65° CONGRESSO ABM INTERNACIONAL
65th ABM INTERNATIONAL CONGRESS
ANAIS PROCEEDINGS
ISSN 1516-392X

RESIDUAL COMPRESSIVE STRESSES APPLIED DUE TO SHOT PEENING PROCESS IN THE TI 6AL 4V ALLOY[1]

Paulo Renato Unger Lavor[2]
Carlos de Moura Neto[3]
Sérgio Delijaicov[4]
Valdemir Soares de Campos[5]

Abstract

The objective is to measure the residual stresses in the Ti 6Al 4V alloy due the shot peening process. The specimens were manufactured in the conditions: 1st machined without Shot Peening; 2nd machined and submitted to Shot Peening in the range: 0,13 N(mm) – 0,46 N(mm); 3rd Machined and submitted to Shot Peening in the range: 0,15 A(mm) – 0,25 A(mm). The residual stresses were measured through the incremental hole drilling technique and the data obtained in a graphic form and are important for stress analysis in order to verify the influence of the residual stresses in the fatigue life. The graphics show the curves of the compressive tensions through the thickness of the three conditions studied and herein follows an idea of the obtained measurements: 1st Machined test specimens without shot peening application: residual compressive stresses of 200 MPa. 2nd Machined test specimens and submitted to Shot Peening application in the range: 0.13 N(mm) – 0.46 N(mm): Residual Compressive Stresses of 500 MPa. 3rd: Machined test specimens and submitted Shot Peening application in the range: 0.15 A(mm) – 0.25 A(mm): Residual Compressive Stresses of 1000 MPa.

Key words: Shot peening; Titanium; Residual stresses; Fatigue.

TENSÕES COMPRESSIVAS RESIDUAIS APLICADAS DEVIDO AO PROCESSO DE *SHOT PEENING* NA LIGA Ti 6Al 4V

Resumo

O objetivo é medir as tensões residuais na liga Ti 6 Al 4V devido ao processo de *shot peening*. Corpos de prova foram fabricados nas condições: 1ª usinada sem *shot peening*; 2ª usinados e submetidos ao *shot peening* na faixa de: 0,13 N(mm) – 0,46 N(mm); 3ª usinada e submetida ao *shot peening* na faixa de 0,15 A(mm) – 0,25 A(mm). As tensões residuais foram medidas através da técnica de medição da furação incremental e os dados obtidos na forma gráfica e são importantes para a análise de tensões para se verificar a influência das tensões residuais na vida em fadiga. Os gráficos mostram as curvas das tensões compressivas através da espessura das três condições estudadas e segue uma idéia das medições obtidas: 1ª Corpos de prova usinados e sem *shot peening*: tensões compressivas residuais de 200 MPa. 2ª Corpos de prova usinados e submetidos à aplicação de *shot peening* na faixa de 0.13 N(mm) – 0.46 N(mm): tensões compressivas residuais de 500 MPa. 3ª Corpos de prova usinados e submetidos à aplicação de *shot peening* na faixa de 0.15 A(mm) – 0.25 A(mm): tensões compressivas residuais de 1.000 MPa.

Palavras-chave: *Shot peening*; Titânio; Tensões residuais; Fadiga.

1 *Contribuição técnica ao 65º Congresso Anual da ABM,26 a 30 de julho 2010, Rio de Janeiro, RJ, Brasil.*

2 *Engenheiro / Tecsis Tecnologia e Sistemas Avançados.*
3 *Professor Doutor / Instituto Tecnológico de Aeronáutica - ITA*
4 *Professor Doutor / Centro Universitário da FEI.*
5 *Engenheiro / Empresa Brasileira de Aeronáutica - Embraer*

1 INTRODUCTION

In a large quantity of parts submitted to cyclic tensions which failed during the work, the failure occurred due to the surface treatments that in general reduce fatigue life due, the shot peening was indicated as a treatment useful to improve this property. The shot peening process prevents fatigue crack initiation and delay fatigue crack propagation by inducing a compressive residual stress field in the upper layers of the substrate.(1)

"Against this improvement we have the deteriorating effect of the high roughness and also the fact that the local tensions are higher in the areas near the holes and at notch root that determine the resistance to fatigue crack nucleation.(2)

Considering a condition that a component is submitted to cyclic tension loads, with the application of the shot peening process introducing compressive residual stresses, these stresses will reduce the effect of the applied tension loads, so this reduction in the resultant tension stresses improves the fatigue life. There are experimental evidences that residual compressive stresses can drastically reduce the growth rate of tiny surface cracks.

This work has the objective to obtain the profiles of the residual compressive stresses introduced through the Shot Peening process in the Ti 6Al 4V alloy.

2 MATERIALS AND METHODS

In this present work which considers the applications in the field of aeronautical industries it was selected a Ti 6Al 4V alloy. This alloy was select due to its good strength to weight ratio which is desirable in the design of part for aircraft applications. Considering the fact that the compressive strength of this alloy is high it becomes feasible, through the shot peening process, to store high residual compressive stresses induced through the shot peening process, with the final target to improve the fatigue life of the part.

2.1 The Shot Peening Process

The shot peening process is a cold work process in which the surface of the part is submitted to a blasting with small spheres called shots. The shots striking the surface introduce small deformations in the form of dimples, these cause the surface to yield under tension. Just below the surface the compressed grains will try to restore the original form before the blasting process, doing so this process provides a surface subjected to a cold work process with compression tensions.

The objective of this process is to obtain compressive residual stresses in the material to retard significantly the crack initiation and the growth of such cracks under fatigue conditions. As the crack growth is reduced under compressive conditions, so increasing the depth of layer submitted to compressive tensions this cold work obtained through the shot peening process will provide an improvement in the fatigue life.

2.2 Shot Peen Media

Different materials can be used in the shot peening process, e. g., small spheres of cast steel and cut wire obtained from stainless or carbon steel. The stainless steel has to be the material chosen whenever iron contamination in the part can cause

ISSN 1516-392X

problems, that is, the carbon steel can not be used in such conditions where parts contamination is a concern.
In this work test specimens were submitted to shot peening process using the media classified as S230 Cast Steel, this media shall be spherical and free as practical from elongated and angular particles.

2.3 Intensity

The intensity used in the shot peening process is a measurement of the energy of the shot stream applied to the component being submitted to this process. It is important that the equipment maintains, guarantees the process repeatability through the cycles.
The shot peening used in this work had the shot peening applied in the machine CMV - BLASTIBRAS – ZIRTEC REG. 1157, with the characteristics: 2 cars of 7m lenght and 24 (12+12 each side) injection nozzles.
The applied intensities used had the following ranges : 0.13 N(mm) – 0.46 N(mm) and 0,15 A(mm) – 0,25 A(mm).

2.4 Coverage Control

The coverage is the measurement related to surface which was covered by the shot peen media forming the dimples. In the shot peening process the coverage shall be never be less than 100%. This is due considering that the fatigue cracks can develop in areas not peened, and so not having compressive residual stresses which can retard the crack growth. In this work the coverage used during the processing of the test specimens was 200%.

2.5 Compressive Layer

The depth of the compressive layer is of course influenced by the shot peening process parameters, such as for example, the metal base strength, shot peening intensity and the material of the shots. Considering for example, maintaining the same shot peening process parameters, such as intensity, shot materials, parts made of harder materials shall have a depth affected less deeper than those made out of softer materials.

2.6 Incremental Hole Drilling Method

In this work to obtain the residual stress evaluations in a graphic form it was chosen the Incremental Hole Drilling technique due to the residual stress distribution introduced by the shot peening process.
It can expected n accordance with can be expected error of 16% in the residual stress when in the full yield condition and also the highest errors occurred for hole diameters of 1.52 mm and that for the hole diameters of 2.16 mm, the maximum error was 12%.(3) In this present work the hole diameter used in the IHD measurements was 1.85 mm.
Considering the difficulties inherent to the Incremental Hole Drilling technique, this residual stresses evaluation method is possibly the most widely used, and useful of surface residual stress measurements.(4)

Recent work according to the error in residual stress calculation arises when the stress ratio attains values higher than 60%.[5]

2.7 The Shot Peening Residual Stress

As already mentioned the nature of the residual stresses generated through the shot peening process is compressive. These compressive stresses will offset or lower the applied stresses due to loads during the part's work life.
It is shown in the Figure 1 an example of a residual stress profile due to a shot peening process applied in a test specimen of the alloy Ti 6Al 4V.
It can be seen in the graphic that the maximum compressive stress induced is usually adjacent to the surface, and also the depth of the compressive layer which is required to improve the crack growth resistance.

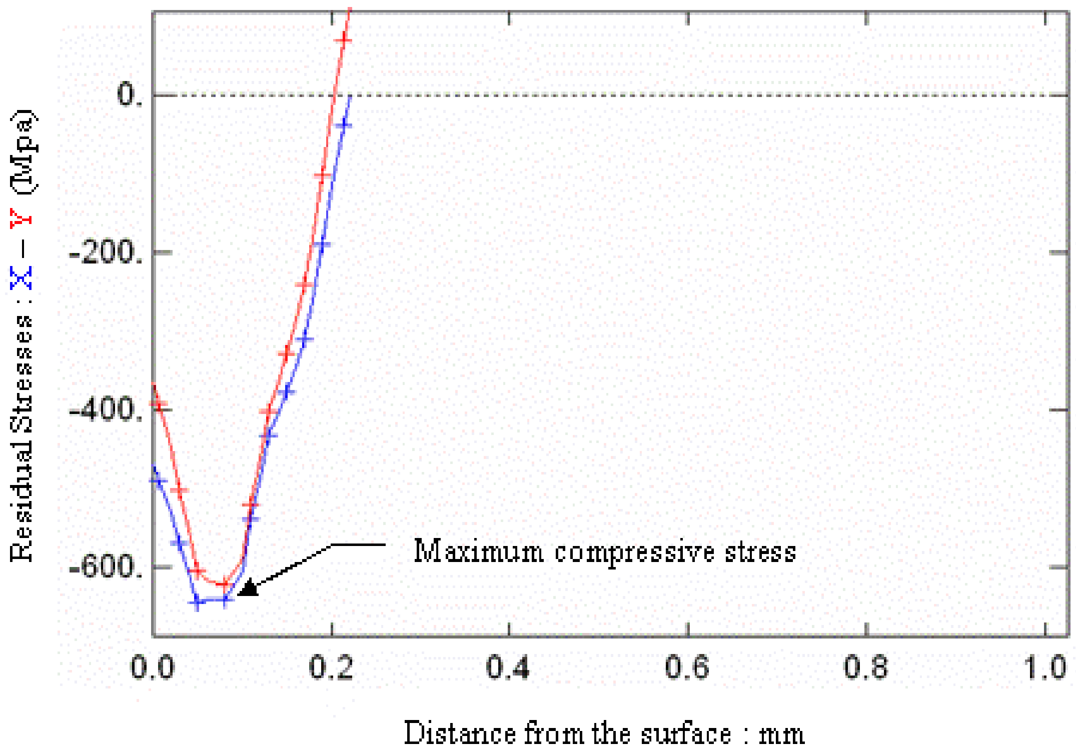

Figure 1. Residual stresses.

The graphic shows that beyond the thickness of approximately 0.2mm we have tension stresses that were originated as reactions to the compressive induced stresses.

2.8 Test Specimen

For this work samples were manufactured of a Ti 6Al 4V alloy to be submitted to shot peening process. The test specimens were manufactured in accordance with the following drawing as shown in the Figure 2".

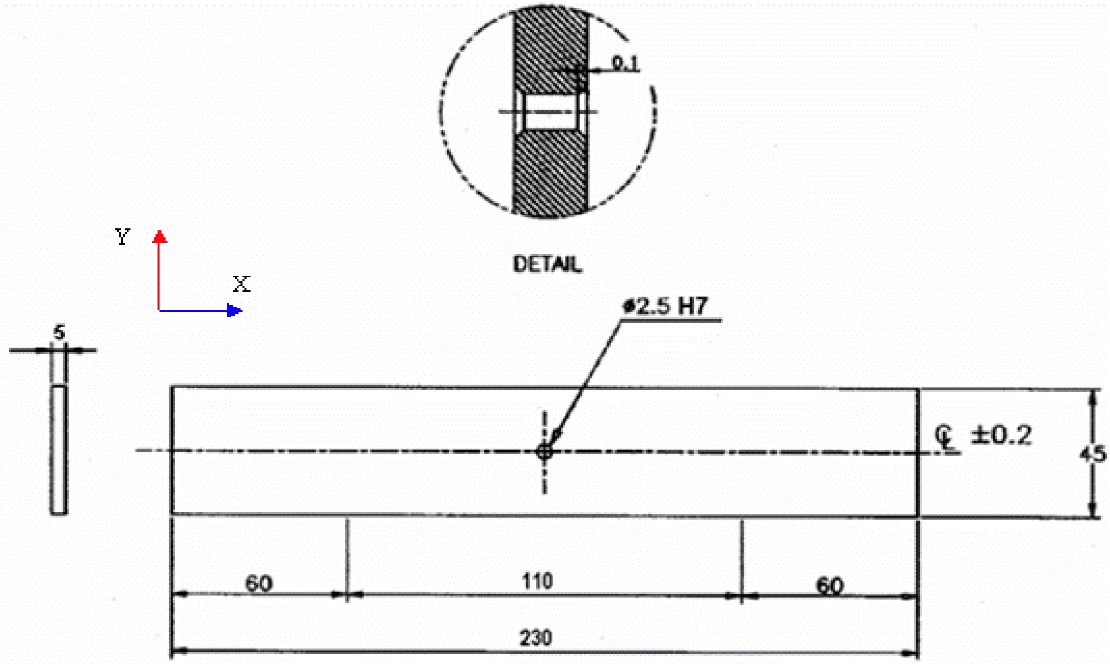

Figure 2. Test specimen (mm).

3 RESULTS

3.1 Residual Stress Profiles – Ti 6Al 4 V

As mentioned in the item 2.3 the following intensities were applied in the samples: 0.13 N (mm) – 0.46N (mm) and 0.15 A (mm) – 0.25 A (mm). The Table 1 shows the test specimen numbers and the respective intensities applied.

Table 1. Test specimen

TEST SPECIMEN	CONDITION
T.S. 4 – T.S 5 – T.S. 18	As machined
T.S. 24 – T.S 31 – T.S. 33	Machined + shot Peened : 0.13 N(mm) – 0.46 N(mm)
T.S. 48 – T.S 50 – T.S. 52	Machined + shot Peened : 0.15 A(mm) – 0.25 A(mm)

The graphics shown in the Figure 3 below show the residual compressive stresses measured through the incremental hole drilling method for the conditions as machined and as machined with shot peening intensity 0.13 N (mm) – 0.46N (mm).

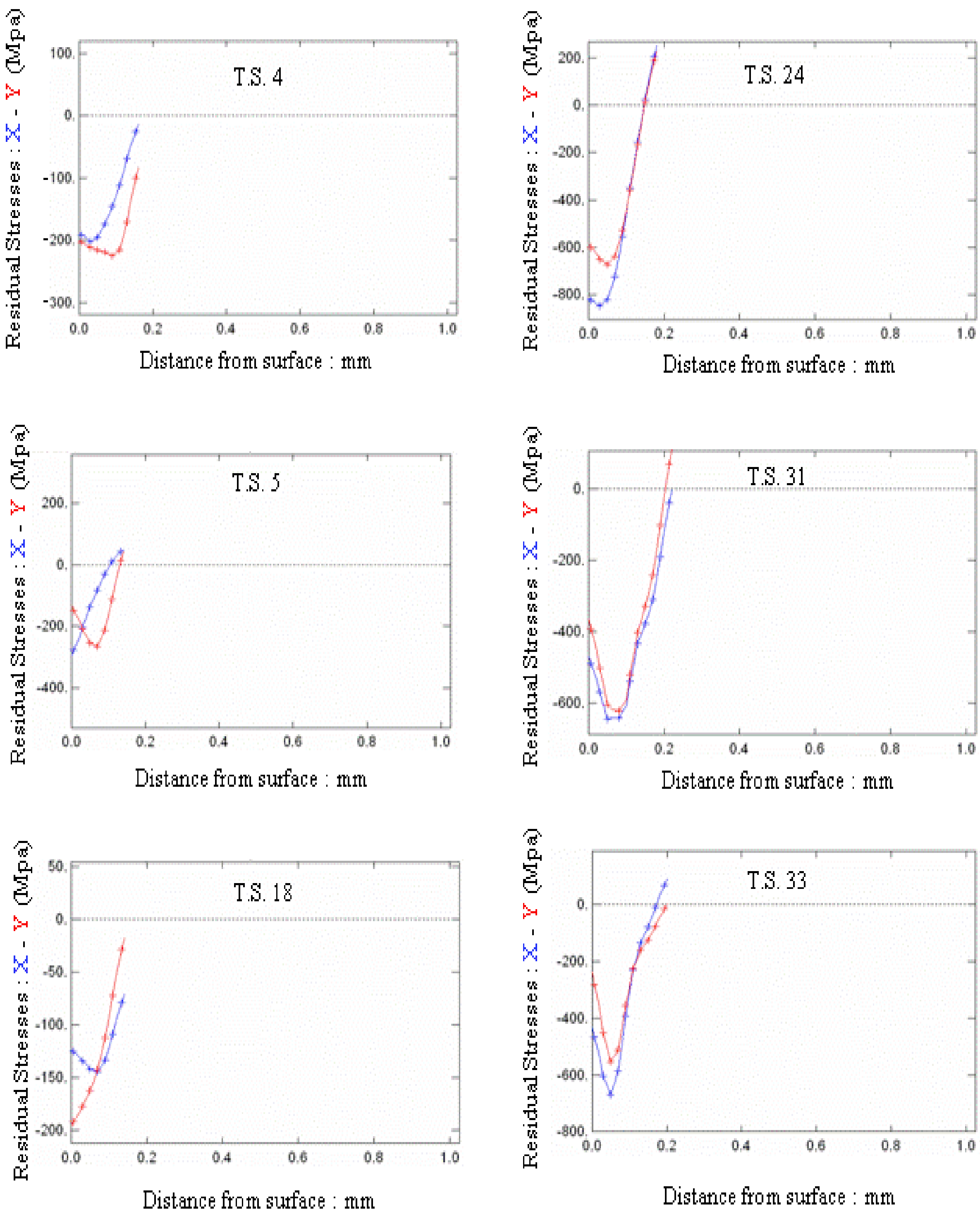

Figure 3. Compressive residual stresses versus depth.

The next Figure 4 shows the residual compressive stresses measured through the incremental hole drilling method for the conditions as machined and as machined with shot peening intensity 0.15 A(mm) – 0.25 A(mm).

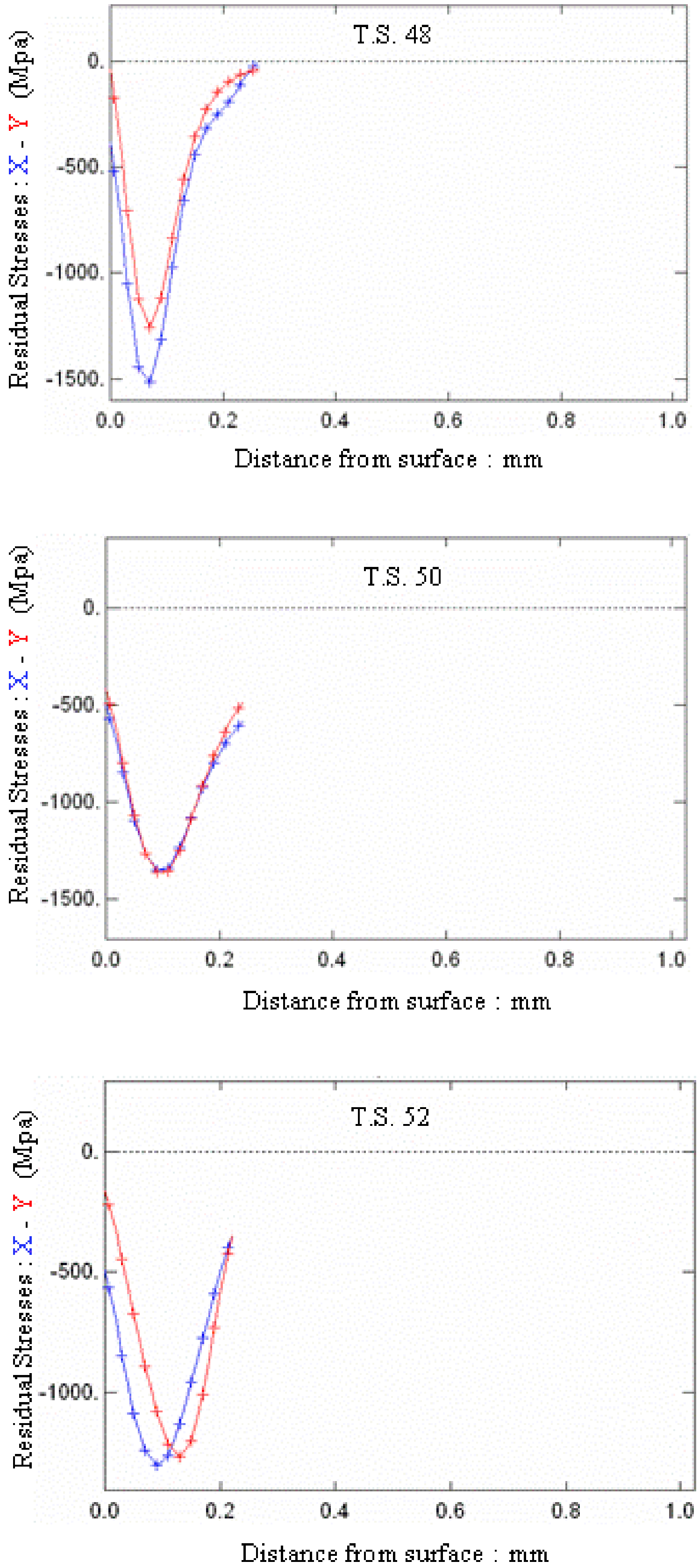

Figure 4. Compressive residual stresses versus depth.

4 DISCUSSION

As expected the residual compressive stresses shown in the Figures 3 and 4 increased with the increasing of the shot peening intensity for the two conditions of studied in this work, however the depth affected showed to be limited to a depth of about 0,2 mm for the higher intensity applied in the studied titanium alloy.
Once cyclic tensile tensions increase the tendency of the cracks propagation, an application of compressive residual stress through the shot peening process will help to reduce the crack propagation trend through lowering the tensile tensions, but as shown in the data set of this work, this action is limited to a depth.
It was not found specific available data of compressive residual stresses introduced due the shot peening process for the standard conditions ranges studied in this work for the titanium alloy then the efforts of this work for this obtaintion through Embraer, FEI and ITA.
It is relevant to consider the cases of parts which have holes, for example, fasteners as bolts, in these cases the shot peening and it's depth limit to induce compressive stress will not avoid crack initiation starting from the hole drilled surface deeper than the verified limit measured in this work. In this case compressive stresses can be introduced through the use of cold work increasing the hole drilled diameter introducing in this way compressive stresses.

5 CONCLUSION

This work showed the residual stress levels for the conditions: as machined, machined and with shot peening applications in the standard ranges: 0.13 N(mm) – 0.46 N(mm) and 0.15 A(mm) – 0.25 A(mm) and the respective depth limits.
The knowledgement of the induced compressive residual stresses provides interesting oportunities to optimize the structural design of parts, this can be obtained considering the reduction of the tension loads applied to the parts considereing the compressive stress tensions induced through the shot peening.
As mentionend above a continuation of this study shall be the fatigue tests for the three conditions studied and also inluding test samples submitted also to cold work in the drilled holes.
Another interesting continuation of this work will be measurements of the residual tensions introduced due to the machining process in the same studied titanium alloy, since the machining process induced residual stresses the machining parameters shall be studied with the objective to induce more specific and desirable compressive tensions in order to improve the fatigue life of the parts.

Acknowledgements

FEI University Center which supplied all the required measurements for this work.
EMBRAER by the manufacture and the shot peening applications in the test specimens and its interest in the results and continuation of this work.

REFERENCES

1 1 CIOFFI, M.O.H., COSTA, M.Y.P., CRUZ, T.G., VENDITTI, M.L.R., VOORWALD, H.J.C., 2009," Materials Science and Engineering "A507 p 29-36.

2 ATOURA, J; LUDIAN, T and WAGNER,L., 2008, " Influence of Shot Peening and Burnishing on Smooth and Notched Fatigue Strengths of Titanium Alloys", ICSP10 p.377.

3 BEANEY, E.M., 1976 "Accurate Measurement of Residual Stress on any Steel using the Center Hole Method Strain, Strain, 12.p 99 -106.

4 BOAG, J.M., FLAMAN, M.T. and MILLS, B.E., 1987, "Analysis of Stress Verification with Depth Measurement Procedures for the Center Hole Method of Residual Stress Measurement" Exp. Tech. p 35-37.

5 DIAS, A.M., GIBMEIR, J., KORNMEIR, M., NOBRE, J.P., 2006 "Local Stress-Ratio Criterion for Incremental Hole-Drilling Measurements of Shot Peening Stresses" ASME 2006 vol. 128 pp 193-200.