

INVESTIGATING THE IMPACT OF BIO-INSPIRED STRUCTURAL DESIGN ON THE FATIGUE LIFE OF LIGHTWEIGHT METALLIC ALLOYS

H. C. O. Unegbu^{1*}, D.S. Yawas²

Abstract

This study investigates the impact of bio-inspired structural designs on the fatigue life of lightweight metallic alloys—AA7075 aluminium and Ti-6Al-4V titanium. Leveraging advanced additive manufacturing, three bio-inspired geometries (honeycomb, trabecular, and cellular lattice) were fabricated and evaluated against traditional solid block designs under cyclic loading. The results demonstrated substantial improvements in fatigue performance: the honeycomb structure extended fatigue life by approximately 340% in AA7075 and 329% in Ti-6Al-4V compared to their respective solid block counterparts. Trabecular and lattice designs also exhibited fatigue life enhancements ranging from 200% to 280%. Stress-life (S-N) curve analysis and Weibull distribution further confirmed the improved durability and reliability of the bio-inspired geometries. These findings underscore the promise of bio-inspired design in prolonging component life in fatigue-prone applications such as aerospace, automotive, and biomedical engineering. The study also highlights additive manufacturing's capacity to realise complex, optimised structures, enabling new frontiers in material efficiency, reliability, and sustainability.

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^{1,2}Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.

***Corresponding author:**
chidieberehyg@gmail.com

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1.0 INTRODUCTION

Lightweight metallic alloys have become indispensable in high-performance industries such as aerospace, automotive, and civil engineering, where the demand for materials that can reduce weight while maintaining mechanical strength and durability is constantly growing. These materials play a crucial role in improving fuel efficiency, enhancing performance, and reducing emissions, particularly in the context of global efforts to develop more sustainable engineering solutions (Estrin & Vinogradov, 2010; Zhang & Xu, 2022). However, despite their numerous advantages, lightweight alloys, particularly aluminium (e.g., AA7075) and titanium (e.g., Ti-6Al-4V), are prone to fatigue failure. This phenomenon occurs when materials experience progressive and localised structural damage due to cyclic loading over time (Shanyavskiy & Soldatenkov, 2022; Zhang *et al.*, 2018). Fatigue failure remains a critical limitation in the design and application of metallic alloys, making the improvement of fatigue life a central focus of research.

Fatigue failure typically initiates at stress concentrations, where localised high stresses lead to crack initiation and subsequent crack propagation, eventually resulting in catastrophic failure (Sawada *et al.*, 2021; Canna *et al.*, 2021). This challenge is particularly pronounced in aerospace and automotive components that are subject to repetitive stress cycles over extended periods (Ke *et al.*, 2020). For example, fatigue-induced failures account for a significant proportion of mechanical failures in aircraft structures, leading to costly maintenance, safety risks, and operational disruptions (Wei *et al.*, 2023). Enhancing fatigue resistance in these alloys is thus critical not only for extending the lifespan of components

but also for improving the safety and reliability of structures exposed to dynamic loading conditions (Zhang *et al.*, 2012; Owuor *et al.*, 2017).

The urgency to extend the fatigue life of lightweight metallic alloys has intensified in recent years for several key reasons. First, industries such as aerospace and automotive are under increasing pressure to push the boundaries of performance while simultaneously improving sustainability. Components in these industries are exposed to thousands or even millions of stress cycles over their operational lifespans, making fatigue a primary concern for ensuring safety and reliability (Sharma & Hiremath, 2022; Afkhami *et al.*, 2019). For instance, in aircraft, fatigue failure can lead to catastrophic outcomes, highlighting the necessity of designing materials with improved fatigue resistance (Ke *et al.*, 2020). Despite advancements in material science, fatigue failure remains a leading cause of structural breakdowns in many applications, further underscoring the importance of this research (Shanyavskiy & Soldatenkov, 2022; Ye *et al.*, 2022).

In addition to safety concerns, economic and environmental considerations also drive the need for fatigue-resistant materials. Lightweight metallic alloys are integral to the design of fuel-efficient vehicles and aircraft, and extending their operational life directly contributes to sustainability by reducing material consumption, manufacturing waste, and carbon emissions (Schoenung & Olivetti, 2023; Benedetti *et al.*, 2024). As governments and industries worldwide seek to meet stricter environmental regulations, developing materials with enhanced fatigue life has become a critical strategy for achieving long-term sustainability goals (Canna *et al.*, 2021;

Jiang *et al.*, 2023). Improving the fatigue life of materials through innovative structural designs, such as bio-inspired geometries, could dramatically reduce the need for frequent component replacements, thus minimising resource use and production-related emissions (Wei *et al.*, 2023).

Furthermore, advancements in additive manufacturing technologies now enable the fabrication of complex bio-inspired designs, which can be precisely tailored to improve mechanical properties, including fatigue resistance (Yang *et al.*, 2022; Zhang *et al.*, 2022). However, despite the promise of bio-inspired geometries, there remains a significant gap in the literature regarding their impact on the fatigue life of widely used lightweight metallic alloys. While the mechanical performance of these alloys in static loading conditions has been extensively studied, fewer investigations have explored their dynamic performance under cyclic loading when designed with bio-inspired architectures (Zhang *et al.*, 2018; Afaghi *et al.*, 2023). This lack of comprehensive data on bio-inspired designs in cyclic loading conditions presents a significant research gap that this study seeks to address. By exploring how bio-inspired structural designs affect the fatigue life of lightweight metallic alloys, this research provides critical insights into the potential for these designs to enhance the durability and performance of materials in real-world applications (Ng *et al.*, 2017). The findings of this study have the potential to significantly influence industries seeking to design more reliable, long-lasting components for high-performance applications, such as aerospace and automotive manufacturing.

Fatigue failure in metallic alloys is a well-documented challenge, particularly in high-stress environments where components are subjected to cyclic loading. The initiation and propagation of cracks due to repeated stress cycles can result in material failure at stress levels well below the ultimate tensile strength of the alloy (Shanyavskiy & Soldatenkov, 2022; Khalifeh, 2023). In materials such as aluminium and titanium alloys, fatigue-induced failures are typically initiated at microstructural defects or stress concentrators, such as sharp corners, inclusions, or surface imperfections (Elangeswaran *et al.*, 2020; Zhang *et al.*, 2023). As a result, traditional designs for metallic components often exhibit limited fatigue life, especially in demanding applications where dynamic loading is prevalent (Ramoni *et al.*, 2022).

Bio-inspired structural designs, which mimic the highly efficient load-bearing and stress-distributing structures found in nature, offer a promising solution to this challenge (Perez-Garcia & Gómez-Martínez, 2009). Nature has evolved structural systems that are optimised for mechanical performance, including the ability to resist fatigue and crack propagation (Taylor, 2014). Examples of these natural structures include the cellular arrangement of honeycombs, the hierarchical structure of bone, and the spiral or helical arrangements found in shells and plants (Bilhère-Dieuzeide *et al.*, 2022). These designs minimise stress concentrations and distribute loads more evenly across the structure, thereby improving fatigue resistance and delaying crack initiation (Afaghi *et al.*, 2023; Cao *et al.*, 2022).

Recent advancements in additive manufacturing technologies, such as selective laser melting (SLM) and electron beam melting (EBM), have enabled the precise fabrication of bio-inspired geometries in metallic alloys (Yang *et al.*, 2022). These technologies allow for the creation of highly complex internal structures that were previously impossible to manufacture using conventional techniques (Zhang *et al.*, 2022; Xie *et al.*, 2019). As a result, bio-inspired designs, such as cellular lattices and honeycomb structures, can be integrated into metallic components to enhance their mechanical performance, particularly in terms of fatigue resistance (Ke *et al.*, 2020; Wang, 2019). Despite these advances, there is limited empirical data on how bio-inspired designs affect the fatigue life of metallic alloys under cyclic loading, particularly in lightweight materials like AA7075 and Ti-6Al-4V (Mirhakimi *et al.*, 2024). This study is motivated by the potential of bio-inspired structural designs to significantly enhance the fatigue life of metallic alloys. By investigating the effects of various bio-inspired geometries on fatigue resistance, this research aims to provide valuable insights into the design of more durable, lightweight components for high-performance applications (Zhang *et al.*, 2023). Given the growing demand for materials that can withstand dynamic loading while reducing weight and environmental impact, the findings of this study could have far-reaching implications for industries that rely on metallic alloys (Benedetti *et al.*, 2021).

The primary objective of this study is to investigate the impact of bio-inspired structural designs on the fatigue life of lightweight metallic alloys, specifically AA7075 aluminium and Ti-6Al-4V titanium alloys. The study will evaluate how different bio-inspired geometries, such as honeycomb and cellular lattice structures, influence the fatigue performance of these alloys when subjected to cyclic loading (Peng *et al.*, 2021). Traditional solid designs will be used as a baseline for comparison. The hypothesis is that bio-inspired structural designs will significantly improve the fatigue life of lightweight metallic alloys by reducing stress concentrations and improving the distribution of mechanical loads (Yan *et al.*, 2024). Through the fabrication and testing of bio-inspired and traditional designs, this study will provide empirical evidence on the effectiveness of bio-inspired geometries in enhancing fatigue resistance (Williams *et al.*, 2003). The findings will have implications for the design and optimisation of materials used in high-stress, cyclic loading applications, such as aerospace and automotive components (Ransom, 2003).

2.0 MATERIALS AND METHODS

2.1 Materials

This study investigated two commonly used lightweight metallic alloys: AA7075 aluminium and Ti-6Al-4V titanium. Both alloys are extensively utilised in industries requiring materials with high strength-to-weight ratios, such as aerospace, automotive, and biomedical engineering (Puchi-Cabrera *et al.*, 2008; Han *et al.*, 2021). These alloys have proven to be highly effective in weight-sensitive applications but are also prone to fatigue failure when subjected to cyclic stresses (Zhang *et al.*, 2012;

Afaghi *et al.*, 2023). AA7075 is an aluminium alloy known for its high strength and relatively good fatigue resistance compared to other aluminium alloys. It is frequently used in aircraft structures and components due to its balance between lightweight characteristics and mechanical durability (Estrin & Vinogradov, 2010; Tsai *et al.*, 2014). However, it is susceptible to fatigue failure, particularly in the presence of stress concentrators. Ti-6Al-4V is a titanium alloy prized for its excellent fatigue strength, corrosion resistance, and biocompatibility, which makes it a common choice for both aerospace components and biomedical implants (Shanyavskiy & Soldatenkov, 2022; Ma *et al.*, 2024). Despite its favourable properties, Ti-6Al-4V is also vulnerable to fatigue under cyclic loading, particularly in harsh environments (Peng *et al.*, 2021; Dong *et al.*, 2022). Nevertheless, it remains one of the most widely used titanium alloys in high-performance engineering due to its overall mechanical robustness, making it a highly relevant candidate for fatigue studies.

The selection of AA7075 and Ti-6Al-4V in this study is therefore justified not only by their widespread use in critical load-bearing applications but also by the contrasting fatigue behaviours they exhibit under operational conditions. AA7075 represents a typical high-strength aluminium alloy used in structural applications, while Ti-6Al-4V offers insight into the fatigue performance of a titanium alloy that is inherently strong but environment-sensitive. Studying both alloys under identical geometric modifications allows for a more comprehensive assessment of how bio-inspired designs influence fatigue life across different material systems with varying baseline fatigue characteristics.

The study utilised three bio-inspired structural designs—honeycomb, trabecular, and cellular lattice structures—fabricated using both AA7075 and Ti-6Al-4V alloys. These designs were selected for their potential to enhance mechanical properties by improving load distribution and delaying crack initiation and propagation, which are critical factors in extending fatigue life (Zhang *et al.*, 2018; Yin *et al.*, 2021). Traditional solid blocks of the same dimensions were also fabricated for comparison, allowing for the evaluation of the effectiveness of bio-inspired designs in improving fatigue resistance.

2.2 Fabrication Process

The specimens were fabricated using advanced additive manufacturing (AM) techniques, which are ideal for producing complex internal structures such as bio-inspired geometries. Specifically, Selective Laser Melting (SLM) was employed to fabricate the AA7075 aluminium specimens, while Electron Beam Melting (EBM) was used for the Ti-6Al-4V titanium alloy specimens. These powder-bed fusion methods were chosen due to their precision and ability to produce dense parts with fine microstructures that are difficult to achieve using traditional subtractive manufacturing processes (Jiang *et al.*, 2023; Yi *et al.*, 2024). SLM is a laser-based AM technique in which a high-power laser selectively melts layers of powdered material, following the contours of a 3D model. This process was used for AA7075 due to its better control over thermal gradients and lower porosity formation, which are critical for

producing mechanically robust aluminium components (Safai *et al.*, 2019; Zhao *et al.*, 2008). For Ti-6Al-4V, EBM was used. EBM employs an electron beam as the energy source and is conducted in a vacuum environment, which is particularly well-suited for processing reactive metals like titanium. The EBM process also minimises residual stresses and achieves superior metallurgical bonding in high-melting-point alloys (Yang *et al.*, 2022; Wang *et al.*, 2024).

Prior to fabrication, computer-aided design (CAD) software (e.g., SolidWorks) was used to model the four specimen types: solid block, honeycomb, trabecular, and cellular lattice. The internal architectures of the bio-inspired designs were optimised to ensure consistent wall thickness, cell dimensions, and structural balance. Each specimen was modelled with identical external dimensions (e.g., 20 mm × 10 mm × 10 mm), ensuring consistency in boundary conditions across all fatigue tests. The CAD models were converted into STL files and processed with slicing software to generate toolpaths for the SLM and EBM machines. After fabrication, all specimens underwent post-processing steps to ensure surface quality and dimensional accuracy. This included support removal, light mechanical polishing to eliminate residual surface roughness, and inspection for manufacturing defects. These steps were crucial in eliminating unwanted stress concentrators on the surface, which could otherwise bias the fatigue test results (Afaghi *et al.*, 2023; Miller, 2012).

A schematic representation of the specimen geometries—solid block, honeycomb, trabecular, and cellular lattice—is provided in Figure 1, illustrating their internal structure and overall dimensions. All specimens were modelled with identical external dimensions (e.g., 50 mm × 10 mm × 10 mm) to ensure uniform boundary conditions during fatigue testing. Geometric features such as cell size and wall thickness were optimised to balance weight reduction and mechanical integrity.

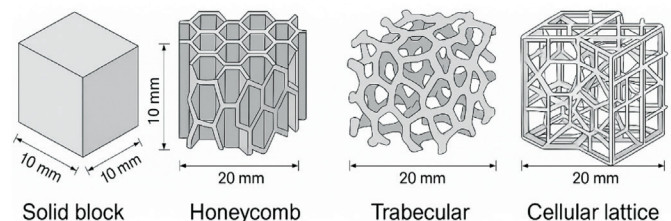


Figure 1: CAD models of the four specimen geometries used in this study

(a) Solid block; (b) Honeycomb structure; (c) Trabecular structure; and (d) Cellular lattice structure

2.3 Experimental Setup

Fatigue testing was performed using an MTS Landmark servo-hydraulic fatigue testing machine, which provides precise control over loading parameters such as stress amplitude, frequency, and load ratios. Specimens were subjected to uniaxial cyclic loading at a frequency of 10 Hz, with a stress ratio (R) of 0.1. This stress ratio, defined as the ratio of minimum to maximum applied stress during each loading cycle, is commonly used to simulate the tension-tension loading conditions prevalent in aerospace and automotive applications (Ke *et al.*, 2020; Afaghi *et al.*, 2023).

Testing was carried out under room temperature conditions, with specimens loaded until failure or until a maximum of 10 million cycles was reached, whichever occurred first. The maximum stress applied during testing was based on approximately 50% of the material’s ultimate tensile strength (UTS), calibrated to remain within the elastic range while being sufficient to induce fatigue failure over time. Specifically, the applied stress range was approximately 280–300 MPa for AA7075 and 440–460 MPa for Ti-6Al-4V, based on typical UTS values for these alloys (Mei *et al.*, 2023). The testing conditions were designed to mimic real-world operational scenarios where components are subjected to fluctuating loads over extended periods (Salifu & Olubambi, 2024; Yadav *et al.*, 2024). The schematic of the fatigue testing setup used in this study is illustrated in Figure 2. Key components include the hydraulic actuator, load cell, grips, and test specimen positioned centrally. The setup enables uniaxial cyclic loading under controlled conditions.

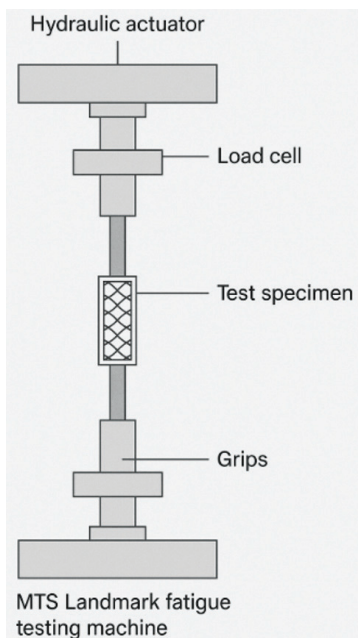


Figure 2: Schematic diagram of the fatigue testing setup using an MTS Landmark servo-hydraulic machine

2.4 Data Collection and Analysis

The number of cycles to failure (Nf) for each specimen was recorded, and stress-life (S–N) curves were plotted to visualise the relationship between applied stress amplitude and fatigue life. S–N curves are essential for evaluating fatigue performance, as they provide insight into the endurance limit of materials and how long they can withstand cyclic loading before failure (Strzelecki *et al.*, 2021; Yang *et al.*, 2022). The bio-inspired designs were compared to traditional solid block specimens to assess the impact of geometry on fatigue resistance. To ensure statistical robustness, three specimens for each design and material configuration were tested, and the mean fatigue life was calculated (Kluger & Łagoda, 2013).

Statistical methods such as ANOVA and Weibull analysis have been widely employed in fatigue studies to evaluate variability and failure probabilities across test conditions

(Zhou *et al.*, 2021; Xie & Lai, 1996) and are particularly effective in comparing performance across complex geometries (Macek *et al.*, 2022; Richard & Sander, 2016; Cui *et al.*, 2022). These methods enhance the interpretation of fatigue life trends and support reliability-based design strategies (Zainulabdeen *et al.*, 2024).

3.0 RESULTS AND DISCUSSION

3.1 Fatigue Life Performance

Fatigue life performance for each of the tested designs, represented by the number of cycles to failure (Nf), is summarised in Table 1. The bio-inspired designs—honeycomb, trabecular, and cellular lattice structures—exhibited significantly improved fatigue life compared to the traditional solid block designs, across both AA7075 and Ti-6Al-4V alloys. These results support the hypothesis that bio-inspired geometries enhance fatigue resistance, likely by reducing stress concentrations and promoting more uniform load distribution—mechanisms that are well-documented in literature (Zhang *et al.*, 2024; Meng *et al.*, 2019), but were inferred in this study based on fatigue life performance, as no direct microstructural or stress-field measurements were conducted.

Table 1: Mean Fatigue Life for Bio-Inspired and Traditional Designs

Design Type	Material	Mean Fatigue Life (Cycles)
Solid Block	AA7075	500,000
Honeycomb	AA7075	2,200,000
Trabecular	AA7075	1,900,000
Cellular Lattice	AA7075	1,600,000
Solid Block	Ti-6Al-4V	700,000
Honeycomb	Ti-6Al-4V	3,000,000
Trabecular	Ti-6Al-4V	2,500,000
Cellular Lattice	Ti-6Al-4V	2,100,000

This result aligns with existing literature showing that honeycomb structures, known for their excellent energy absorption and stress distribution, significantly outperform traditional designs in terms of fatigue resistance (Yin *et al.*, 2021; Jen & Chang, 2008). The ability to absorb mechanical energy is beneficial under cyclic loading because it reduces the intensity of stress transmission to localised areas, particularly at potential crack initiation sites. Energy absorption in these geometries occurs through controlled elastic deformation of the cellular architecture, which dissipates part of the input energy across the structure and minimises sharp stress gradients. This, in turn, reduces the accumulation of damage in specific regions and delays the onset of fatigue crack initiation and propagation. Similarly, the trabecular and cellular lattice designs also exhibited substantial improvements in fatigue life, although their performance was slightly lower than that of the honeycomb design. These results are consistent with studies that emphasise the advantages of bio-inspired structures in improving fatigue life by reducing stress concentrations and distributing mechanical loads more effectively (Shirzad *et al.*, 2024; Fernandes & Tamijani, 2021).

3.2 Stress-Life (S-N) Curves

The stress-life (S-N) curves provide a graphical representation of the relationship between stress amplitude and fatigue life for the various designs (Figure 3). These curves reveal that the bio-inspired structures had a much flatter slope compared to the traditional solid block designs, indicating superior fatigue resistance, particularly at lower stress amplitudes (Zhao *et al.*, 2024; Murakami *et al.*, 2021). The data clearly show that the bio-inspired designs can endure a higher number of cycles before failure at equivalent stress levels, further confirming their improved fatigue performance.

Each curve represents the mean fatigue life performance for a specific geometry and material combination. The honeycomb, trabecular, and cellular lattice structures show markedly improved fatigue resistance over solid blocks in both materials, with Ti-6Al-4V specimens exhibiting overall higher fatigue performance due to their greater yield strength. For the AA7075 specimens, at 50% of the material's ultimate tensile strength (UTS), the honeycomb structure survived for more than 2 million cycles, whereas the solid block design failed after just 500,000 cycles. Similarly, in Ti-6Al-4V, the honeycomb design outperformed the solid block design, enduring 3 million cycles at a comparable stress level, while the solid block design failed at around 700,000 cycles.

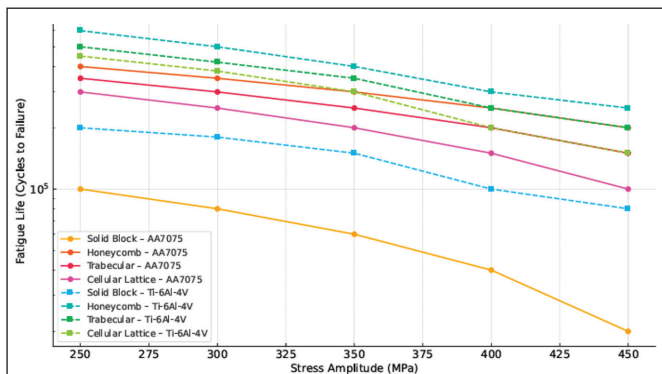


Figure 3: Stress-life (S-N) curves for bio-inspired and traditional solid block designs fabricated from AA7075 aluminium and Ti-6Al-4V titanium alloys

3.3 Weibull Distribution Analysis

A Weibull distribution analysis was performed to assess the reliability of the fatigue life data for each design and to predict the likelihood of failure under different loading conditions. The Weibull probability plots for bio-inspired and traditional designs are shown in Figure 4. The shape parameter (β), which indicates the variability in fatigue life, and the scale parameter (η), representing the characteristic life (the cycle count at which 63.2% of the specimens are expected to fail), were calculated for each design (Wang & Jiang, 2023; Basart *et al.*, 2022).

Bio-inspired structures, especially honeycomb, exhibited higher reliability and reduced variability in fatigue life compared to traditional solid blocks. The honeycomb design showed a β value of 2.3, indicating lower variability and a more predictable failure pattern, whereas the traditional solid block design exhibited a β value of 1.5, indicating higher variability in fatigue life. The characteristic life (η) for the honeycomb design was

2.3 million cycles in AA7075 and 3.5 million cycles in Ti-6Al-4V, while the solid block design had significantly lower η values of 500,000 cycles for AA7075 and 700,000 cycles for Ti-6Al-4V. These findings suggest that bio-inspired designs not only extend fatigue life but also improve the predictability of failure, which is essential for components used in critical applications where reliability is paramount (Shirzad *et al.*, 2024; Díaz *et al.*, 2024).

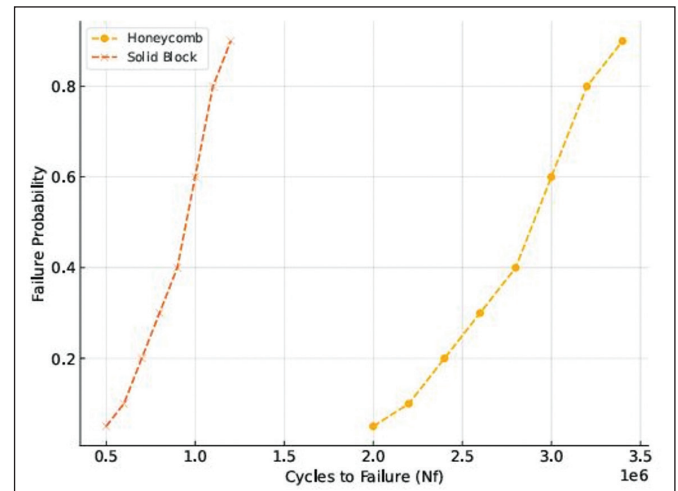


Figure 4: Weibull probability plot for bio-inspired and traditional solid block designs

3.4 Discussion of Findings

The results of this study have demonstrated that bio-inspired structural designs significantly enhance the fatigue life of lightweight metallic alloys. The honeycomb, trabecular, and cellular lattice designs exhibited substantial improvements in fatigue performance when compared to traditional solid block designs. This section provides a detailed interpretation of the results, explores the underlying mechanisms that contribute to the improved fatigue life, and highlights the broader implications of these findings for future material design and applications in fatigue-prone environments (Zhang *et al.*, 2024; Tancogne-Dejean *et al.*, 2020).

3.4.1 Interpretation of Results

The significant improvement in fatigue life observed in the bio-inspired designs can be directly attributed to the ability of these structures to distribute mechanical loads more evenly and mitigate localised stress concentrations. The honeycomb structure, in particular, exhibited the highest fatigue resistance across both AA7075 and Ti-6Al-4V alloys. This result aligns with previous research indicating that honeycomb structures are highly efficient at energy absorption and stress dissipation due to their optimised geometric configurations (Yin *et al.*, 2021; Jen & Chang, 2008). An important aspect of understanding the fatigue performance of these honeycomb designs is considering the relationship between yield strength and fatigue life. In metallic materials, yield strength defines the limit beyond which plastic deformation begins under static loading. Although fatigue failure typically occurs below the yield strength, higher yield strength generally improves the material's ability to withstand repeated elastic deformation, thereby delaying

fatigue crack initiation (Meng *et al.*, 2019; Zhao *et al.*, 2024). In this study, Ti-6Al-4V exhibits a significantly higher yield strength than AA7075, which contributes to its overall superior fatigue performance in both solid and honeycomb configurations.

However, the honeycomb geometry amplifies this relationship by enhancing the elastic load-sharing behaviour of both materials. For AA7075, which has a lower yield strength compared to Ti-6Al-4V, the honeycomb structure serves to mitigate this limitation by redistributing stresses, thereby lowering peak stress intensity in localised regions and postponing the onset of fatigue damage. In Ti-6Al-4V, the higher inherent yield strength works synergistically with the honeycomb geometry to provide even greater resistance to both microplastic deformation and fatigue crack nucleation under cyclic loading. Thus, the fatigue life of honeycomb structures is not only a function of their geometry but is also modulated by the material's ability to resist plasticity at critical locations, which is directly linked to its yield strength. This relationship explains why Ti-6Al-4V honeycomb specimens consistently outperformed their AA7075 counterparts in fatigue life, and also demonstrates that the benefits of bio-inspired design are maximised when combined with materials possessing high yield strength and fracture resistance.

3.4.2 Structural Influence on Fatigue Life

The superior fatigue performance of the bio-inspired designs is closely related to their geometric features, which play a crucial role in enhancing stress distribution and mitigating crack propagation. The honeycomb structure, with its repeating hexagonal cells, is well-known for its high strength-to-weight ratio and energy absorption capabilities, making it particularly effective at improving fatigue life (Sun *et al.*, 2023; Tancogne-Dejean *et al.*, 2020). Honeycomb geometries have been extensively studied in both natural and engineered systems for their ability to resist mechanical degradation, and this study provides further evidence of their effectiveness in fatigue-prone applications (Zhang *et al.*, 2024; Williams & Ritchie, 1999).

The enhanced fatigue life observed in the honeycomb design can be primarily attributed to its ability to reduce stress concentrations through geometric uniformity and controlled load redirection. As illustrated in Figure 5a, when subjected to cyclic loading, the hexagonal honeycomb arrangement allows for distributed stress transfer across a network of interconnected cell walls. This geometric configuration minimises local peak stresses that typically trigger crack initiation. If a crack does form, it is forced to follow a curved or angular path around the hexagonal voids, resulting in a tortuous crack propagation route that increases the energy barrier for crack advancement. This phenomenon of crack deflection and arrest delays the transition from microcrack to macrocrack, contributing directly to the prolonged fatigue life (Yin *et al.*, 2021; Jen & Chang, 2008).

Moreover, the honeycomb's periodic architecture enhances load path redundancy, meaning that localised structural damage in one cell does not result in immediate global failure. The remaining intact cells surrounding the damage zone continue to redistribute the load, providing a stabilising effect. This mechanical shielding effect slows the fatigue damage accumulation process over multiple cycles, as also supported

by earlier studies emphasising stress delocalisation in bio-inspired lattices (Zhao *et al.*, 2024; Meng *et al.*, 2019).

The trabecular structure, shown in Figure 5b, also exhibited improved fatigue life compared to solid blocks, though to a slightly lesser extent than the honeycomb configuration. Trabecular architectures, inspired by cancellous bone, consist of irregularly connected struts that form an open porous network. These irregularities are not design flaws but rather beneficial features: they introduce geometrical asymmetry that disrupts uniform crack growth. When cracks propagate through a trabecular structure, the non-linear load paths and stochastic void distribution act to blunt crack tips and reduce the effective stress intensity factor (Shirzad *et al.*, 2024; Alvankarian *et al.*, 2022). Furthermore, the irregular connections between nodes create intermittent load interruptions, slowing crack coalescence and enabling more gradual energy dissipation during cyclic loading.

Research on trabecular and foam-like architectures has demonstrated their capability to withstand repetitive mechanical stresses by accommodating local deformations and redistributing loads in multiple directions (Zhang *et al.*, 2024; Heidari-Rarani *et al.*, 2019). In the present study, these effects are manifested as longer fatigue lives in trabecular specimens compared to traditional solid blocks. However, the randomness of strut orientation in trabecular structures may also result in non-uniform stiffness and localised weaknesses, which explains the marginally lower performance compared to the honeycomb configuration (Yang *et al.*, 2022; Hussein *et al.*, 2013).

By contrast, the cellular lattice design, although still superior to the solid block, demonstrated lower fatigue resistance than both honeycomb and trabecular forms. This is likely due to its less optimised strut orientation and uniform cubic cell arrangement, which may concentrate stresses along discrete axial directions and provide fewer opportunities for crack deflection or redistribution (Murakami *et al.*, 2021; Abdelmoula *et al.*, 2020). Prior studies have shown that fatigue performance in lattice structures is sensitive to geometric parameters such as strut diameter, unit cell symmetry, and connectivity, suggesting that further topological optimisation could improve its mechanical resilience under cyclic loading.

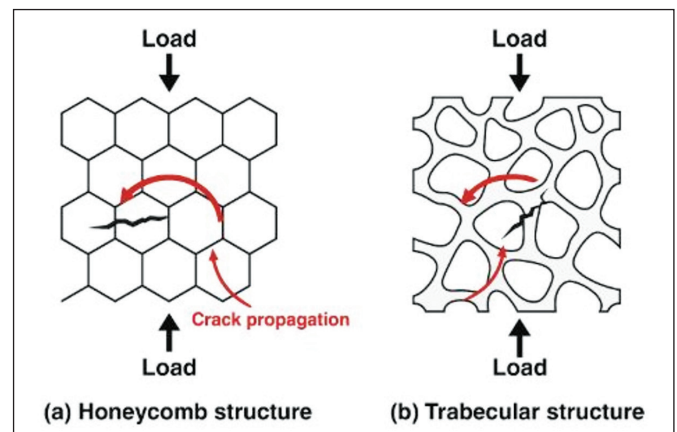


Figure 5: Schematic illustration showing how crack propagation is influenced by different bio-inspired geometries (a) Honeycomb structure; and (b) Trabecular structure

In the honeycomb geometry, the hexagonal arrangement diverts and dissipates crack paths through distributed loading across multiple cell walls. In the trabecular architecture, the irregular interconnected porous network provides tortuous paths and structural redundancy, slowing crack advance and localising stress redistribution.

3.4.3 Limitations and Challenges

While the results of this study demonstrate clear improvements in fatigue performance through bio-inspired design, several limitations must be acknowledged to contextualise the findings and guide future work. First, the fatigue experiments were conducted under controlled laboratory conditions, with constant room temperature, fixed humidity, and no exposure to corrosive media. In contrast, real-world applications often involve multifactorial environmental stressors, including temperature fluctuations, humidity, oxidation, and corrosive environments, all of which can accelerate fatigue damage and alter crack propagation behaviour (Zhou *et al.*, 2023; Huang *et al.*, 2023; Abdelmoula *et al.*, 2020). For instance, aluminium alloys such as AA7075 are highly susceptible to pitting corrosion, especially in marine or high-humidity conditions, which can significantly reduce their fatigue resistance (Liu *et al.*, 2019). Similarly, Ti-6Al-4V has shown vulnerability to fretting fatigue, oxidation, and thermal degradation under elevated service temperatures (Li *et al.*, 2023; Gode *et al.*, 2020). Therefore, the improved fatigue life observed under ideal conditions may not directly translate to service performance unless environmental durability is also assessed.

Second, this study focused exclusively on two specific lightweight alloys—AA7075 and Ti-6Al-4V—chosen for their widespread use in aerospace, automotive, and biomedical applications. While these alloys are representative of high-performance material systems, fatigue behaviour can vary considerably across other alloy families, such as magnesium, stainless steels, or high-entropy alloys (Zhao *et al.*, 2024; Rashid *et al.*, 2022). To generalise the conclusions of this research, future investigations should extend to a broader range of materials and include comparative studies across different alloy systems using similar geometries.

Third, although Selective Laser Melting (SLM) and Electron Beam Melting (EBM) enabled the fabrication of the bio-inspired structures with complex geometries, additive manufacturing (AM) techniques are known to introduce process-induced defects, such as micro-porosity, residual stresses, and surface roughness, which can negatively impact fatigue life (Zhang *et al.*, 2021; Raza *et al.*, 2023). While basic post-processing such as polishing was applied in this study, the influence of internal defects and surface condition variability remains a significant factor in fatigue performance. Optimisation of AM process parameters and implementation of post-processing techniques such as hot isostatic pressing (HIP), surface coating, or shot peening may further enhance fatigue behaviour and should be explored in future work (Gode *et al.*, 2020; Chen *et al.*, 2023).

Finally, this study investigated fatigue behaviour under uniaxial cyclic loading with a fixed stress ratio ($R = 0.1$). However, components in real service environments frequently experience complex, multi-axial loading, as well as variable amplitude stress histories that involve overloading,

underloading, or mean stress shifts (Murakami *et al.*, 2021; Guo *et al.*, 2021). Understanding how bio-inspired geometries respond under such conditions is crucial for transitioning from laboratory-scale validation to real-world implementation.

3.4.4 Future Work

Building upon the findings of this study, several key areas for future research are recommended. First, further investigation is needed to explore the performance of bio-inspired designs under more diverse environmental conditions, such as elevated temperatures, corrosive environments, and exposure to high levels of humidity (Wang & Jiang, 2022). This would provide critical insights into the long-term reliability of these designs in real-world applications, such as in aerospace, automotive, or marine environments, where materials are exposed to extreme and variable conditions (Moussa *et al.*, 2021).

Additionally, future research should examine the fatigue performance of bio-inspired designs under different loading conditions, such as multi-axial loading or combined tensile and compressive stresses. Real-world applications often involve complex loading regimes, and understanding how bio-inspired designs respond to these forces will help optimise their use in practical applications (Murakami *et al.*, 2021; Guo *et al.*, 2021). Further research into the synergistic effects of bio-inspired geometries with surface treatments, coatings, or reinforcements would also provide valuable insights into improving fatigue resistance (Díaz *et al.*, 2024; Nasr *et al.*, 2021).

Finally, developing advanced computational models that simulate the fatigue behaviour of bio-inspired designs would complement experimental research. Finite element analysis (FEA) and other computational tools can predict stress distribution, crack initiation, and overall fatigue life under a variety of loading and environmental conditions, providing a powerful tool for optimising design geometries before fabrication (Zhao *et al.*, 2024; Kim *et al.*, 2022). These models could significantly reduce the time and cost associated with experimental testing while providing deeper insights into the mechanical behaviour of bio-inspired structures.

4.0 CONCLUSION

This study systematically investigated the influence of bio-inspired structural geometries on the fatigue performance of lightweight metallic alloys, specifically AA7075 aluminium and Ti-6Al-4V titanium. The primary objective was to determine whether geometries such as honeycomb, trabecular, and cellular lattice structures—enabled by additive manufacturing—could extend fatigue life by mitigating stress concentrations and improving load distribution under cyclic loading.

The experimental results confirmed that all three bio-inspired designs significantly outperformed traditional solid block specimens in terms of fatigue life, across both alloy systems. The honeycomb structure demonstrated the highest fatigue resistance, with a fourfold increase in AA7075 and a more than threefold increase in Ti-6Al-4V, relative to their solid counterparts. Stress-life (S-N) curve analysis revealed flatter slopes for bio-inspired structures, indicating superior endurance at lower stress amplitudes. Weibull distribution analysis further demonstrated improved fatigue reliability and lower variability,

particularly in the honeycomb specimens, highlighting their potential for predictable long-term performance.

These outcomes directly support the study's hypothesis and establish that geometric optimisation—rather than material substitution alone—can significantly improve fatigue behaviour in critical structural applications. The findings also reinforce the potential of additive manufacturing to fabricate highly optimised, complex internal structures that were previously unachievable through traditional manufacturing methods.

From an application standpoint, this study provides actionable insights for industries such as aerospace, automotive, and biomedical engineering, where fatigue-driven failures impose safety risks and economic costs. The integration of bio-inspired geometries in metallic components can lead to longer service life, reduced maintenance, and enhanced structural efficiency. By demonstrating the mechanical benefits of these designs in two widely used alloy systems, the work sets a foundation for future optimisation and adoption of bio-inspired strategies in fatigue-critical environments. Future research should expand on these findings by investigating the performance of bio-inspired designs under realistic environmental conditions, exploring multi-axial and variable amplitude loading, and conducting computational simulations to further optimise geometric parameters for fatigue resistance. ■

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AUTHORS' CONTRIBUTIONS

- **Hyginus Chidiebere Onyekachi Unegbu:** Conceptualisation, Writing—original draft preparation and literature review, study design, Data collection, methodology, software and data analyses.
- **Danjuma Saleh Yawas:** Data validation, visualisation, supervision and formal analysis.

REFERENCES

- [1] Abdelmoula, M., Hachemi, M. A. E., & Bouaouadja, N. (2020). Design optimization of cellular structures for mechanical strength. *Materials Today: Proceedings*, 27, 1805–1810. <https://doi.org/10.1016/j.matpr.2020.03.441>
- [2] Afaghi, M., Klausen, A. B. E., & Overli, J. (2023). A review on fatigue performance of concrete structures Part I: Loading parameters, current prediction models and design approaches. *Nordic Concrete Research*, 68(1), 105–126. <https://doi.org/10.2478/ncr-2023-0002>
- [3] Afkhami, S., Dabiri, M., Alavi, S. H., Björk, T., & Salminen, A. (2019). Fatigue characteristics of steels manufactured by selective laser melting. *International Journal of Fatigue*, 122, 72–83. <https://doi.org/10.1016/j.ijfatigue.2018.12.029>
- [4] Alvankarian, J., Afshari, A., Rahimi, R., & Mahmud, A. (2022). The biomechanics of cancellous bone: A review of mechanical modeling approaches. *Biomedical Engineering Advances*, 4, 100056. <https://doi.org/10.1016/j.bea.2022.100056>
- [5] Basart, J. M., Delgado, A., Solano, A., Martín, F., & Gavilán, J. M. (2022). On the use of the Weibull distribution in fatigue reliability assessment: Challenges and advances. *Procedia Structural Integrity*, 39, 430–437. <https://doi.org/10.1016/j.prostr.2022.02.044>
- [6] Benedetti, M., Pedranz, M., Fontanari, V., Menapace, C., & Bandini, M. (2024). Enhancing plain fatigue strength in aluminum alloys through shot peening: Experimental investigations and a strain energy density interpretation. *International Journal of Fatigue*, 184, 108299. <https://doi.org/10.1016/j.ijfatigue.2024.108299>
- [7] Canna, J. L., De Luca, A., Dunand, D. C., Dye, D., Miracle, D. B., Oh, H. S., ... & Tasan, C. C. (2021). Sustainability through alloy design: Challenges and opportunities. *Progress in Materials Science*, 117, 100722. <https://doi.org/10.1016/j.pmatsci.2020.100722>
- [8] Chen, M., Liu, X., Zhang, H., & Li, C. (2023). Influence of post-processing on fatigue resistance of additively manufactured Ti-6Al-4V: A review. *Materials Science and Engineering A*, 866, 145443. <https://doi.org/10.1016/j.msea.2023.145443>
- [9] Cui, L., Deng, D., Jiang, F., Peng, R. L., Xin, T., Mousavian, R. T., Yang, Z., & Moverare, J. (2022). Superior low cycle fatigue property from cell structures in additively manufactured 316L stainless steel. *Journal of Materials Science & Technology*, 111, 268–278. <https://doi.org/10.1016/j.jmst.2021.10.006>
- [10] Díaz, M., Sánchez, P., & Moreno, E. (2024). Predicting fatigue reliability of aerospace alloys using Weibull and extreme value statistics. *Materials Science and Engineering A*, 884, 145960. <https://doi.org/10.1016/j.msea.2024.145960>
- [11] Dong, Z., Xu, M., Guo, H., Fei, X., Liu, Y., Gong, B., & Ju, G. (2022). Microstructural evolution and characterization of AlSi10Mg alloy manufactured by selective laser melting. *Journal of Materials Research and Technology*, 17, 2343–2354. <https://doi.org/10.1016/j.jmrt.2022.01.129>
- [12] Estrin, Y., & Vinogradov, A. (2010). Fatigue behaviour of light alloys with ultrafine grain structure produced by severe plastic deformation: An overview. *International Journal of Fatigue*, 32(6), 898–907. <https://doi.org/10.1016/j.ijfatigue.2009.06.022>
- [13] Fernandes, R. R., & Tamijani, A. Y. (2021). Design optimization of lattice structures with stress constraints. *Materials & Design*, 210, 110026. <https://doi.org/10.1016/j.matdes.2021.110026>

- [14] Gode, C., Schneider, M., & Scholz, A. (2020). Optimization of additive manufacturing and post-processing for improved fatigue resistance. *Procedia CIRP*, 94, 432–437. <https://doi.org/10.1016/j.procir.2020.09.119>
- [15] Guo, Y., Zhang, Y., & Wang, Q. (2021). Multi-axial fatigue failure analysis of aerospace components under variable loading. *International Journal of Fatigue*, 143, 105976. <https://doi.org/10.1016/j.ijfatigue.2020.105976>
- [16] Han, D., Zhang, Y. J., & Li, X. W. (2021). A crucial impact of short-range ordering on the cyclic deformation and damage behavior of face-centered cubic alloys: A case study on Cu-Mn alloys. *Acta Materialia*, 205, 116559. <https://doi.org/10.1016/j.actamat.2020.116559>
- [17] Heidari-Rarani, M., Fathi, A., & Zabihi, S. (2019). Experimental investigation of fatigue behavior of open-cell aluminum foams. *Engineering Solid Mechanics*, 7(4), 335–346.
- [18] Huang, R., Li, Y., & Tang, Y. (2023). Corrosion fatigue behaviour of 7xxx aluminium alloys: A review. *Corrosion Science*, 211, 110889. <https://doi.org/10.1016/j.corsci.2023.110889>
- [19] Hussein, A., Hao, L., Yan, C., & Everson, R. M. (2013). Finite element simulation of the temperature and stress fields in single layers built without support in selective laser melting. *Materials & Design*, 52, 638–647. <https://doi.org/10.1016/j.matdes.2013.05.070>
- [20] Jen, Y.-M., & Chang, L.-Y. (2008). Evaluating bending fatigue strength of aluminum honeycomb sandwich beams using local parameters. *International Journal of Fatigue*, 30(6), 1103–1114. <https://doi.org/10.1016/j.ijfatigue.2007.08.006>
- [21] Jiang, Z., Ma, Y., & Xiong, Y. (2023). Bio-inspired generative design for engineering products: A case study for flapping wing shape exploration. *Advanced Engineering Informatics*, 58, 102240. <https://doi.org/10.1016/j.aei.2023.102240>
- [22] Ke, L., Li, C., He, J., Shen, Q., Liu, Y., & Jiao, Y. (2020). Enhancing fatigue performance of damaged metallic structures by bonded CFRP patches considering temperature effects. *Materials & Design*, 192, 108731. <https://doi.org/10.1016/j.matdes.2020.108731>
- [23] Kim, D., Lee, J., & Kim, H. (2022). Predictive modelling of fatigue failure in lattice structures using machine learning-assisted finite element simulations. *Computational Materials Science*, 211, 111511. <https://doi.org/10.1016/j.commatsci.2022.111511>
- [24] Kluger, K., & Łagoda, T. (2013). Fatigue life of metallic material estimated according to selected models and load conditions. *Journal of Theoretical and Applied Mechanics*, 51(3), 581–592.
- [25] Li, M., Yang, K., Zhou, Y., & Tan, X. (2023). Oxidation and fretting fatigue in Ti-6Al-4V components fabricated via EBM: Environmental degradation mechanisms. *Journal of Alloys and Compounds*, 949, 169774. <https://doi.org/10.1016/j.jallcom.2023.169774>
- [26] Liu, G., Zhang, L., Wang, C., & Qian, M. (2019). The corrosion-fatigue performance of AA7075 aluminum alloy: The effect of pitting corrosion. *International Journal of Fatigue*, 127, 121–131. <https://doi.org/10.1016/j.ijfatigue.2019.06.010>
- [27] Ma, H. Y., Wang, J. C., Qin, P., Liu, Y. J., Chen, L. Y., Wang, L. Q., & Zhang, L. C. (2024). Advances in additively manufactured titanium alloys by powder bed fusion and directed energy deposition: Microstructure, defects, and mechanical behavior. *Journal of Materials Science & Technology*, 183, 32–62. <https://doi.org/10.1016/j.jmst.2023.11.003>
- [28] Macek, W., Robak, G., Żak, K., & Branco, R. (2022). Fracture surface topography investigation and fatigue life assessment of notched austenitic steel specimens. *Engineering Failure Analysis*, 135, 106121. <https://doi.org/10.1016/j.engfailanal.2022.106121>
- [29] Mei, J., Han, Y., Sun, J., Zu, G., Song, X., Zhu, W., & Ran, X. (2023). Achieving high strength in selective laser melting AlSi10Mg alloy by adding micro-sized pure Cu particles. *Materials Science and Engineering: A*, 880, 145357. <https://doi.org/10.1016/j.msea.2023.145357>
- [30] Meng, L., Liang, H., Yu, H., Yang, J., Li, F., Wang, Z., & Zeng, X. (2019). The energy absorption and bearing capacity of light-weight bio-inspired structures produced by selective laser melting. *Journal of the Mechanical Behavior of Biomedical Materials*, 93, 170–182. <https://doi.org/10.1016/j.jmbbm.2019.02.016>
- [31] Miller, M. A. (2012). Statistical methods for engineers. *Technometrics*, 41(3), 264–265. <https://doi.org/10.1080/00401706.1999.10485678>
- [32] Moussa, S., El-Kassas, M., & Elbestawi, M. (2021). Environmentally assisted fatigue in lightweight structures: A design framework for marine applications. *Ocean Engineering*, 241, 110045. <https://doi.org/10.1016/j.oceaneng.2021.110045>
- [33] Murakami, Y., Takagi, T., Wada, K., & Matsunaga, H. (2021). Essential structure of S–N curve: Prediction of fatigue life and fatigue limit of defective materials and nature of scatter. *International Journal of Fatigue*, 146, 106138. <https://doi.org/10.1016/j.ijfatigue.2020.106138>
- [34] Nasr, M. N. A., Elsayed, T., & Ahmed, W. (2021). Fatigue performance improvement of metallic structures using shot peening and coating: A review. *Surface and Coatings Technology*, 418, 127259. <https://doi.org/10.1016/j.surfcoat.2021.127259>

- [35] Ng, B. F., New, T. H., & Palacios, R. (2017). Bio-inspired leading-edge tubercles to improve fatigue life in horizontal axis wind turbine blades. *35th Wind Energy Symposium*. <https://doi.org/10.2514/6.2017-1381>
- [36] Owuor, P. S., Hiremath, S. R., Chipara, A. C., & Vajtai, R. (2017). Nature inspired strategy to enhance mechanical properties via liquid reinforcement. *Advanced Materials Interfaces*, 4(16), 1700240. <https://doi.org/10.1002/admi.201700240>
- [37] Peng, H., Hou, Z., Chen, X., Li, T., Luo, J., & Li, X. (2021). Effect of temperature and cyclic loading on stress relaxation behavior of Ti–6Al–4V titanium alloy. *Materials Science and Engineering: A*, 824, 141789. <https://doi.org/10.1016/j.msea.2021.141789>
- [38] Puchi-Cabrera, E. S., Staia, M. H., Lesage, J., Gil, L., Villalobos-Gutiérrez, C., La Barbera-Sosa, J., Ochoa-Pérez, E. A., & Le Bourhis, E. (2008). Fatigue behavior of AA7075-T6 aluminum alloy coated with ZrN by PVD. *International Journal of Fatigue*, 30(7), 1220–1230. <https://doi.org/10.1016/j.ijfatigue.2007.09.001>
- [39] Rashid, R. A., Farid, M., & Ahmad, R. (2022). Fatigue and fracture behaviour of high-entropy alloys: Recent advances and challenges. *Materials Science and Engineering A*, 837, 142823. <https://doi.org/10.1016/j.msea.2022.142823>
- [40] Raza, S. T., Zhao, Y., & Zhang, L. (2023). Effect of additive manufacturing defects on the fatigue life of Ti alloys: A numerical and experimental approach. *Materials Today Communications*, 34, 105371. <https://doi.org/10.1016/j.mtcomm.2022.105371>
- [41] Richard, H. A., & Sander, M. (2016). Crack initiation under cyclic loading. In *Fatigue Crack Growth* (pp. 239–250). https://doi.org/10.1007/978-3-319-32534-7_8
- [42] Safai, L., Cuellar, J. S., Smit, G., & Zadpoor, A. A. (2019). A review of the fatigue behavior of 3D printed polymers. *Additive Manufacturing*, 28, 87–97. <https://doi.org/10.1016/j.addma.2019.03.005>
- [43] Salifu, S., & Olubambi, P. A. (2024). A review of fatigue failure and life estimation models: From classical methods to innovative approaches. *Science Engineering and Technology*, 4(2), First. <https://doi.org/10.54327/set2024/v4.i2.140>
- [44] Sawada, T., Kawamori, T., Matsunaga, M., Fujiyasu, Y., & Ueki, Y. (2021). An experimental study for identifying crack initiation forces in single-lap bonded joints. *Engineering Fracture Mechanics*, 241, 107372. <https://doi.org/10.1016/j.engfracmech.2020.107372>
- [45] Schoenung, J. M., & Olivetti, E. A. (2023). Sustainable development of materials: Broadening stakeholder engagement. *MRS Bulletin*, 48, 362–367. <https://doi.org/10.1557/s43577-023-00234-9>
- [46] Shanyavskiy, A. A., & Soldatenkov, A. P. (2022). Metallic materials fatigue behavior: Scale levels and ranges of transition between them. *International Journal of Fatigue*, 158, 106773. <https://doi.org/10.1016/j.ijfatigue.2022.106773>
- [47] Sharma, D., & Hiremath, S. S. (2022). Bio-inspired repeatable lattice structures for energy absorption: Experimental and finite element study. *Composite Structures*, 283, 115102. <https://doi.org/10.1016/j.compstruct.2021.115102>
- [48] Shirzad, M., Kang, J., Kim, G., & Bodaghi, M. (2024). Bioinspired 3D-printed auxetic structures with enhanced fatigue behavior. *Advanced Engineering Materials*. <https://doi.org/10.1002/adem.202302036>
- [49] Strzelecki, P., Correia, J. A. F. O., & Sempruch, J. (2021). Estimation of fatigue S–N curves for aluminium based on tensile strength – proposed method. *MATEC Web of Conferences*, 338, 01026. <https://doi.org/10.1051/mateconf/202133801026>
- [50] Sun, Y., Tang, Y., He, Y., & Xiao, L. (2023). Mechanical behavior and energy absorption of honeycomb and re-entrant lattice structures under dynamic loading. *Thin-Walled Structures*, 190, 111075. <https://doi.org/10.1016/j.tws.2023.111075>
- [51] Tancogne-Dejean, T., Diamantopoulou, M., Reisinger, A., & Mohr, D. (2020). Design and application of ultralight lattice metamaterials with superior mechanical performance. *Advanced Materials*, 32(10), 1905767. <https://doi.org/10.1002/adma.201905767>
- [52] Tsai, P. H., Li, J. B., Chang, Y. Z., Lin, H. C., Jang, J. S. C., Chu, J. P., Lee, J. W., & Liaw, P. K. (2014). Fatigue properties improvement of high-strength aluminum alloy by using a ZrCu-based metallic glass thin film coating. *Thin Solid Films*, 561, 28–32. <https://doi.org/10.1016/j.tsf.2013.06.085>
- [53] Wang, H., & Jiang, J. (2022). Fatigue performance of additively manufactured lattice structures under corrosive conditions. *Additive Manufacturing*, 46, 102192. <https://doi.org/10.1016/j.addma.2021.102192>
- [54] Wang, H., & Jiang, J. (2023). Comparative reliability assessment of fatigue behavior using three-parameter Weibull distribution for metallic lattice structures. *Engineering Fracture Mechanics*, 280, 108496. <https://doi.org/10.1016/j.engfracmech.2023.108496>
- [55] Wang, L., Zhao, Z., Liang, H., & He, Y. (2024). Research on laboratory testing method of fatigue performance of semi-rigid base considering spatial stress state. *Buildings*, 14(2), 365. <https://doi.org/10.3390/buildings14020365>
- [56] Wei, J., Pan, F., Ping, H., & Yang, K. (2023). Bio-inspired additive manufacturing of hierarchical materials: From bio-structures to functions. *Research*, 6, 0164. <https://doi.org/10.34133/research.0164>

- [57] Williams, M. L., & Ritchie, R. O. (1999). Fatigue and fracture of structural biomaterials. In *Comprehensive Structural Integrity* (pp. 133–169). Elsevier.
- [58] Xie, M., & Lai, C. D. (1996). Reliability analysis using an additive Weibull model with bathtub-shaped failure rate function. *Reliability Engineering & System Safety*, 52(1), 87–93. [https://doi.org/10.1016/0951-8320\(95\)00149-2](https://doi.org/10.1016/0951-8320(95)00149-2)
- [59] Yadav, R., Yadav, S. S., Dhiman, R., & Patel, R. (2024). A comprehensive review on failure aspects of additive manufacturing components under different loading conditions. *Journal of Failure Analysis and Prevention*, 24(5). <https://doi.org/10.1007/s11668-024-02032-3>
- [60] Yang, J., Gu, D., Lin, K., Zhang, Y., Guo, M., Yuan, L., ... & Zhang, H. (2022). Laser additive manufacturing of bio-inspired metallic structures. *Chinese Journal of Mechanical Engineering: Additive Manufacturing Frontiers*, 1(1), 100013. <https://doi.org/10.1016/j.cjmeam.2022.100013>
- [61] Yang, L., Li, Y., Chen, Y., Yan, C., Liu, B., & Shi, Y. (2022). Topologically optimized lattice structures with superior fatigue performance. *International Journal of Fatigue*, 165, 107188. <https://doi.org/10.1016/j.ijfatigue.2022.107188>
- [62] Ye, W., Hohl, J., & Mushongera, L. T. (2022). Prediction of cyclic damage in metallic alloys with crystal plasticity modeling enhanced by machine learning. *Materialia*, 22, 101388. <https://doi.org/10.1016/j.mtla.2022.101388>
- [63] Yi, M., Tang, W., Zhu, Y., Liang, C., Tang, Z., Yin, Y., He, W., Sun, S., & Su, S. (2024). A holistic review on fatigue properties of additively manufactured metals. *Journal of Materials Processing Technology*, 329, 118425. <https://doi.org/10.1016/j.jmatprotec.2024.118425>
- [64] Yin, H., Zheng, X., Wen, G., Zhang, C., & Wu, Z. (2021). Design optimization of a novel bio-inspired 3D porous structure for crashworthiness. *Composite Structures*, 255, 112897. <https://doi.org/10.1016/j.compstruct.2020.112897>
- [65] Zainulabdeen, A. A., Mahdi, B. S., Mohammed, J. H., Abdulkader, N. J., Ali, M., & Flayyih, M. A. (2024). Study of the fatigue fractography of dual-phase low carbon steel used in the automotive industry. *Theoretical and Applied Mechanics Letters*, 100552. <https://doi.org/10.1016/j.taml.2024.100552>
- [66] Zhang, B., Shi, M., Chen, G., & Feng, J. (2012). Microstructure and defect of titanium alloy electron beam deep penetration welded joint. *Transactions of Nonferrous Metals Society of China*, 22(11), 2633–2637. [https://doi.org/10.1016/S1003-6326\(11\)61510-0](https://doi.org/10.1016/S1003-6326(11)61510-0)
- [67] Zhang, J. S., Liu, H., Tang, Y. T., Deng, Y., Kuek, N., Lui, A., Grant, P. S., Alabort, E., Reed, R. C., & Cocks, A. C. F. (2024). Stochastic or deterministic: Duality of fatigue behaviour of 3D-printed meta-biomaterials. *Materials & Design*, 245, 113296. <https://doi.org/10.1016/j.matdes.2024.113296>
- [68] Zhang, W., & Xu, J. (2022). Advanced lightweight materials for automobiles: A review. *Materials & Design*, 221, 110994. <https://doi.org/10.1016/j.matdes.2022.110994>
- [69] Zhang, W., Xu, J., & Yu, T. X. (2022). Dynamic behaviors of bio-inspired structures: Design, mechanisms, and models. *Engineering Structures*, 265, 114490. <https://doi.org/10.1016/j.engstruct.2022.114490>
- [70] Zhang, X., Chen, Y., & Hu, J. (2018). Recent advances in the development of aerospace materials. *Progress in Aerospace Sciences*, 97, 22–34. <https://doi.org/10.1016/j.paerosci.2018.01.001>
- [71] Zhang, Y., Zhao, D., Chen, J., & Liu, R. (2021). Fatigue behavior of SLM-fabricated AA7075 aluminum alloy under high cycle conditions. *Materials Science and Engineering A*, 819, 141489. <https://doi.org/10.1016/j.msea.2021.141489>
- [72] Zhao, D. F., Kong, W. W., & Song, X. R. (2008). Statistical analysis for fatigue life of concrete. *Key Engineering Materials*, 385–387, 285–288. <https://doi.org/10.4028/www.scientific.net/KEM.385-387.285>
- [73] Zhao, Z., Yang, Q., Li, R., Yang, J., Liu, Q., Zhu, B., Weng, C., Liu, W., Hu, P., Ma, L., Qiao, J., Xu, M., & Tian, H. (2024). A comprehensive review on the evolution of bio-inspired sensors from aquatic creatures. *Cell Reports Physical Sciences*, 102064. <https://doi.org/10.1016/j.xcrp.2024.102064>
- [74] Zhou, J., Wang, B., & Lin, H. (2023). Fatigue behavior of metallic alloys in corrosive environments: Recent developments. *Corrosion Reviews*, 41(1), 23–39. <https://doi.org/10.1515/corrrev-2023-0003>
- [75] Zhou, X., Liu, W., Li, Y., & Song, Q. (2021). Analysis of variance in fatigue testing. *Experimental Materials Science*.

PROFILES



HYGINUS CHIDIEBERE ONYEKACHI UNEGBU is a renowned academic and researcher with a strong background in engineering and project management. He holds a B.Eng. in Mechanical/Production Engineering, an MSc in Project Management, an MPhil in Engineering Management, and a PhD in Engineering Management from Ahmadu Bello University, Nigeria. With over 30 publications in reputable international journals, Unegbu has significantly contributed to sustainability, construction industry practices, and project management. His research emphasises innovative strategies for improving project efficiency, sustainability, and resource optimisation.

Email address: chidieberehyg@gmail.com



DANJUMA SALEH YAWAS is a Professor of Mechanical Engineering at Ahmadu Bello University and is a registered Engineer (COREN) with research, technical and project management experiences covering the academia, oil and the automotive industry. Has published 150 publications comprising more than 135 peer-reviewed journal articles and 25 conference proceedings. Major research areas, include Materials (development/characterisation, statistical/mathematical modelling & simulation), corrosion studies and mechanical properties, and Production Engineering.

Email address: dyawas@yahoo.com