PAPER REF: 4008

# EVALUATION OF SHOT PEENING ON THE FATIGUE STRENGTH OF CUSTOM 465 STAINLESS STEEL FOR AERONAUTIC APPLICATION

**Rafael Gustavo Bonora [1(*)], Herman Jacobus Cornelis Voorwald [2], Maria Odila Hilário Cioffi[3]**
[1, 2, 3]Fatigue and Aeronautical Materials Research Group - DMT/FEG/UNESP, State University of Sao Paulo, Sao Paulo, Brazil.
[(*)]*Email:* rafael_bonora@hotmail.com

## ABSTRACT

This project was originated from the national aircraft industry requirements to reduce the use of coated materials with electroplated chromium or cadmium that produce waste, which is harmful to health or the environment. The selected material is a Custom 465 stainless steel used in the aeronautical field due to its high mechanical strength. Considering the load sustained by the wheel axis of the landing gear, the Custom 465 is tested in axial fatigue. The objective is to compare the behavior of the Custom 465 with plated AISI 4340 steel coated with cadmium. X-ray diffraction method was used to determine the residual stress field induced by shot peening.

**Keywords:** fatigue, Custom 465, AISI 4340

## 1. INTRODUCTION

Metallic materials subjected to cyclic loads may fail in lower tensile required for static loading. These failures are called fatigue failure, which can be sudden and occur without previous indication of their occurrence (Dieter, 1988).

Fatigue failure is a main concern application related to structural materials. Among the many methods available to describe the different aspects of fatigue behavior, traditional approach based on curves S-N is the most used in comparative evaluations of materials (Lee, 2005).

Currently, high strength materials, especially AISI 4340 steel, are widely used as landing gear components. Due to the high resistance to wear and corrosion requirements, components are usually coated with hard chromium or cadmium. Treatments can produce wastes such as cyanide and $Cr^{+6}$, for example, generated after the application hard chromium and cadmium coatings, which are harmful to health and environment (Sahraoui, 2004).

One of the known ways to improve fatigue strength is by using the shot peening process. Shot peening is one of the most common industrial processes used to increase the fatigue life of metallic components. In this process, the plastic deformation produced by the impact of a stream of small spherical projectiles on the surface of a metallic element to induce a compressive residual stress field in the surface layers of the material which results in an enhanced fatigue performance (Sanjurjo, 2010). An increase in the shot peening intensity resulted in an increase in the maximum compressive residual stress and also the width of the field generated (Carvalho, 2007).

Another direct consequence of the shot peening treatment is the modification of the surface finish of the treated component. If the peening parameters are not carefully controlled, the roughness generated after peening could deteriorate the fatigue behaviour of the part, and the benefits of the compressive residual stress field could be significantly reduced (Tekeli, 2002).

In the present paper the availability of replacing the AISI 4340 steel coated cadmium, applied to the axis of wheel landing gear, for Custom 465 stainless steel, will be evaluated. The tests performed to compare these two materials were axial fatigue test and residual stresses.

## 2. EXPERIMENTAL PROCEDURE

*2.1 Materials and mechanical properties*

Aeronautic AISI 4340 steel, is a low alloy steel which has the following chemical composition: 0,41C, 0,73Mn, 0,25Si, 0,80Cr, 1,74Ni and 0,25Mo wt%. The mechanical properties were obtained by a hardening heat treatment at 815 °C for 45 minutes with cooling in oil between 20 and 60 °C, followed by double tempering at 220 °C for 2 h with cooling in air. The mechanical properties obtained were: 50 - 53 HRc, yield strength of 1500 MPa and tensile strength of 2000 MPa.

Aeronautic Custom 465 stainless steel is a martensitic steel high strength which has the following chemical composition: 0,02C max., 0,25Mn max., 0,015P max. , 0,010S max., 0,25Si max., 11,0 – 12,5Cr, 10,75 – 11,25Ni, 0,75 – 1,25Mo and 1,5 – 1,8Ti wt%. Custom 465 was solubilized and aged to get the following mechanical strength: 48 – 52 HRc, yield strength of 1700 MPa and tensile strength of 1800 MPa.

These materials were treated with the following parameters of shot peening: 0,008A, outflow of 3kg/min, a speed of 250mm/min, a distance of 200 mm and rotation of 30 rpm. The shot used was S 230 (Ø 0,7mm) with a coverage of 120% carried out on an air-blast machine according to standard AMS-S-13165.

*2.2 Axial fatigue strength*

Specimens for axial fatigue test were prepared according to ASTM E466 (ASTM, 2007), with the geometries shown in Fig.1.

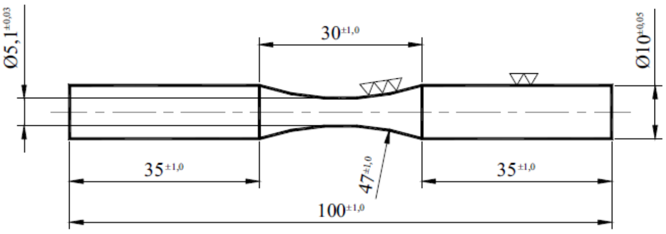


Fig.1. Axial fatigue testing specimen.

Fatigue tests were conducted using a sinusoidal load of 10 Hz with a load ratio of R = -1, at room temperature. Experimental tests consider as fatigue strength the complete facture of the specimen or $10^6$ load cycles. Five groups of fatigue specimens were prepared to obtain S-N curves for axial fatigue tests. The sample size was 12 for each material condition.

1. Smooth specimens of AISI 4340 steel;
2. Smooth specimens of AISI 4340 steel shot peened;
3. Smooth specimens of AISI 4340 steel shot peened and cadmium electroplated;
4. Smooth specimens of Custom 465 stainless steel;
5. Smooth specimens of Custom 465 stainless steel shot peened.

*2.3 Residual stresses measurement*

The X-ray diffraction method was used to determine the residual stress field induced by shot peening and electroplated cadmium coated. The accuracy of the stress measurement was $\Delta\sigma = \pm$ 10MPa. In order to obtain the stress distribution by depth, layers of specimens were removed by electrolytic polishing with a nonacid solution.

## 3. RESULTS AND CONCLUSIONS

The results from axial fatigue test are represented in figure 2.

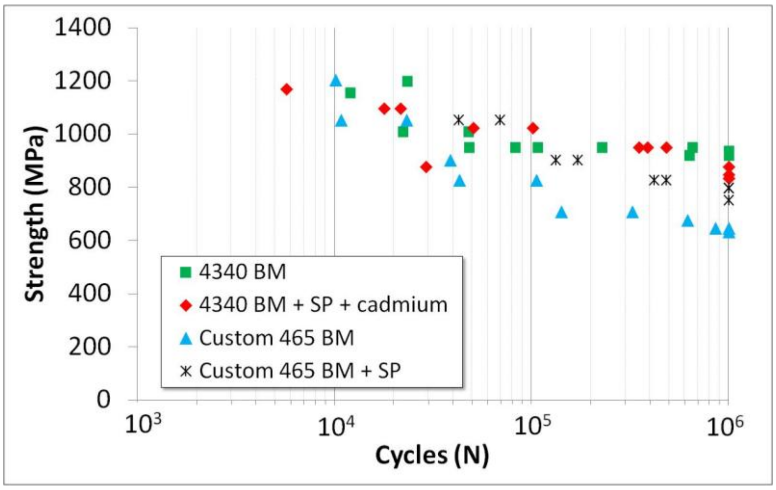


Fig.2 S-N curves for axial fatigue test

In Figure 2 it is possible to observe the influence of shot peening process on the increase in fatigue strength of AISI 4340 steel and Custom 465 stainless steel. Table 1 shows a comparison of fatigue strength at $10^6$ cycles, for both materials. In the same figure the range between the behavior of low cycle fatigue and fatigue strength at $10^6$ cycles is compared for each situation. For AISI 4340 steel the range is 265 MPa, from 23.337 cycles (1.200 MPa) to $10^6$ cycles. For shot peened ASIS 4340 steel the range is 320 MPa, from 22.718 cycles (1.400 MPa) to $10^6$ cycles. On the case shot peened and electroplated cadmium results are 220 MPa and also fatigue strength equal to 880 MPa for $10^6$ cycles. Custom 465 stainless steel shows 405 MPa from 23.121 cycles (1.055 MPa) to $10^6$ cycles.  Shot peened Custom 465 stainless steel indicates a range of 370 MPa from 23.931 cycles (1.200 MPa) to $10^6$ cycles.

In Table 1, the comparison between fatigue strength of AISI 4340 steel shot peened and cadmium electroplated and shot peened Custom 465 indicates a difference of 6%.

Table 1 – Comparison of fatigue strength at $10^6$ cycles between AISI 4340 and Custom 465 stainless steel.

| **MATERIAL** | **$10^6$ Cycles** |
|---|---|
| | **Strength (MPa)** |
| AISI 4340 BM | 935 |
| AISI 4340 BM + SP | 1100 |
| AISI 4340 BM + SP + cadmium | 880 |
| Custom 465 BM | 650 |
| Custom 465 BM + SP | 830 |

The residual stresses were measured using the method of X-ray diffraction. Figure 3 and figure 4 show residual stresses for AISI 4340 steel and Custom 465 stainless steel. The minus (-) means compressive residual stress and the plus (+) means tensile residual stress. Table 2 shows the results of residual stresses for AISI 4340 steel and Custom 465 stainless steel.

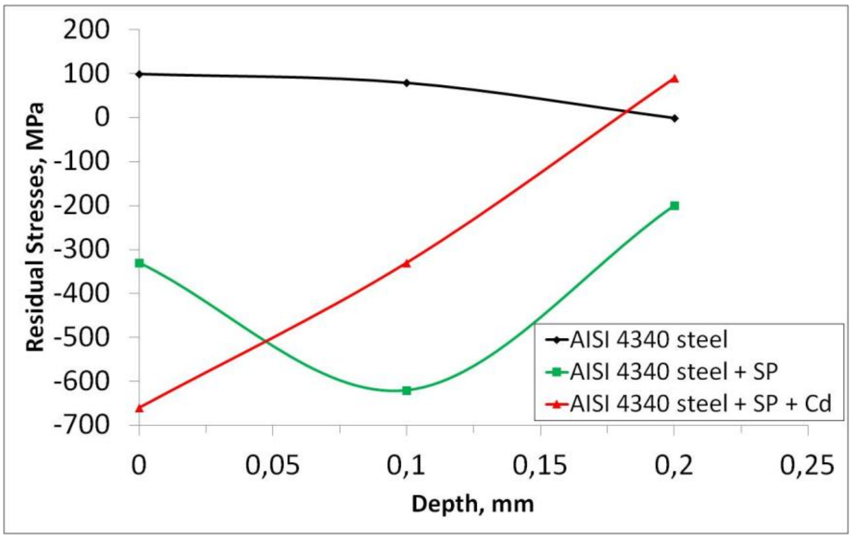


Fig.3 Residual stresses for AISI 4340 steel.

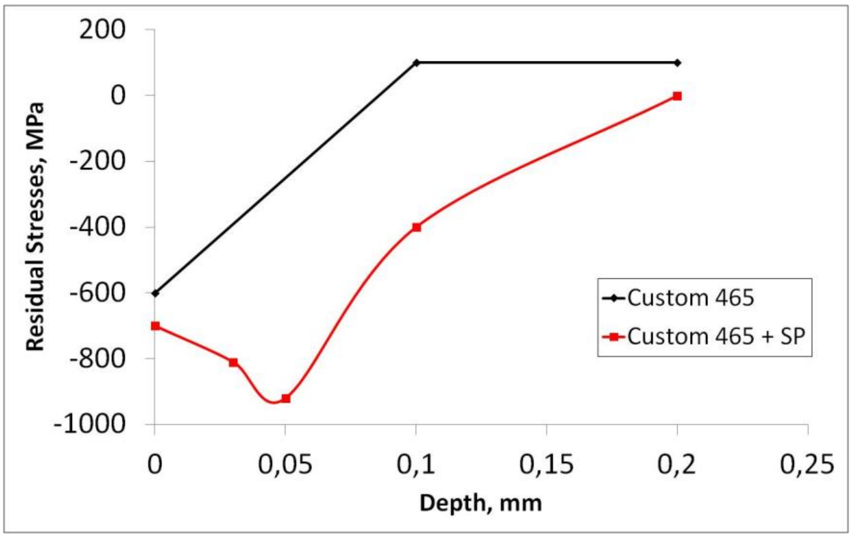


Fig.4 Residual stresses for Custom 465 stainless steel.

Table 2 – Residual stresses for AISI 4340 steel and Custom 465 stainless steel.

| SPECIFICATION OF THE SPECIMEN | DEPTH, mm | | | | |
|---|---|---|---|---|---|
| | 0,00 | 0,03 | 0,05 | 0,10 | 0,20 |
| | ABSOLUTE VALUE OF STRENGTH, MPa | | | | |
| AISI 4340 BM | **+100** | **-----** | **-----** | **+80** | **0** |
| AISI 4340 BM + shot peening | **-330** | **-----** | **-----** | **-620** | **-200** |
| AISI 4340 BM + shot peening + cadmium | **-660** | **-----** | **-----** | **-330** | **+90** |
| Custom 465 BM | **-600** | **-----** | **-----** | **+100** | **+100** |
| Custom 465 BM + shot peening | **-700** | **-810** | **-920** | **-400** | **0** |

For AISI 4340 steel, the production process and the manufacturing processes applied on the specimens induce tensile residual stresses on the surface of +100 MPa, reached +80 MPa at a depth of 0,10 mm and tends to zero at a depth of 0,20 mm. For AISI 4340 steel shot peened, it is concluded that shot peening not only neutralized the tensile residual stresses induced during the manufacturing process as well as compressive residual stresses in the surface layers to a depth of approximately 0,20 mm. For AISI 4340 steel shot peened and cadmium electroplated, the residual stress is -660 MPa on the surface, being reduced to -330 MPa to a depth of 0,10 mm from the surface and achieving a tensile residual stress of +90 MPa at a depth of 0,20 mm from the surface. The reversal of the compressive stress to tensile stress from a particular depth is due to the equilibrium condition resulting stress null along the cross section.

For Custom 465 stainless steel, the production process and the manufacturing processes applied on the specimens induce compressive residual stresses on the surface of -600 MPa, reached +100 MPa at a depth of 0,10 mm and keeping the tensile residual stress of +100 MPa at depth of 0,20 mm. For Custom 465 stainless steel shot peened, the compressive residual stress is -700 Mpa on the surface, and its greatest intensity measured, -920 MPa, was a depth of 0,05 mm. At a depth of 0,10 mm has a compressive residual stress in the order of -400 MPa, and residual stress equal a zero in the depth reached 0,20 mm from the surface.

## 4. CONCLUSION

Experimental results proves that shot peening process is efficient in introducing compressive residual stresses at the surface and subsurface layers for AISI 4340 steel and Custom 465 stainless steel.

Fatigue strength of Custom 465 stainless steel shot peened, in $10^6$ cycles, is compatible when compared with AISI 4340 steel shot peened and cadmium electroplated.

## 5. ACKNOWLEDGMENTS

Authors wish to express their gratitude to the Brazilian funding agencies FAPESP through the process number 2009/04699-3 for the financial support.

## 6. REFERENCES

ASTM E 466. ASTM International, Pennsylvania; 2007.

Carvalho, A.L.M., Voorwald, H.J.C., Influence of shot peening and hard chromium electroplating on the fatigue strength of 7050-T7451 aluminum alloy, International Journal of Fatigue, 2007, 1282 – 1291.

Dieter, G. E. Mechanical Metallurgy (SI metric edition). McGrow Hill Book Co., 3 ed., 1988.

Lee, Y. L.; Pan, J.; Hathaway, R.; Barhley, M. Fatigue testing and analysis: theory and practice. Oxford: Elsevier, 2005.

Sahraoui, T., Fenineche, N.E., Montavon, G., Coddet, C. Alternative to chromium: characteristics and wear behavior of HVOF coatings for gas turbine shafts repair (heavy-duty). Journal of Materials Processing Technology. 152 (1) (2004) 43-55.

Sanjurjo, P., Rodríguez, C., Pariente, I.F., Belzunce, F.J., Canteli, A.F., The influence of shot peening on the fatigue behaviour of duplex stainless steels, Procedia Engeneering, 2010, 1539 – 1546.

Tekeli, S. Enhancement of fatigue strength of SAE 9245 steel by shot peening. Mater Lett 2002; 57:604–8.