Residual compressive stress benefits on core aerospace materials using ultrasonic shot peening

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Introduction

Ultrasonic Shot Peening (USP) emerged within the past few decades as a promising alternative to Conventional Shot Peening (CSP) methods. SONATS is a leading designer and manufacturer of USP tooling and equipment. Previous shot peening studies investigated the benefits of CSP on the fatigue life of commonly used aerospace materials, such as the Army Research Lab (ARL) study, "Shot Peening Sensitivity of Aerospace Materials"(1). Following the same technical approach used in ARL's study, Avion Solutions and SONATS conducted a qualification study to compare the effects of USP to the commonly used CSP(2). Avion compared these materials through saturation curves, coverage charts, surface roughness measurements, residual stress profiles, and fatigue testing to qualify this system for repair use on Critical Safety Items (CSI) for the U.S. Army.

In order to expand the qualification data on USP, Avion, Clausthal University of Technology (TUC), and SONATS teamed together to complete additional testing on 6061 aluminum, non-carburized 9310 steel, and carburized 9310 steel. Testing was designed to mimic previous qualification testing of USP to be a continuation of the original study. This study aims to display the similarities between shot peening the same materials at the same intensities while using different media activation methods. Fatigue life and compressive residual stresses are used to determine the equivalence between peening processes based on activation with either air pressure (CSP) or ultrasonic vibrations (USP).

USP is a non-conventional method used to induce compressive residual stresses in the surface layers of metals. This system utilizes a titanium sonotrode head vibrating at an ultrasonic frequency, 20 kHz, to supply kinetic energy to the media for shot peening; whereas conventional methods derive this kinetic energy from air pressure or centrifugal force. Since this process relies on the contact of the media to this ultrasonically vibrating sonotrode, a chamber is created to contain the media to a given area during peening. This closed chamber continuously re-energizes high quality media during each peening process. Since the chamber created establishes a sealed peening environment between the surface of the component to peen and the vibrating sonotrode head, this system mitigates the risk of Foreign Object Debris (FOD). This sealed peening chamber allows for peening on-aircraft, subassemblies, or on the shop floor with minimal set-up and tear down time. USP is computer controlled and adheres to many AMS Specifications including AMS 2580 and 2585, which corresponds to Ultrasonically Activated Shot Peening and USP Media, respectively.

Objectives

Many flight critical aircraft components are sensitive to fatigue damage and require shot peening to provide increased fatigue strength. This process is conducted by the OEM before the critical aircraft components are installed on the aircraft. Through standard use the parts originally shot peened become damaged with nicks, scratches, and corrosion. This damage can be locally removed, but this process also removes the compressive residual stress achieved by shot peening. In order to complete the repair, the blended areas must be re-shot peened. To date, the repairs of these components are limited to the Original Equipment Manufacturers (OEM) and approved CSP vendors. Qualification of a portable system such as USP capable of performing these repairs on a shop floor or on aircraft would assist in lowering the repair cost and total Turn-Around Time (TAT). Many structural areas of the aircraft are shot peened and are difficult to re-peen if a repair is required. Since CSP propels the shot through an air pressure and nozzle system, the media moves freely after hitting the repair area. When this repair area is located on the structure of an aircraft, the area must be precisely tented to contain the ricocheting media. Set up and tear down time for tenting can increase the time the aircraft downtime, as well as increases the repair cost.

This paper will focus on comparing USP to CSP in order to expand the qualification of this technology to additional aviation materials. Successful testing will reveal similar fatigue results and residual stress measurements between the two processes at similar intensities. Successful USP results can then be translated into repair procedures for aircrafts.

Methodology

Through comparative testing using saturation curves and coverage charts, residual stress profiles, and fatigue testing, the similarities and differences between the benefits of the two methods were discovered. This qualification was conducted on both notched and un-notched fatigue coupons at similar intensities on three different materials: 6061-T6 aluminum, carburized 9310 steel, and non-carburized 9310 steel. Each material was broken into three categories for testing: CSP, USP, and machine polished. All USP samples were peened with a StressVoyager® utilizing StressSonic® technology. Samples were peened to 0.2 mmA intensity with 200% coverage. Saturation curves and coverage charts for both processes were completed IAW AMS J2597 and AMS J2277, respectively. Baseline, unpeened samples were machine polished (MP) before fatigue testing to significantly reduce crack potentials. All samples were fatigue tested with rotating-beam bending to allow for testing at high frequencies to achieve high cycle fatigue. Samples will be tested to failure or run-out, which is defined as 10,000,000 cycles for this test.

Both notched and un-notched coupons were prepared from bar stock with rotary swaging before final machining. All coupons were inspected prior to peening for visible cracks or noticeable incongruences between samples.

Table 1: Material Properties

Material	Material Strength (KSI)	Material Hardness
9310 Steel Non-Carburized	190 UTS 156 YS	38-40 HRC
9310 Steel Carburized	187 UTS 162 YS	60-64 HRC
Aluminum 6061 – T6	42 UTS 35 YS	60 HRB

Table 1 shows the material properties for those materials selected for this study. These materials were selected based on their common use with shot peening in aviation. 9310 steel is often found in gears and gearboxes as well as other aerospace applications. A 6000 series aluminum was selected as it is most commonly found in structural components on fixed wing aircraft.

9310 steel samples were carburized per AMS 2759/7 at 1650°F for four hours, after the equipment was allowed to preheat for thirty minutes. Next, the samples were equalized to 1550°F using an oil quench. In order to achieve a hardness of 60-64 HRC with a case depth of 0.4 mm, the samples were then placed in deep freeze at -120°F for one hour. Finally, the samples were tempered at 275°F and held for two hours.

Results and analysis

Fatigue testing for the un-notched samples is complete. The notched fatigue results are expected to be presented with this paper at ICSP-13. All fatigue testing was conducted at TUC with a small sample size, fewer than ten specimen per test condition.

Fatigue results for Al6061-T6 show a slight improvement in fatigue strength for both CSP and USP over the baseline MP samples, shown in Figure 2. Additional testing would be required to determine an intensity which would yield better fatigue properties after peening for Al60-61-T6.

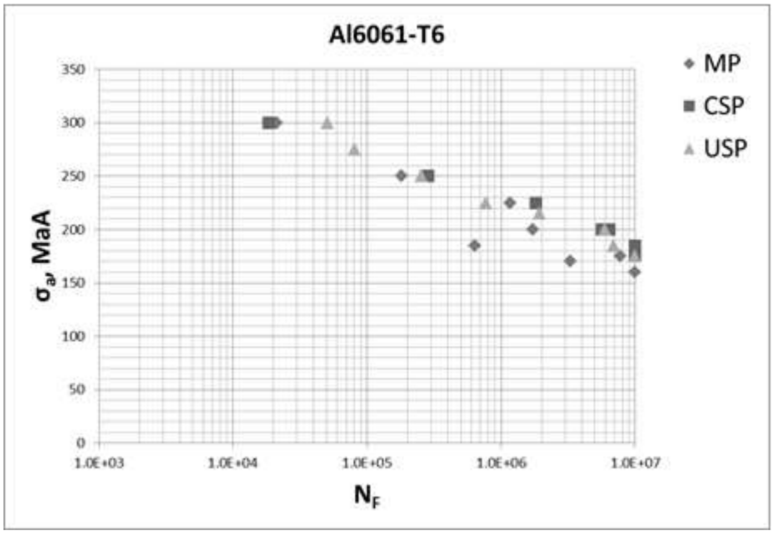

Figure 1: Fatigue Results for Al6061 – T6

Figure 2 shows fatigue results for 9310 non-carburized steel. There is an increase in fatigue life for both shot peened test groups over the baseline MP specimen. Both USP and CSP resulted in a similar fatigue life.

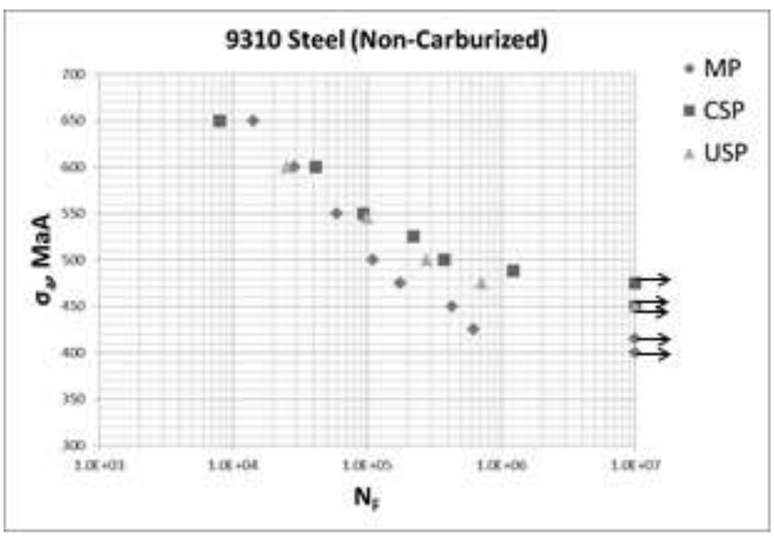

Figure 2: Fatigue Results for 9310 Steel (Non-Carburized)

Next, a case hardness test was performed by TUC to ensure a minimum case depth of 400 μm for successful completion of carburization on the 9310 steel samples. Results showed a case approximately 450 μm deep with a hardness of 64 HRC, shown in Figure3.

After the carburization check, samples were divided and shot peened using either CSP or USP to 0.2 mmA intensity with 200% coverage. The hardness did not increase after shot peening. However, after shot peening did significantly improve the compressive residual stresses from carburizing alone, shown in Figure 4. This significant increase in compressive residual stresses can be translated to the significant fatigue increase in Figure 5.

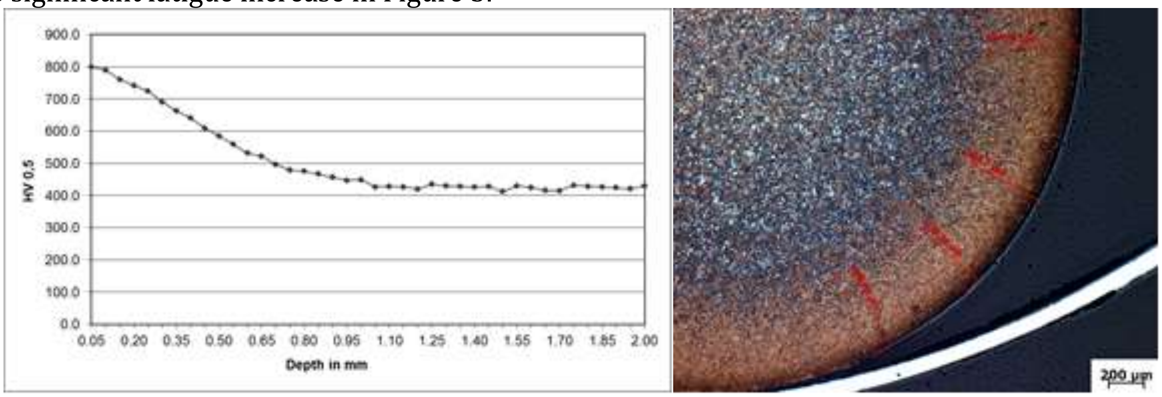

Figure 3: Case Hardening of 9310 Steel (Carburization)

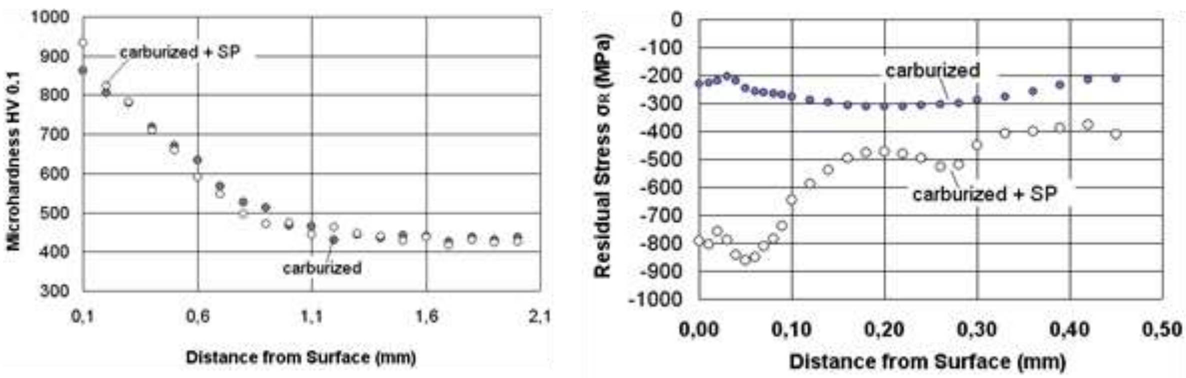

Figure 4: (a) Microhardness and (b) Compressive Residual Stress Profiles for 9310 carburized steel samples

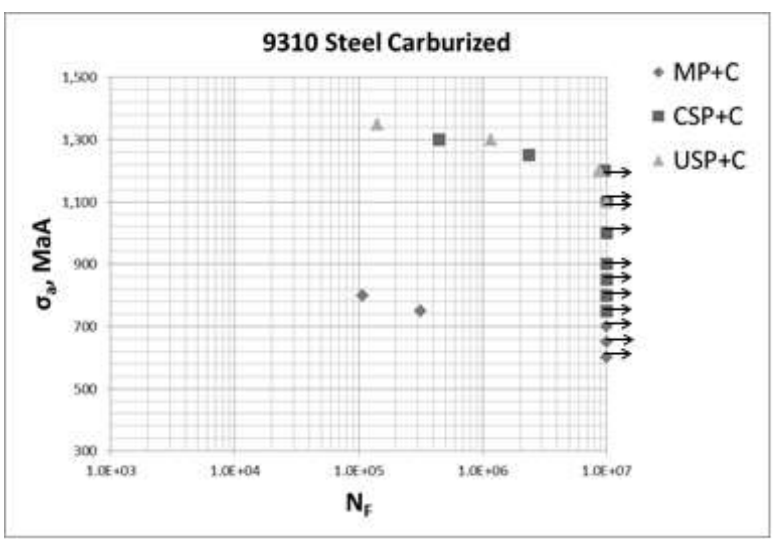

Figure 5: Fatigue Results for 9310 Steel (Carburized)

Fatigue Results for Carburized 9310 steel show a significant increase in fatigue strength for samples that were shot peened after carburization for both USP and CSP (Figure 5). USP and CSP on 9310 Carburized steel show very similar fatigue strengths that are considerably higher than carburizing alone. Results for both carburized and non-carburized 9310 steel are shown in Figure 6. Carburizing 9310 steel shows a significant fatigue life advantage before and after shot peening procedures.

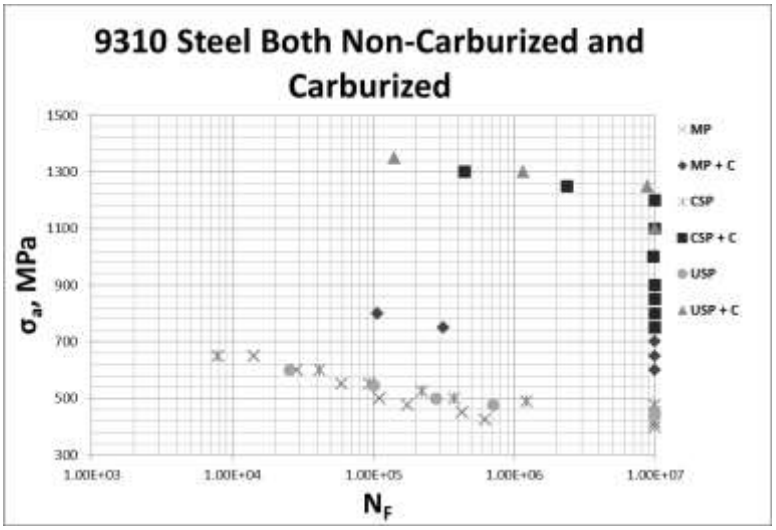

Figure 6: 9310 Fatigue Results for both non-carburized and carburized samples

Conclusions

Residual stress measurements showed similar superficial residual stress, maximum compressive stress, and depth of compression between USP and CSP on similar materials when peened to the same intensities. Additional hardness testing on the carburized steel samples showed no noticeable difference in the peened over unpeened samples. However, the peened carburized samples showed significant fatigue life improved over the unpeened carburized samples. In conclusion, the preliminary results show that USP is a suitable and comparable replacement for CSP repairs at similar intensities.

Additional testing will be completed to include the notched samples for each material. This information will be included in the September presentation of this paper.

Acknowledgments

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