# CHARACTERIZATION OF ASTM A743 CA6NM ALLOY STEEL USED IN HYDROGENATOR COMPONENTS

**Braitner Lobato da Silva, lobatodecristo@yahoo.com.br**
**Felipe de Oliveira, felipeol@gmail.com**
**Marcus Vinícius Costa Sá, marcuscsa@gmail.com**
**Jorge Luiz de Almeida Ferreira, jorge@unb.br**
**José Alexander Araújo, alex07@unb.br**

Department of Mechanical Engineering, Campus Universitário Darcy Ribeiro, Brasília, Brazil, 70940-910.

University of Brasília

***Abstract.***

*ASTM A743 CA6NM alloy steel is a stainless inox martensitic steel typically used in hydrogenator components as it can be possible to find in Tucuruí, which is located in the north of Brazil. The design process of these components requests the knowledge of the main static mechanical properties from tensile tests. Furthermore, there is necessity to assess the fatigue properties in order to characterize the material under dynamic condition. Besides, it is important to know fracture parameters in order to understand the crack propagation during the dynamic loading. In that sense, this work proposes to evaluate these static and dynamic properties through the static tests to investigate the hardness, ultimate strength, $S_{rt}$, and yield strength, $S_y$; fatigue tests under uniaxial loads fully reversed to identify the fatigue limit, $S_f$; fatigue crack growth tests in order to determine the threshold of stress intensity factor, $\Delta K_{th}$, according to standard specifications. The obtained results shown a Brinell Hardness of 280 HB, Sy = 550 MPa, Srt = 755 MPa, Sf = 309 MPa to $10^7$ cycles and $\Delta K_{th} = 4{,}12 MPa\sqrt{m}$. The main importance of this paper is to supply the industry and to support engineers in the correct choice of the best design parameters to reduce costs and to optimize the hydraulic components.*

***Keywords**: ASTM A743 CA6NM , mechanic properties, fatigue properties, fracture properties.*

## 1. INTRODUCTION

The definition of the fatigue crack initiation and growth in hydraulic turbine blades by stainless inox martensitic steel are very important. Although the characterization fatigue methodology to be common, the value of this research is accentuated by the fact that alloy steel, used in the production of hydraulic components, does not have their defined properties in the scenery scientific and technological. Therefore, the aim this work is to investigate the mechanic, fatigue and fracture properties of ASTM A743 alloy steel. The obtained results will supply subsidies to definition of design criteria and selection of materials to assemble hydrogenator components.

## 2. EXPERIMENTAL MATERIAL

### 2.1. Base material

In order to investigate the variability of the chemical and mechanic characteristics of the ASTM A743 CA6NM alloy steel, two different samples were tested. The Tab. (1) shows the chemical composition of this material according to ASTM A 743/A 743M standard.

Table 1. Chemical composition of the ASTM A743 CA6NM alloy steel according to standard

| Composition (%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| C | Mn | Si | Cr | Ni | Mo | P | S |
| $\leq$0,06 | $\leq$1,00 | $\leq$1,00 | 11,5-14 | 3,5–4,5 | 0,4–1,0 | $\leq$0,04 | $\leq$0,03 |

The Tabs. (2) and (3) show the chemical composition of both samples. The chemical analysis was accomplished according to ASTM E 327 standard.

Table 2. Chemical composition of the sample A of the ASTM A743 CA6NM alloy steel

| Composition (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C | Mn | Si | Cr | Ni | Mo | P | S | Cu | V |
| 0,05 | 0,67 | 0,52 | 12,94 | 3,21 | 0,4 | 0,036 | 0,01 | 0,173 | 0,037 |

Table 3. Chemical composition of the sample B of the ASTM A743 CA6NM alloy steel

| Composition (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C | Mn | Si | Cr | Ni | Mo | P | S | Cu | V |
| 0,016 | 0,7 | 0,43 | 12,5 | 3,7 | 0,45 | 0,03 | 0,016 | 0,15 | 0,03 |

## 2.3. Fatigue specimens design

The specimen 1 was designed according to ASTM E 606-04 and specimen 2 was starting from ASTM E 466-96. These standards specify the principal dimensions. For this work were used three different specimens: specimen for sample A, Fig. (1); specimen 1 for sample B, Fig. (1) and specimen 2 for sample B, Fig (2) where the Tab. (5) shows the respectively data.

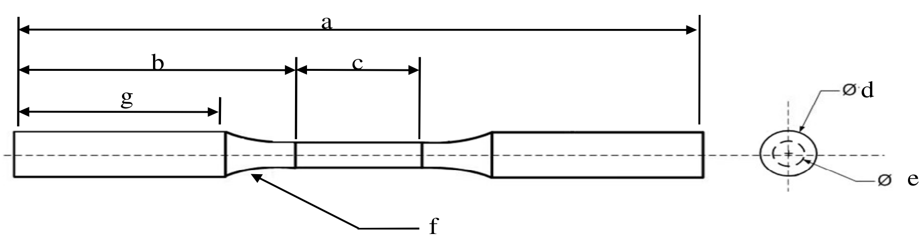


Figure 1. Fatigue specimen 1 for sample A and B

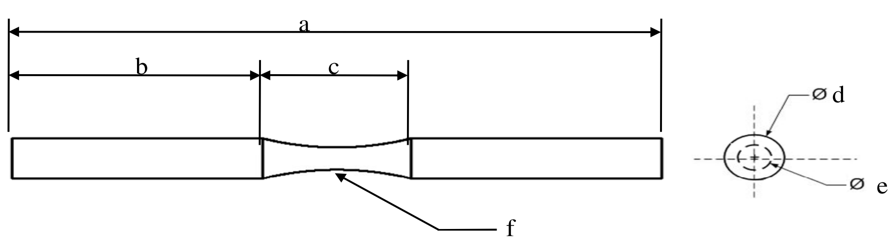


Figure 2. Fatigue specimen 2 for sample B

Table 5. Fatigue specimen data

| Specimen / Sample | a (mm) | b (mm) | c (mm) | d (mm) | e (mm) | f (mm) | g(mm) |
|---|---|---|---|---|---|---|---|
| 1 / A | 151,42 | 63,71 | 24,00 | 10,00 | 6,00 | 48,00 | 50,00 |
| 1 / B | 151,13 | 61,57 | 28,00 | 12,00 | 7,00 | 28,00 | 50,00 |
| 2 / B | 152,40 | 58,87 | 34,66 | 12,50 | 7,00 | 56,00 | |

### 2.3. Fatigue crack growth design

The fracture specimen was designed according to ASTM E 647. These standards specify the principal dimensions, Fig (3), and the Tab. (6) shows the respectively data.

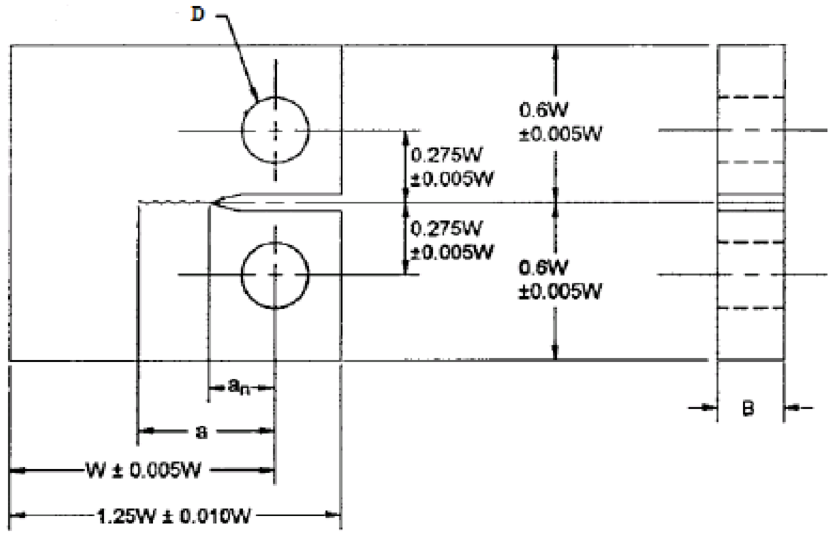


Figure 3. Fracture specimen

Table 6. Fracture specimen data

| Dimension | Size (mm) |
|---|---|
| W | 50 |
| B | 12,5 |
| $a_n$ | 10 |
| D | 14 |

## 3. EXPERIMENTAL PROCEDURE

### 3.1. Tensile properties

Tensile tests were carried out on tensile tester (MTS 810: universal testing machine). The specimens were prepared according to the specification above. The crosshead speed was two millimeters per minute with displacement control. Simple tension tests were performed with two millimeters per minute, with displacement control, in a MTS 810, according to NBR 6152. The Brinell hardness tests were accomplished by HPO 250 VEB Werkstoffprufmaschignen Leipzig machine. Two different lots from the sample B were analyzed. These lots were extracted from different part of the material. Five measurements were made in the sample A, five in the sample $B_1$ and seven in the sample $B_2$.

### 3.2. Fatigue tests

The fatigue tests under uniaxial loads fully reversed, R = -1, performed in a MTS 810 universal testing machine. As recommended by ASTM E468-90 and ASTM E 739-91 standards, the minimum number of specimens necessary to obtain the S-N curve depends on the type of testing program intended. In this work, the purpose is determining critical design values. In this sense, a minimum number of 12 specimens were necessary with a reproduction of the tests between 50 and 75%. Therefore, 11 specimens of sample A and 22 specimens of sample B were experimentally evaluated. For a preliminary analysis, 2 specimens associated to each one of 5 stress levels were tested. In the three levels where a higher scatter of the results was observed, the tests were replied. The stress levels used in the fatigue tests are presented on Tab. (4).

Table 4. Stress levels used to obtain S-N curves

| Sample | $S_a/S_{rt}$ (%) | | | | |
|---|---|---|---|---|---|
| | 1º | 2º | 3º | 4º | 5º |
| A | 46,9 | 49,4 | 52,1 | 57,2 | 63,3 |
| B | 38.4 | 39.6 | 43.6 | 47.9 | 55.5 |

### 3.3. Fatigue crack growth tests

Notched specimens were prepared, Fig (3), to obtain the threshold stress intensity factor, $\Delta K_{th}$, according to ASTM E 647. In this sense, it was used decreasing rate of *K*, stress intensity factor, about $10^{-7}$ mm/cycle.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Hardness test

The Tab. (5) presents the obtained results of the hardness tests in base material as well as its statistical characterization.

Table 5. Hardness of the base material

| | Sample A (HB) | Sample $B_1$ (HB) | Sample $B_2$ (HB) |
|---|---|---|---|
| Mean | 269,6 | 264,0 | 282,0 |
| Deviation | 5,36 | 8,57 | 5,50 |
| CV (%) | 1,98 | 3,20 | 1,90 |

In order to evaluate if there is significant variation on the measurements, the simple analysis of variance was made testing if the hypotheses that the samples A, $B_1$ and $B_2$ are equals. The Tab. (6) presents the obtained results.

Table 6. Analysis of variance among base material samples

| Source of variation | Degrees of freedom | Sum of squares | Mean square | F | P-value | F-critical |
|---|---|---|---|---|---|---|
| Between groups | 1 | 84,74 | 84,74 | 0,827 | 0,377 | 4,543 |
| Within groups | 15 | 1536,2 | 102,41 | | | |
| Total | 16 | 1629,9 | | | | |

Starting from the obtained results in Tab. (6), the two lots of sample B have the same mean hardness because $F <$ *F-critical*. However, the samples A and B present high scatter as show the Tab. (5). The mean Brinell hardness is equal to 280 HB.

### 4.2. Tensile properties

The obtained results are shown in the Tab. (7).

Table 7. Mechanical properties

| Sample | Test | E (GPa) | $S_y$ (MPa) | $S_{rt}$ (MPa) |
|---|---|---|---|---|
| A | 1 | 198 | 637 | 890 |
| B | 1 | 200 | 600 | 919 |
| | 2 | 195 | 550 | 917 |
| Mean | | 198 | 575 | 918 |
| Deviation | | 4 | 35 | 1 |

Considering that the standard to demand $S_y > 550$ MPa and $S_{rt} > 755$ MPa, can be to conclude that the material tested has mechanical properties similar to ASTM A743 CA6NM.

### 4.3. Fatigue results

The Tabs. (8) and (9) show the statistical fatigue behavior for estimate lives for such stress level and the Fig. (4) presents the trend lines for such sample. In that tests were used 11 specimens of the sample A and 22 specimens of the sample B.

Table 8. Statistical fatigue behavior - Sample A

| $S_a$ (MPa) | 417 | 440 | 463 | 509 | 566 |
|---|---|---|---|---|---|
| $S_a/S_{rt}$ (%) | 46,9 | 49,4 | 52,1 | 57,2 | 63,3 |
| Mean | 9,63 e+05 | 3,51 e+05 | 1,99 e+05 | 8,03 e+04 | 9,38 e+03 |
| Deviation | 5,46 e+05 | 5,73 e+04 | 4,92 e+02 | 2,63 e+04 | * |
| CV (%) | 56,7 | 16,3 | 0,2 | 32,7 | * |

Table 9. Statistical fatigue behavior - Sample B

| $S_a$ (MPa) | 353 | 364 | 400 | 540 | 509 |
|---|---|---|---|---|---|
| $S_a/S_{rt}$ (%) | 38,4 | 39,6 | 52,143,6 | 47,9 | 55,5 |
| Mean | 1,73 e+06 | 1,13 e+06 | 4,53 e+05 | 2,61 e+05 | 5,75 e+04 |
| Deviation | 5,49 e+05 | 8,82 e+05 | 8,32 e+04 | 1,09 e+03 | 9,74 e+03 |
| CV (%) | 31,6 | 78,1 | 18,4 | 0,4 | 16,9 |

Starting from Fig. (5) can be concluded that the two samples are not same. The behavior their S-N curves is different. The sample B does not have an endurance limit for $10^6$ cycles instead of the sample A. The Tabs. (10) and (11) presents the S-N curve parameters for samples A and B.

Table 10. S-N curve parameters - Sample A

| Parameter | Expected value | | Confidence limits | |
|---|---|---|---|---|
| | Estimative | Deviation | Lower | Upper |
| A | 1049,01 | 84,26 | 850,00 | 1236,00 |
| b | -0,067 | 0,006 | -0,082 | -0,052 |

Table 11. S-N curve parameters - Sample B

| Parameter | Expected value | | Confidence limits | |
|---|---|---|---|---|
| | Estimative | Deviation | Lower | Upper |
| A | 1659,14 | 116,40 | 1416,34 | 1901,94 |
| b | -0,108 | 0,006 | -0,120 | -0,097 |

Evaluating the presented results in Tabs. (10) and (11), although the chemical and mechanical characteristics were statistically equivalent it was possible to conclude that the fatigue behavior is strongly dependent of sample tested. Therefore, the S-N curve that best will represent the material will be that involves the two samples. Considering this hypothesis, the parameters that best describe the fatigue behavior of this alloy steel is shown in Tab. (13).

Table 12. S-N curve parameters - Sample A and B

| Parameter | Expected value | | Confidence limits | |
|---|---|---|---|---|
| | Estimative | Deviation | Lower | Upper |
| A | 1406,94 | 102,91 | 1197,05 | 1616,83 |
| b | -0,094 | 0,006 | -0,106 | -0,082 |

In that way, the fatigue strength for all cases above for $10^6$ and $5.10^6$ cycles are shown in Tab. (14).

Table 13. Fatigue strength

| | $S'_f$ (MPa) | | |
|---|---|---|---|
| N (cycles) | Sample A | Sample B | Sample A and B |
| $10^6$ | 416 | 373 | 384 |
| $10^7$ | 356 | 291 | 309 |

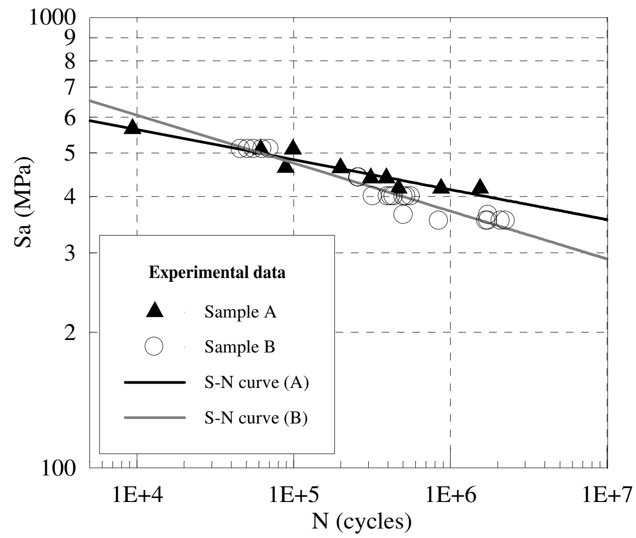


Figure 4. S-N curves of the samples A and B.

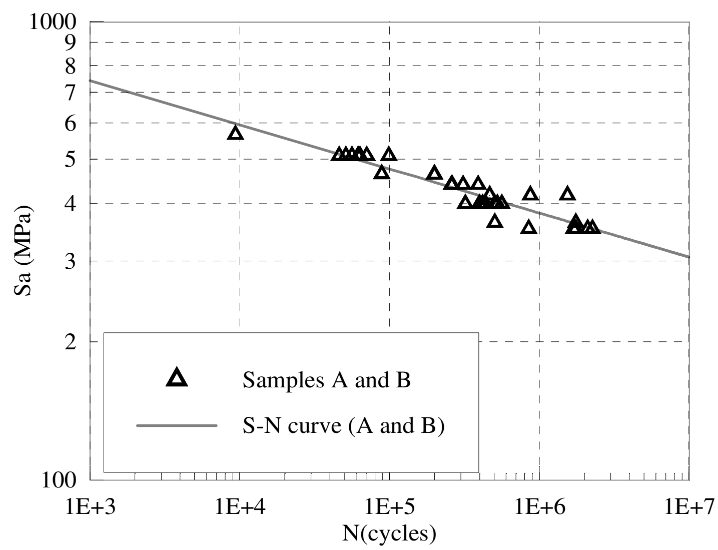


Figure 5. S-N curve of the samples A and B together.

### 4.4. Fracture result

The results were obtained from the linear regression of da/dN curve *versus* $\Delta K_{th}$ using at least five points with equal distance between the following growth rates: $10^{-6}$ and $10^{-7}$ mm/cycle, according recommendations of the ASTM E 647, Fig. (6). In that way, the threshold stress intensity factor is equal to $4{,}12 MPa\sqrt{m}$ . According to recommendations from ASTM E 647

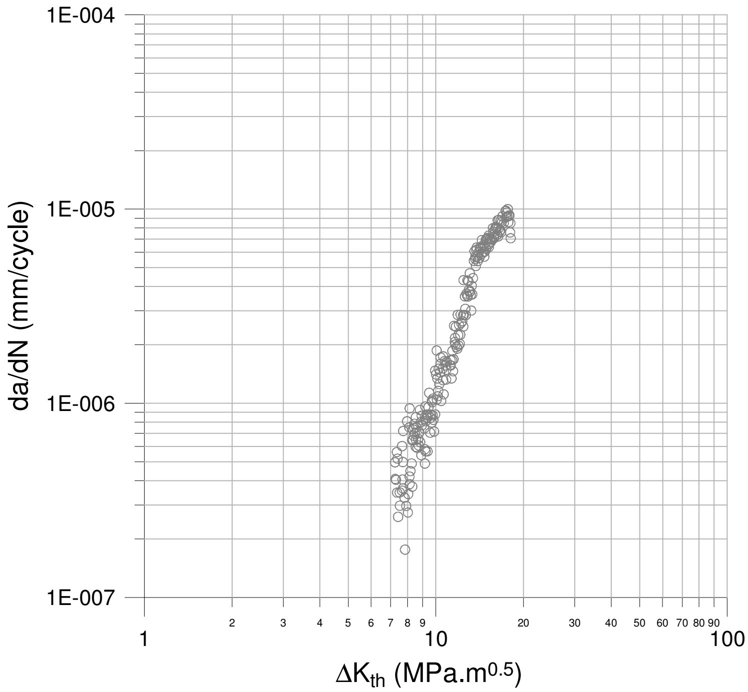


Figure 6. da/dN curve *versus* $\Delta K_{th}$ .

## 5. CONCLUSION

The scope of this work was to characterize the mechanic properties, fatigue behavior and fracture parameters of ASTM A743 CA6NM alloy steel. This material is very important to design process of hydraulic components. In this sense, tension tests were carried out for two different samples, A and B, and verified are statistically similar. This alloy steel has 280 HB of Brinell hardness; yield strength: 550 MPa, ultimate tensile strength: 755 MPa, fatigue limit approximately 309 MPa to $10^7$ cycles and threshold stress intensity factor: $\Delta K_{th} = 4,12 MPa\sqrt{m}$ . The main importance of this paper is to supply the industry and to support engineers in the correct choice of the best design parameters to reduce costs and to optimize the hydraulic components.

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