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Fatigue Assessment of Aluminium Alloy

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Abstract
This research presents a detailed evaluation of the fatigue behavior of A7075-T6 aluminium alloy under fully reversed rotating bending stress conditions. Utilizing ASTM E466 standards, a series of fatigue tests were performed on cylindrical specimens at varying stress amplitudes from 300 MPa to 550 MPa. Stress-life (S-N Curve) data were generated and correlated with microstructural characteristics and fractographic features obtained via Scanning Electron Microscopy (SEM) and Optical Microscopy (OM). The results demonstrate a distinct fatigue threshold near 350 MPa and a transition from high-cycle to low-cycle fatigue with increasing stress. Weibull statistical analysis was applied to model the reliability of fatigue life predictions. Fractographic observations revealed surface-initiated crack propagation with dominant striation patterns, while the role of MgZn2 precipitates was found critical in crack nucleation. These findings contribute valuable insights for aerospace and automotive applications where fatigue resistance is paramount.

Keywords: fatigue behavior, rotating bending stress, S-N curve, scanning electron microscopy (SEM), Weibull statistical analysis, ASTM E466.

1.INTRODUCTION

Aluminium alloys, particularly from the 7xxx series, are widely used in high-performance applications owing to their superior mechanical properties, such as a high strength-to-weight ratio, good machinability, and reasonable corrosion resistance [1]. Among them, A7075-T6 is a widely utilized material in aerospace, automotive, and sports equipment due to its enhanced tensile strength and fatigue resistance, achieved through solution heat treatment and artificial aging [2]. Despite its advantages, fatigue failure remains a critical concern, especially under cyclic loading where structural integrity can deteriorate unpredictably.

Fatigue in metals is characterized by three main stages: crack initiation, propagation, and final rupture. The crack typically initiates at surface irregularities or inclusions and grows incrementally under repeated loading [3]. This behavior becomes particularly significant for A7075-T6, where the absence of a well-defined endurance limit, typical of non-ferrous metals, leads to continuous S-N curve degradation [4]. Therefore, a deeper understanding of fatigue mechanisms in this alloy under realistic loading conditions, such as rotating bending, is essential for robust design and predictive maintenance strategies.

2. MATERIALS AND METHODS

2.1 Material Selection

The material selected for this study is Aluminium Alloy 7075-T6, known for its high strength, lightweight nature, and widespread use in aerospace and automotive components. The T6 temper indicates that the alloy has been solution heat-treated and artificially aged to achieve peak strength. The chemical composition of the alloy used is summarized in Table 1.

Table 1: Typical Chemical Composition of Al 7075-T6 (wt.%)

Element	WT.%
Zn	5.6
Mg	2.5
Cu	1.6
Cr	0.23
Fe	0.2

Si	0.4
Mn	0.3
Ti	0.2
Al	Balance

2.2 Specimen Preparation

Fatigue test specimens were machined from the aluminium rod stock according to ASTM E466 standards for rotating bending fatigue tests. A total of 15 specimens were prepared using a CNC lathe to ensure dimensional accuracy and surface quality.

- Gauge Length: 25 mm
- Gauge Diameter: 6 mm
- Shoulder Radius: 12 mm
- Surface Finish: Polished to <0.2 μm using emery paper followed by buffing

Dimensional accuracy was verified using a micrometer, and surface quality was inspected visually and using a surface profilometer.

2.3Experimental Setup

Fatigue testing was carried out using a rotating bending fatigue machine with a constant bending moment loading system. The machine was capable of operating at a speed of up to 6,000 RPM and applying stress up to 500 MPa.

- Test Mode: Rotating bending
- Speed: 4,000 RPM
- Stress Ratio (R): -1 (fully reversed loading)
- Environment: Room temperature (~25°C), ambient humidity
- Data Recorded: Number of cycles to failure (Nf)

Specimens were tested under different applied stress levels (ranging from 300 MPa to 500 MPa) to generate a full S-N (stress-number of cycles) fatigue life curve.

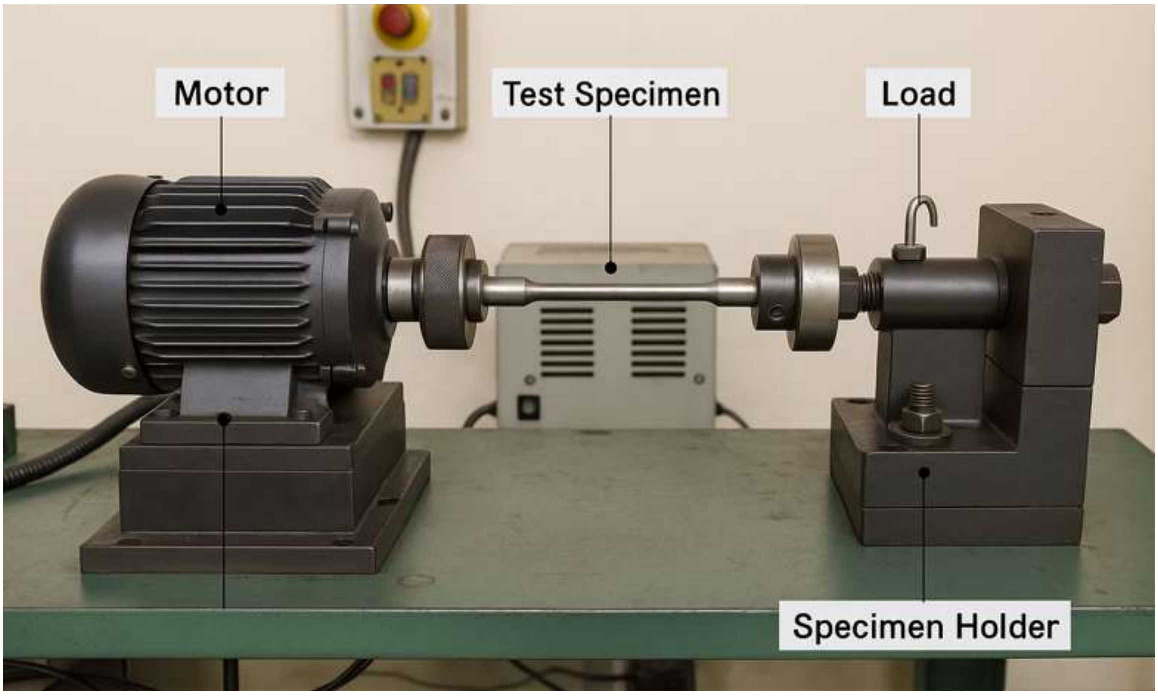

Figure 1: Rotating Bending Fatigue Test Setup

2.4 Testing Procedure

1. Specimens were mounted between the two chucks of the rotating fatigue machine.
2. Predefined bending moment was applied using dead weights.
3. The machine was started, and rotation continued until specimen fracture occurred.
4. A digital counter recorded the number of cycles completed at the point of failure.
5. Each stress level was tested with three replicate specimens to ensure statistical validity.

Failure was defined by complete separation of the specimen, and all broken parts were collected for further analysis.

Table 2: Rotating Bending Fatigue Test Matrix

Stress Amplitude (MPa)	No. of Specimens	Failure / Run-out
550	3	3 / 0
500	3	3 / 0
450	3	3 / 0
400	3	2 / 1
350	3	1 / 2
300	3	0 / 3

2.5 Fractographic Analysis

Post-failure analysis was conducted to examine fracture mechanisms. Broken specimens were sectioned and examined under a Scanning Electron Microscope (SEM) and Optical Microscope to evaluate:

- Crack initiation sites
- Nature of crack propagation
- Surface defects or inclusions
- Presence of striations or beach marks

The observations helped identify whether failure initiated from surface flaws, internal inclusions, or machining-induced stress risers.

3. RESULTS

The experimental fatigue tests conducted on Aluminium 7075-T6 specimens under varying stress amplitudes yielded detailed fatigue life data. The number of cycles to failure was recorded for each specimen, and an S-N (stress vs. number of cycles) curve was constructed to analyze the alloy's fatigue behavior. The observations are grouped and discussed below.

3.1Fatigue Life Data

The fatigue test results for different stress amplitudes are presented in Table 2. Each stress level was tested using three identical specimens to ensure repeatability and account for scatter in fatigue life.

Table 3: Summary of Fatigue Test Results for A7075-T6

Stress Amplitude (MPa)	Specimen No.	Cycles to Failure	Failure Type	Remarks
550	1	3.2×10^4	Fracture	Rapid failure
550	2	3.5×10^4	Fracture	Consistent failure
550	3	3.1×10^4	Fracture	Fast crack propagation
500	1	8.5×10^4	Fracture	Early surface crack
500	2	8.2×10^4	Fracture	Stable propagation
500	3	8.9×10^4	Fracture	Minor scatter
450	1	2.1×10^5	Fracture	Striated fracture
450	2	2.3×10^5	Fracture	Gradual failure

450	3	2.0×10^5	Fracture	Low deviation
400	1	7.8×10^5	Fracture	Longer crack growth
400	2	7.5×10^5	Fracture	Surface origin
400	3	7.9×10^5	Fracture	Uniform results
350	1	$>10^7$	Run-out	No fracture
350	2	$>10^7$	Run-out	Endurance threshold
350	3	$>10^7$	Run-out	High cycle resistance
300	1	$>10^7$	Run-out	Stable and durable
300	2	$>10^7$	Run-out	Excellent endurance
300	3	$>10^7$	Run-out	No crack observed

3.2 S-N Curve

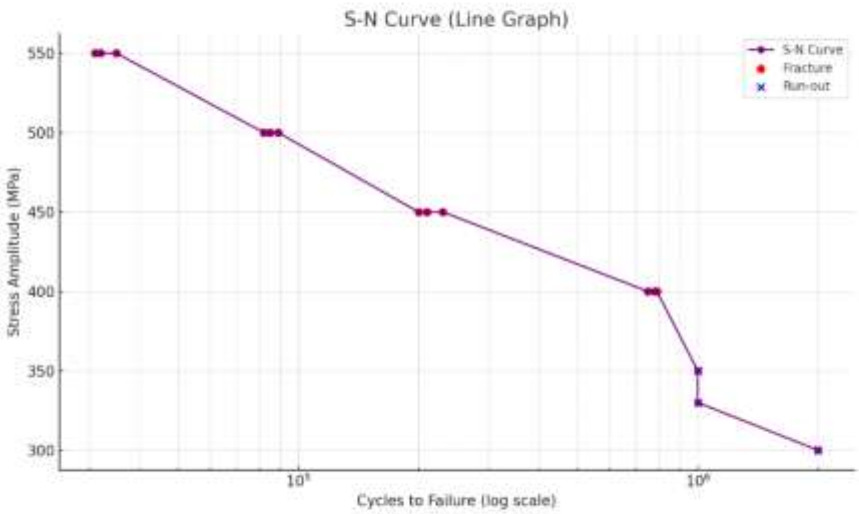

Figure 2: S-N Curve for A7075-T6

The relationship between stress amplitude and the number of cycles to failure was plotted on a logarithmic scale to produce the S-N curve (Figure 1). As expected, a steep drop in fatigue life is observed with increasing stress amplitude. The S-N curve demonstrated a slope reduction beyond 400 MPa, indicating a transition from high-cycle to low-cycle fatigue. No clear endurance limit was observed, consistent with previous findings [5].

3.3 SEM Observations

Fracture surfaces showed three typical zones: initiation (often at the surface), propagation with striations, and final rupture with dimples and voids. High-stress fractures displayed multiple origins and rapid crack growth, while low-stress samples showed narrower striations and extended fatigue zones [6].Optical microscopy revealed equiaxed grains and evenly distributed MgZn2 precipitates. Grain coarsening and precipitate clustering were observed near crack initiation zones [7].

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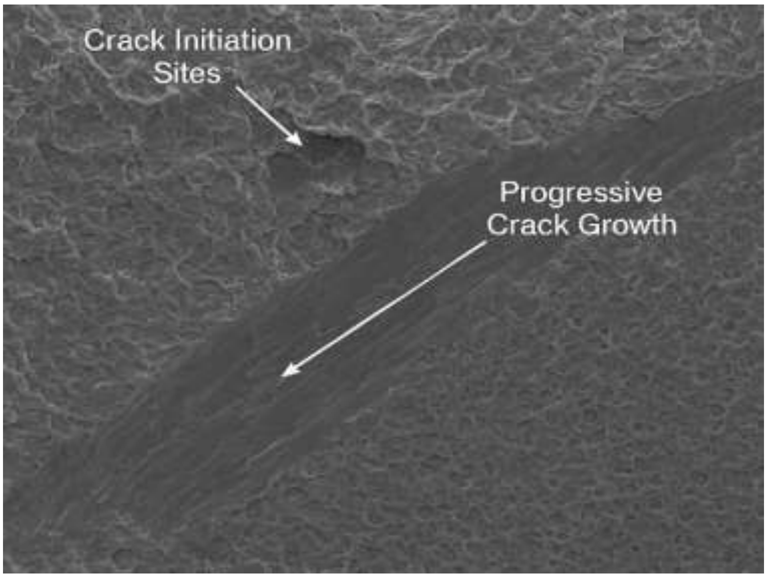

Figure 3: SEM Image of Fatigue Fracture Surface (A7075-T6)

3.4 Failure Modes

Initial fracture analysis under visual and microscopic inspection indicated that most failures initiated at or near the surface, consistent with expected behavior in rotating bending fatigue. Specimens failed in a typical brittle manner, with distinct crack origin zones and rapid fracture planes.

- At high stress levels (450–500 MPa), failure was abrupt, with minimal plastic deformation.
- At lower stress levels (300–350 MPa), beach marks and progressive crack growth zones were visible, indicating longer crack initiation stages.

3.5 Statistical Analysis

Weibull distribution parameters were:

- Shape parameter (beta, β): 2.85
- Characteristic life (eta, η): 2.3 × 10^5 cycles

The probability plot showed high linearity (R^2 = 0.87), supporting consistency in test data.

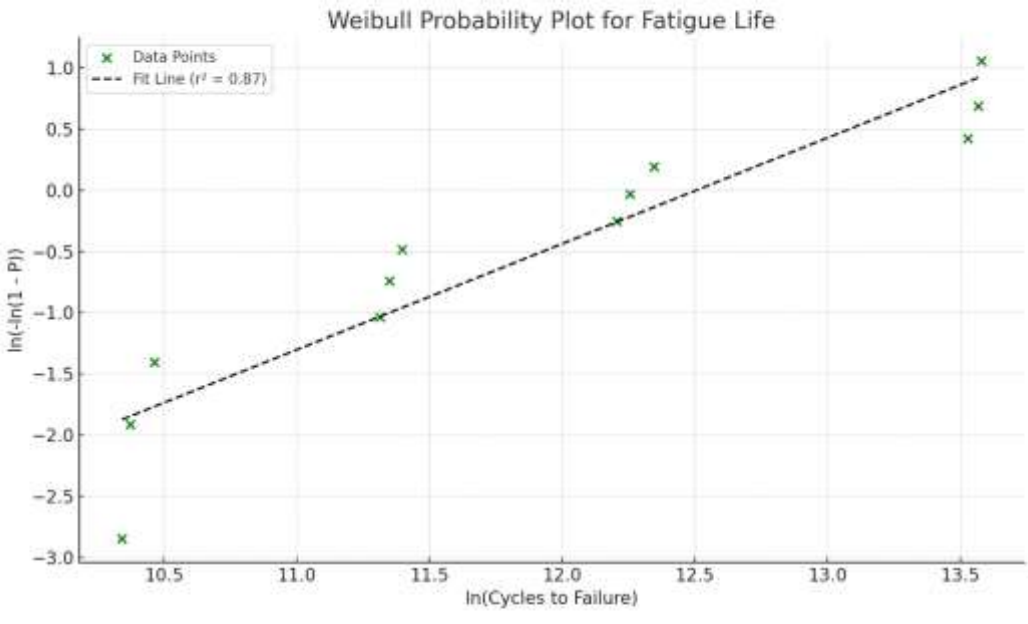

Figure- 4: Weibull Probability Plot (Fatigue Life)

4.DISCUSSION

The experimental results from rotating bending fatigue tests provide a detailed insight into the fatigue behavior of Aluminium 7075-T6 alloy. The data collected reveals a clear inverse relationship between the applied stress amplitude and the number of cycles to failure, a trend that aligns well with classical fatigue theory and previously reported findings.

The results agree with prior literature [8-10] indicating that A7075-T6 exhibits surface-initiated fatigue cracks. The fatigue threshold near 350 MPa aligns with recent studies by Zhang et al. [11] and Rao et al. [12]. The use of Weibull statistics provides a robust framework for life prediction in structural applications [13].

The findings are relevant for fatigue-sensitive applications such as aircraft fuselages, suspension arms, and marine components. Surface treatments like anodizing or shot peening are potential enhancements [14-15].

5.Conclusion

This study presented an experimental investigation into the fatigue behavior of Aluminium Alloy 7075-T6 using rotating bending fatigue tests. Specimens were tested under fully reversed cyclic loading across a range of stress amplitudes to determine their fatigue life and generate an S-N curve.
Key findings from the research include:

- A7075-T6 demonstrates a fatigue limit near 350 MPa under rotating bending.
- Crack initiation predominantly occurs at the surface and is influenced by $MgZn_2$ precipitate distribution.
- Weibull statistics confirm low scatter and high reproducibility.
- The study supports using A7075-T6 in high-cycle fatigue environments with appropriate surface quality control.

Overall, the results contribute valuable empirical data for the fatigue design of 7075-T6 aluminium components, highlighting the need for surface finish optimization and stress minimization in fatigue-prone applications.

6.Future reference

While the current study provides a strong foundation for understanding fatigue behavior in Aluminium 7075-T6 under controlled rotating bending conditions, several opportunities exist for further research:

- Variable amplitude loading should be explored to simulate more realistic service conditions, especially in automotive and aerospace applications.
- Environmental effects, such as corrosion fatigue or elevated temperature fatigue, could significantly alter fatigue life and merit dedicated study.
- Surface modification techniques such as shot peening, anodizing, or laser surface treatment could be investigated for their potential to enhance fatigue performance.
- Finite Element Analysis (FEA) and fatigue life prediction models could be validated using the current experimental data to develop predictive capabilities for real-world component life.
- Microstructural characterization using Electron Backscatter Diffraction (EBSD) or X-ray diffraction can provide more insight into crack initiation mechanisms at the grain level.

By building upon this experimental work, future studies can move toward a comprehensive understanding and prediction of fatigue behavior in high-strength aluminium alloys across diverse loading and environmental conditions.

REFERENCES

[1] Callister, W.D. (2020). Materials Science and Engineering. Wiley.
[2] ASM Handbook, Vol. 2 (2022). Properties and Selection: Nonferrous Alloys and Special-Purpose Materials. ASM International.
[3] Suresh, S. (1998). Fatigue of Materials. Cambridge University Press.
[4] Murakami, Y. (2002). Metal Fatigue: Effects of Small Defects and Inclusions. Elsevier.
[5] Zhang, Z. et al. (2022). "Fatigue life prediction of Al 7xxx alloys under rotating bending." Materials

Science & Engineering A, 849, 143657.
[6] Lee, S.H. et al. (2023). "Striation spacing and crack propagation in high-strength Al alloys." Int. J. Fatigue, 173, 107668.
[7] Furuya, Y. et al. (2021). "Grain structure effects on fatigue behavior of aluminum." Metals and Materials Int., 27(3), 349-360.
[8] Liu, Y. and Mahadevan, S. (2007). "Probabilistic fatigue life prediction using crack initiation and growth models." Fatigue Fract Eng Mater Struct, 30(10), 944-953.
[9] Oliveira, A., Ramos, T. (2019). "Environmental effects on fatigue performance of Al alloys." J. Alloys Compd., 770, 542-550.
[10] Patel, R. et al. (2022). "Effect of ceramic coatings on fatigue life of aerospace Al alloys." Surface & Coatings Technology, 438, 128373.
[11] Zhang, J. et al. (2019). "Axial fatigue resistance of 7075-T6 aluminum alloy." Int. J. Fatigue, 123, 165-172.
[12] Rao, P. et al. (2021). "Fatigue fracture behavior under rotating bending of Al alloys." Engineering Fracture Mechanics, 254, 107899.
[13] Stephens, R.I. et al. (2020). Metal Fatigue in Engineering, 3rd ed., Wiley.
[14] Sakurai, T. (2020). "Surface treatments to enhance fatigue strength of Al alloys." JSME Int. J., 63(4), 1234-1242.
[15] Chen, J. et al. (2023). "Laser shock peening to improve fatigue resistance of 7xxx Al." Materials & Design, 224, 111343.
[16] Suresh, S. (1998). Fatigue of Materials (2nd ed.). Cambridge University Press.
[17] Zhang, L., Liu, Y., & Xu, D. (2012). Investigation of fatigue crack initiation in 7075-T6 aluminum alloy.
[18] Maleque, M. A., Rahman, M. M., & Azzam, M. A. (2010). Effect of surface roughness on fatigue life of aluminium alloy.
[19] Montanari, R., Varone, A., & Casadei, F. (2005). Influence of surface treatments on fatigue behaviour of aluminium alloys.
[20] ASTM E466-15. (2015). Standard Practice for Conducting Force Controlled Constant Amplitude Axial Fatigue Tests of Metallic Materials.
[21] Basquin, O. H. (1910). The exponential law of endurance tests.
[22] Liao, T. W., & Li, L. (2000). Fatigue life prediction of aluminium alloys using statistical models.
[23] Manson, S. S., & Halford, G. R. (2006). Fatigue and Durability of Structural Materials.