[1.]Quazi Md. Zobaer SHAH, [2.]Md. Arefin KOWSER, [3.]Mohammad Asaduzzaman CHOWDHURY

INVESTIGATION ON THE FRETTING FATIGUE FAILURE MECHANISM OF HEAT TREATED Al 6061-T6

[1-3.] Dhaka University of Engineering & Technology, DUET, Gazipur-1707, Dhaka, BANGLADESH

Abstract: Being a prime constituent in various sophisticated applications like aerospace design, Aluminum alloy has ranked the apex point of interest for researchers in the field of fatigue. In this present study, effect of fretting fatigue on heat treated Al-Mg-Si alloy (Al 6061-T6) has been investigated. Experimental observation has been authenticated by developing a FEM model using simulation software ANSYS 14.5. It has been observed that, within lower stress range, fretting reduces the lifetime of Aluminum significantly than the normal fatigue. On the other hand, fretting effect almost vanishes at higher order loading as well as stress in comparison with normal fatigue. Nevertheless, crack initiation and catastrophic rupture follows the aspect of fretting loading parameter which shows that fretting affects not only in quantity but also in quality of the fatigue behavior of Al 6061-T6.

Keywords: fretting fatigue, ANSYS, Bending loading, crack propagation, rapid rupture

INTRODUCTION

Aluminum alloys have become essential parts in modern applications like aerospace, automotive industries and other light weight desirable sectors. Al6061-T6 is tempered heat treatable alloy that has good corrosion resistance, weld ability. Aluminum alloys does not show any distinguishable knee on life-stress diagram. Fatigue limit for giga (10^9cycle) of Al 6061-T6 was investigated by Y. Takahashi et al [1]. Two types of specimen, one smoother and another one with small hole were used. Though smoother sample didn't show notable limit, however, holed sample exhibits distinct fatigue limit. J. Hao et al [2] showed weldable Al alloy 6061 fatigue life comparison in atmosphere and water. In water, significant decrease in life was noticed. Under giga cycle reversed (R = -1) loading, various Al alloys have been tested at 20 kHz by Q. Wang [3]. For giga cycle, tearing occurs instead of striation. Fatigue crack propagation was studied by H. Noguchi [4]. Rotating bending fatigue test of Al6061-T6 with pitting hole was shown by G. Almaraz [5]. He studied the fatigue characteristics of single or double pitting holes. H. Lin et al [6] showed the fatigue properties of Al6061-T6 welded butt joints. Recent advances on fatigue research of aluminum alloys can be found in [7-15]. Current authors have reviewed and carried out some researches on fatigue in [16-18].

MATERIAL PROPERTIES

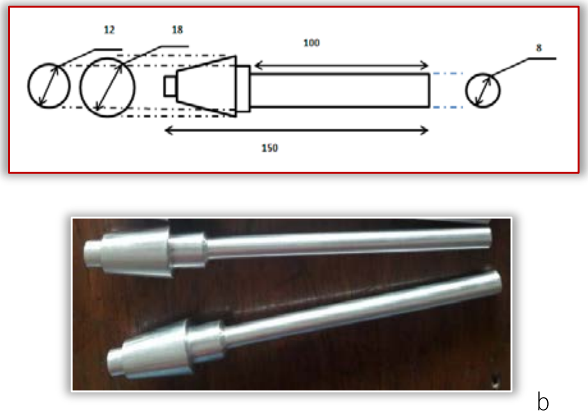
In this present study, fretting fatigue of Al6061-T6 has been carried out through experimental & numerical approaches. General rotating bending fatigue setup has been used with screwed ring type fretting setup. Analytical results along with graphical & fracture surface has been monitored to conclude the consequence of fretting on fatigue life.

Table 1: Chemical properties of Al 6061-T6

Mg	Al	Si	Cr	Mn	Fe
1.75	94.42	0.79	0.20	0.32	0.47

Table 2: Mechanical properties of Al 6061-T6:

Density	UTS	YTS	Young's Modulus	Poison's ratio	Elastic limit
2.7 g/cc	310 MPa	276 MPa	68.9 MPa	0.33	96.5 MPa



a

b

Figure 1: Designed specimen (dimensions are in mm) (a), prepared Specimens (b)

EXPERIMENTAL SETUP

Jockey loaded rotating bending machine is used here. Fretting loading is supplied by rotatable circular ring. Details of similar experimental procedure with calibration can be found in [14, 15, and 18]. To avail fretting fatigue, a ring system with screwed bolts inserted inside is provided as shown in figure 1(b). By adjusting bolts, fretting pressure can be applied manually.

Figure 2: Experimental setup for fatigue test

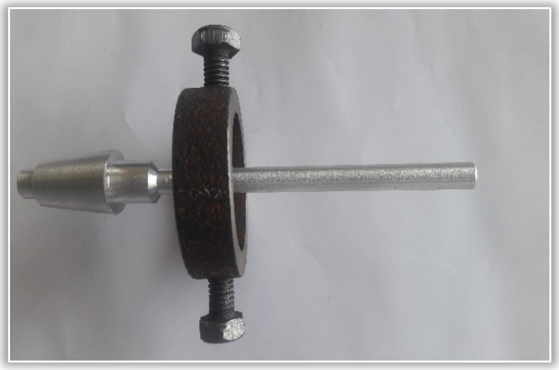


Figure 3: Fretting arrangement

NUMERICAL SIMULATION

For FEM analysis, ANSYS 14.5 was used here. CONTA 174 and TARGE170 has been used as contact and target element. Refinement for meshing has been adopted for result convergence. Co-efficient of 0.2 has been taken between contacts. Fretting force of 1000 N has been taken as constant loading on pads.

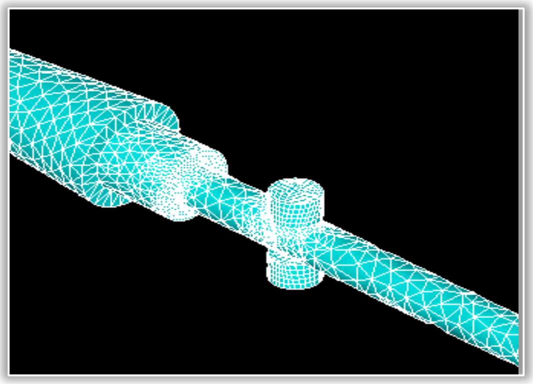


Figure 4: Geometry & Mesh convergence

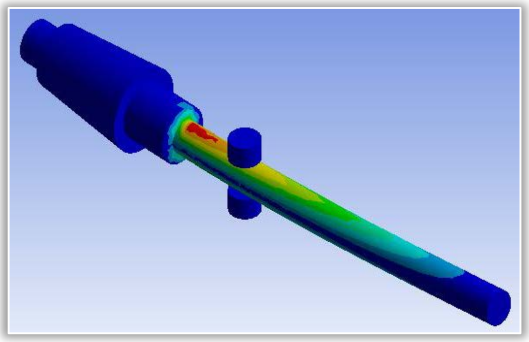


Figure 5: FEM analysis for life under applied loading

Figure 6 shows the cracked surfaces of specimens used under different loading conditions. Most outer part of the periphery of circular shape observes the crack initiation by gradual but steady loading. Ratchet marks characterizes itself by continuous development of cracks. Each point of ending root of ratchet is introduced by crack initiation point. The middle zone, known as propagation period is characterized by striation and sometimes benchmarks like oval or circular shape that speaks about the sudden up gradation of stress to tear off the limited stressed circumference. The most inner differentiable circular zone is comparatively rough than other zones, marked as catastrophic failure zone. It happens because of sudden implied load upon which the specimen cannot withstand anymore.

FRACTURE FAILURE MECHANISM

At higher stress level along bending side, the nucleus zone slides away from the center due to both greater loading & higher rpm as well as low load impact period with higher stress (figure 6 a1, a2). For lower level of applied bending loading, gradual crack formation is observed that causes dartboard shaped classified zones for crack initiation, propagation & fracture as shown in figure 6(b1, b2). Because of dual action of tensile stress and bending stress in fretting fatigue, sample cracks at the collar/smaller neck area of the specimen that covers larger area for catastrophic failure zone as a result of extreme applied stress. Unlike the horizon cracked surfaces of previous cases (figures 6a, 6b), It cracks deeper to exert tensile stress into the head of specimen (figure 6 c1, c2).

a1 a2
b1 b2
c1 c2

Figure 6: fractured surfaces

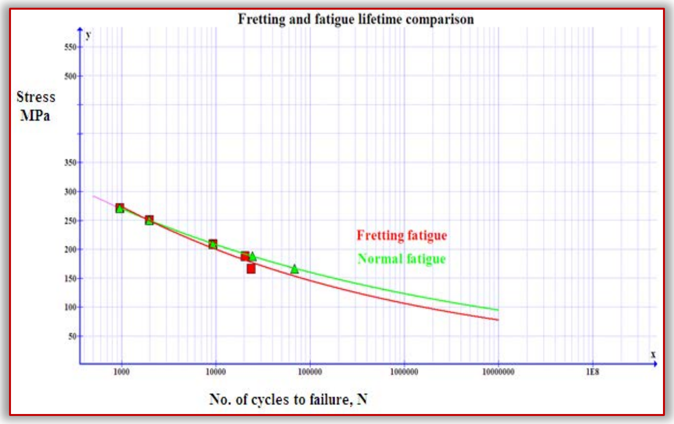


Figure 7: Comparison of fretting fatigue lifetime with normal fatigue

RESULTS AND DISCUSSION

From S-N diagrams, it is obvious that, fretting reduces fatigue life considerably. For higher order loading it coincides with general fatigue life but as load level decreases for 1000 N fretting load life cycles decreases abruptly. In other words, it can be said that effect of notch and edge corner has much more impact on specimen than fretting load of even 1000 N at high bending loading. Fretting effect becomes obvious for low order loadings.

From Basquin equation, we know that

$$S = AN^B$$

Solving the above equation by taking log both sides yields the values of A and B from which we can get the value of endurance limit. Figure 7 shows that, for higher order bending stresses fretting doesn't affect the fatigue lifetime significantly whereas it shows noticeable reduction in lifetime for low order bending stresses. It is clear that, for high value bending loading under constant 1000N fretting loading, lifetime cycles remain the same which implies that for high order bending loading, fretting effects are not so obvious as those in low order bending loadings. So, corner edged and notched portions are as dangerous as fretting fatigue loads. Endurance limit is 94 MPa at 10^7 cycles for normal fatigue whereas for fretting fatigue, it becomes 77 MPa at 10^7 cycles. Endurance limit has been reduced of about 22% due to fretting of 1000 N while fatigue life time reduces 30-33% for low order loading.

CONCLUSION

On the basis of above discussed results, it can be said that fatigue associated with fretting affects the lifetime of Al 6061-T6 badly than the normal one significantly at lower order loading. However, at the peak value bending loading with greater stress it is difficult to differentiate individual effect of sharp corner and fretting effect, respectively. Here, preference of fillet edged corner over sharp edged object subjected to cyclic loading comes afore. Fretting effect is pre dominant for lower valued bending stresses by reducing the fatigue limit. Nevertheless, crack initiation & propagation as well as final rupture nucleus core direction is proved as an indicator of loading and rpm where fretting implies tensile effect in addition to bending fatigue.

References:

[1] Takahashi, Y., Yoshitake, H., Nakamichi, R., Wada, T., Takuma, M., Shikama, T., & Noguchi, H. (2014). Fatigue limit investigation of 6061-T6 aluminum alloy in giga-cycle regime. Materials Science and Engineering: A, 614, 243-249.

[2] Hao, J., Chengyu, Z., & Shengru, Q. (2015). Fatigue Life of 6061 Aluminium Alloy Welding Samples both in Atmosphere and Water. Rare metal materials and engineering, 44(5), 1116-1118.

[3] Wang, Q. Y., Lib, T., & Zenga, X. G. (2010). Gigacycle fatigue behavior of high strength aluminum alloys. Procedia Engineering, 2(1), 65-70.

[4] Shikama, T., Takahashi, Y., Zeng, L., Yoshihara, S., Aiura, T., Higashida, K., & Noguchi, H. (2012). Distinct fatigue crack propagation limit of new precipitation-hardened aluminium alloy. Scripta Materialia, 67(1), 49-52.

[5] Almaraz, G. M. D., Lemus, V. H. M., & Lopez, J. J. V. (2010). Rotating bending fatigue tests for aluminum alloy 6061-T6, close to elastic limit and with artificial pitting holes. Procedia Engineering, 2(1), 805-813.

[6] Lin, H., Hwang, J. R., & Fung, C. P. (2016). Fatigue properties of 6061-T6 aluminum alloy butt joints processed by vacuum brazing and tungsten inert gas welding. Advances in Mechanical Engineering, 8(4), 1687814016643454.

[7] Gong, B. S., Liu, Z. J., Wang, Y. L., Zhang, Z. J., Zhang, P., Jiang, H. C., ... & Zhang, Z. F. (2019). Improving the fatigue strength of A7N01 aluminum alloy by adjusting Si content. Materials Science and Engineering: A, 742, 15-22.

[8] Guo, S., Shah, L., Ranjan, R., Walbridge, S., & Gerlich, A. (2019). Effect of quality control parameter variations on the fatigue performance of aluminum friction stir welded joints. International Journal of Fatigue, 118, 150-161.

[9] Zhao, Y., Peng, Y., Fan, T., Kai, X., Chen, G., & Wang, W. (2019). U.S. Patent Application No. 15/771,432.

[10] Nelaturu, P., Jana, S., Mishra, R. S., Grant, G., & Carlson, B. E. (2018). Influence of friction stir processing on the room temperature fatigue cracking mechanisms of A356 aluminum alloy. Materials Science and Engineering: A, 716, 165-178.

[11] Sun, N., Jones, W. J., & Apelian, D. (2018). Friction Stir Processing of Aluminum Alloy A206: Part II—Tensile and Fatigue Properties. International Journal of Metalcasting, 1-11.

[12] Nambu, K., & Okumiya, M. (2018, July). Influence of Soft Particle Peening Treatment on Fatigue Strength of Aluminum Alloy A5052. In Fracture, Fatigue and Wear (pp. 390-400). Springer, Singapore.

[13] Nadot, Y., Houria, M. I., Fathalah, R., & Maijer, D. (2018). Through Process Modelling applied to the fatigue resistance of cast Aluminum. Procedia engineering, 213, 296-302.

[14] Zalnezhad, E., Sarhan, A.A.D. & Jahanshahi, P. Int J Adv Manuf Technol (2014) 70: 2211

[15] Zalnezhad, E., Sarhan, A.A.D. & Hamdi, M. Int J Adv Manuf Technol (2013) 69: 1153

[16] Chowdhury, M. A., Kowser, M. A., Zobaer Shah, Q. M., & Das, S. (2018). Characteristics and damage mechanisms of bending fretting fatigue of materials. International Journal of Damage Mechanics, 27(4), 453-487.

[17] M.A Kowser, M. A. Chowdhury, Q M Zobaer Shah, Effect of loading parameter on fretting fatigue. AIP Conference Proceedings **1851**, 020095 (2017)

[18] Zobaer Shah, Q.M., Asaduzzaman Chowdhury, M. & Arefin Kowser, M. J Fail. Anal. and Preven. (2019)

ISSN: 2067-3809