] SAE AMS 2430 Rev T. (2015). Society of Automotive Engineers.
[7] Huyton, P. (2014, January). Peening Media Classification and Alternatives. Metal Finishing News (MFN) Vol.15 - January Issue. Metal Finishing News.
[8] Child, D.J., West, G.D. and Thomson, R.C., 2011. Assessment of surface hardening effects from shot peening on a Ni-based alloy using electron backscatter diffraction techniques. Acta Materialia, 59(12), pp.4825-4834.
[9] SAE AMS 2431/8 Rev B. (2007). Society of Automotive Engineers.