Controlled Rotary Flap Peening for Repair Applications

S. Forgues[1], B. Labelle[1], M. King[2], N. Manor[2]

1 Shockform Inc., Quebec, Canada
2 3M Company, Minnesota, USA

Abstract
Shot peening is an important process that improves fatigue life of components without increasing their weight. It is used extensively in the aerospace industry where weight and fatigue are key issues. During the manufacturing and service life of a component, a peened surface might get scratched or slightly damaged. In this case, re-peening is necessary to restore the compressive residual stress layer after removal of the damage area. When re-peening is necessary, rotary flap peening, also known as flapper peening, is often used because it is quick, clean and cost effective.

Although the rotary flap peening process has many advantages, it has recently been improved with the introduction of a new controller that continuously monitors and adjusts the rotational speed of the flap. The controller gives the process better repeatability, more visibility and a faster turn-around time. Although the rotary flap peening process has existed for quite some time, very little published data is available on how it compares with conventional peening. The advent of a new controller is a great opportunity to see how rotary flap peening compares to conventional peening in a controlled environment.

In this paper, the new controller is used to flapper peen cylindrical fatigue coupons made of 7475-T7351aluminum. Surface roughness, compressive residual stress profiles and fatigue lives are presented and compared with results for conventional peening, using compressed air.

Keywords
Flapper peening, roto-flap peening, rotary flap peening, 3M, peening repair, portable peening, re-peening, AMS 2590

Introduction
Rotary flap peening has been used in the aerospace industry for more than 50 years. First developed by 3M™ for helicopters in the early 1960`s, it is known as an efficient method to re-peen small areas after blending to remove a scratch or surface damage [1]. The 3M TC-330 rotary flap peen material is the most common tool used for rotary flap peening. The rotary flap peen process is quick, clean and cost effective, but may lack proper control of its main parameter, the rotational speed of the flap, when used on a non-regulated line of compressed air [2]. This is the case when using a compressed air die grinder to do the peening. When several operators are working on the same compressed air supply line, the drop in available air sometimes affects the rotational speed of the die grinder during the rotary flap peening process. If gone un-noticed, the intensity of the peening could be significantly lower than intended, potentially resulting in a lower fatigue life for the component.

The FlapSpeed™ controller, developed by Shockform Inc. has recently been introduced to address this issue. The controller includes a rotational speed sensor attached to a 3M™ die grinder model 20239 to send data back to the controller. This data is analysed by a microprocessor which in turn adjusts the air pressure to the power tool to obtain the desired rotational speed. If the speed is too high, the air pressure is diminished accordingly. If the speed is too low the air pressure is increased unless insufficient air is available. In this case, the controller shuts off the air supply and sounds an alarm. This ensures that the requested rotational speed is maintained at all times, thus providing an optimal and repeatable peening intensity [3].

Experimental Procedure

In this study, the controlled rotary flap peening process is compared with conventional peening for 7475-T7351 aluminum. This alloy is commonly used in the aerospace industry for structural components, such as lower wing skins. On these components, peening is often used to increase the fatigue performance and lower the inspection requirements of the component. If the component incurs a scratch or a small surface defect, rotary flap peening is commonly used to re-introduce the required compressive residual stresses in the component. The mechanical properties for the material are presented in Table 1.

Table 1. Mechanical Properties of Tested Material

Properties	Al7475-T7351 [4]
Shape	Plate 76.2-101.6 mm
0.2% Yield (MPa)	438
Tensile Strength (MPa)	506
Elongation (%)	15.6
Specification	AMS 4202

Thirty-three cylindrical coupons were machined from a 76.2mm (3") thick plate. The cylindrical coupons design, illustrated in Figure 1, was selected for its ease of peening and for its commonality with most uniaxial load frames. The design offers a stress concentration factor (Kt) equal to one. Of the thirty three coupons, 11 received conventional peening, 11 were peened using the FlapSpeed™ controller and the rotary flap peening tool, TC-330, and 11 were left without peening to serve as a baseline.

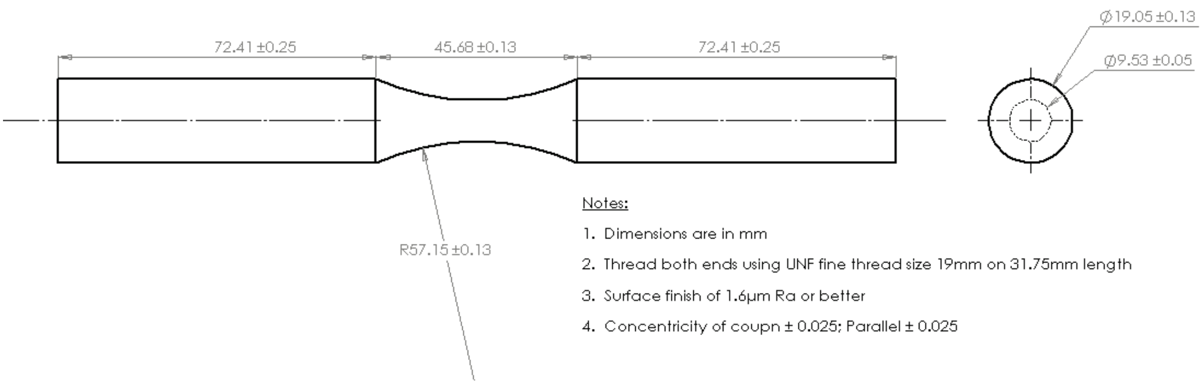

Figure 1 Coupon Design

Details of the peening performed on the coupons are presented in Table 2. The conventional peening was performed to AMS2430 using a computer controlled robotic system. The head of the robot was rotated around the coupon to peen the complete surface. The controlled rotary flap peening was performed to the new AMS2590 specification for flapper peening and the coupon was rotated manually to achieve uniform peening of the surface. The 3M TC-330 flaps were used for the rotary flap peening along with a 3M mandrel, and magnetic block. The FlapSpeed™ controller was used to control the rotary speed of the flap to within +/- 30 RPM.

Table 2. Peening Details for Al7475-T7351 Coupons

	Conventional	**Controlled Rotary Flap**
Intensity	0.0201A mm (0.008A)	0.0201A mm (0.008A)
Coverage	100%	100%
Shot	ASH 230	3M Flap 14.29x31.75mm (9/16 x 1 ¼ inch)
Specification	AMS 2430	AMS 2590

For both the conventional peening and the rotary flap peening, the peening intensity was 0.0201A mm (0.008A inch) as determined by a 5 point saturation curve using a curve solver software [5]. The threads of the peened coupons were glass bead peened at 0.0177A mm (0.007A inch) intensity using 0.150-0.211mm diameter shot to prevent premature failure in the threads.

After shot peening, the surface roughness of the peened coupons was evaluated using a linear profilometer. Several measurements were performed on each coupon and the average value in Ra is presented.

The compressive residual stress profile was measured by the X-ray diffraction method on one coupon treated with conventional peening, one coupon treated with controlled rotary flap peening and one coupon with no peening. The coupon with no peening offers a baseline value for the machined surface before the coupons are treated. Measurements were performed in the axial direction in the center of the coupon as illustrated by Figure 2.

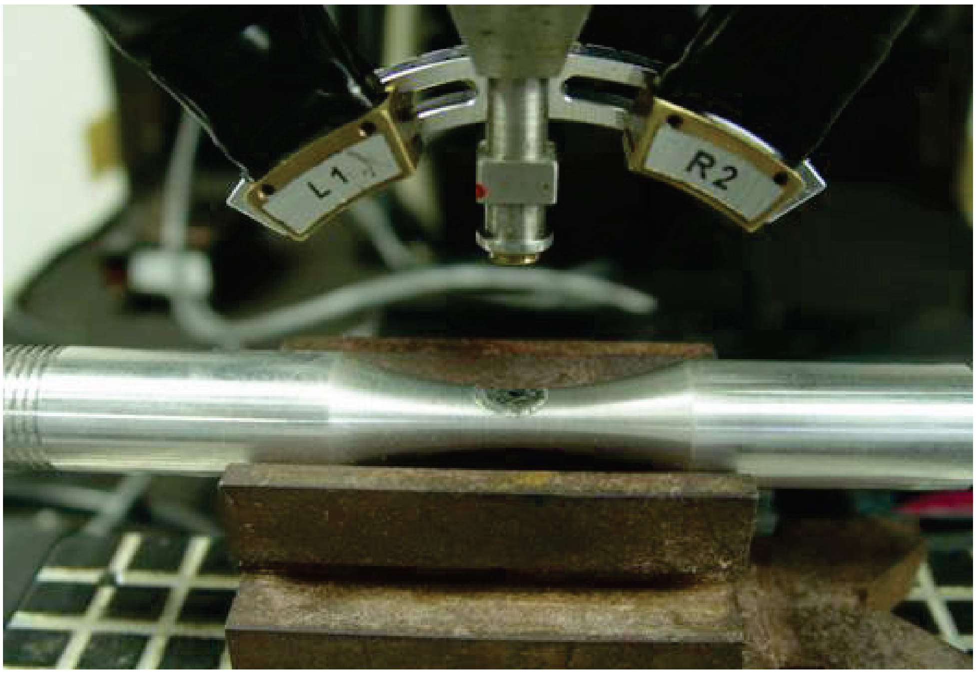

Figure 2 X-Ray diffraction Measurement of Residual Stress

The coupons were fatigue tested in a uniaxial servo-hydraulic load frame. A sinusoidal shaped, fully reversed (R=-1) loading was applied to the coupons at a frequency of 10 Hz. A minimum of three coupons were tested at each of the three different load levels. The maximum load level used is 207, 259 and 310 MPa (30, 37.5 and 45 ksi). Fatigue data is presented as the best fit curve using a lognormal linearization approach detailed in Reference [6] and presented in Equation 1.

$$Log(N_F) = A_1 + A_2 Log(S_{MAX}) \quad (1)$$

In equation 1, N_F is the number of cycles to failure, S_{MAX} is the maximum applied stress level and A_1 and A_2 are respectively the intercept and the slope obtained from the linearizarion of the data.

Results and Discussion

Looking at surface roughness, the coupons treated with controlled rotary flap peening were 40% smoother than the coupons with conventional peening (Figure 3). Since the peening intensities were the same, the difference can be attributed to the difference in shot size. The ASH230 shot used in conventional peening has an average shot diameter of 0.58mm where the tungsten carbide balls on the flaps used for controlled rotary flap peening have an average diameter of 1mm. In general, larger shots result in a smoother surface and a smoother surface results in better fatigue life for a selected intensity. Since conventional peening is often performed with S230, flapper peening will usually offer a better surface finish on repairs than the original peening.

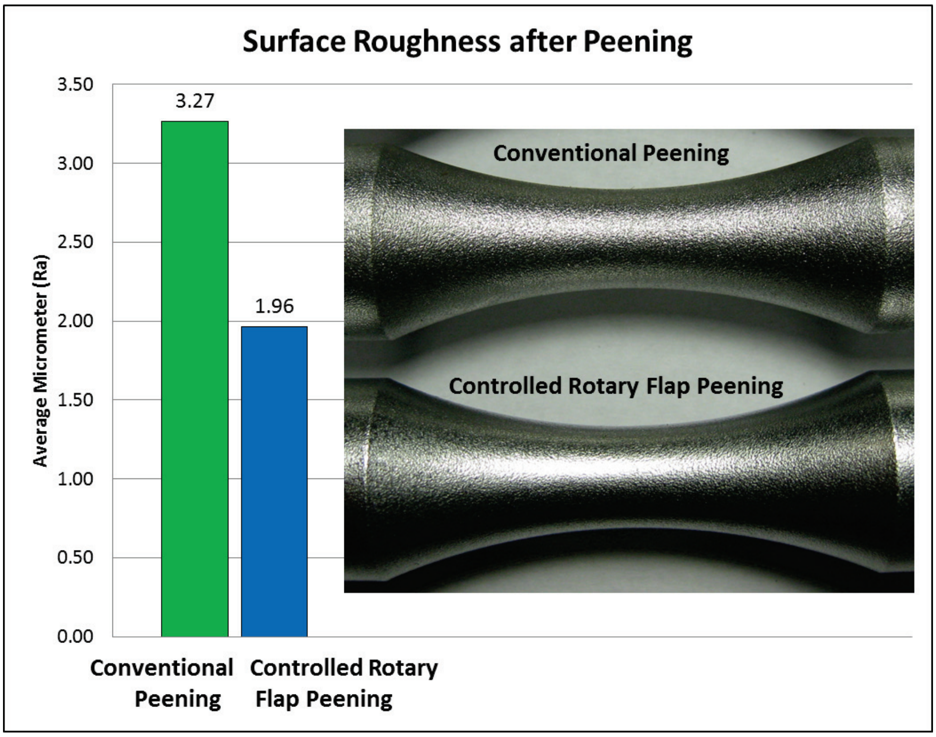

Figure 3 Surface Roughness After Peening

The residual stress profile for the as machined coupon (Figure 4 and Table 3) shows a value of minus 150MPa at the surface increasing to a value approaching zero at a depth of 0.08 mm and deeper. Both curves for the conventional peening and the controlled rotary flap peening show similar trends. They start with a surface stress near -200 MPa and become more compressive as the depth increases around 0.15mm. The curves then become less compressive as the depth increases. Although the values are nearly identical at the surface where peening has the most effect, the controlled rotary flap peening offers a slightly more compressive residual stress profile as the depth increased. This again should result in a better fatigue life under similar loading conditions.

The fatigue results are presented in Figure 5 and Table 4. The baseline as machined curve matches very well with data found in Ref [5]. Both the conventional and the controlled rotary flap peening provide equivalent life improvement. The rotary flap peening appears better at lower stress levels while the conventional peening appears slightly better at higher stress levels. Both peening methods offer a Fatigue Life Improvement factor of 3 or better throughout the tested range.

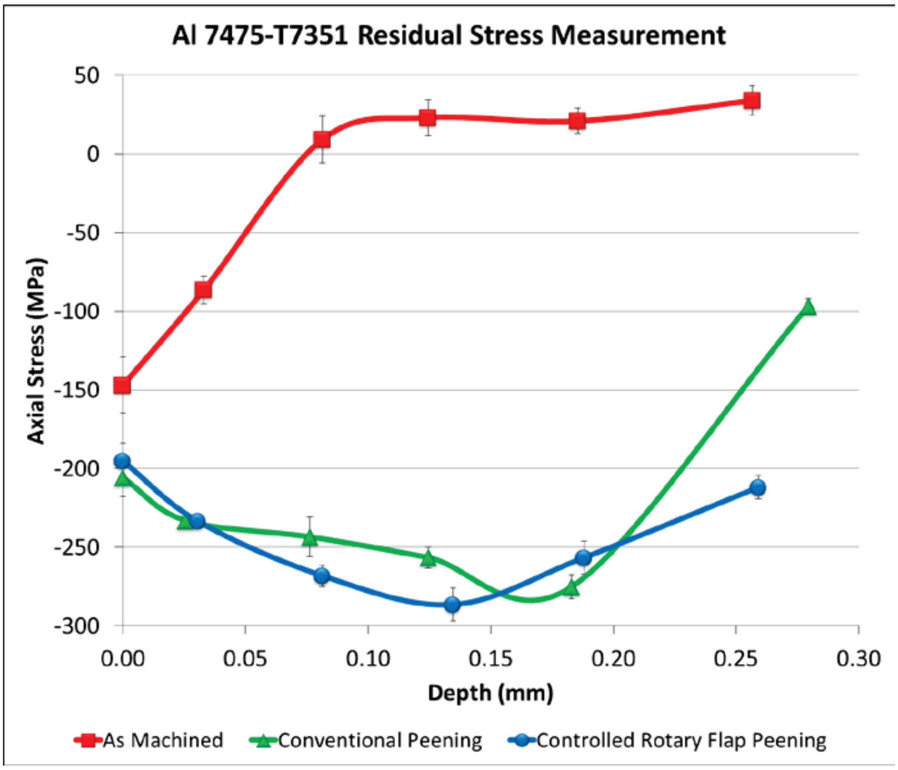

Figure 4 Residual Stress Measurements

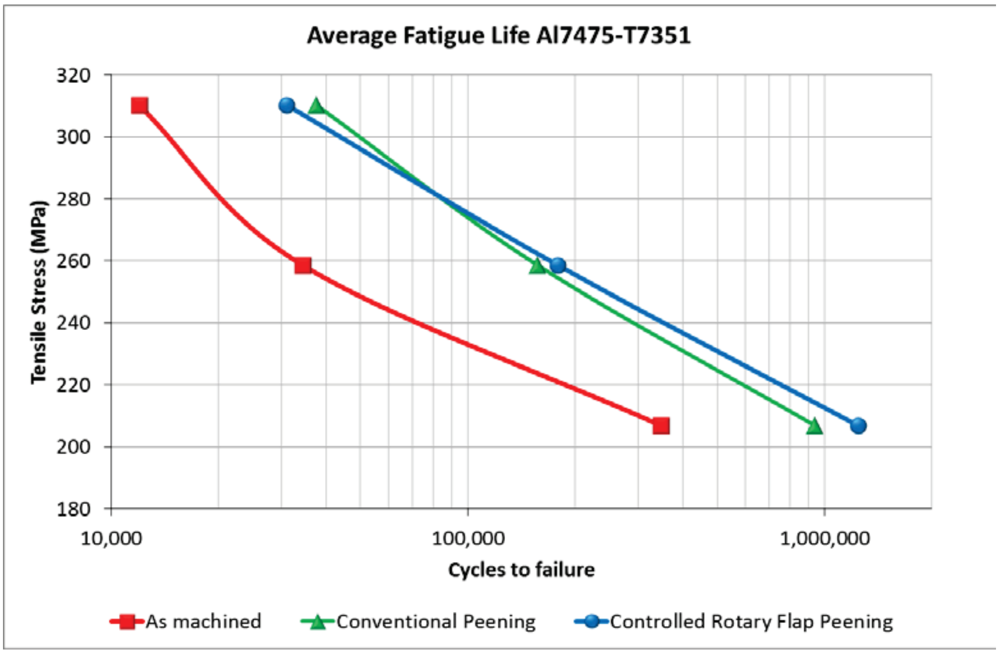

Figure 5 Fatigue Results

Table 3. Residual Stress Measurements

Depth (mm)	As Machined (MPa)	Conventional Peening (MPa)	Controlled Rotary Flap Peening (MPa)
0.00	-147	-206	-195
0.03	-86	-233	-233
0.08	9	-243	-268
0.12	23	-256	-286
0.19	21	-275	-257
0.26	34	-97	-212

Table 4. Fatigue Results

As machined		Conventional Peening		Controlled Rotary Flap Peening	
Stress (MPa)	Cycles to Failure	Stress (MPa)	Cycles to Failure	Stress (MPa)	Cycles to Failure
310	10,650	310	29,142	310	27,746
310	11,469	310	29,643	310	31,493
310	13,714	310	53,717	310	33,663
259	27,867	259	127,358	259	123,181
259	31,190	259	158,193	259	191,325
259	43,978	259	184,164	259	220,507
207	241,643	207	539,415	207	637,004
207	250,488	207	582,983	207	1,106,895
207	547,213	207	889,205	207	1,200,782
		207	1,734,235	207	2,000,000

Conclusion

The curves confirm that controlled rotary flap peening can provide the same fatigue life improvements as conventional peening. Using a speed controller to ensure optimal peening parameters, rotary flap peening offers a better surface finish, equivalent or better compressive residual stress profiles and equivalent fatigue lives to conventional automated peening. Combined with the fact that it is quick, clean and cost effective, controlled rotary flap peening offers the best possible solution for the re-peening of small damaged areas.

References

[1] P.M. Winter, *The Use of 3M Brand Roto Peen Products in Conditioning Metal Surfaces*, 3M internal Report, May 11, 1970
[2] P.G. Bailey, *Manual Peening With the Rotary Flap Process*, Conf Proc: ICSP-7, 1999, pp 405-414
[3] S. Forgues, *Variability Study of the Flapper Peening Process*, The Shot Peener, Vol 24 /Issue 2, Spring 2010
[4] Kaiser Aluminum*, Certified Test Report*, Serial Number 4193384
[5] Kirk, Dr. D., Saturation Curve Solver Software, Release 9, 2009
[6] Mil-Handbook 5J, *Metallic Materials and Elements for Aerospace Vehicle Structures*, Jan, 2003.

Acknowledgement

Special thanks to Jean-Philippe Gagnon of Tekalia for his experimental assistance during the conventional peening of the coupons.