WELDED JOINTS FATIGUE LIFE IMPROVEMENT DUE TO SHOT-PEENING PROCESS

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Abstract. *The design stresses in welded structures subjected to cyclic loading are limited by low fatigue strength of welded elements. With the objective of increase the fatigue properties of welded components, it is possible to influence the following three parameters: weld quality, local geometry and residual stresses. Post-weld treatment changes one or more of these parameters. The most common are shot peening, grinding, hammer peening, ultrasonic peening and TIG dressing. A compressive stress induced by post-weld treatment is beneficial by eliminating the tensile residual stresses and generating compressive residual stresses, which improves fatigue strength of welded structures. This paper show the shot peening beneficial influence to increase the fatigue resistance of low carbon steel and aluminum alloys welded joints. Three point bending tests were carried out on butt-joint specimens for as-welded conditions and specimens treated by shot peening until the fatigue fracture. The number of fatigue cycles was computed for every specimen and a comparison was made between as-welded and treated specimens. Result and corresponding conclusions about this experimental study are presented in this paper.*

Keywords*: residual stresses, shot-peening, fatigue*

1. INTRODUCTION

Residual stress can significantly affect engineering properties of materials and structural components, notably fatigue life, distortion, dimensional stability, corrosion resistance etc. Such effects usually lead to considerable expenditures in repairs and restoration of parts, equipment and structures. For that reason, the residual stress analysis is a compulsory stage in the design of structural elements and in the estimation of their reliability under real service conditions (Kudryavtsev *et al*, 2004).

The residual stresses, therefore, are one of the main factors determining the engineering properties of materials, parts and welded elements and this factor should be taken into account during the design and manufacturing of different products. Al-though certain progress has been achieved in the development of the techniques for residual stress management, a consider-able effort is still required to develop efficient and cost-effective methods of residual stress measurement and analysis as well as technologies for the beneficial redistribution of residual stresses.

Systematic studies had shown that, for instance, welding residual stresses might lead to a drastic reduction in fatigue strength of welded elements. In multi-cycle fatigue (N>106 cycles), the effect of residual stresses can be compared with the effect of stress concentration.

Even more significant are the effects of residual stresses on the fatigue life of welded elements in the case of relieving harmful tensile residual stresses and introducing beneficial compressive residual stresses in the weld toe zones. The results of fatigue testing of welded specimens in as-welded condition and after application of ultrasonic peening showed that in case of non-load caring fillet welded joint in high strength steel, the redistribution of residual stresses resulted in approximately two-fold increase in the limit stress range (Barrios *et al*, 2007).

This paper shows the traditional shot-peening process beneficial effects on the fatigue behavior of butt welded joints. What is shot peening? What happens when a part, machine element or a structural piece is shot peened? When a part is pelted/bombarded with a stream of round metallic media (referred to as shot), each shot dents the surface of the part that it impacts. Impingement of metallic media (shot or cut wire) causes plastic deformation on the part surface.

This extends the superficial layer creating compressive stresses underneath and providing a balance to the applied working (tensile) stresses. This residual compressive stress delays the formation of fatigue cracks thereby increasing the useful life of a component (Balan, 2007).

Shot peening is a cold working process and is different from metal flow at high temperatures, even though there is a momentary increase in temperature of the surface being peened. The layer of compressive stress commonly extends to depths varying from 0,12 to 0,78 mm (Calle *et al*, 2007).

Greater depths, if desired, are achieved by altering process parameters such as shot size, velocity of impingement, angle of impingement, exposure time, etc.

2. EXPERIMENTAL PROCEDURES

2.1 Material

The material used is the ABNT 1020 steel and the 6351 aluminum alloy. The chemical composition of ABNT 1020 used was 0,2 % C, 0,4 % Mn, 0.04 % P, 0.05 % S. The mechanical properties were obtained through mechanical tests showing a yield stress of 210 MPa and the ultimate stress of 380 MPa. The chemical composition of 6351 aluminum alloy used was 1,0 % Si, 0,6 % Mn, 0.6 % Mg. The mechanical properties shows a yield stress of 283 MPa and the ultimate stress of 310 MPa.

Eight test specimen of ABNT 1020 steel were prepared, two with dimension of 100 x 50 x 16 mm (numbered as 1 and 2), four with dimensions of 100 x 50 x 10 mm (numbered as 3, 4, 5 and 6) and two of 180 x 70 x 5 mm (numbered as 7 and 8), four of them were treated with shot-penning, leaving the others in as-welded condition. Figure 2.1 show the test specimens with and without shot-peening.

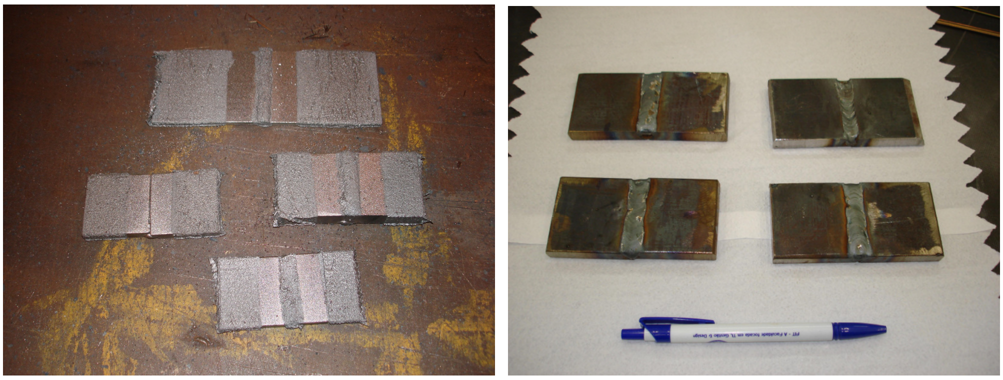


Figure 2.1 Test specimens with and without shot-peening

2.2 Hardness measurement

After the shot-peening process applications were made it a hardness measure (in HRB) at the points presented in a Figure 2.2 for the eight test specimens of steel, with and without shot-penning.

The points were chosen following a symmetric straight line from the weld toe until a thermally affected region (see Figure 2.2).

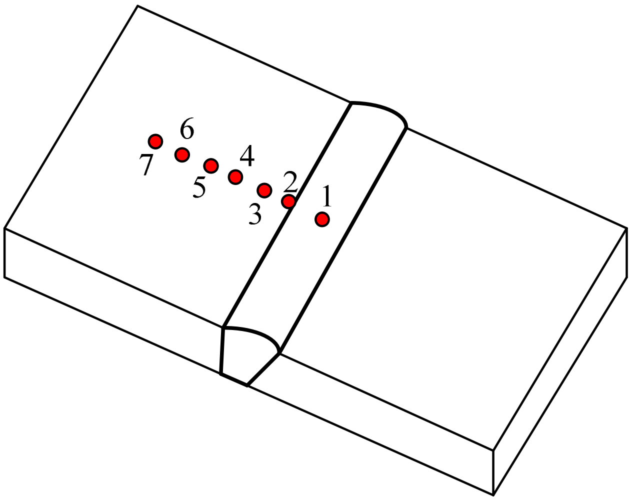


Figure 2.2 Points were the hardness (HRB) was measured

The Figure 2.3 shows the durometer employing to obtain the hardness values.

Figure 2.3 Durometer. (Engineering School of Mackenzie Presbyterian University)

The Table 2.1 presents the hardness values obtained.

Table 2.1 Hardness values (HRB)

Test specimen	Hardness at the weld toe (HRB)	Hardness at the chosen points (HRB)					
1	34	X	58	56	58	60	64
2*	50	X	68	69	73	74	-
3	52	68	72	72	72	73	74
4*	72	77	75	74	76	75	68
5	80	76	77	76	77	75	-
6*	76	75	70	80	78	77	-
7	63	X	76	88	89	90	88
8*	66	97	97	94	96	97	94

Comments:

(*) – Test specimens with shot-peening;
(X) – Not considered values cause of the great difference in comparison with the other measurements;
(-) – Without measurement.

The points, for the aluminum alloy test specimens, were chosen following a symmetric straight line from the weld toe until a thermally affected region (see Figure 2.4).

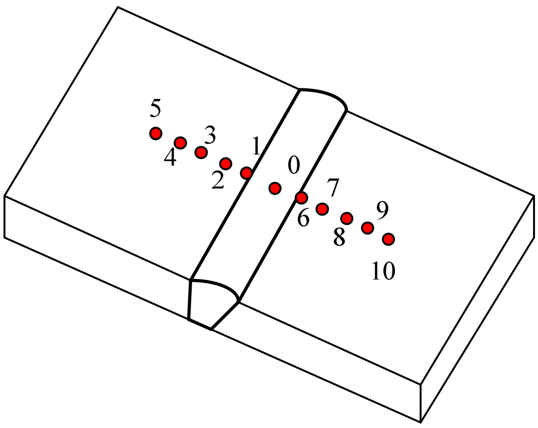


Figure 2.4 Points were the hardness (HB) was measured

The Table 2.2 presents the hardness values obtained.

Table 2.2 Hardness values (HB)

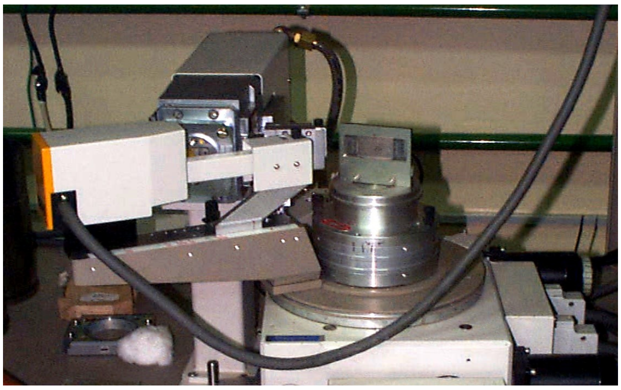
	Points	HB									
Test specimen	0	1	2	3	4	5	6	7	8	9	10
1	50,9	53,4	52,5	52,5	52,5	52,5	53,8	52,5	52,5	52,5	52,5
2	50,9	52,5	52,5	52,5	52,5	62,5	50,9	52,5	52,5	52,5	52,5
3	49,7	52,5	53,4	53,4	53,4	53,4	53,4	53,4	53,4	54,8	53,4
4	54,8	54,8	57,5	54,8	54,8	54,8	54,8	56,1	56,1	57,5	56,1
5	57,5	57,5	57,5	57,5	57,5	57,5	56,1	57,5	57,5	57,5	57,5
6	57,5	56,1	59	59	59	57,5	56,1	57,5	59	57,5	57,5

In both cases, steel and aluminum alloy, it is possible to observe a slightly increment at the hardness values in the case of those test specimens submitted to the shot-peening process. In general, the shot-peening process increases the mechanical properties of the treated surface.

2.3 X-rays measurements

The analysis of the surface residual stress values induced by the shot-peening process and for the test specimens in as-welded condition was carried out employing the XRD (X- Rays Diffraction) technique.

The XRD stress measurements are based on the sin2ψ method. Figure 2.4 shows the experimental arrangement to measure the residual stress values at the test specimens' surface.



2.4 X-rays diffraction experimental arrangement (IPEN Laboratory)

Seven and six points were chosen for two steel test specimens, one in as-welded condition and the other with the surface treated by shot-peening. Figure 2.5 shows the location of those points for the test specimen in as-welded condition and Figure 2.6 for the treated test specimen with shot-peening.

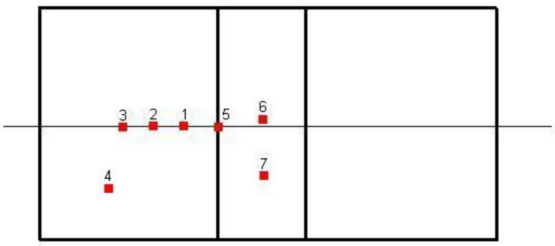


Figure 2.5 Points of measure in as-welded condition steel test specimen

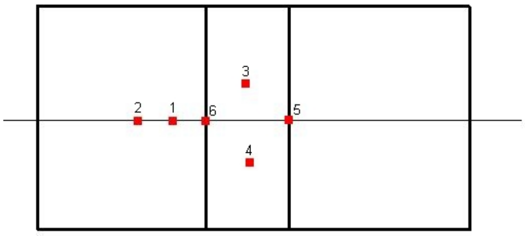


Figure 2.6 Point of measure in a treated steel test specimen

Each measure took among one hour from the surface preparations until the measurement to obtain the residual stress value. The surface residual stress values are showed in a Tables 2.2 and 2.3.

Table 2.2 Surface residual stress values for the test specimen in as-welded condition

POINT	STRESS (MPa)
1	29,69
2	-15,64
3	-36,13
4	-66,57
5	9,61
6	-28,29
7	73,67

Table 2.3 Surface residual stress values for the treated test specimen with shot-peening

POINT	STRESS (MPa)
1	-237,53
2	-235,85
3	-98,32
4	52,38
5	-168,63
6	-64,98

Tables 2.2 and 2.3 shows the great difference between the surface residual stress values in a test specimen subjected to the shot-peening process and the test specimen in as-welded condition. Must be noticed that, in this experimental work, the weld toe was not treated by shot-peening, and this cause a tensile residual stress values, ex. at point number 4, Figure 2.6, Table 2.3. On the other hand, at the points 1 and 2 (Figure 2.6, Table 2.3) can be observed approximately the same compressive stress value due to shot-peening process application at the heat affected zone.

Table 2.2 presents those surface residual stress values obtained by X-rays diffraction in the as-welded conditions test specimen, showing a residual stress heterogeneous distribution.

To measure the residual stress values the points, for the aluminum alloy test specimens, were chosen following a symmetric straight line from the weld toe until a thermally affected region (see Figure 2.7).

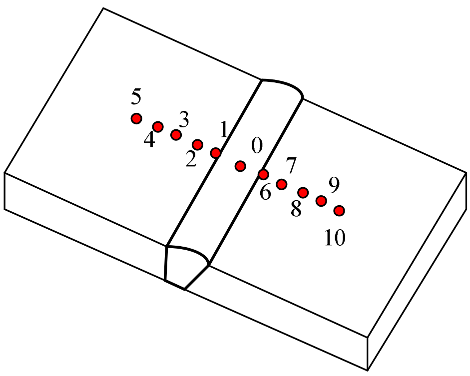


Figure 2.7 Point of measure in the aluminum alloy test specimens

The surface residual stress values are showed in a Table 2.4.

Table 2.4 Surface residual stress values for the aluminum alloy test specimens

POINT	STRESS (MPa) (without shot peening)	STRESS (MPa) (with shot peening)
0	-26	-28
1	-17	-44
2	-16	-47
3	-7	-40
4	8	-39
5	-3	-43
6	9	-41
7	-9	-44
8	-1	-40
9	-15	-38
10	-7	-43

Table 2.4 shows the great difference between the surface residual stress values in a test specimen subjected to the shot-peening process and the test specimen in as-welded condition. Surface residual stress values obtained by X-rays diffraction in the as-welded conditions test specimen, shows a residual stress heterogeneous distribution.

2.4 Fatigue tests

Only the eight test specimens of steel, four in as-welded conditions and four treated by shot-peening, were subjected to a three point bending test, considering the quantity of cycles until the crack initiation starts as a parameter for comparison. Fatigue testing was carried out using a universal test machine showed at Figure 2.7.

Loading was conducted in a typical three point bend configuration, see Figure 2.7. Constant amplitude loading was applied with a stress ratio R=0.3 approximately at a range of maximum stress values between 68 and 258 MPa. Table 2.5 shows the obtained results.

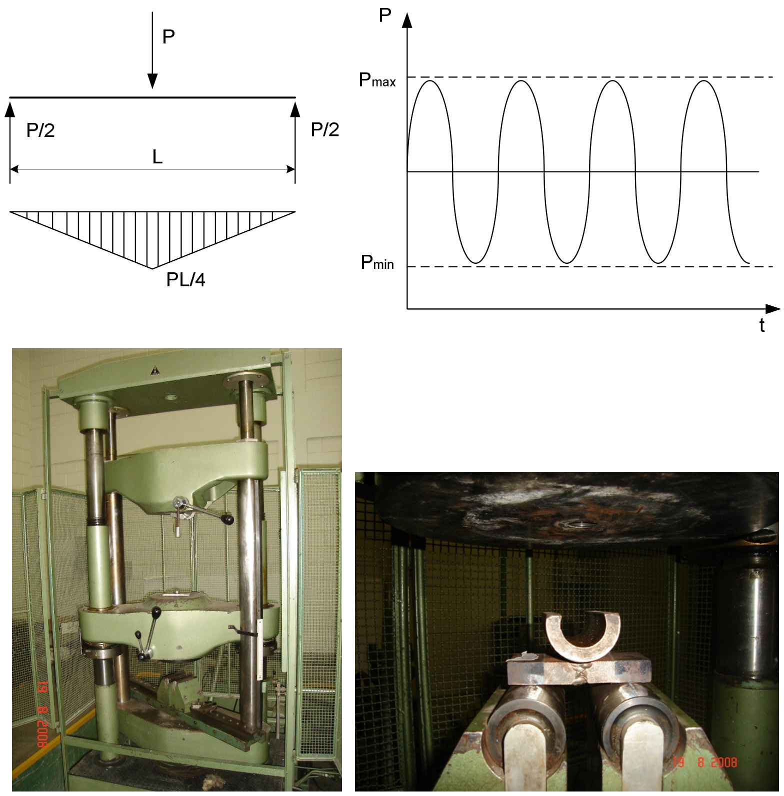


Figure 2.7 Three point bending test (Engineering School Laboratory, Mackenzie Presbyterian University)

Table 2.5 Fatigue tests results (WSP-without shot-peening; SP-shot-peening)

T. Spec.	Pmin & Pmax	σmin & σmax	Number of cycles	Observed result
1 (WSP)	1000 kgf & 3150 kgf	79,40 MPa & 250,11 MPa	146100	Crack initiation
2 (SP)			179200	Crack initiation
3 (WSP)	400 kgf & 1100 kgf	93,57 MPa & 257,34 MPa	300600	Crack initiation
6 (SP)			725400	Interrupted without cracks
5 (WSP)	400 kgf & 1100 kgf	93,57 MPa & 257,34 MPa	318300	Crack initiation
4 (SP)			418300	Interrupted without cracks
7 (WSP)	100 kgf & 380 kgf	67,44 MPa & 256,29 MPa	219400	Crack initiation
8 (SP)			461900	Interrupted without cracks

Observing the values in a Table 2.5 can be notice the beneficial influence of the shot peening process to increase the fatigue resistance in the treated steel test specimens. That is one of the most important advantages of this technique.

3. CONCLUSIONS

The obtained results show, in general, the beneficial effects of the shot peening process to improve the mechanical properties in welded joints. This is a preliminary work and would be necessary major quantity of experimental values to be more conclusive.

In Brazil, the shot peening techniques used as post welded treatment, in general, is not employed. This paper pretends to help to create a technical culture in this way. There are many applications in several engineering field were those techniques may be used, mainly in those cases where the fatigue loading are present.

Large pieces and structures cannot be treated cause of its dimensions, but, evidently only the critical regions must be treated. There is a traditional techniques such as the Hammer Peening and other more modern like Ultrasonic Peening that permit only treat those critical zones.

3. ACKNOWLEDGEMENTS

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4. REFERENCES

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