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RESEARCH ARTICLE

Torsion fatigue endurance and load ratio confrontation R=0 VS. R=-1 on the AISI 6061-T6 aluminum alloy.

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Abstract

Torsion Fatigue test were carried out on the aluminum alloy 6061-T6 for two load ratios: R=-1 and R=0, both of them at 10Hz of frequency, room temperature and without control of environmental humidity. Results reveal a noticeable fatigue endurance reduction on tests with R=0 against tests at R=-1. Load ratio was fixed by changing only the start angle of testing. In this paper is also showed the torsion fatigue machine developed by the authors; that is capable of commissioning torsion tests at different frequencies and load ratios, such machine is under patent consideration to the Mexican Institute of Industrial Property. Fatigue life and fracture surfaces at macro and micro scale were analyzed for both torsion fatigue load ratios and finally, corresponding conclusions were enlisted.

INTRODUCTION

Aluminum alloys are widely used as structural materials of engineering components because of their high strength, excellent fatigue resistance, and good strength-to weight ratio (Rodríguez-Millán M. et al., 2015), the best application can be obtained in some typical cases, which are characterized in getting profit at least of one of the main basic properties: lightness, corrosion resistance and functionality (Mazzolani, F.M., 2006); other investigation on a different aluminum alloy point out that fatigue cracking behavior is dependent on the loading path as well as the loading magnitude (Tianwen and Yanyao, 2008). The present article deals with determining the torsion fatigue response of the 6061-T6 aluminum alloy for four levels of applied load: 70, 60, 50 and 40% regarding the shield strength of this material. This work also includes the confrontation of torsion fatigue results with two different load ratios, R=0 versus R=-1. Experimental tests were carried out at 10 Hz of frequency, room temperature and without control of environmental humidity neither control of roughness surface; nevertheless, all specimens where machined similarly in order to maintain the roughness surface with not large variation. The experimentation process was carried out under the two mentioned applied load ratios, in which torsion fatigue testing was obtained under similar conditions of frequency and applied load. Confrontation of torsion fatigue was obtained with the two load ratio: concerning the load ratio R=0, stress was applied from a no stress position attaining the high stress with a single rotation of motion; whereas for the load ratio R= -1, the starting point was the same as previously, but the applied rotation was on two opposite directions. In last both cases, the amplitude of the torsion rotation angle was the same.
In Figure 1 is presented schematically the two cases of load ratio, for a torsion angle of 14 degrees. Figure 1a represents the case for R=0 and Figure 1b the case for R= -1.

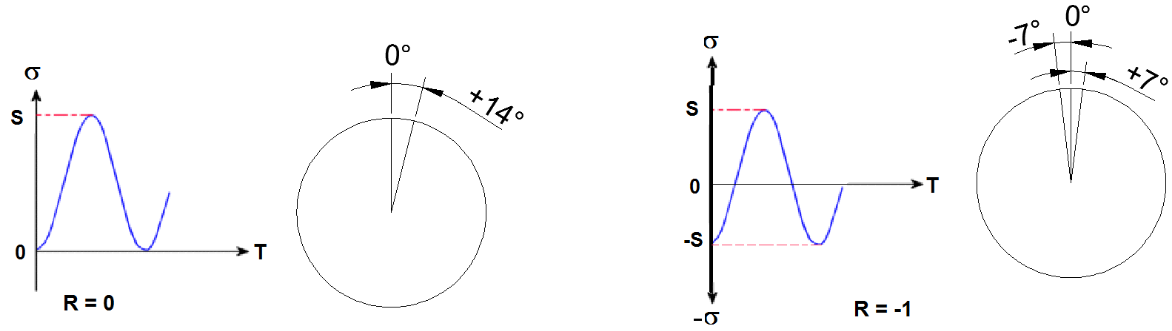


Fig. 1.
Loading rates under torsion fatigue testing: a) Load ratio R=0, b) load ratio R=-1.

Material and Methods

The testing material is the aluminum alloy AISI 6061-T6, which is used in wide industrial applications: aircrafts, wing tension members, truck wheels, scientific instruments, and orthopedic braces, among others ratio (Niknam S.A., and Songmene V., 2013; Taban E. et al 2010; Sanchez U. S. et al, 2006; McKenna S. P. et al, 2002).

Chemical composition in weigh and principal mechanical properties are shown in Table 1 and Table 2, respectively.

Result and Discussion

Table 1. Chemical composition of aluminum alloy 6061-T6.

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	95.8 - 98.6	Mg	0.8 – 1.2	Si	0.4 – 0.8
Cr	0.04 – 0.35	Mn	Max. 0.15	Ti	Max. 0.15
Cu	0.15 – 0.4	Other, each	Max. 0.05	Zn	Max. 0.25
Fe	Max. 0.7	Other, total	Max. 0.15		

Table 2. Principal mechanical properties of aluminum alloy 6061-T6

Shear strength	Ultimate tensile strength	Elongation	Shear modulus	Hardness
MPa	MPa	%	GPa	Brinell
207	310	0.33	26	95

In Figure 2 is shown the torsion machine developed in our laboratory, allowing obtaining the torsion fatigue endurance of this aluminum alloy. The high controlled frequency of this machine is 10Hz and stops automatically when the specimen is broken. Additionally, an incorporated electronic system is destined to count the number of cycles and to stop the test when the specimen is broken.

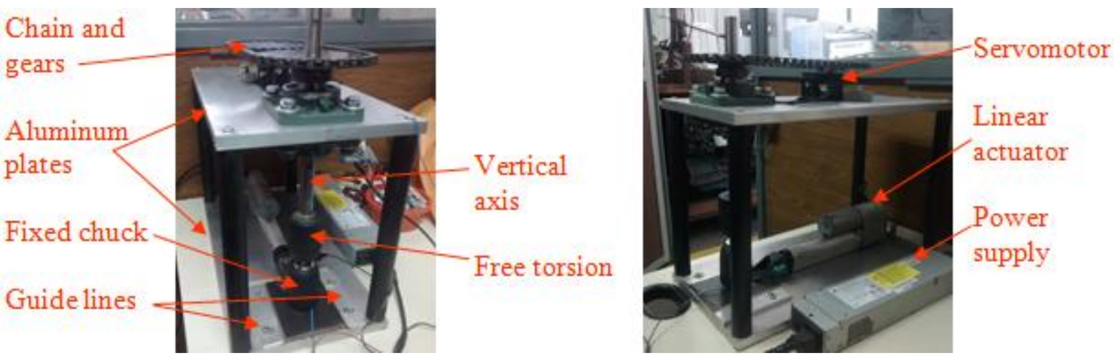


Fig. 2

Torsion fatigue machine developed in our laboratory (in process of patent demand).

Experimental results are plotted on Figure 3. Load ratio R = 0 shows lower fatigue lives than R = -1, for the lower applied loads. For the higher applied loads, there aren't significant differences in fatigue strength between both load ratios, furthermore when applied load decreases, differences in torsion fatigue life increases between R = 0 and R = -1.

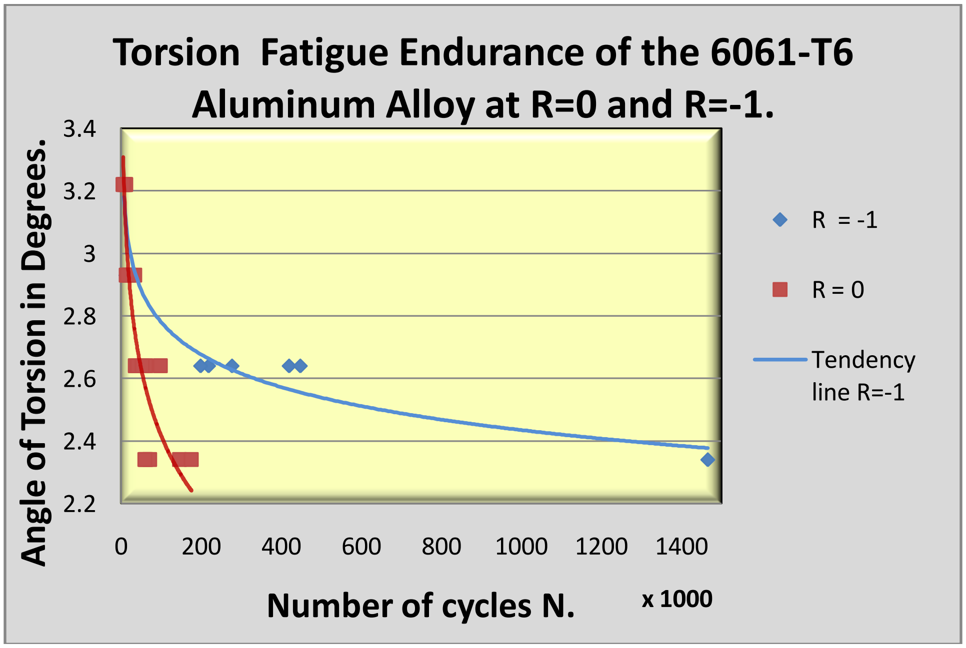


Fig. 3
Experimental results for fatigue endurance under torsion modality and logarithmic tendency curves for the two load ratios on 6061-T6 aluminum alloy.

The experimental points plotted on Figure 3 show that for the high loading (torsion angle from 2.8 to 3.2 degrees), no difference is observed on fatigue endurance for the two loading rates; whereas in decreasing the torsion angle, fatigue endurance decrease for the specimens tested at load ratio R=0 in regard the specimens tested at load ratio R = -1. These results are obtained for a similar amplitude of torsion angle under the two test ratios (R=0 and R=-1). Furthermore, a resent work has pointed out the variation under axial torsion fatigue on this aluminum alloy, when the sequence of applied load is modified (Lin H. et al 2008).

Experimental results are listed in the following tables concerning torsion fatigue tests, for the torsion angles of: 3.22, 2.93, 2.64 and 2.34 and the fatigue endurance confrontation between the two load ratio: R = 0 and R = -1.

The torsion angle of 3.22°, 2.93°, 2.64° and 2.34° induces stress amplitudes on the neck section of test specimens near of 70%, 60%, 50% and 40% of shear strength of this aluminum alloy. In Figure 4 is presented the dimensions of testing specimen in mm, the constraints for the specimen and the numerical simulation under a torsion angle of 1 degree with the corresponding high stress at the neck section of specimen.

Table 3. Fatigue endurance for tests with R=0 versus R=-1, at 3.22° of torsion.

Torsion angle	Number of cycles with R= 0	Number of cycles with R= -1
3.22°	5800	7560
3.22°	10200	8870
3.22°	12140	8810
3.22°	12340	8350
3.22°	7620	7000

Table 4. Fatigue endurance for tests with R=0 versus R=-1, at 2.93° of torsion.

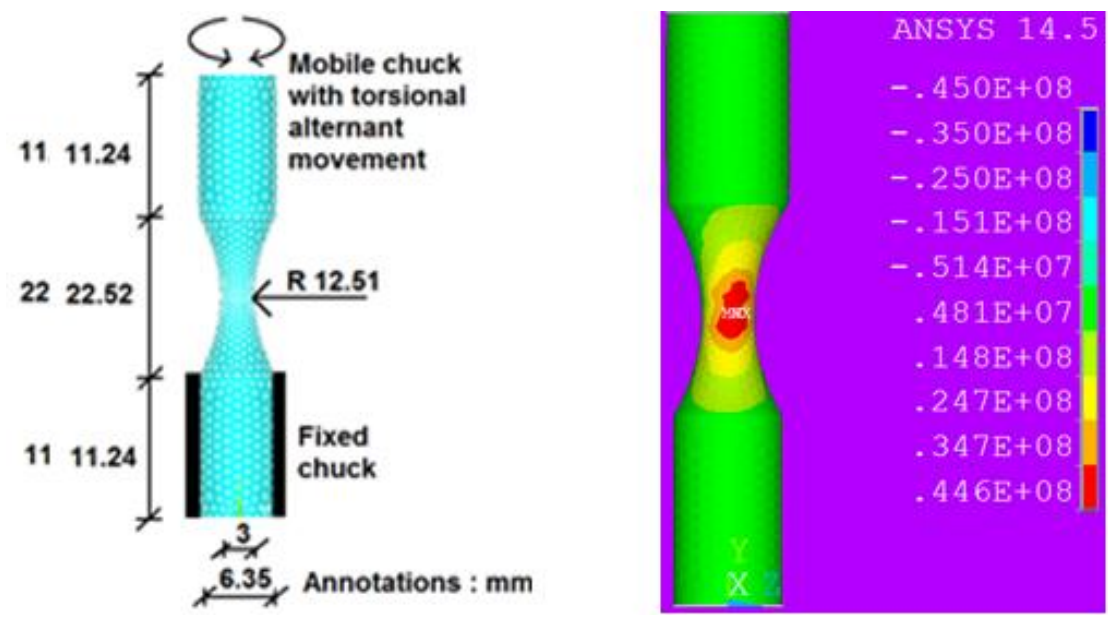
Torsion angle	Number of cycles with R= 0	Number of cycles with R= -1
2.93°	21790	11710
2.93°	13250	22310
2.93°	19160	33940
2.93°	15990	26770
2.93°	35100	24690

Table 5. Fatigue endurance for tests with R=0 versus R=-1, at 2.64° of torsion.

Torsion angle	Number of cycles with R= 0	Number of cycles with R= -1
2.64°	36350	218980
2.64°	99460	198400
2.64°	42140	420540
2.64°	63450	448180
2.64°	176500	277200

Table 6. Fatigue endurance for tests with R=0 versus R=-1, at 2.64° of torsion.

Torsion angle	Number of cycles with R=0	Number of cycles with R=-1
2.34°	63100	1465480
2.34°	72400	
2.34°	54000	
2.34°	146760	
2.34°	60350	



a) b)

Fig. 4.
The dimensions of testing specimen (mm), and constraints a), numerical simulation under torsion angle of 1° and induced stress along the testing specimen.

The Tables from 3 to 6 show that the torsion fatigue endurance (R=0), in this aluminum alloy is close to 9.6×10^3 cycles at 70% the shear limit of this material; whereas at same load and R=-1, fatigue life is close to 8.1×10^3 cycles. On the other hand for low applied load, fatigue life is close to 59×10^3 cycles for 50% the shear strength of this material under R=0; fatigue life and 312 x 10^3 cycles under R=-1. This tendency confirms that fatigue life at high applied load is similar for both load ratios; whereas for the low applied load, the fatigue endurance under R = -1 is considerably higher in regard the load ratio R=0.

The lateral crack paths for torsion fatigue testing are shown in Figure 5. A ductile crack behavior (Billington E. W., 1981) is present in this material which is perpendicular to principal axis, Figure 5a,b. Furthermore, it is observed a brittle crack behaviour (McClaflin D and Fatemi A., 2004) that develops simultaneously under an angle close to 45º in regard the specimen' principal axis, Figure 5c,d. Both crack propagation behaviours are observed on this material under torsion fatigue testing. The last results reveal patterns of crack propagation on an intermediate ductile-brittle material as this alloy (Gilath I. et al, 1988). Crack propagation perpendicular to principal axis is related to ductile behavior under torsion fatigue loading; whereas crack propagation with an angle close to 45º is associated with brittle behavior, under torsion fatigue loading.

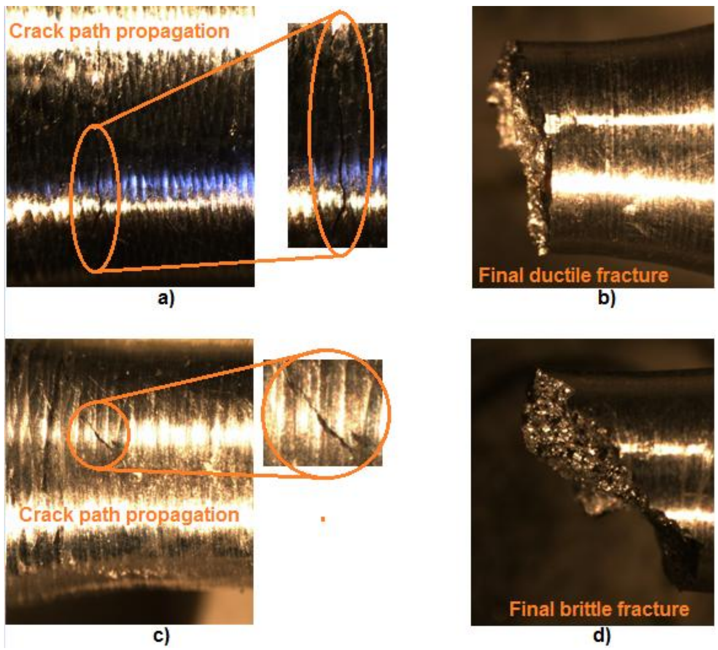


Fig. 5

Crack paths for torsion fatigue tests: ductile crack, perpendicular to principal axis of specimen a) b), brittle crack along an angle close to 45°.

Frontal fracture surface have been obtained by SEM microscopy; in Figure 6 are shown two fracture surfaces with 2 and 3 crack initiation sites.

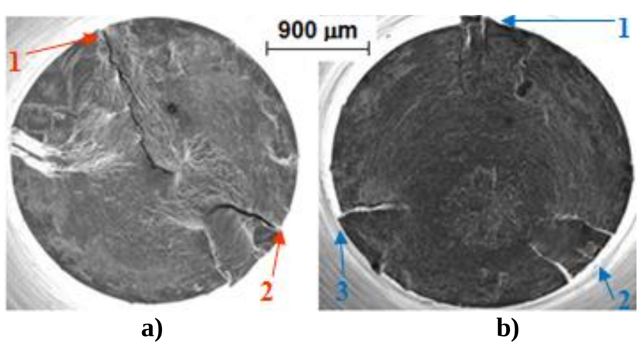


Fig. 6

Fracture surface with high applied load and two points of crack initiation a), fracture surface with 3 points of crack initiation that converge to the granular zone b).

Differences in applied load are traduced on fracture surfaces: high applied load conduces to an irregular fracture surface as shown on Figure 6 a), whereas a low applied load is related to a more regular fracture zone, Figure 6 b).

Conclusions

The following conclusions can be dressed from this research work:

1. Load ratio induces an important difference in torsion fatigue endurance, for similar low applied load.
2. For a high level of applied load: 70% and 60% of shear strength of this material, torsion fatigue endurance on this material apparently has not large variation between load ratios of R= 0 and R= -1.
3. Concerning the low applied load: 50% and %40 the shear strength of this material, torsion fatigue endurance presents a difference of around 4.5 times between load ratios of R= 0 and R= -1.
4. On this aluminum alloy, fatigue life is higher on tests with R= -1 than the ones with R= 0 for applied loads under 50% of shear strength.
5. Crack propagation under torsion fatigue testing on this material, presents a competition between ductile and brittle behaviors: some testing specimens are broken perpendicularly in regard the principal axis of the specimen (ductile behavior), and others are broken with an angle close to 45° in regard the principal axis of specimen (brittle behavior).

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