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Influence of Stress Cycles under the Fatigue Endurance Limit on Strength and Life of Aluminum Nanocomposite

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Keywords:
Aluminum; Al_2O_3 nanoparticle; Cyclic Stress below endurance limit; Fatigue life; Strength.

Highlights:

- *A groundbreaking reflection of the cyclic stress impact that remains under the endurance fatigue limit on the fatigue characteristics of a nanocomposite (AA2017 with 0.8 wt.% Al_2O_3).*
- *Sub-endurance limit cyclic loading and its distinctive influence on nanocomposites represents an original contribution to the materials science.*
- *Enhancing the mechanical properties of aluminum alloys by integrating ceramic nanoparticles.*

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Abstract: Experimental testing revealed that adding ceramic nanoparticles of alumina Al_2O_3 to the aluminum alloy AA2017 by a casting route significantly enhanced the mechanical and fatigue properties. Understanding the behavior of materials under cyclic loads is necessary; engineers can ensure that structures and components perform reliably throughout their intended lifespan. This work explicitly focuses on the role of these nanoparticles in the fatigue behavior of the aluminum matrix (AA2017) and the resulting (AA2017 – 0.8 wt. %, Al_2O_3) nanocomposite. The test influences of the stress- number of cycles S – N curves showed that cyclic stress below the endurance limit for fatigue, followed by cyclic stress above the endurance limit, decreased the fatigue life and strength. Specifically, the fatigue life was decreased more than twice for the nanocomposite and about 4% for the base metal, while the fatigue strength was lowered by (140.8 to 137.8) MPa for the matrix and (155.5 to 142.4) MPa for the final product of (AA2017 – 0.8 wt. %, Al_2O_3).

تأثير اجهاد الدورات تحت حد التحمل على عمر الكلال وقوة النانومركب الالمونيوم

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الخلاصة

عززت إضافة جسيمات الألومينا Al_2O_3 النانوية السيراميكية إلى سبيكة الألومنيوم AA2017 عن طريق الصب بشكل كبير من الخواص الميكانيكية والإجهاد، كما كشفت الاختبارات التجريبية. يركز هذا العمل بشكل خاص على دور هذه الجسيمات النانوية في سلوك إجهاد مصفوفة الألومنيوم (AA2017) وما ينتج عن مركب نانوي (0.8 - AA2017٪ بالوزن، Al_2O_3). أظهرت تأثيرات الاختبار لمنحنيات الإجهاد - عدد الدورات S - N أن الإجهاد الدوري أقل من حد التحمل للإجهاد، يليه إجهاد دوري يتجاوز حد التحمل، أدى إلى انخفاض في عمر التعب والقوة. وعلى وجه التحديد، انخفض عمر الكلال أكثر من مرتين بالنسبة للمركب النانوي وحوالي ٤٪ بالنسبة للمعدن الأساسي، بينما انخفضت قوة الكلال بنسبة (١٤٠,٨ إلى ١٣٧,٨) ميجا باسكال للمصفوفة و(١٥٥,٥ إلى ١٤٢,٤) ميجا باسكال للمنتج النهائي من (0.8 - AA2017٪ بالوزن، Al_2O_3).

الكلمات الدالة: الألومنيوم؛ جسيمات نانوية من أكسيد الألومنيوم ($Al2O3$)؛ الإجهاد الدوري أقل من حد التحمل؛ عمر التعب؛ القوة.

1.INTRODUCTION

Fatigue failure accounts for 90% of mechanical failures. This phenomenon ensues when the material is exposed to variable loads. The surface elongates and is subject to catastrophic failure. Failure occurs when stress is less than the yield stress [1]. Aluminum alloy AA2017 is predominantly utilized in the aerospace sector due to its exceptional strength-to-weight ratio, which is crucial for the integrity of aircraft structures. With a tensile strength of approximately 430 MPa, it is well-suited for components that demand high durability. Furthermore, this alloy exhibits superior machinability and is economically viable for manufacturing processes. Although it possesses lower corrosion resistance compared to other aluminum alloys, the performance characteristics of AA2017 can be improved through various treatments and natural aging processes [2]. These attributes render it a favorable option for essential structural applications. Nanoparticles improve alloys by incorporating a small quantity of nanoceramic particles. Incorporating a limited amount of ceramic nanoparticles into these alloys forms nanocomposites, further enhancing their properties. With a relatively uniform distribution of Al_2O_3 particles and excellent damage tolerance, nanocomposite modifies the alloy by adding several ceramic nanoparticles [3]. Metal matrix nanocomposite (MMNC) is a multiphase metallic material where the reinforcements have one dimension less than 100 nm [4]. Syazwain et al. [5] studied the composite oxide films incorporating graphite and how they were produced through anodizing on AA2017-T4 aluminum alloy in a diluted sulfuric acid solution (20 wt%). This study, which is unique in its focus on the influence of graphite on the films' growth and its effects on the self-lubricating properties and durability of the composite films, aimed to evaluate these factors. The surface morphology, topography, and chemical composition were analyzed using scanning electron microscopy (SEM), three-dimensional optical profiling, and energy-dispersive spectroscopy (EDS). The films' microhardness was measured at the surface and cross-section using a Vickers microhardness tester. The structural characteristics of the oxide films and graphite were also investigated through X-ray diffraction (XRD) and Raman spectroscopy. The surface properties were assessed through a ball-on-disk sliding wear test conducted under a dry process. The formation of a non-porous barrier layer commenced within 5 to 10 mins. At the 20-mins mark, pore development began, leading to the disruption of the barrier layer. The complete formation of the porous composite oxide film was obtained at 60 mins, characterized by pore dimensions of 23.74 ± 8.91 µm in width and 27.9 ± 9.09 µm in depth. The thickness of the oxide film at a concentration of 1 g/L after 60 mins was approximately 32.45 ± 4.92 µm. Adding graphite decreased the porosity from the surface of the oxide films, thereby enhancing the mechanical and tribological properties. The durability of the composite oxide film was influenced by the hardness and self-lubricating properties of the graphite layer. The matrix alloy was AA7075 aluminum reinforced with a consistent seven-weight percent of TiO2, utilizing various particle sizes of 30, 70, and 100 nm. Nayeeif et al. [6] enhanced the mechanical properties, specifically impact strength, Young's modulus, and fatigue characteristics of metal matrix composites based on the AA7075 alloy. The stir casting technique was successfully employed to fabricate AA7075 composites with a consistent weight percentage of 7 wt. % TiO2 while varying the particle size. These results greatly influenced materials science and engineering. Microstructural examinations revealed that nanocomposites with a particle size of 30 nm displayed superior particle distribution and lower porosity than those with different particle sizes. This specific nanocomposite achieved notable enhancement in ultimate tensile strength and yield strength by 20.45% and 12.87%, respectively, although it also showed the lowest elongation. Additionally, increased particle size was associated with reduced fatigue life and strength. The maximum endurance fatigue limit recorded for the 30 nm nanocomposite was 23.875 MPa. The methodologies used in Mayer et al.'s [7] study have proven reliable, as evidenced by results indicating that the cyclic loads that remained below the endurance limit significantly reduced life, mainly when applied to high, low-stress capacities. The use of special measures and extrapolation of the S-N curve, particularly in the range under the tolerance boundary, has proven exceptionally effective in accurately predicting the ages of organisms. It is worth noting that several low-load cycles have produced encouraging results, significantly when the peak pressure within the sequence slightly exceeds the specified tolerance limit. Investigations into fracture mechanics have revealed that the crack propagation rate is heightened in sequences where the stress intensity levels exceed the critical threshold. The progression of fatigue cracks can be effectively mitigated through multiple cycles beneath the threshold stress intensity. Additionally, Tolephih et al. [8] analyzed the shot peening effects on the strain life of aluminum alloy AA2017 – T4. The findings, which are significant and relevant, demonstrated that shot peening markedly enhanced strain life in deformation elastic and plastic, compared to the untreated specimens. The alloy exhibited bilinear characteristics before and after shot peening, with a 15-minute duration resulting in a notable increase in the strain hardening exponent (n) and the strength coefficient (k). The changing life (NT), signifying the transition of the material from elastic to plastic deformation, peaked at 15 min of shot peening, with the fracture surface evidencing plastic deformation. Alalkawi et al. [9] found that, at 15 min, the peak plays a significant role in the optimal shot peening duration for enhancing the strain life of the material. The research further explored the effects of cyclic stresses under the endurance limit for the fatigue lifespan of 40Cr medium-strength carbon steel. The thorough findings indicated that exposing materials to cyclic stresses that remain beneath the endurance limit before applying elevated stresses can produce beneficial results. Al-Helli and Hamza [2] concluded that stress amplitude, the number of cycles, and loading sequence predominantly affected the strengthening effect. Cyclic stress with different combinations showed apparent effects on strengthening, characterized by an initial rise in fatigue strength and a decrease with increasing cyclic loading. Cyclic stresses at 85% of the endurance limit yielded the most pronounced strengthening effect. In multi-level cyclic loading scenarios, the enhancement in strength at additional cyclic stress levels exhibited a nonlinear increase, and the final stress amplitude level within the loading sequence notably influenced the overall fatigue life. The fluctuations observed in fatigue life exhibited a significant relationship with the loading conditions and the influence of strengthening. As the strengthening influence intensified, the coefficient of variation of the fatigue life results diminished, suggesting a conceivable enhancement in the material's uniformity. The investigation studied the fatigue strength of aluminum alloy through surface treatment (laser). Circling fatigue samples were manufactured and processed, i.e., half were subjected to treatment by operating a 1 Joule laser apparatus. Research was conducted to establish the S-N curves for treated and untreated samples by applying various loads in fatigue testing. The findings revealed that laser treatment improved the fatigue stability of the alloy, which is a significant refinement in materials science and engineering. Also, this study analyzed the effects of altering stress amplitudes during the loading operation. A research examination revealed that sequences characterized by high-low loading delivered more great lifespans compared to those with low-high loading sequences. Lazer's treatment improved the hardness and enhanced its mechanical and fatigue properties with residual stresses. Comparison between the empirical findings and numerical finite element analysis demonstrated a strong correlation, with the maximum error recorded at 9.68% [2]**.** Finding the accuracy of the product gives trust in their use in materials science. This case suggests that high-low loading sequences and laser treatment could improve the fatigue strength of materials, providing valuable for future investigation and potential practical applications in materials engineering. The present study offers a distinctive analysis of the impact of cyclic stress maintained under the endurance limit on the fatigue properties of (AA2017 with 0.8 wt. % $Al2O_3$), a nanocomposite. The focus on cyclic loading within this threshold and its specific implications for nanocomposites marks a notable advancement in materials science. It provides practical insights for engineers and researchers, especially in enhancing the mechanical properties of aluminum alloys by integrating ceramic nanoparticles.

2. EXPERIMENTAL PROGRAM.

2.1.Apparatus and Procedures

The present investigation employed commercially available sheets of aluminum alloy AA2017 precipitation-hardening, each two millimeters thick. The data provided by the supplier concerning the chemical composition of the material are listed in Table 1.

Table 1 Aluminum Alloy the Chemical Analyses.

Composition (mass %)	Si	Cu	Mg	Mn	Fe	Ti	Zn	Cr	Al_2O_3
Aluminum	0.420	3.680	0.530	0.640	0.260	0.050	0.0240	0.017	-
Standard [8,10,11]	0.440	0.780	0.550	0.670	0.240	0.0550	0.020	0.019	0.80

The tensile test specimens, produced according to ASTM standards, had a diameter of 8.5 mm, a gauge length of 35 mm, and a total length of 135 mm. The tensile tests utilized a (WDW-100) testing device with a capacity of 100 kN. The results were based on the average of three measurements. The experiments were conducted at a 1 mm/min crosshead speed. The tensile test sample was produced in cylindrical form in accordance with the ASTM standard (A370-11), as illustrated in Fig. 2. The fatigue device employed was a Schench rotating bending designed for performing fatigue assessments below a steady load, as demonstrated in Fig. 3. The fatigue specimens, shown in Fig. 4, were subjected to a force that generated uniform bending stress.

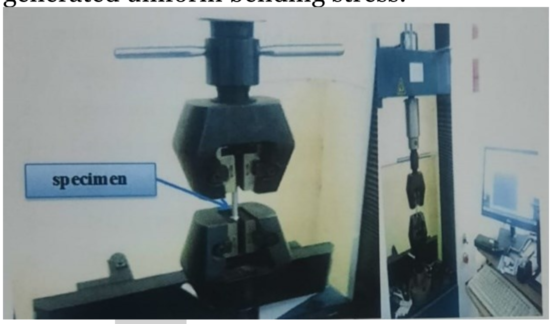


Fig. 1 The Tensile Machine.

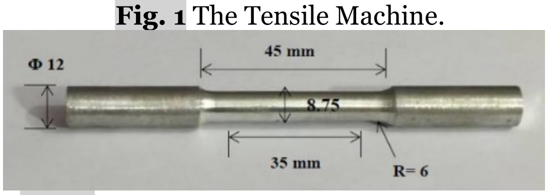


Fig. 2 The Dimensions of Sample in mm for Tensile Test.

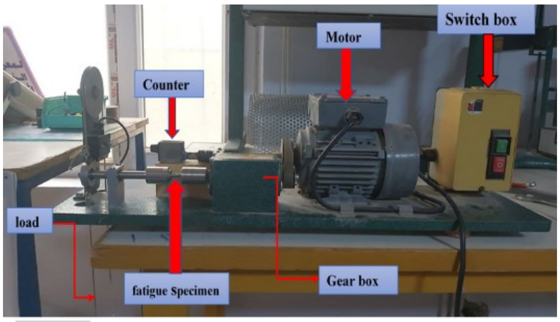


Fig. 3 Fatigue Machine of Rotating Bending.

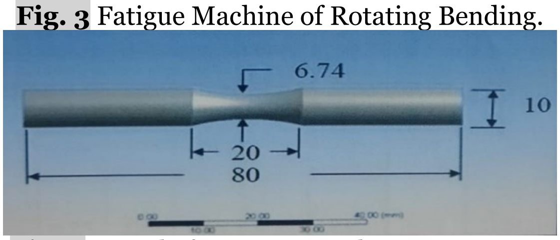


Fig. 4 Sample for Fatigue with Dimensions in mm [12].

2.2.Experimental Procedure

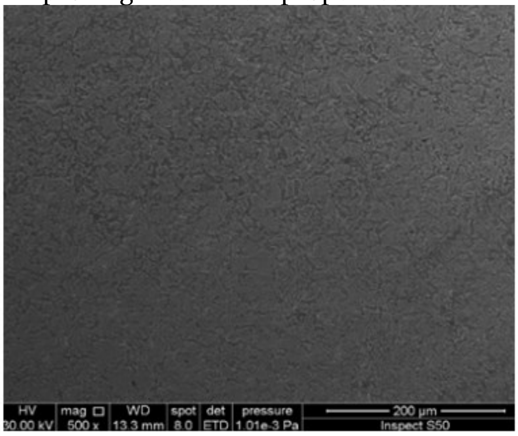
The samples of this work were fabricated with the same nanoparticles of Ref. [13]. The mold made from metal components of cast iron measuring (14×180) mm plays a pivotal role in casting aluminum alloy materials (AA2017). Using nanomaterial alumina (Al_2O_3) further improves the operation. The samples were set by melting aluminum using a gas furnace at an elevated temperature of 750 °C inside a crucible. The alloys for other materials were covered in aluminum foil and stayed for 2-3 min; the mixture was combined thoroughly using an electric mixer. The exact qualities of this mixing procedure guarantee the excellence of the end product shown in Fig. 5. To eliminate slag, aluminum chloride was formed at a rate of 1 gram per 180 grams of the mixture. This process ensures the purity of the final product. Alumina nanoparticles were subsequently encased in foil and incorporated at a concentration of 0.8 wt.% following verifying the process's execution. After an additional 2-3 min, the mixture was stirred for 5-10 min to achieve homogeneity. Upon the conclusion of the alloying process, the resultant mixture was poured into a cast iron mold after being heated to 250 °C.

Fig. 5 Production of Casting Samples.

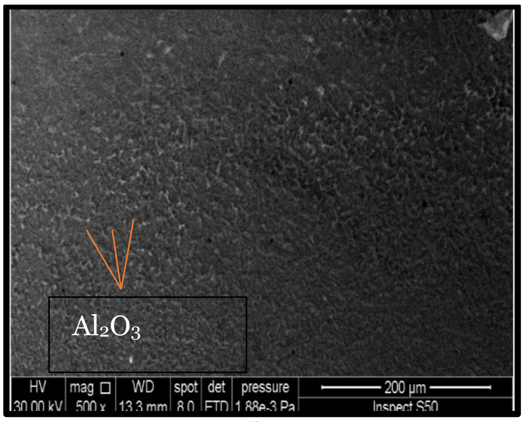
3.RESULTS AND DISCUSSION

3.1.Results of Microstructure and the Mechanical Properties

Figures 6 (a) and (b) show SEM images of the microstructure, the microstructure of the as-cast AA2017matrix, and the 0.8 wt.% Al_2O_3 nanocomposite revealed a homogenous, consistent dispersion of Al_2O_3 particles compared to the base metal. Furthermore, the metal matrix nanocomposite (MMNCs) microstructure with 0.8 wt.% Al_2O_3 demonstrated a high level of Al2O3 distribution throughout the composite. This consistent distribution of Al_2O_3 and reduced porosity contributed to the enhanced ultimate tensile strength and yield strength of the MNCs when combined with the cast matrix. The homogeneous distribution of reinforcing nanoparticles in Hemanth's study [14] and Bharath's study [15] is consistent with the present research, suggesting that the homogeneous distribution of nanoparticles in the base metal and low porosity is a key factor in improving mechanical properties.



(a)



(b)

Fig. 6 (a) Aluminum Microstructure (b) Nanocomposite (0.8 wt. % Al2O3) Microstructure.

The mechanical tensile properties of the matrix and nanocomposites are presented in Table 2, which shows the mechanical tensile properties of the base metal and the nanocomposite AA2017-0.8 wt.% Al_2O_3. The table shows that adding 0.8wt.% Al_2O_3 nanoparticles to the AA2017 matrix resulted in an increase in Ultimate Tensile Strength from 455 MPa to 466 MPa, Yield Strength from 261 MPa to 272 MPa, and Young's Modulus from 78 GPa to 80 GPa. While the elongation decreased slightly, the overall results indicated an enhancement in mechanical properties due to the incorporation of nanoparticles. This enhancement is consistent with previous studies. Mushehdany [16] similarly used nano-reinforced materials fabricated by stir casting to improve the mechanical and fatigue properties of the nanocomposite AA7075-Al_2O_3 under constant and variable loading conditions. Their findings also demonstrated enhanced mechanical properties and fatigue behavior due to the uniform distribution of Al_2O_3 within the matrix and reduced porosity. Huda et al. [17] also found that adding 5wt.% Al_2O_3 to an AA7075 matrix resulted in a 14.3% increase in tensile strength and a 34.3% increase in yield stress, further supporting the consistent trend observed in the present research. This trend confirms that the dispersion of Al_2O_3 nanoparticles improves the mechanical properties of metal matrix composites in different aluminum alloys and with different weight percentages of Al_2O_3.

Table 2 The Mechanical Properties of Aluminum and Nanocomposite.

Ultimate stress /MPa	Yield stress/ MPa	Elongation	Young Modules/GPa
Aluminum 2017			
455.0	261.0	27.0	78.0
Nanocomposite			
466.0	272.0	25.0	80

3.2. Fatigue Testing Results

Table 3 and Fig. 7 present the S-N curves and shows the experimental result for AA2017 and nanocomposite with 0.8wt.%. The fatigue properties at 10^7 cycles are tabulated in Table 4.

Table 3 The Results from the Experimental Work with Constant Fatigue test for Matrix and Nanocomposite.

Substance	Applied Stress (N/mm²)	Number of cycles to failure (N_f)	Average Number of cycles ($N_{f\,av}$)	The equation for the S-N curve	R^2	Endurance limit for fatigue test (N/mm²) (MPa)
Aluminum results after fatigue test						
Aluminum AA2017 (Base metal)	300	6600,8400,9000	8000	$\sigma_f = 842.57 \times N_f^{-0.111}$	0.9270	140.8
	270	97000,86000,110800	97933			
	220	143800,117000,125600	128800			
	190	428000,348000,460800	412267			
Nanocomposite results after fatigue test						
AA2017 - 0.8wt.% Al2O3	300	16800,22800,19800	19800	$\sigma_f = 1170 \times N_f^{-0.124}$	0.94210	158.5
	270	122800,142600,130000	131800			
	220	186600,177600,190000	184733			
	190	580000,612600,623000	605200			

Table 4 The Fatigue Properties of AA2017 -T_4 and AA2017 – 0.8 wt.% Al_2O_3

Aluminum Matrix		**Nano Composite**	
Life at stress 200 (N/mm²)	Fatigue Strength at (10^7) cycles	Life at stress 200 (N/mm²)	Fatigue Strength at (10^7) cycles
423458.00 cycles	140.80 (MPa)	1537237.00 cycles	158.55 (MPa)
Enhancement in the Fatigue Properties Percentage.			
FLI%		FSI%	
72.4		11.2	

The values of improving life and strength were 72.4% and 11.2%, respectively. Table 4 demonstrates the superior fatigue strength and nanocomposite lives compared to aluminum. The significant enhancements are likely attributed to the microstructure of 0.8 wt.% Al_2O_3, which was a homogeneous distribution of Al_2O_3 within the base metal, as illustrated in Fig. 6 (b). In contrast to the base metal, the superior mechanical characteristics of Al_2O_3 particles served as the principal contributor to the improvement of tensile and fatigue properties. In this field, studies AL-Mushehdany [16] and Jaber [18] agreed with this work that the homogenous distribution of nanoparticles into the aluminum matrix enhanced the mechanical and fatigue properties due to the uniform distribution of nanoparticles, diminished porosity, and small grain size. The findings are presented in Table 3 and illustrated in Fig. 7. Figure 7 depicts the fatigue behavior of the base metal and the nanocomposite, leading to the formulation of S-N curve equations.

$$\sigma_f = 842.57 * N_f^{-0.0111} \ , R^2 = 0.927 \quad (1)$$

$$\sigma_f = 1170 * N_f^{-0.0124} \ , R^2 = 0.9462 \quad (2)$$

Table 5 illustrates the fatigue outcomes associated with constant loading before reaching 10^5 cycles, explicitly focused on the endurance fatigue that remained under the endurance limit for fatigue ($\sigma_{EL.}$). The information presented in Table 5 is illustrated in Fig. 8. The S-N curves for the base metal and the nanocomposite have been designed for a prior cycle count of 10^5, remaining below the endurance fatigue limit (σ). This analysis yields the corresponding equations for the S-N curves.

$$\sigma_f = 894 * N_f^{-0.116} \ , R^2 = 0.942 \quad (3)$$

$$\sigma_f = 969.43 * N_f^{-0.011} \ , R^2 = 0.928 \quad (4)$$

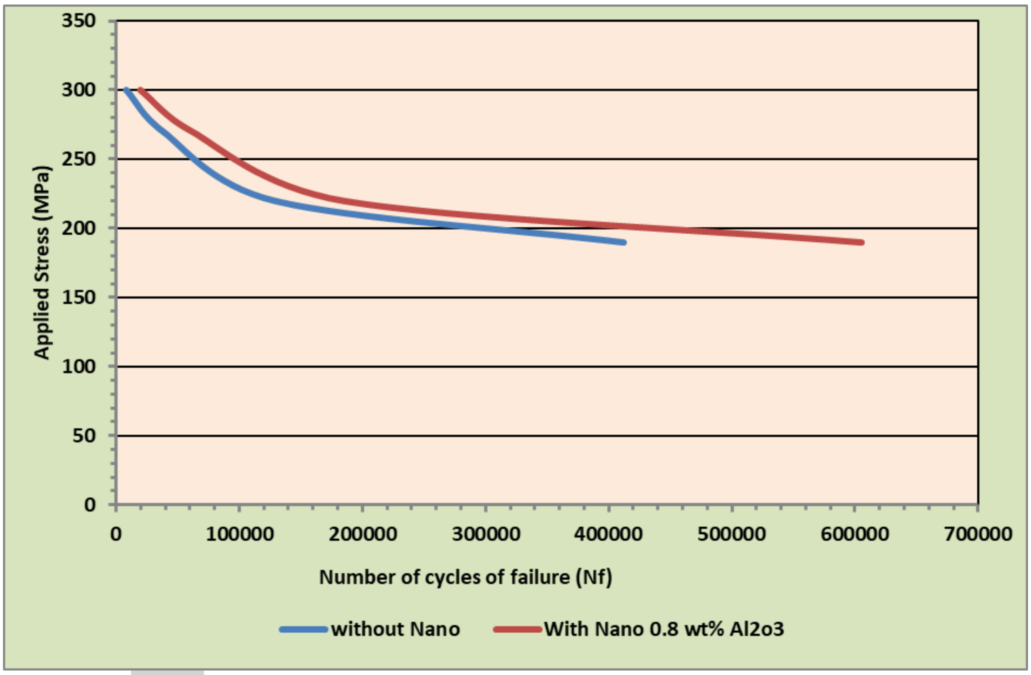


Fig. 7 The S – N Curves for Base Aluminum and Nanocomposite.

Table 5 The S-N Curve for Rotating Bending at 90% of ($\sigma_{EL.}$) over 10^5 Cycles.

Substance	Fatigue St. (N/mm^2)	Number of Cycles (N_f)	Av. Number. of cycles (N_f av)	The equation for S – N	Reg.	Endurance limit for fatigue (N/mm^2)
Cycles under 90% of the Endurance Limit for fatigue of (AA2017 -T4) After 100000						
(Base metal)	300	7000,12500,10000	9833	$\sigma_f = 894 \times N_f^{-0.116}$	0.942	137.8
	270	102500,96800,122000	107100			
	220	150000,122500,132800	138433			
	190	516200,448000,406000	456733			
Cycles under 90% of the Endurance Limit for Fatigue (AA2017 - 08 wt.% Al2O3) After 100000						
Nanocomposite	300	11600,18200,13600	14467	$\sigma_f = 969.43 \times N_f^{-0.11}$	0.928	142.4
	270	133000,118800,141000	130933			
	220	188600,190000,166500	181700			
	190	710800,668500,590200	656500			

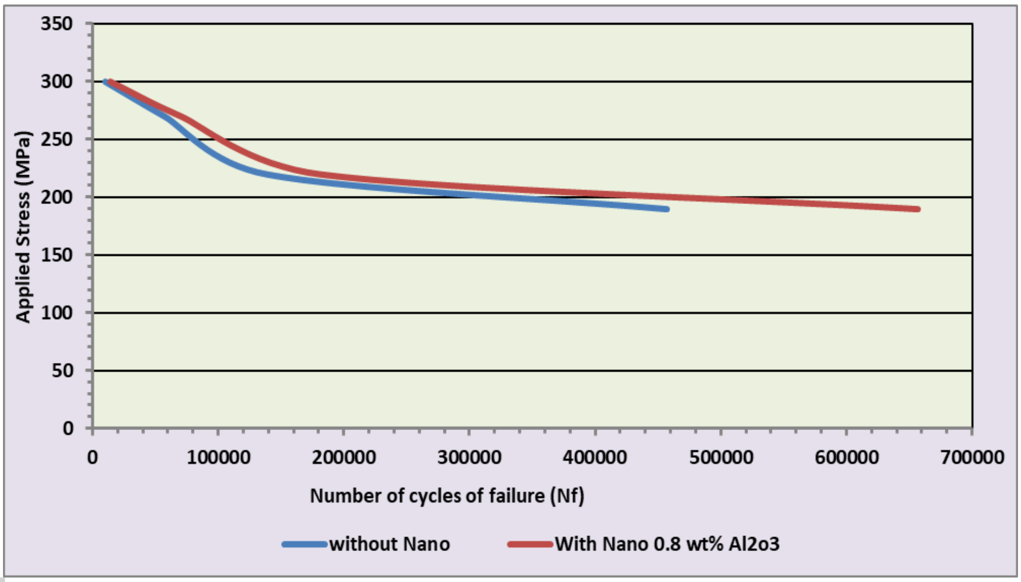


Fig. 8 The S – N Curves Trend for Aluminum and Nanocomposite below 10^5 Cyclic Loading before Fatigue Test Exceeding Endurance Limit.

Table 5 presents the experimental fatigue life of the matrix and the nanocomposite before cycles reach the endurance limit. The findings indicated a decrease in the endurance fatigue limit, decreasing from 158.5 MPa for the nanocomposite without cycles to 142.4 MPa for the same nanocomposite subjected to cycles, representing a less than 8.45% reduction. Miller et al. [19] noted a critical phenomenon involving persistent slip bands occurring below the fatigue limit, precisely at 85% of the fatigue limit stress. Their assertion that damage accumulation at stress levels beneath the fatigue limit can considerably influence subsequent damage accumulation at higher stress levels enriches the present research context.

3.3.The Influence of Cyclic Stress under the Endurance Limit (σ_{EL})

It can be observed in Table 5 that the fatigue and strength following (10^5) cycles of loading at levels under the (σ_{EL}) were approximately 90% of σ_{EL}. This information regarding the matrix nanocomposite AA2017 with 0.8 wt.% Al_2O_3 is further detailed in Table 6.

Table 6 Assessment of the Fatigue Properties Pre- and Post-Testing.

Aluminum at (10^5)cyclic loads under σEL		**AA2017 - 0.8wt.% AL_2O_3 at (10^5) cyclic loads under σEl**	
$\sigma_f=894xN_f^{-0.116}$		$\sigma_f=969.43xN_f^{-0.119}$	
Cycles at stress 200MPa	(σ_{EL}) at 10^7cycles	Cycles at stress 200MPa	(σ_{EL}) at 10^7cycles
403737.0	137.8 MPa	573814.0	142.4 MPa

Applying (10^5) cycles below the (σ_{EL}) decreased fatigue life and strength-specifically, the fatigue life of the matrix diminished from 420.884 cycles to 403.737 cycles. Concurrently, the fatigue strength experienced a decline from 140.8 MPa to 137.8 MPa due to the (10^5) cyclic loading below the (σ_{EL}), resulting in a life reduction percentage of 4%. By the analyses producing nanocomposite, the fatigue strength declined strength values from (158.55 to 142.4) MPa under identical loading conditions, corresponding to a 10% reduction in fatigue strength. This finding has implications for designing and using materials in engineering applications, underscoring the practical relevance of the present research. The S – N Curves trend for aluminum and nanocomposite under 10^5cyclic loading before the fatigue test exceeded the endurance fatigue limit; however, a factor of more than two could alter the fatigue life, reducing the predicted life without cyclic loading. In the present study, it was observed that the damages initiated were below a certain threshold. It is crucial to understand that not all the damage can bear cracks. However, some reproduce when increasing the stress class overhead, significantly decreasing fatigue properties, underscoring the urgent and critical need for a deeper understanding of the damage initiation process agree with [7, 20].

4.CONCLUSIONS

To examine the influence of cyclic stress that remains beneath the endurance limit (σ_{EL}) for aluminum alloys and the nanocomposite, tests were performed under constant fatigue loading conditions. The subsequent observations are proposed.

- Applying low cycle loading beneath the endurance fatigue limit significantly hastened crack propagation when the stress level was increased beyond the endurance fatigue limit for aluminum alloy and nanocomposites.
- The fatigue strength for aluminum alloy at 10^7 cycles decreased from (140.8 to 137.8) MPa, while for the nanocomposite, it diminished from (155.5 to 142.4) MPa when

subjected to a loading of 10^5 cycles that remained below the endurance fatigue limit.

- The base metal's fatigue life decreased from 423,458 cycles to 403.737 cycles, while it increased from 153,737 cycles to 573.814 cycles when subjected to a loading of 10^5 cycles, which is below the endurance fatigue limit.
- Incorporating Al_2O_3 into the base metal, AA2017, resulted in a significant enhancement, evidenced by a 72.4% increase in fatigue life and an 11.2% improvement in fatigue strength.

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NOMENCLATURE

AA2017	Aluminum alloy
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
Al_2O_3	Alumina
BPL	Black Paint Laser Peening
EDS	Energy-Dispersive Spectroscopy
FLI	Fatigue Life Improves
FSI	Fatigue Strength Improves
MMCs	Metal Matrix Composites
MMNCs	Metal Matrix Nanocomposite
R	The Stress Ratio
RT	Room Temperature
S-N	Stress-Number of Cycles Curve
SEM	Scanning Electron Microscopy
WDW	Name of Testing Machine
XRD	X-ray Diffractometer
Greek Symbols	
σ	Fatigue stress (MPa)
N	Number of cycles
R^2	Regression
Subscripts	
f	Fatigue
EL	Endurance Limit

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