Comparison between vibratory peening and shot peening processes

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Introduction

Vibratory finishing is a surface treatment in which components are inserted in an oscillating bowl containing polishing media. The media flow around the component polishes its surface and decreases its roughness [1-3]. Shot peening (SP) is another surface treatment that involves projecting hard particles onto a components surface, at high velocity. These impacts induce surface compressive residual stresses which increase fatigue life. However, the process increases surface roughness, which have a detrimental effect on fatigue life. Vibratory finishing is often used after shot peening to improve the surface finish. Vibratory peening (VP) is a relatively new process that relies on the same principles as vibratory finishing for inducing compressive residual stresses like those induced by shot peening. The process combines the improved surface finish from vibratory finishing and compressive residual stresses induced by shot peening, which should deliver better fatigue lives than conventional methods. While the effects of shot peening on fatigue life have been extensively studied in the literature, very few authors studied the fatigue life improvement induced by vibratory peening [4, 5]. The process is relatively new and high technology industries, like aerospace, require sound investigations of the underlying fundamental mechanisms involved in the process before considering investing in more extensive studies that would eventually lead to the process acceptance.

Objectives

The objective of this project was to compare the shot peening and vibratory peening effects such as roughness, residual stress, and microstructure on AA7050-T7451 samples as well as their influences on fatigue life.

Methodology

Shot peening was performed on cylindrical fatigue samples with ceramic shot Z425 leading to Almen intensity of 8A and at 100% coverage. Shot peening was applied with an air pressure shot peening machine. The shot peening machine was manufactured by Canablast. The machine was custom designed to perform shot peening with cut wire, cast steel and ceramic media. Two different MagnaValve® and Nonferrous MagnaValve® mass flow valves supplied by EI Corporation Inc. were installed in order to control the mass flow for steel and ceramic shots, respectively. Shotmeter® provided by Progressive Technologies Company was used to measure the shot flow velocity. A six-axis Fanuc robot and a rotating table were installed inside the shot peening cabinet to control the movement of the nozzle. Shot peening was performed with a nozzle diameter of 12.2mm and stand-off distance of 300mm. The rotational speed of the rotatory table was 22rpm, the air pressure was 20psi and the mass flow was 10lb/min.

Vibratory peening was carried out at Vibra Finish Ltd. with their vibropeening machine. The machine was a tub type machine filled with 3mm, 4.5mm and 6mm hard steel balls. A frequency of 50Hz, an amplitude of 9mm, and a media mass of 1740lbs were required to reach an Almen intensity of around 8A and full coverage.
Surface roughness of as machined, shot peened and vibratory peened samples was measured using Mitutoyo SV-C4000 series surface measuring instrument which was equipped with 2-axis simultaneous control in the X- and Z-directions. Each axis had a maximum drive speed of 200mm/s.

Residual stress profiles after vibratory peening and shot peening were measured using the XRD method by Proto manufacturing company with “LXRD” machine. Residual stress measurements were performed using the multiple exposure technique as per SAE HS784. The instrument was aligned as per ASTM E915.

Fatigue testing was carried out with a MTS single-axis servo hydraulic test system. Two maximum stress σ_{max} values of 350MPa and 310MPa have been selected to compare the effect of shot peening and vibratory peening on fatigue lives in low cycle fatigue (LCF) and high cycle fatigue (HCF) regimes, respectively. All the fatigue tests were carried out with stress ratio R=0.1 and frequency of 20Hz at room temperature.

The fracture surfaces of the fatigue samples were examined using both Olympus optical microscope and a scanning electron microscopy (SEM) model JSM-7600 identify crack initiation sites.

Figure 1 Vibratory peening machine at VibraFinish.

Figure 2 Vibratory peening on Almen strips for saturation test.

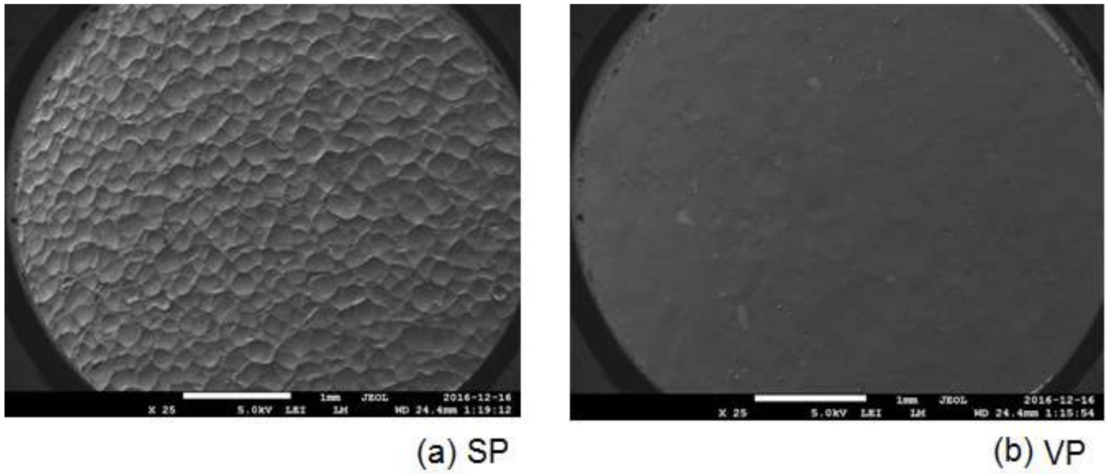


Figure 3 Surface of shot peened (a) and vibratory peened (b) samples taken by SEM.

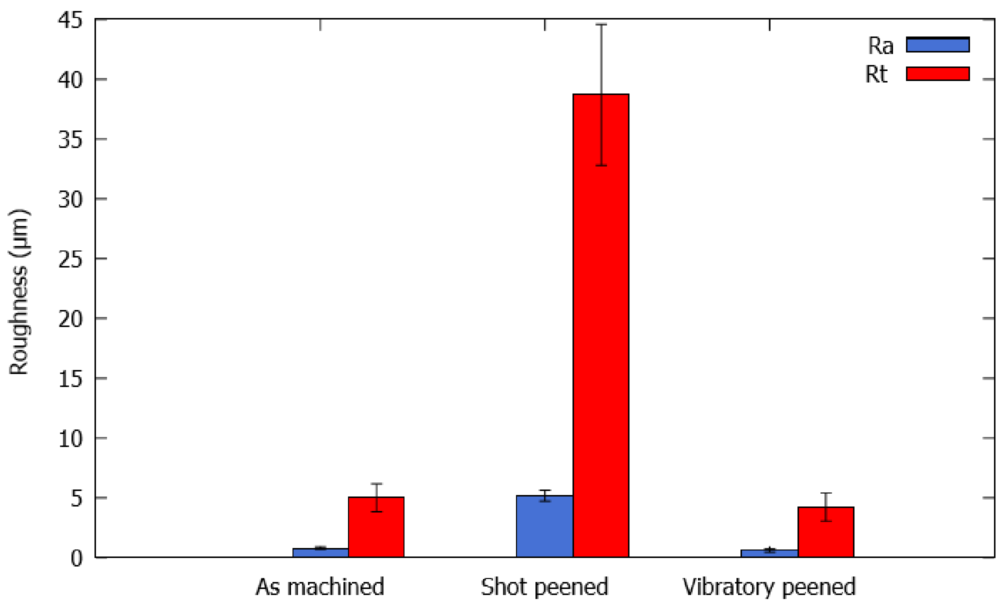


Figure 4 Surface roughness after shot peening and vibratory peening.

Results and analysis

Surface roughness

Figure 3 shows the visual aspects of the shot peened and vibratory peened surfaces take from SEM. Surface roughness were measured on 3 as machined (AM), 3 shot peened (SP) and 3 vibratory peened (VP) cylindrical samples. For each sample, 3 surface roughness profiles were extracted at different locations within the sample's reduced section. According to DIN EN ISO 4288: 1998 standard, a cut off length of 0.8mm and a total measured length of 4mm were selected for the AM and VP samples while a cut off length of 2.5mm and a total measured length of 12.5mm were selected for the SP samples. Figure 4 compares the arithmetic mean surface roughness **Ra** and largest peak to valley height **Rt** for the three cases. The figure shows that vibratory peening produced a much better surface condition, when compared to the shot peening process. When compared to as machined samples, VP decreased Ra by 25% and Rt by 16%, while SP increased **Ra** by 656% and **Rt** by 772%.

Residual stresses

Figure 5 compares the experimentally measured compressive residual stresses induced by shot peening and vibratory peening processes. The figure shows that, for an Almen intensity of 8.26A for shot peening and an Almen intensity of 8.72A for vibratory peening, shot peening produced larger surface (-212MPa for SP and -148MPa for VP) and maximum compressive residual stresses (-297MPa for SP and -225MPa for VP) than vibratory peening. However, when compared to shot peening, vibratory peening produced deeper compressive residual stresses (SP produced compressive stress of -50MPa 340μm below the surface while VP produced led to the same residual stresses 520μm below the surface.

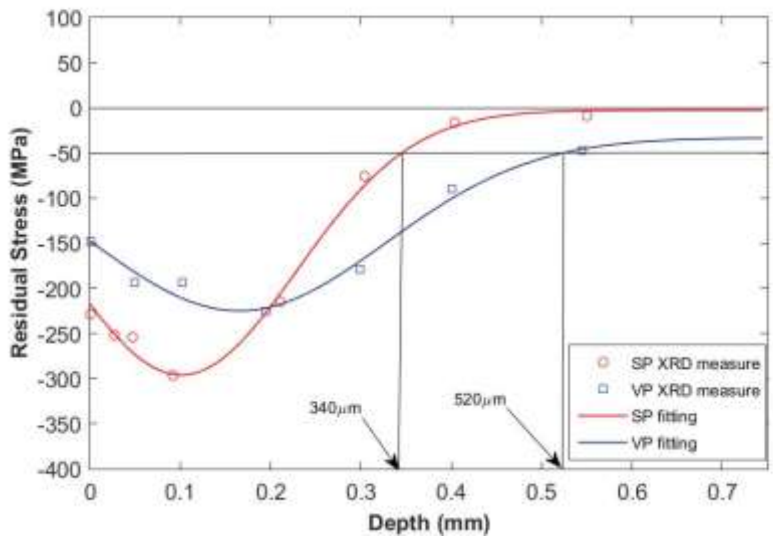


Figure 5 Comparison of XRD measured residual stresses induced by SP and VP

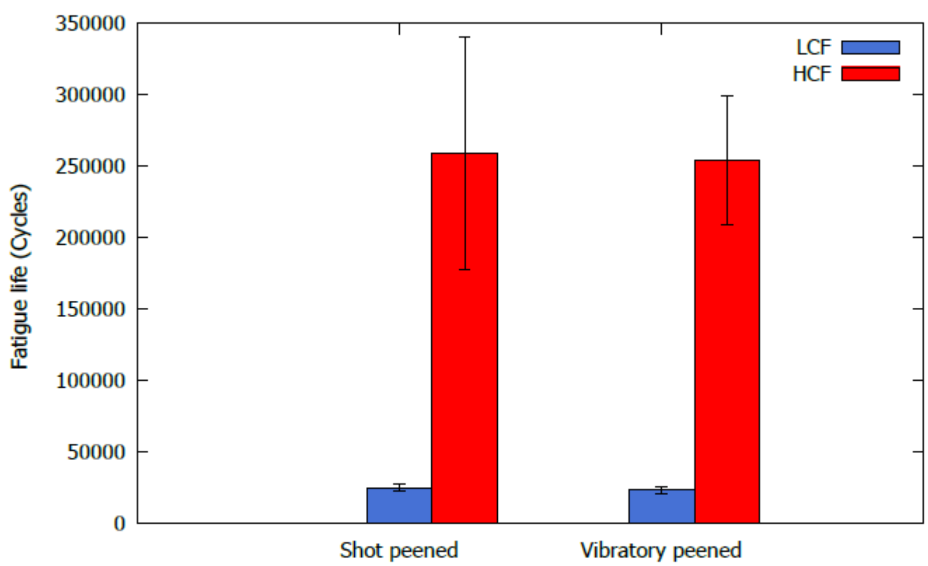


Figure 6 Fatigue life of shot peened and vibratory peened samples at LCF (σ_{max} = 450MPa) and HCF (σ_{max} = 310MPa).

Fatigue life

Figure 6 compares the fatigue lives for both processes at two stress loadings. The figure shows that shot peening and vibratory peening produced similar average fatigue lives for both LCF and HCF.

Fractography

Figure 7 presents fracture surface observations using the optical microscope for shot peened samples submitted to fatigue loadings $\sigma_{max} = 310$MPa and $\sigma_{max} = 450$MPa, respectively. Figure 8 presents fracture surface observations using the optical microscope for vibratory peened samples subjected to the same fatigue loadings. It can be seen that, for both shot peening and vibratory peening, the crack initiated from multiple surface locations at high stress loading and sub-surface initiation at low stress loading.

Figure 9 show the fracture surface of a shot peened sample fatigue tested at $\sigma_{max} = 310$MPa for magnifications of 25X and 100X, respectively. The figure shows that the fatigue crack initiated below the surface. Similar observations were made for the other samples. Figure 10 show the fracture surface of a vibratory peened sample fatigue tested at $\sigma_{max} = 310$MPa at magnifications of 25X and 100X, respectively. These figures also confirm that the crack initiated below the surface.

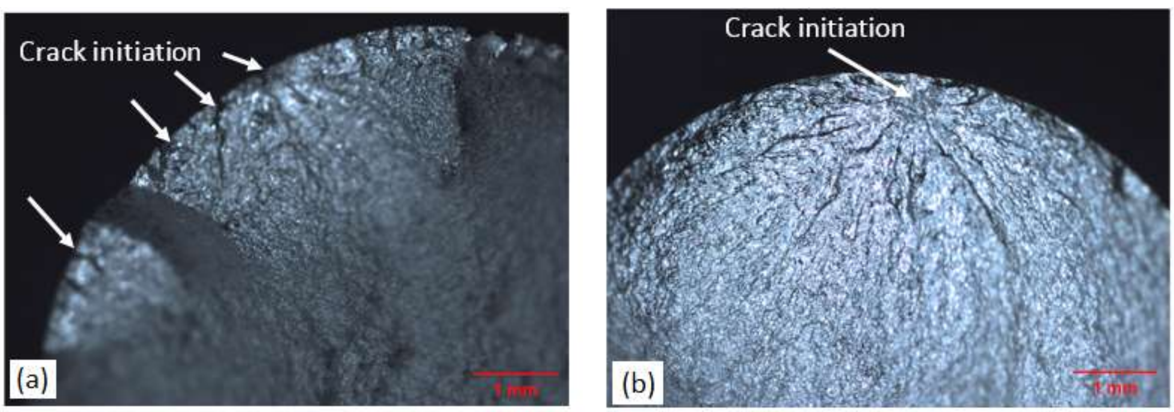


Figure 7 Fracture surface of SP samples fatigue tested at (a) $\sigma_{max} = 310$MPa (a) and (b) $\sigma_{max} = 450$MPa

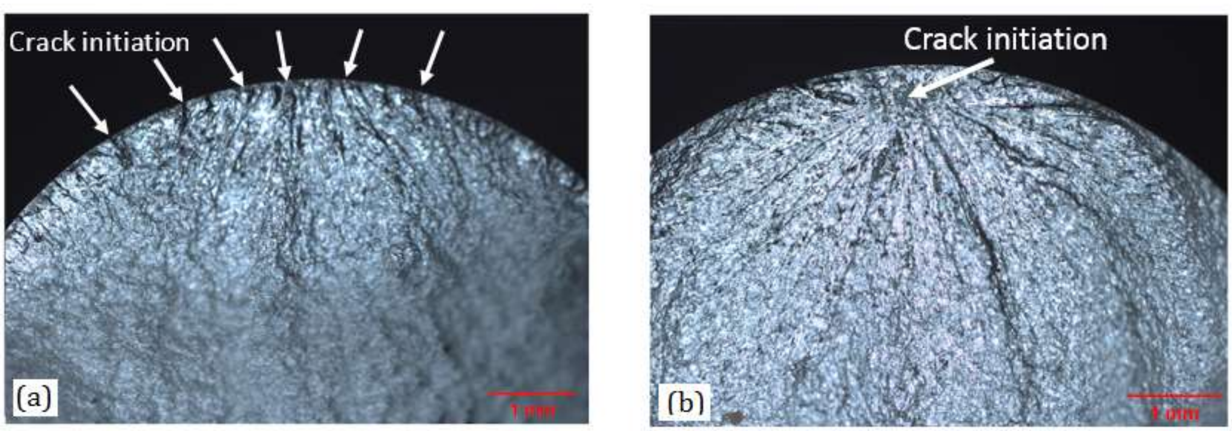
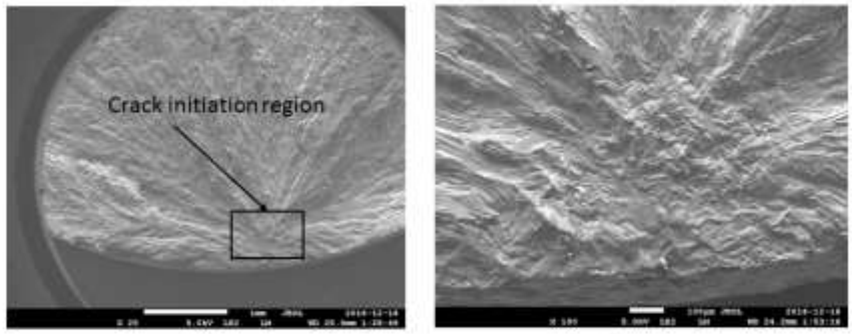
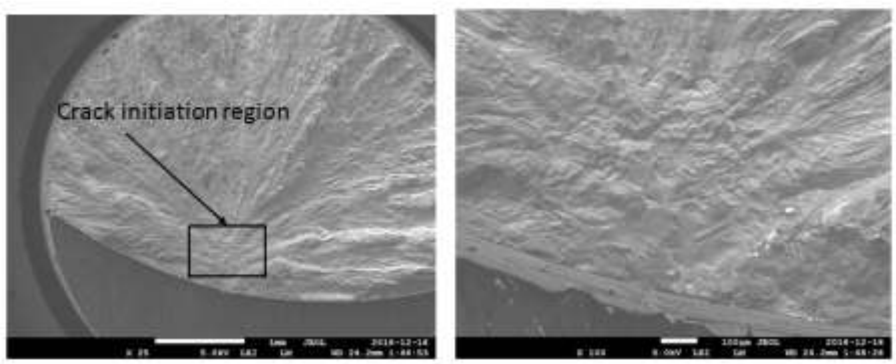


Figure 8 Fracture surface of VP samples fatigue tested at (a) $\sigma_{max} = 310$MPa (a) and (b) $\sigma_{max} = 450$MPa



(a) 25X (b) 100X

Figure 9 SEM observation of fracture surface of shot peened sample fatigue tested at $\sigma_{max} = 310$MPa.



(a) 25X (b) 100X

Figure 10 SEM observation of fracture surface of vibratory peened samples fatigue tested at $\sigma_{max} = 310$MPa.

Conclusions

This paper compared shot peening and vibratory peening effects on AA7050-T7451 fatigue tested samples. For the same shot peening and vibratory peening conditions (8A intensity and full coverage), the main conclusions presented in this report are as follows:

1) Vibratory peening produces much better surface finish than shot peening.
2) Shot peening produced higher surface compressive and maximum compressive residual stresses than vibratory peening. On the other hand, vibratory peening produced deeper compressive residual stresses than shot peening.
3) Both shot peening and vibratory peening resulted in similar fatigue lives. However, VP led to a smaller standard deviation smaller than SP at HCF. The failure initiation sites were of similar nature for the same applied fatigue load.

References

1. Domblesky, J., Cariapa, V., and Evans, R., *Investigation of vibratory bowl finishing.* International Journal of Production Research, 2003. **41**(16): p. 3943-3953.
2. Hashimoto, F. and DeBra, D.B., *Modelling and Optimization of Vibratory Finishing Process.* CIRP Annals - Manufacturing Technology, 1996. **45**(1): p. 303-306.
3. Wang, S., Timsit, R.S., and Spelt, J.K., *Experimental investigation of vibratory finishing of aluminum.* Wear, 2000. **243**(1-2): p. 147-156.
4. Feldmann, G., Haubold, T., Wong, C.C., and Wei, W., *Application of Vibropeening on Aero-Engine Components.* International conference of shot peening 12nd, 2014: p. 535-540.
5. Feldmann, G., Wong, C.C., Wei, W., and Haubold, T., *Application of Vibropeening on Aero – Engine Component.* Procedia CIRP, 2014. **13**: p. 423-428.