

## COB-2019-0142

# FATIGUE LIFE OF ALUMINUM ALLOY 7075 - T6511 IN THE PRESENCE OF SMALL DEFECTS

**Vinicius Rodrigues M. Silva**

**Natália G. Torres**

University of Brasilia. Department of Mechanical Engineering, Campus Darcy Ribeiro – 70910-900 Brasília, DF, Brazil

viro2202@gmail.com

nataliatorres.acc@gmail.com

**Edgar N. Mamiya**

University of Brasilia. Department of Mechanical Engineering, Campus Darcy Ribeiro – 70910-900 Brasília, DF, Brazil

mamiya@unb.br

**Abstract.** *The fatigue life of the 7075-T6511 alloy and the effect caused by artificial small defects are investigated. S-N curves were obtained with and without defects. A significant reduction in the fatigue life of the material was observed in the former case. This indicates a high sensibility of this material to small stress concentrators.*

**Keywords:** *Fatigue life, small defects, aluminum alloy, 7075-T6511*

## 1. INTRODUCTION

Machine parts and structural components are often subject to cyclic loading. This condition causes microscopic damage to the material, even if the applied loads do not exceed the yield strength. The accumulation of these damages can lead to the formation and propagation of cracks and, consequently, to the failure of the material. This process is called fatigue.

Investigations show that virtually all fatigue failures start at stress concentrators such as holes, notches and cracks. From this, the relationship between the size, the shape of the defects and the fatigue life must be studied for a correct design of components. The study of the influence of small defects on the fatigue strength of materials has attracted attention of several researchers over the years, including as Murakami (1989); Nadot *et al.* (2004); Endo and McEvily (2011); Yanase and Endo (2014); Beretta *et al.* (2011), among others.

The aluminum alloys of the 7xxx series combine their high mechanical strengths with low densities and good corrosion resistance (ASM (1998)). These materials have been used for more than 50 years in aircraft structural parts and other applications where a combination of lightness and high strength is required. On the other hand, such materials exhibit high sensitivity to stress concentrators due to its low ductility (J.C. Bian (1995)). Therefore, an evaluation of the sensitivity to small defects is very important. In this work, the influence of the small defects in the fatigue life of the 7075-T6511 aluminum alloy is experimentally evaluated.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Material Characterization

The material studied is an Al-Zn-Mg-Cu alloy, specifically the 7075-T6511. A sample of the material was subjected to chemical analysis by energy dispersive X-ray spectroscopy. Table 1 shows the composition of the material.

Table 1: Chemical composition of the aluminum alloy 7075, in wt.%

Si	Fe	Cu	Mg	Mn	Cr	Zn	Ti
0.195	0.275	1.121	4.464	0.046	0.201	4.738	0.037

The measured Brinell hardness of this material was 169.5 Hb.

Monotonic tensile tests were performed according to the recommendations of ASTM E8 / E8M-13 (2013) for the determination of the mechanical properties of the material, listed in Tab. 2. Comparison of these properties with existing data in the literature, such as those obtained by Arcari and Dowling (2012), resulted in variations of less than 5%.

This aluminum alloy exhibits fragile characteristics with high hardness and yield strength combined with low fracture deformation.

Table 2: Mechanical properties of Al 7075 – T6511

Yield Strength (MPa)	Ultimate Strength (MPa)	Young's Modulus (GPa)	Elongation (%)
595	644	72	11.8

## 2.2 Specimens, Defects and Fatigue Tests

Axial fatigue tests were carried out on hourglass type specimen with cross section with 7.5 mm diameter (Fig. 1), according to the recommendations in the ASTM E466-96 (1996) standard. The specimens were grinded up to a 4000 grit in order to obtain a roughness ( $R_a$ ) below  $0.2 \mu\text{m}$ , according to ASTM E606 / E606M-12 (2012). To analyze the effect of the small defects, cylindrical holes of 0.75 mm and 0.425 mm in diameter and 0.75 mm and 0.425 mm in depth, respectively, were milled as shown in Fig. 2. Measurements on the resulting defects were performed using a confocal laser measuring microscope with a magnification of 200X. Table 3 shows the dimensions of the holes. Figures 3 and 4 illustrate the top and profile views of the defects.

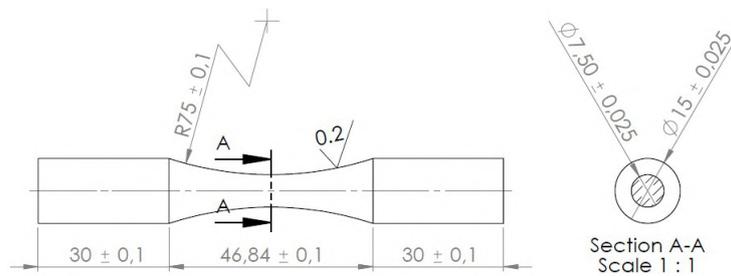


Figure 1: Dimensions of the specimens submitted to the fatigue tests.

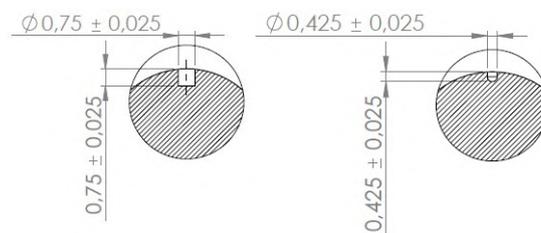


Figure 2: Detail view of the cross section of the specimens with small defects.

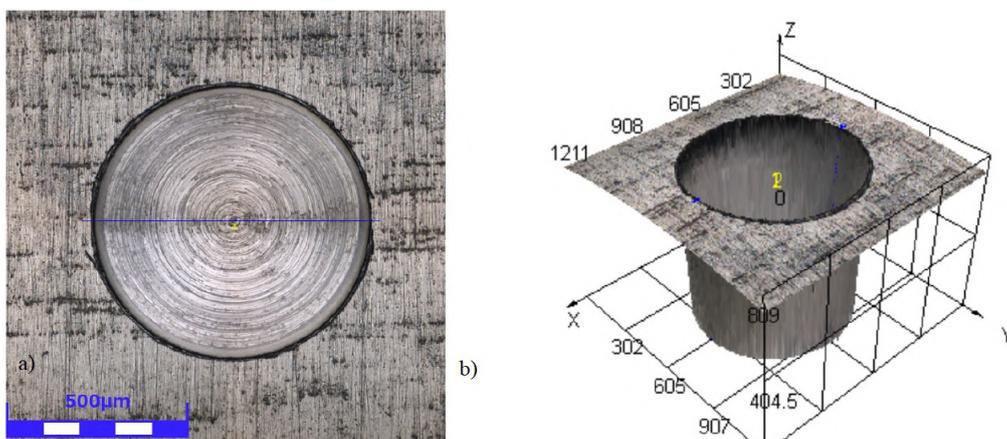
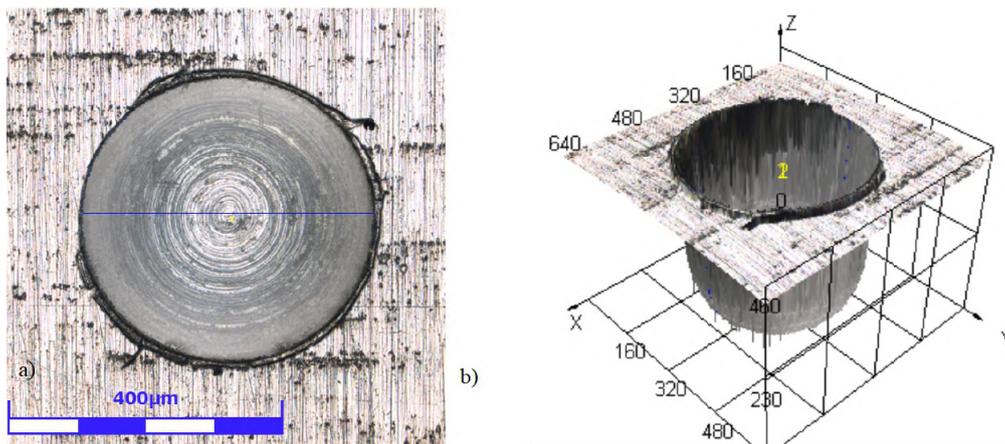


Figure 3: Specimen Al7075H75 – 1: a) Top image of the 0.75 mm defect and b) Profile view.



**Figure 4:** Specimen Al7075H425 – 1: a) Top image of the 0.425mm defect and b) Profile view.

Table 3: Dimensions of the holes

Identification	Diameter (mm)	Depth (mm)
Al7075H75-1	0.73	0.76
Al7075H75-2	0.73	0.75
Al7075H75-3	0.72	0.75
Al7075H75-4	0.72	0.75
Al7075H75-5	0.72	0.75
Al7075H75-6	0.72	0.75
Al7075H425-1	0.425	0.431
Al7075H425-2	0.423	0.423
Al7075H425-3	0.424	0.426
Al7075H425-4	0.422	0.424
Al7075H425-5	0.422	0.425
Al7075H425-6	0.424	0.424

The axial, force controlled fatigue tests were performed with sinusoidal loading, at a stress ratio  $R = -1$  and frequency of 8 Hz. A MTS810 TestFrame uniaxial servo-hydraulic machine with load capacity of up to 100 kN was used.

### 3. RESULTS AND DISCUSSION

The fatigue tests were performed applying stress amplitudes between 175 and 400 MPa. The applied stress amplitudes and the corresponding fatigue lives, in cycles, are shown in Tab. 4 and Fig. 5.

Both baselines were produced considering relation:

$$\sigma_a = \sigma'_f (2N_f)^b, \quad (1)$$

where  $\sigma_a$  is the tension amplitude,  $\sigma'_f$  is the fatigue strength coefficient,  $N_f$  is number of cycles to failure and  $b$  is the fatigue strength exponent. The resulting parameters were  $\sigma'_f = 1072$  MPa and  $b = -0.1082$  for smooth specimens,  $\sigma'_f = 2126$  MPa and  $b = -0.2343$  for that with 0.75 mm defects and  $\sigma'_f = 1426$  MPa and  $b = -0.1809$  for 0.425 mm defects. The correlation coefficient is  $R^2 = 0.9522$  for the smooth specimens,  $R^2 = 0.9595$  for ones these with 0.75 defects and  $R^2 = 0.9639$  for specimens with 0.425 mm defects.

Considering the smaller stress amplitude at which the three specimens (250 MPa) failed, there was a life reduction of approximately 99.1% for the 0.75 mm defect and 89.8% for the 0.425 mm defect. By analyzing the higher stress amplitude applied in common for the three specimens (291 MPa), the life reduction was of the order of 93.6% for the largest defect and 89.7% for the lowest. As expected, the baselines show that the larger the defect, the shorter the life of the material. The life reductions reveal a high sensitivity of this material to the presence of stress concentrators when compared to other materials, such as low carbon steel obtained by Torres *et al.* (2019).

The crack initiation phase accounts for more than 90% of the life of the material (ASM (1987)). Thus, identifying this region is an important step in the material failure analysis process. Fracture initiation produces certain characteristic marks on the surface of the fracture, such as river marks, radial lines, chevrons, or beach marks, which indicate the direction of

Table 4: Experimental results for smooth specimens and with defects.

Specimen Type	Identification	Stress Amplitude (MPa)	Cycles to Failure
Smooth	Al7075S-1	225	2,000,000
	Al7075S-2	250	1,022,198
	Al7075S-3	276	312,370
	Al7075S-4	291	83,344
	Al7075S-5	370	21,204
	Al7075S-6	400	9,920
0.75 mm defect	Al7075H75-1	175	42,926
	Al7075H75-2	200	29,092
	Al7075H75-3	221	11,932
	Al7075H75-4	237	12,071
	Al7075H75-5	250	8,865
	Al7075H75-6	291	5,304
0.425 mm defect	Al7075H425-1	175	123,166
	Al7075H425-2	200	58,764
	Al7075H425-3	221	11,932
	Al7075H425-4	237	18,440
	Al7075H425-5	250	12,344
	Al7075H425-6	291	8,548

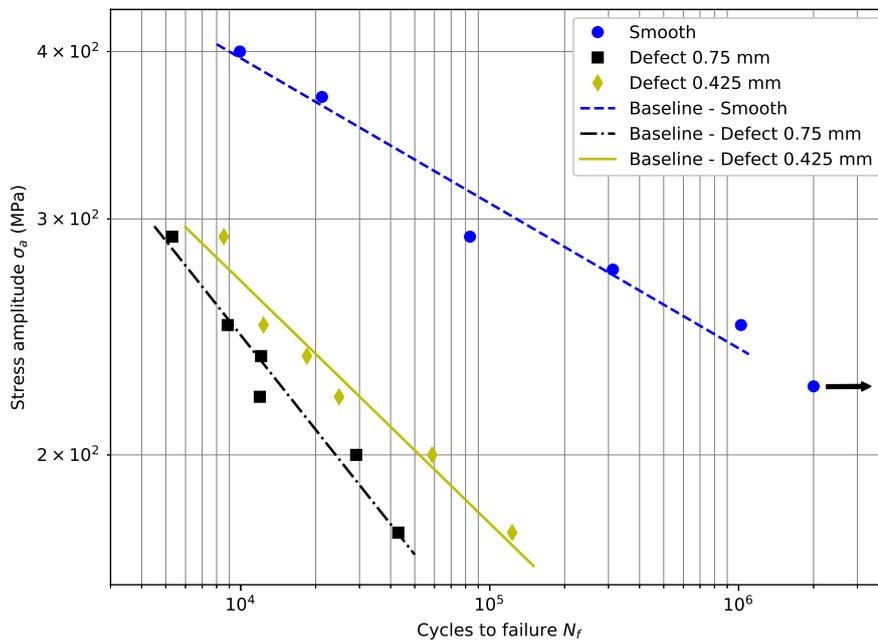
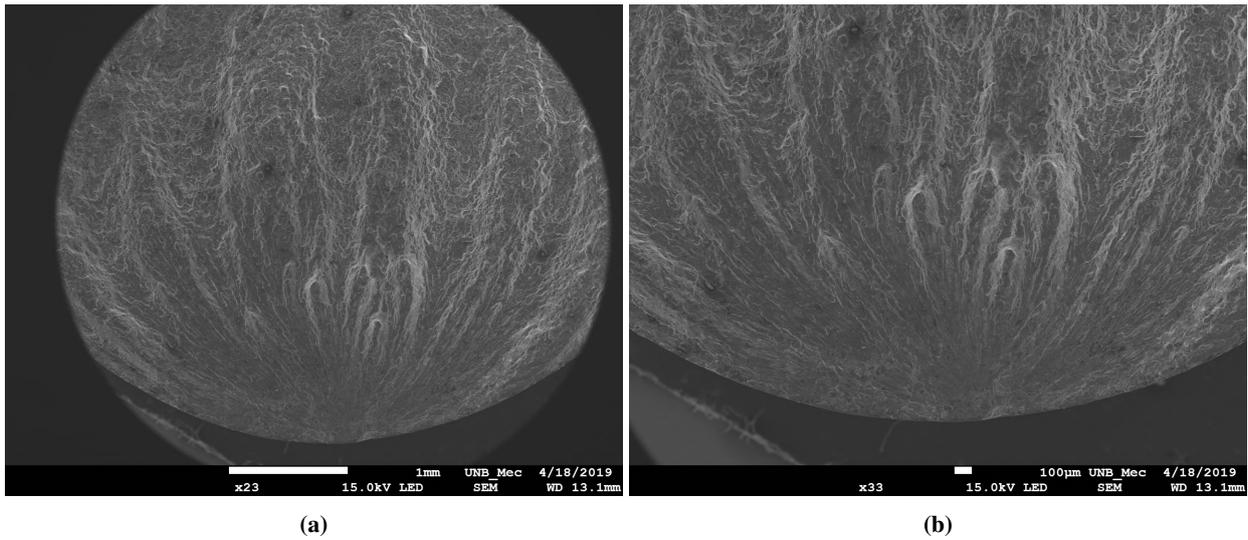


Figure 5: S–N curve obtained for Al 7075 – T6511

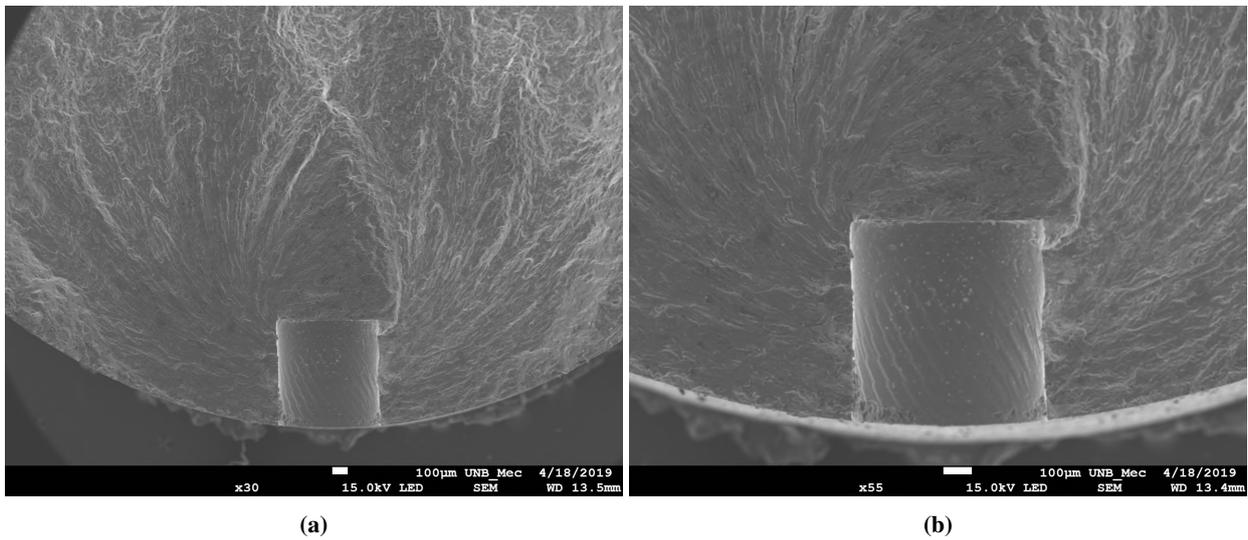
crack growth (ASM (1987)). By observing the failure surfaces of the specimens, the presence of river marks diverging from the region of crack initiation in all specimens is observed macroscopically.

A fractographic analysis was performed using a scanning electron microscope for a more precise identification of the region where the crack was started and also to identify the crack initiation mode.

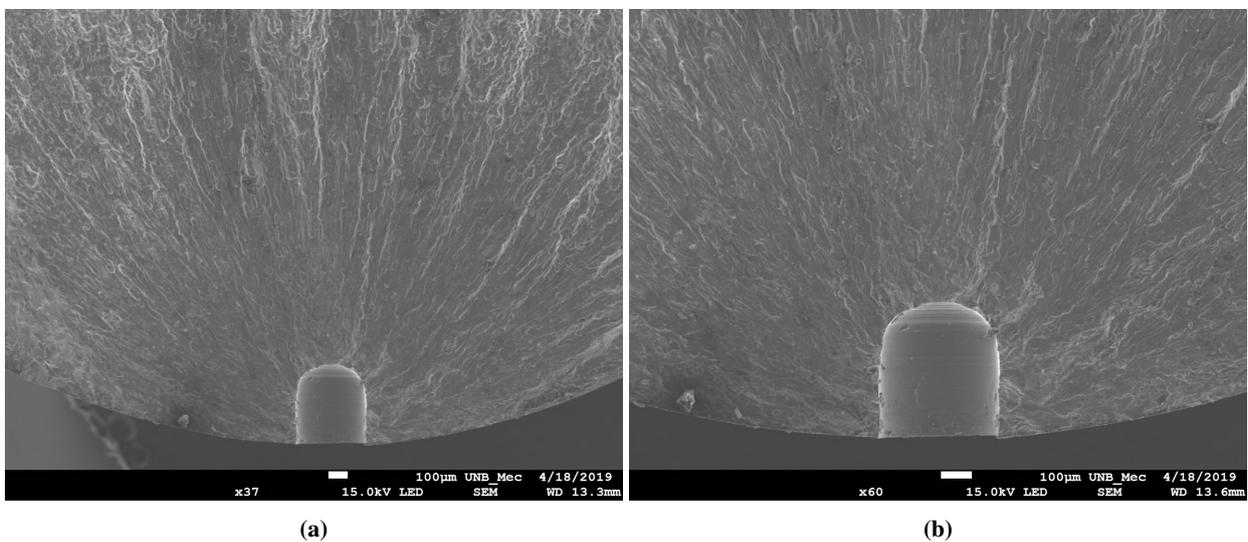
Figure 6 reveals river marks diverging from a region near to the edge of the specimen where the crack started. For the 0.75 mm defect (Fig. 7 - (a) and (b)), the river marks indicate that the initiation of the crack was in the side wall of the hole, proving that the failure occurred due to the presence of that stress concentrator. In the 0.425 defect specimen (Fig. 8 - (a) and (b)) the river marks diverge from the entire side surface of the hole, due to the fact that its hole is not flat, as in the previous case



**Figure 6:** Top view of the Specimen Al7075S-3 (a) magnification - 23X and (b) magnification - 33X

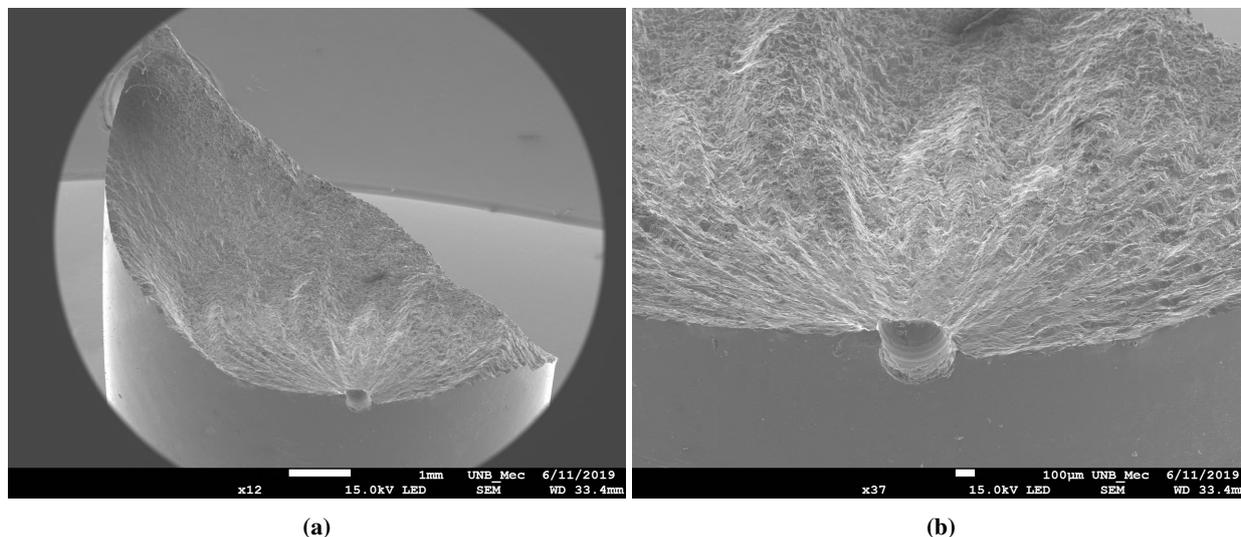


**Figure 7:** Top view of the Specimen Al7075H75-5 (a) magnification - 30X and (b) magnification - 60X



**Figure 8:** Top view of the Specimen Al7075H425-3 (a) magnification - 37X and (b) magnification - 60X

Figure 9 - (a) and (b) show the fracture surface of Al7075H425-3. Note that the crack initiation and propagation occurred in a plane perpendicular to the load application and the catastrophic fracture occurred with an inclination close to 45°, indicating Mode I (ASM (1996)). By analyzing the fracture surfaces of all specimens, it is observed that the failure mode does not depend on the defect, in all cases, even for the smooth specimen. This kind of fracture was expected, given the fragile characteristics of the material.



**Figure 9:** Inclined view of the specimen Al7075H425-3 (a) magnification - 12X and (b) magnification - 37X

#### 4. CONCLUSIONS

In this work, stress-controlled axial fatigue tests were performed, on aluminum alloy 7075-T6511 specimens with and without defects. The results indicate that this material is extremely sensitive to small defects, causing a reduction of more than 99% on the fatigue life. In addition, greater fatigue life reductions were observed for smaller stress amplitudes. The fractographic analysis revealed the presence of river marks indicating the region of initiation of the crack, near the edge of the specimen, for the smooth ones, and near the hole walls, when the small defects were present. Through the images of the fracture surface, it was also possible to observe that Mode I of failure occurs, with the crack initiating and propagating in a plane perpendicular to the load application. Future studies are required to understand the huge reduction in fatigue life.

#### 5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial supports from the Coordination for the Improvement of Higher Education Personnel – CAPES (scholarship), the Brazilian Council for the Scientific and Technological Development – CNPq (scholarship and contract 310063/2018-3) and the Fundação de Apoio à Pesquisa do Distrito Federal (contract 0193.001522/2016).

#### 6. REFERENCES

- Arcari, A. and Dowling, N.E., 2012. “Modeling mean stress relaxation in variable amplitude loading for 7075-t6511 and 7249-t76511 high strength aluminum alloys”. *International Journal of Fatigue*, Vol. 42, pp. 238 – 247. *Fatigue Damage of Structural Materials VIII*.
- ASM, 1987. “Vol. 12: ASM Metals Handbook - Fractography”. ASM International, Ohio, USA.
- ASM, 1996. “Vol. 19: ASM Metals Handbook - Fatigue and Fracture”. ASM International, Ohio, USA.
- ASM, 1998. “Vol. 22: ASM Metals Handbook Desk Edition”. ASM International, Ohio, USA.
- ASTM E466-96, 1996. “Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials”. Standard, ASTM International, West Conshohocken, PA.
- ASTM E606 / E606M-12, 2012. “Standard Test Method for Strain-Controlled Fatigue Testing”. Standard, ASTM International, West Conshohocken, PA.
- ASTM E8 / E8M-13, 2013. “Standard Test Methods for Tension Testing of Metallic Materials”. Standard, ASTM International, West Conshohocken, PA.
- Beretta, S., Foletti, S. and Valiullin, K., 2011. “Fatigue strength for small shallow defects/cracks in torsion”. *International Journal of Fatigue*, Vol. 33, No. 3, pp. 287 – 299.

- Endo, M. and McEvily, A., 2011. "Fatigue crack growth from small defects under out-of-phase combined loading". *Engineering Fracture Mechanics*, Vol. 78, No. 8, pp. 1529 – 1541. Multiaxial Fracture.
- J.C. Bian, K. Tokaji, T.O., 1995. "Notch sensitivity of aluminum-lithium alloys in fatigue". *Fatigue & Fracture of Engineering Materials & Structures*, Vol. 18, No. 1, pp. 119 – 127. ISSN 8756-758X/95.
- Murakami, Y., 1989. "Effects of small defects and nonmetallic inclusions on the fatigue strength of metals". *JSME international journal. Ser. 1, Solid mechanics, strength of materials*, Vol. 32, No. 2, pp. 167–180.
- Nadot, Y., Mendez, J. and Ranganathan, N., 2004. "Influence of casting defects on the fatigue limit of nodular cast iron". *International Journal of Fatigue*, Vol. 26, No. 3, pp. 311 – 319.
- Torres, N.G., Silva, V.R.M. and Mamiya, E.N., 2019. "The effect of small defects on fatigue life of a low carbon steel". In *Proceedings of the 7th International Symposium on Solid Mechanics - MECSOL 2019*. Sao Carlos, Brazil.
- Yanase, K. and Endo, M., 2014. "Multiaxial high cycle fatigue threshold with small defects and cracks". *Engineering Fracture Mechanics*, Vol. 123, pp. 182 – 196. Multiaxial Fracture 2013.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.