

Fatigue Life of Aluminum Alloy 7075-T6511 Considering the Influence of Indentation Defect and Mean Stress

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Abstract: This work investigates the fatigue life of aluminum alloy 7075-T6511 in the presence of small surface defects and considering the effect of the mean stress. Artificial defects with 650 micrometers diameter and 40 micrometers depth were produced with a Brinell hardness test machine. Fully-reversed and positive load ratio ($R = 0.1$) uniaxial fatigue tests were performed. The aluminum alloy showed significant reductions in the presence of defects. For instance, when subjected to a stress amplitude of 240 MPa (less than half the yield stress), the observed life was 30 times shorter than the life of the smooth specimen. When the specimens were subjected to mean stresses, the same life reduction pattern was observed under the presence of indentation defects, as a function of the SWT fatigue parameter.

Keywords: *small defects, fatigue life, aluminum alloy 7075-T6511, mean stress.*

INTRODUCTION

In fatigue studies, it was observed that fatigue life can be reduced when the material exhibits stress concentrators, such as defects, surface flaws and notches (Murakami, 2002). The presence of these stress concentrators in engineering elements is inevitable and therefore a proper understanding of their influence is necessary (Schönbaury, Yanase and Endo, 2017).

Most of the works related to small defects study the fatigue strength of material: Murakami and Takahashi (1998) studied the fatigue strength limit under multiaxial loads, Mari Aman et al (2017) analyzed the interaction between several small defects, Nadot and Billaudeau (2006) proposed the stress gradient method.

More recently, the correlation between defects and fatigue life has attracted attention. Sankaran, Perez and Jata (2001) studied the reduction of the fatigue life of aluminum alloy 7075-T6 in the presence of corrosion pits, widths varying between 36 μm and 430 μm and depths from 9 μm to 51 μm , in uniaxial fatigue tests with $R = 0$.

Another field of study that has attracted the attention is the effect of defects resulting from foreign object damage (FOD). Studies carried out by Ruschau, Nicholas and Thompson (2001) show that the marks produced by impact are similar to those of ballistic impacts or indentations. However, they cannot be analyzed in the same way because they produce different effects on the cyclic behavior of materials. This is mainly due to differences in residual stresses resulting from impacts and indentations.

In the same way, Baragetti et. al. (2011) studied the fatigue behavior of aluminum alloy 7075-T6 in the presence of defects produced by the impact of a steel ball. These defects had depths between 130 μm and 165 μm and caused reductions of up to 30% in the fatigue strength of the material.

During manufacturing or repair routines, the interaction between the mechanical/structural components and tools may produce dents and scratches on the surface. These small defects are comparable to those caused by an indentation, because residual stresses are introduced.

The aluminum alloy 7075 has a huge range of applications, including structural parts in the aeronautical industry. The diversity of use of this material can be explained due to high mechanical strength, yield stress greater than 500 MPa, low density and good corrosion properties (Metals Handbook Desk Edition, 1998).

Within this setting, the main objective of the present study was to quantitatively analyze the reductions in fatigue life of aluminum alloy 7075-T6511, caused by defects produced from indentations, when fully-reversed and positive load ratio ($R = 0.1$) uniaxial fatigue tests were performed.

EXPERIMENTAL PROCEDURE

The material considered in the present study belongs to the 7xxx series, and comes with solubilization heat treatment, followed by quenching and artificial ageing. The material was obtained in the form of Ø15.88 mm extruded bars. The chemical composition of the material is shown in Table 1.

Table 1 – Chemical composition of Aluminum alloy 7075-T6511

Fe	Cu	Mn	Mg	Cr	Zn	Ti
0,5	1,2 - 2,0	0,3	2,1 - 2,9	0,18 - 0,28	5,1 - 6,1	0,2

Hourglass specimens were machined with a minimum diameter of 7.5 mm and length of 46 mm in the test section (Figure 1). After machining, the specimens were polished with 220 to 2500 grit papers. This procedure resulted in a surface roughness less than 0.2µm, as recommended by ASTM E606 / E606M (2019). A monotonic tensile test was performed to obtain the yield stress $\sigma_y = 595\text{MPa}$, ultimate tensile stress $\sigma_u = 697\text{MPa}$ and the Young modulus $E = 72\text{GPa}$. The measured Brinell hardness of the material is 169 HB.

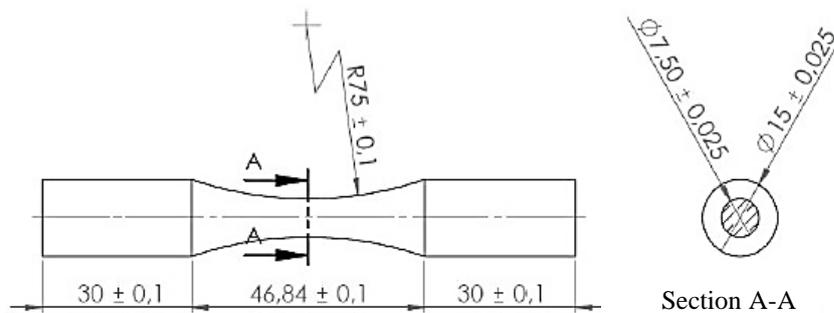


Figure 1 - Geometry of the specimens used in the fatigue tests.

The small defects were produced by indentation – from Brinell hardness tests – with a 2.5 mm diameter steel ball and a load of 62.5 kgf. The defects – measured using a confocal microscope with 200× magnification. – have a spherical cap shape with mean diameter equal to 664 µm and mean depth equal to 45µm (Figure 2).

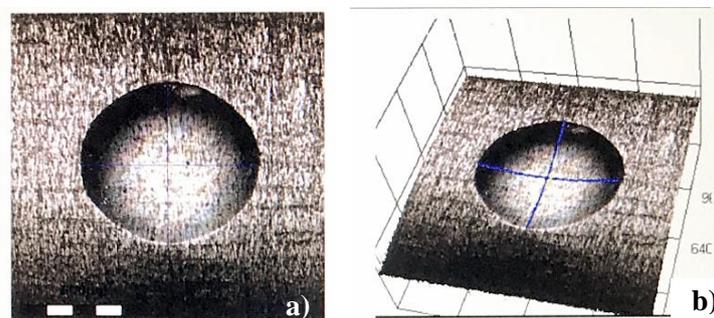


Figure 2 - a) Top view of the defect. b) 3D image of defect.

S-N curves were obtained from force- controlled tension-compression fatigue tests. Smooth as well as indented specimens were considered in the experimentation program. In order to verify the influence of the mean stress on fatigue life, axial tests were performed with loading ratios $R = -1$ and $R = 0.1$. The fatigue tests were performed considering loading frequencies between 6 and 15 Hz. The test run-out condition was defined as 2×10^6 cycles.

RESULTS AND DISCUSSION

Fatigue life analysis

Stress amplitudes and corresponding number of cycles to failure are presented in Table 2. The S-N curves obtained from fully alternated tension-compression loading for smooth and indented specimens is shown in Figure 3, where the lives are shown in terms of the Smith, Watson and Topper - SWT (1970) parameter:

$$SWT = \sqrt{\sigma_{max} \sigma_a} \quad (1)$$

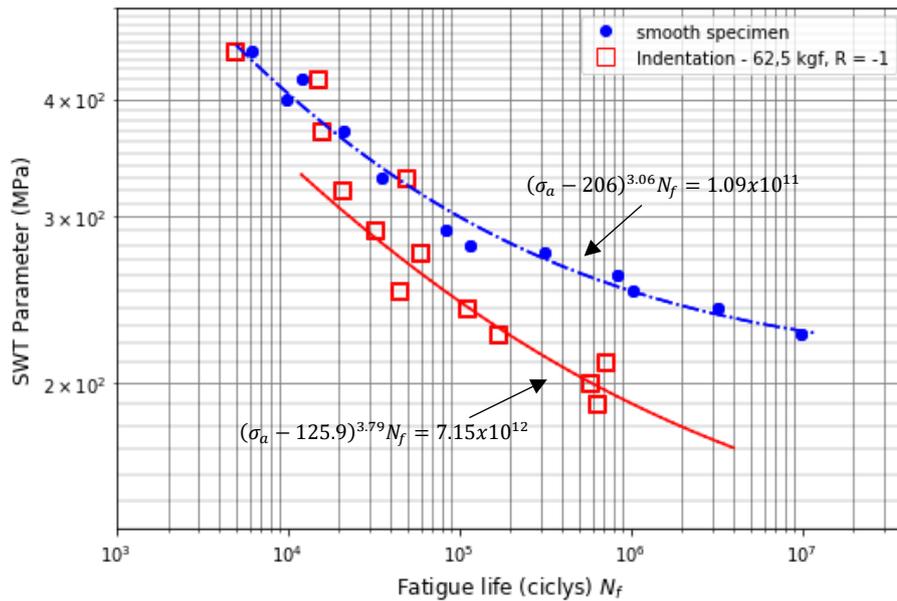


Figure 3 – S-N curve for Al7075-T6511 with fully alternated tension-compression loading.

The results show that, for higher stress amplitudes, the fatigue lives are insensitive to the presence of the defects: the failures did not nucleate at the dent, and fatigue lives were similar to the those observed in smooth specimens. From a geometric point of view, indentation defects are extremely shallow and its influence on fatigue life can be attributed to the inclusion of residual stresses, with magnitudes which can influence the fatigue life under low stress amplitude, but are negligible when compared with higher applied stress amplitudes. Within this setting, the tendency line for the tests on specimens with dents was produced considering only stress amplitudes lower than 350 MPa. The results show that the presence of the small surface defect reduced the fatigue life between 6 and 67 times, for stress amplitudes between 275 and 225 MPa, when compared with smooth specimens. A higher influence of the dents on the fatigue life was observed under smaller stress amplitude.

Figure 4 exhibits the results for the fatigue tests on indented specimens subjected to loading ratios $R = -1$ and $R = 0.1$.

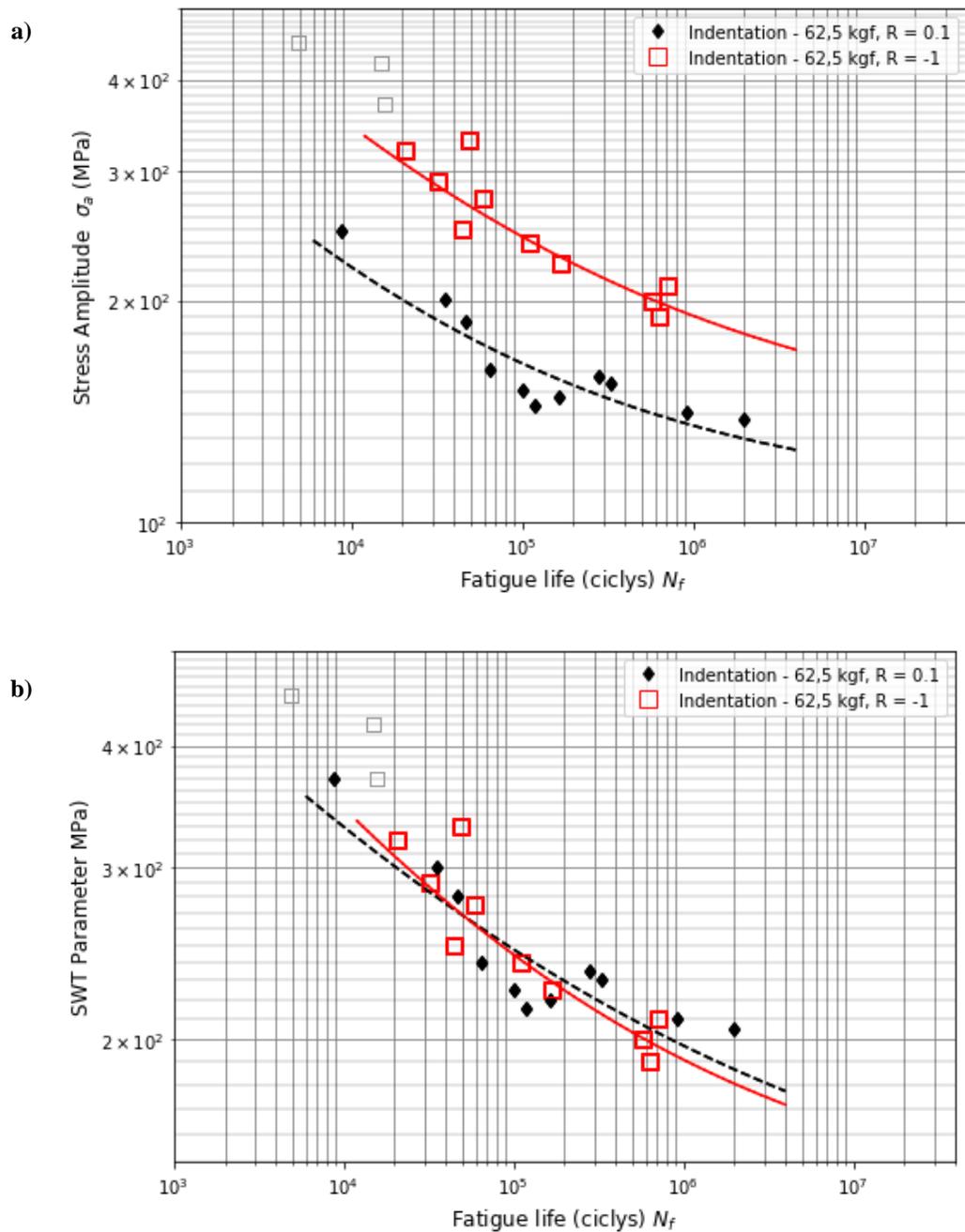


Figure 4 – (a) S-N curve for Al7075-T6511. (b) Fatigue curves for Al7075-T6511 – SWT versus Fatigue life.

The presence of the mean stress caused a reduction in fatigue life between 5 to 16 times, for stress amplitudes between 250 MPa and 200 MPa, when compared with the results obtained for fully reverse loading (Figure 4a). For smaller stress amplitudes, life reduction due to mean stress is correspondingly higher. For stress amplitudes greater than 350MPa (grays rectangular marks) the failures did not nucleate at the dent, and fatigue lives were similar to the those observed in smooth specimens. The data obtained in fatigue experiments for indented specimens subjected to loading ratios $R = -1$ and $R = 0.1$ showed similar tendencies, when the SWT parameter was considered (Figure 4b), indicating that this is a good parameter for estimating the fatigue life of the dented Al 7075-T6511 alloy.

Table 2 – Fatigue tests data of 7075-T6511.

CP type	SWT Parameter (MPa)	Life (cycles)	Frequency (Hz)
Indented specimen with loading R= -1	450	4840	8
	420	14919	8
	370	15676	8
	330	49468	8
	320	20842	8
	290	32196	8
	275	58408	8
	250	45154	8
	240	110828	10
	230	115095	10
	225	169042	10
	220	92.162	10
	210	712138	15
	200	575628	20
Indented specimen with loading R= 0.1	190	632994	20
	370	8748	8
	300	35018	8
	279	46472	8
	239	64094	8
	235	279061	8
	230	333821	8
	225	101744	8
	220	165201	8
	215	119454	8
Smooth specimen with loading R= -1	210	927111	8
	205	2000000	8
	450	6.217	5
	420	12.218	5
	400	9.920	5
	370	21.204	8
	330	35.647	8
	290	83.344	8
	280	116.749	10
	275	312.370	10
	260	840.404	10
	250	1.022.198	15
240	3.268.658	20	

Fracture surface

Some typical fracture profiles of fractured smooth specimen and indented specimens subjected to loading ratios R= -1 and R = 0.1 are shown in Fig. 5. It can be seen that the appearance of the fracture profiles, for these three cases, are fundamentally similar and indicated the fracture Mode I.

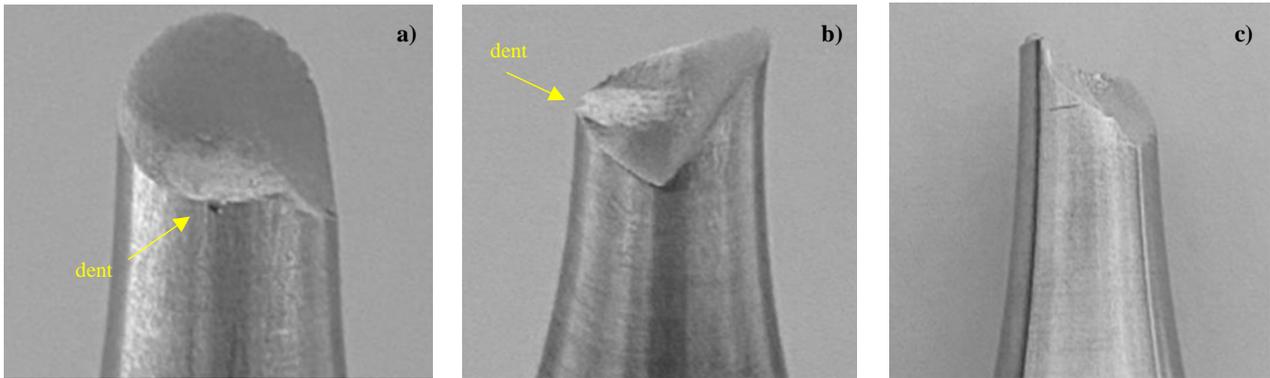


Figure 5 – Typical cracking profiles obtained under: (a) loading $R=-1$. (b) loading with mean stress $R=0.1$ and (c) Smooth specimen with loading $R=-1$.

Observing the fracture surface macroscopically, fatigue failures have some characteristics similar to brittle failures, such as the absence of a neck and the fact that they occur perpendicularly to the loading direction. Figure 6 presents the fracture surface of a specimen with indentation defect. It's possible to notice the region of initiation and crack propagation, characterized by river marks and indicated by arrows.

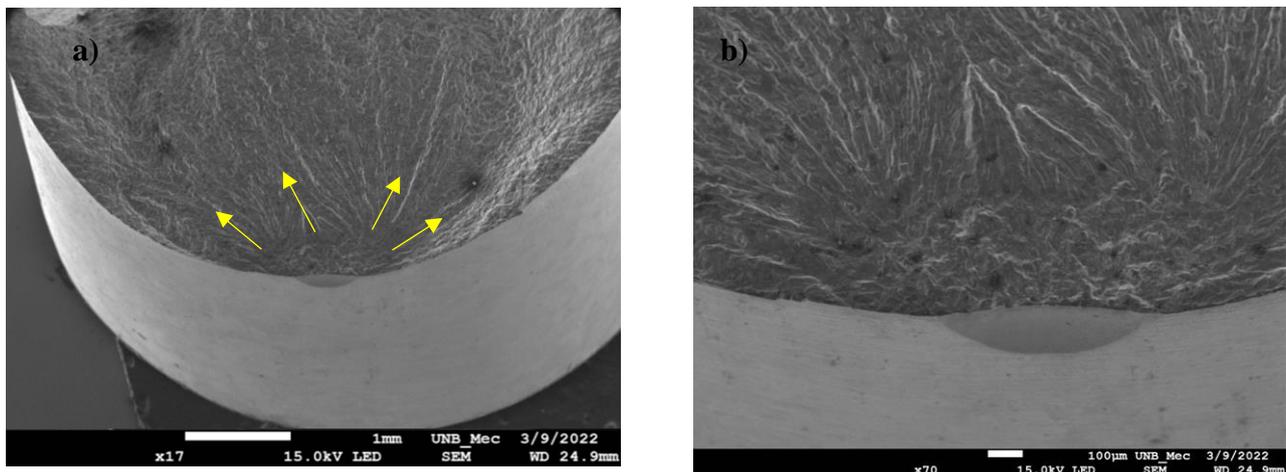


Figure 6 – a) Fracture surface of specimen with indentation defect. MEV. x17. b) Ampliation of the crack initiation zone.

CONCLUSION

Fatigue lives of aluminum alloy 7075-T6511 with dent defects, subjected to loading ratio $R=-1$ and $R=0.1$, were analyzed from a program of axial loading tests. It was concluded that:

- The experiments show that the smaller the stress amplitude, the greater the reduction in material life when compared with smooth specimens. Under fully reverse loading, life reductions of 6 to 67 times were observed for stress amplitudes between 275 and 225 MPa, respectively.
- When compared with the results obtained for fully reverse loading, the presence of the mean stress caused a reduction in fatigue life between 5 to 16 times, for stress amplitudes between 250 MPa and 200 MPa.
- The Smith-Watson-Topper parameter was successful in considering the effect of mean stresses on the fatigue lives of dented specimens.

- Under low stress amplitudes, the river marks observed on the fracture surfaces of the indented specimens indicate that the cracks started close to the defect edges, where the high level of residual stresses produced by the indentation influences the fatigue life.
- On the other hand, the presence of dent does not lower the fatigue life under higher stress amplitudes – above 320 MPa – when the residual stresses produced by indentation are small when compared with the loading stresses.

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