Interdisciplinary Description of Complex Systems 22(2), 142-166, 2024

INTEGRITY ASSESSMENT STRATEGIES FOR THE ENERGY-EFFICIENT COMPONENTS, STRUCTURES AND SYSTEMS

Emanuele V. Arcieri[1,]*, Sergio Baragetti[1] and Željko Božić[2]

[1]University of Bergamo, Department of Management, Information and Production Engineering
Dalmine, Italy

[2]University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Zagreb, Croatia

DOI: 10.7906/indecs.22.2.1
Review article

Received: 27 March 2024.
Accepted: 26 April 2024.

ABSTRACT

The urgent need to combat global warming and environmental pollution underscores the importance of developing energy-efficient systems that effectively reduce emissions. One of the possible strategies for achieving energy efficiency consists in diminishing the mass of mechanical systems since mass reduction implies decreased inertia, lower fuel and energy consumption, and enhanced transportation capabilities, particularly in industries such as aerospace, nautical, and automotive. The key design principle must involve the use of lightweight materials in optimized structures, manufactured through suitable methods like additive manufacturing. Design activity must be conducted with a focus on ensuring structural integrity and durability of systems under various loading and environmental conditions. This article introduces a pivotal method that includes mathematical modelling, numerical simulation and experimental verification. Based on these three approaches, it aims to provide a comprehensive assessment framework for ensuring the integrity and durability of energy-efficient systems, covering topics such as fatigue, impact damage, coating deposition effects, and material selection. The advantages of using metamaterials are presented. Real-world case studies are examined to offer practical strategies for researchers and engineers engaged in the design and assessment of energy-efficient components, structures, and systems, contributing to a sustainable future.

KEY WORDS

energy-efficiency, fatigue, defect and damage, coating, additive manufacturing

CLASSIFICATION

JEL: K32, O13

PACS: 62.20.Mk, 81.70.Bt

*Corresponding author, η: emanuelevincenzo.arcieri@unibg.it; +39 0352052382;
University of Bergamo, Department of Management, Information and Production Engineering,
Dalmine (BG), 24044, Italy

INTRODUCTION

The ongoing necessity to address global warming and environmental pollution underscores the significance of reducing emissions by producing energy efficient systems. A crucial strategy for improving energy efficiency involves diminishing the mass of mechanical systems. Mass reduction carries broad implications, contributing to decreased inertia, lower fuel consumption, and improved ease and load-carrying capability in transportation [1]. It means lightening the mass to be moved or handling a higher quantity of persons/objects for transportation. Beyond the environmental advantages of lowering the carbon footprint, the design of energy-efficient systems also presents economic benefits. These considerations are of relevant importance in the aerospace, nautical, and automotive sectors where the achievement of energy efficiency is strategic [2-4].

The design principle for energy-efficient systems revolves around utilizing fewer materials or materials with high strength-to-density ratio while maintaining or enhancing integrity and durability. An effective approach to achieving energy efficiency in mechanical components and systems involves employing advanced lightweight materials in optimized structures, manufactured using appropriate methods. The primary goal is to distribute materials to minimize usage while enhancing structural performance, including increased strength and stiffness, leading to overall improved performance. However, both material selection and structural optimization processes are constrained by considerations of manufacturability. The advent of emergent technologies, like additive manufacturing, not only facilitates the use of advanced materials but also relaxes constraints, thereby increasing the flexibility of structural optimization.

To achieve mass reduction, a comprehensive understanding of the mechanical performance of materials and components is essential. Studies in the field of integrity and durability of lightweight materials, components, and structures are therefore imperative to comprehend failure mechanisms, proactively address them, and drive advancements in the design of components with high strength-to-mass ratio. Structural integrity and durability must be guaranteed under various loading conditions, including static and dynamic (fatigue) loading, as well as diverse environmental conditions, such as inert, aggressive, and very aggressive environments. Moreover, assessments must encompass scenarios involving modifications in the material and surface of the components, such as deposition of coatings which improve wear and corrosion resistance [5, 6]The analysis must also consider defects in components which are due to manufacturing process or damages induced by the impact of foreign objects. The objective is to ensure the resistance of materials and components in the face of these multifaceted challenges and pave the way for innovative designs that prioritize both strength and mass efficiency, Figure 1.

But which instruments do we have? In the 1600s, Galileo asserted the essential need for both mathematical modelling to predict studied phenomena and experimental procedures to verify them [7]. He introduced the scientific method, which later became the standard for scientists. Despite the validity of Galileo's approach, a contemporary tool emerged: numerical modelling. Positioned between mathematical modelling and experimental confirmation, this tool plays a key role in the scientific method, as the initial confirmation of results may be derived from numerical modelling. It comprises an initial phase, pre-processing, wherein a model of the phenomenon under study is constructed. Subsequently, we enter the processing phase, namely, the calculation phase. Finally, there is the post-processing phase, during which the obtained results are analysed. Numerical modelling finds broad application across scientific disciplines, such as Material Science, Multi-scale Simulation, Machine Design (with Finite Element Modelling), Fluid Dynamics (using Computer Fluid Dynamics), Multi-physics simulations,

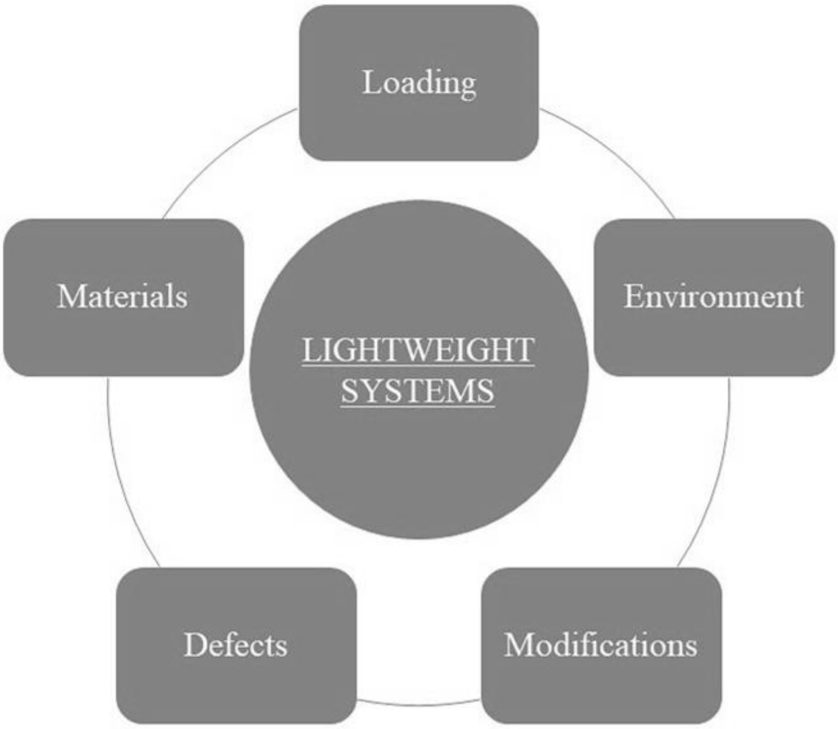


Figure 1. Factors that must be considered in assessing the integrity and durability of lightweight systems.

and various other applied disciplines. Then, in the modern scientific method, we have three approaches (Figure 2), that are theoretical modelling; numerical simulation and experimental testing. The first two approaches provide an estimation of results. Experimental tests then serve to validate or invalidate both the theoretical and numerical results. In essence numerical modelling bridges the gap between mathematical modelling and experimental verification. However, mathematical models are difficult to build and can be difficult to solve, numerical models require the acquisition of software and time for calculation, experimental tests are expensive in terms of necessary setup and instrumentation.

Examples of applications of such approaches are presented in [8-10]This article aims at providing a comprehensive assessment framework to ensure integrity and durability of energy-efficient systems. It presents the critical topics that must be considered

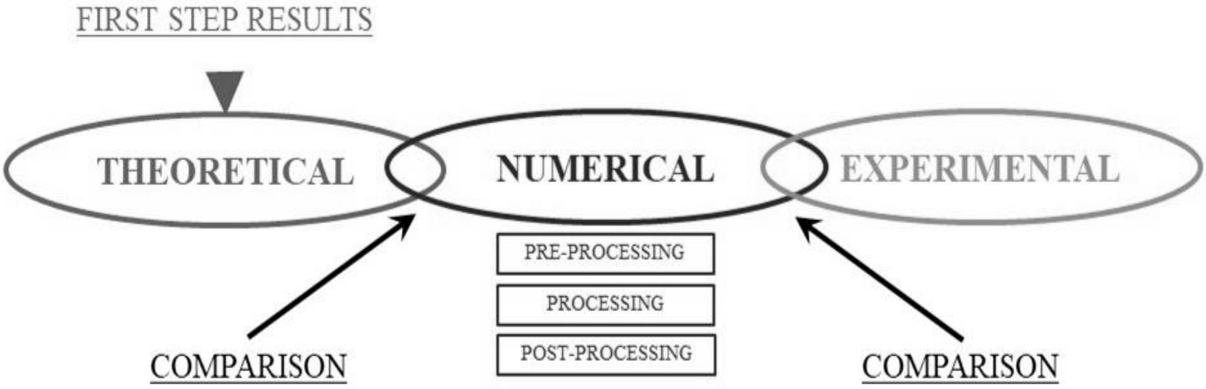


Figure 2. Approaches for a robust analysis of the phenomena.

during the design activity of structures and components, i.e. fatigue, impact damage and coating deposition effects. Then a possible selection of materials such as steel, titanium, aluminum, and composite materials is provided. Moreover, the article explores the innovative realm of additive manufacturing, stressing its role in producing lightweight components but also discussing the effects in terms of structural integrity and durability of the produced parts. In order to ensure a comprehensive exploration of the subject matter, the application of theoretical, numerical, and experimental methods in the analysis of these topics is reported. Finally, by examining real-world case studies in the aircraft, automotive, and turbo machinery sectors, this article tries to provide an understanding of practical strategies to offer a robust foundation for researchers and engineers involved in the design and assessment of energy-efficient components, structures, and systems towards a more sustainable future.

FATIGUE OF MATERIALS: ONE OF THE MOST COMMON CAUSES OF FAILURE

Fatigue is one of the most common and dangerous causes of failure in mechanical components. It occurs when mechanical components are subjected to cyclic loading and it poses a threat to structural integrity as it occurs when the applied stresses are below the elastic limit [11]. Admissible stresses for structures under fatigue are notably lower than those permitted in static loading, where the aim of the design activity is to prevent material yielding or failure under service conditions. Looking at the failure mechanism, cyclic loading induces the multiplication of defects, i.e. dislocations [12, 13], leading to localized strain in the form of microstructural slip bands. With accumulating cycles, slip bands expand, evolving into short cracks [14]. As these cracks progress, they become physically short cracks, with lengths up to 1-2 mm [15]. Physically short cracks propagate, transforming into long cracks. The final failure of a component occurs when the dominant crack surpasses the ligament's load-carrying capacity [16]. The transition from physical short cracks to long cracks corresponds to the shift from the crack initiation process to the crack growth process [17]. The combination of these two processes defines the complete fatigue lifetime of components. The occurrence of distinct characteristics of crack initiation and propagation stages among the materials emphasize the need for a quantitative estimation of the fatigue lifetime of components.

In [18-20], an investigation into the structural integrity of a total hip prosthesis was performed using 3D scanning and finite element analysis. Elevated tensile stresses were observed on the distal region of the femoral component shaft. These stresses are reponsible for the onset of fatigue cracks [18, 20]. The capability to estimate a critical crack size associated with fracture onset under the given loading conditions is reported in [19]. The study in explored the fatigue life of plates with multiple collinear cracks subjected to cyclic tension loading [21]. The work [22] aims to model vibration-induced fatigue behavior in a generalized vibration isolation system. Parametric analysis was used to evaluate isolation quality and provide a fatigue life extension. Cazin et al. [23] conducted a strain-based fatigue evaluation of a rotating demining tiller tool, aiming for cost reduction by substituting high-strength steel with unalloyed structural steels. To maintain durability, the original geometry was enhanced. A two-step assessment procedure involving transient nonlinear mechanical analysis and low cycle fatigue assessment was proposed, resulting in simplified production, cost reduction, and preserved tool life.

Computational analysis was used in [24] to assess the fatigue resistance of different auxetic honeycombs made of aluminum alloy 5083-H111. Chiral and star-shaped auxetic structures were found to exhibit higher fatigue strength. Quantitative estimation of fatigue lifetime can be obtained via numerical investigation and evaluation of fatigue crack initiation and growth processes.

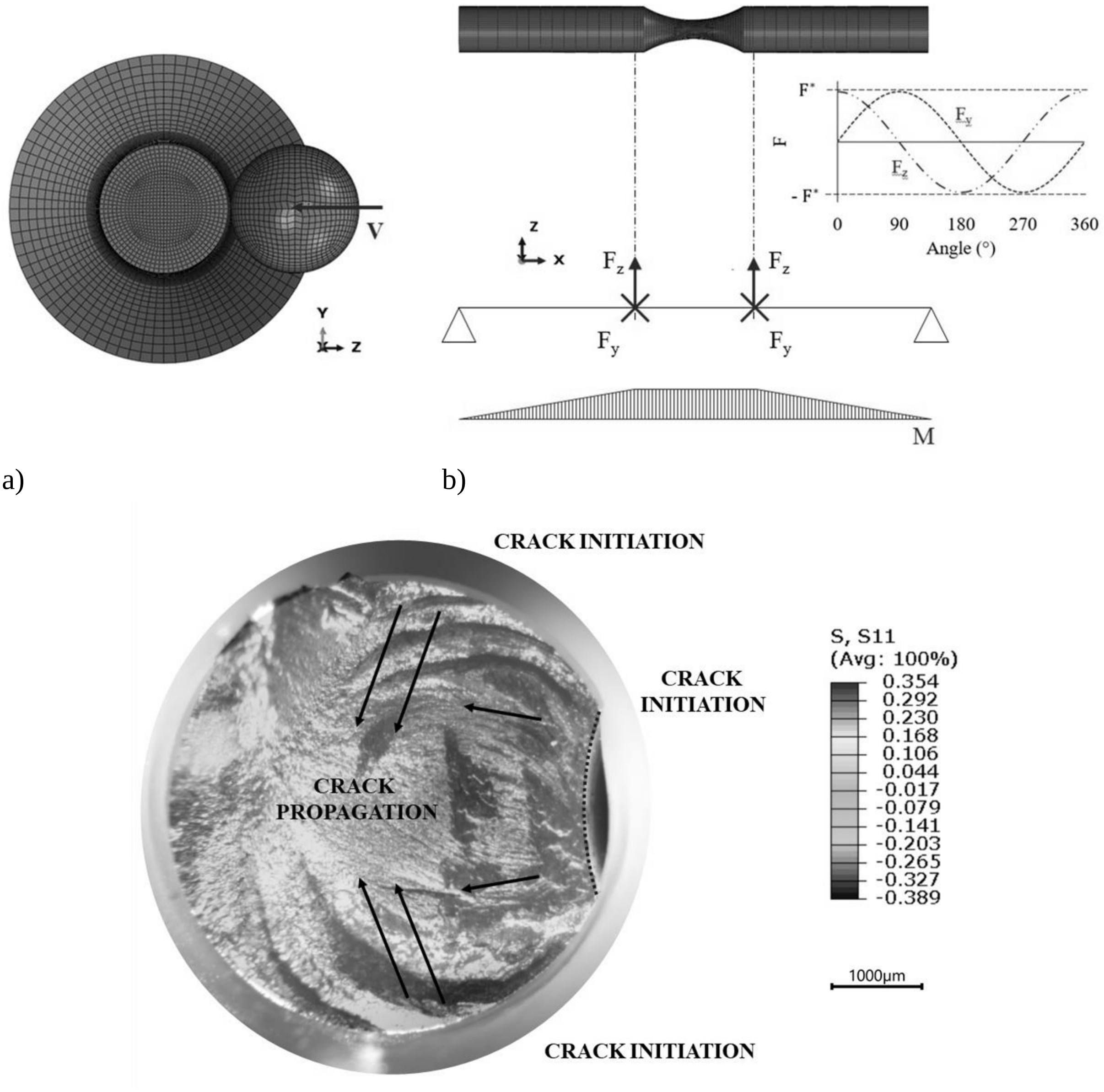
Mlikota et al. [25] used finite element simulation to study short crack initiation and subsequent long crack growth in carbon steel. A model of the microstructure of the material was created with the finite element method followed by the calculation of the corresponding stress distribution. Using the Tanaka-Mura model, the number of cycles for crack initiation was calculated. The Paris law was used to model long crack growth process, obtaining good agreement with experimental results. In [26] the influence of overload on crack initiation in carbon steel was studied using a similar approach. The created model was able to reproduce the acceleration effect on the short crack growth induced by the overload but not the following retardation as residual stresses were not reproduced. The influence of compressive residual stresses on the crack initiation process in steel was modelled in [27]. The study [28] examined the effect of grain size on the fatigue strength of metallic components using finite element method and Tanaka-Mura model and evaluated the corresponding endurance limit.

Shot peening is commonly used for enhancing fatigue properties in cyclically loaded components. It consists in impacting components with hard spheres to create a compressive residual stress field in the material surface layers that prevents fatigue crack initiation and propagation. The efficacy of shot peening, however, is related to an adequate selection of parameters including Almen intensity (degree of surface deformation or curvature resulting from the shot peening process), shot diameter and material, coverage percentage, velocity, and impact angle. High peening intensities can cause surface damage and promote crack initiation, negating the treatment benefits, while low intensities make the treatment ineffective. In [29], the application of Design of Experiments to numerical simulations of shot peening on a smooth steel target made it possible to quickly identify the optimal treatment parameters.

STRUCTURAL INTEGRITY AND DURABILITY OF IMPACT DAMAGED COMPONENTS

Damage to aircraft components caused by foreign particles, e.g. stones and debris, can result in a reduced fatigue life [30-32]. The decline in fatigue resistance is attributed to the initiation of micro-cracks, the appearance of stress concentrations, and the occurrence of residual stresses [33-37]. In [38] blade-like specimens were subjected to impacts from cubical objects, followed by fatigue testing. The results emphasized the significant influence of dent depth on fatigue resistance. The Kitagawa-Takahashi diagram was adopted to predict the variation in fatigue strength with notch size, and comparisons with experimental results revealed discrepancies possibly linked to compression stress state at the notch root, as indicated by finite element analysis. In [39], predictive models for impact speed and energy were presented to simulate damage caused by blade edge impacts. In the study [40], a critical distance theory was introduced, taking into account residual stress and early damage in aerofoil specimens affected by impact. In [41], the fatigue characteristics of aluminum-lithium alloy sheets containing pre-existing cracks and impact-induced dents was studied. Numerical determination of residual stresses and damage resulting from the impact of a sphere against a Ti-6Al-4V plate performed in [42] indicated that quasi-static numerical analyses are sufficient for moderate impact loadings, while dynamic simulations aligned well with experimental results for severe impact loadings. Xu et al. [43] numerically simulated the impact of steel spheres on BT3-1 titanium alloy samples, achieving accurate predictions of impact damage for various speeds. In [44], the impact of objects on 690TT steam generator tubes was simulated, revealing a decrease in fatigue strength with increasing defect depth. Zhang and colleagues [45] explored the impact effects of spherical projectiles on flat dog-bone specimens from AM355 steel, employing a comprehensive approach involving experimental, numerical, and theoretical methods. In the numerical study, an AM355-specific Johnson-Cook model with a failure criterion was adopted, resulting in predicted notch shapes that aligned with experimental outcomes. Moreover, a direct correlation was observed between projectile speed and notch depth. A parallel investigation was undertaken in [46] via finite element analysis to reproduce the impact and consequent damage in simulated airfoil specimens in titanium and steel. The findings unveiled high tension along the notch edge and compression at the notch base.

In [47], a phenomenological perspective on the failure mechanism of a 7075-T6 specimen in hourglass shape subjected to a rotating bending fatigue test was presented, Figure 3. Finite element simulation and macroscopic observation of the fracture surface were adopted. The studied damage was induced by the perpendicular impact of a steel ball at the minimum cross-section of the aluminum specimen. Finite element simulation was carried out to assess the stresses generated by the impact. The total stresses experienced by the specimens undergoing



a) b)

c)

Figure 3. Impact damage on a 7075-T6 specimen in hourglass shape (adapted from [48]): a) section of the finite element model for the impact simulation; b) scheme of the finite element model for the rotating bending moment on the damaged specimen; c) fracture surface of the experimental tested specimen with superposed the axial stress field (GPa) obtained when the maximum level of stress is achieved, the critical areas for crack nucleation are highlighted.

rotating bending were determined by superimposing the residual stresses resulting from impact damage with the rotating bending stresses. The most critical areas in the specimen from a fatigue point of view are those where the highest levels of stress occur after impact [48]. The primary factors influencing the stress distribution in the hourglass specimen after impact damage were assessed in [49]. The speed of the ball emerged as the most influential parameter, with the material of the ball and its diameter following in significance.

COATING DEPOSITION AND ITS EFFECT ON INTEGRITY AND DURABILITY

The deposition of thin films on the surface of component represents a means to enhance the wear and corrosion resistance. If the deposition process occurs at low-temperatures the improvement of the wear and corrosion properties is achieved without causing significant alterations to the mechanical properties of the bulk materials. Coating can be deposited using different techniques, such as phisical vapor deposition, chemical vapor deposition and plasma enhanced chemical vapor deposition [50]. Physical vapour deposition coatings can be deposited on a wide range of materials. Such coatings exhibit remarkable hardness and are characterized by high chemical and thermal stability, as well as exceptional surface finishing [5]. Particularly noteworthy for fatigue behavior, the deposition process introduces compressive stresses due to the thermal expansion discrepancy between the coating and the coated material and their interfacial and structural mismatch [51]. These stresses, typically of the order of 1 GPa [52, 53], effectively hinder the initiation of fatigue cracks on the surface of the base material, when the deposited film remains free of cracks and defects, and delamination does not occur [54, 55]. While the fatigue strength of steel substrates remains largely unaffected by coating deposition [56], it has been observed that the strength of other alloys is diminished, necessitating a recommended subsequent heat treatment in such instances [57].

Studies [58, 59] show the outcomes of rotating bending tests conducted on 7075-T6 specimens, both uncoated and coated with a Diamond-like Carbon coating, Figure 4. The stress field distribution resulting from the residual stresses due to deposition process and bending stresses was assess through finite element analysis. The experimental results revealed that, within fatigue lives from $2\cdot10^5$ to 10^7 loading cycles, coated specimens exhibit lower fatigue strength compared to their uncoated counterparts. The notable reduction in fatigue life for the coated specimens is evident in the $2\cdot10^5$-10^6 cycles range, while fatigue strength converges for both coated and uncoated samples within the $2\cdot10^6$-10^7 cycles range. The finite element study, thanks to the superposition of bending stress and residual stress, indicates that the maximum tensile stress occurs at a depth of around 0,1 mm beneath the specimen surface. Consequently, in the absence of superficial defects, fatigue cracks are probable to nucleate beneath the specimen surface as confirmed by the observations in the fracture surfaces of the tested specimens.

MATERIALS FOR ENERGY-EFFICIENT SYSTEMS

STEEL

Steel is commonly used in engineering applications, as it presents mechanical properties that vary from poor to high. The adoption of shell structures and the application of treatments could help achieve high energy efficiency levels.

The study reported in [60] presents fitness-for-purpose analysis to helping the designer in choosing welding procedures and inspection techniques for steel shell structure elements welded joints. Voorwald et al. [61] analyzed the impact of plasma immersion ion implantation on axial fatigue strength, corrosion, and wear resistance of AISI 4340 steel. The treatment improves fatigue strength and resistance to wear but it is less effective against corrosion.

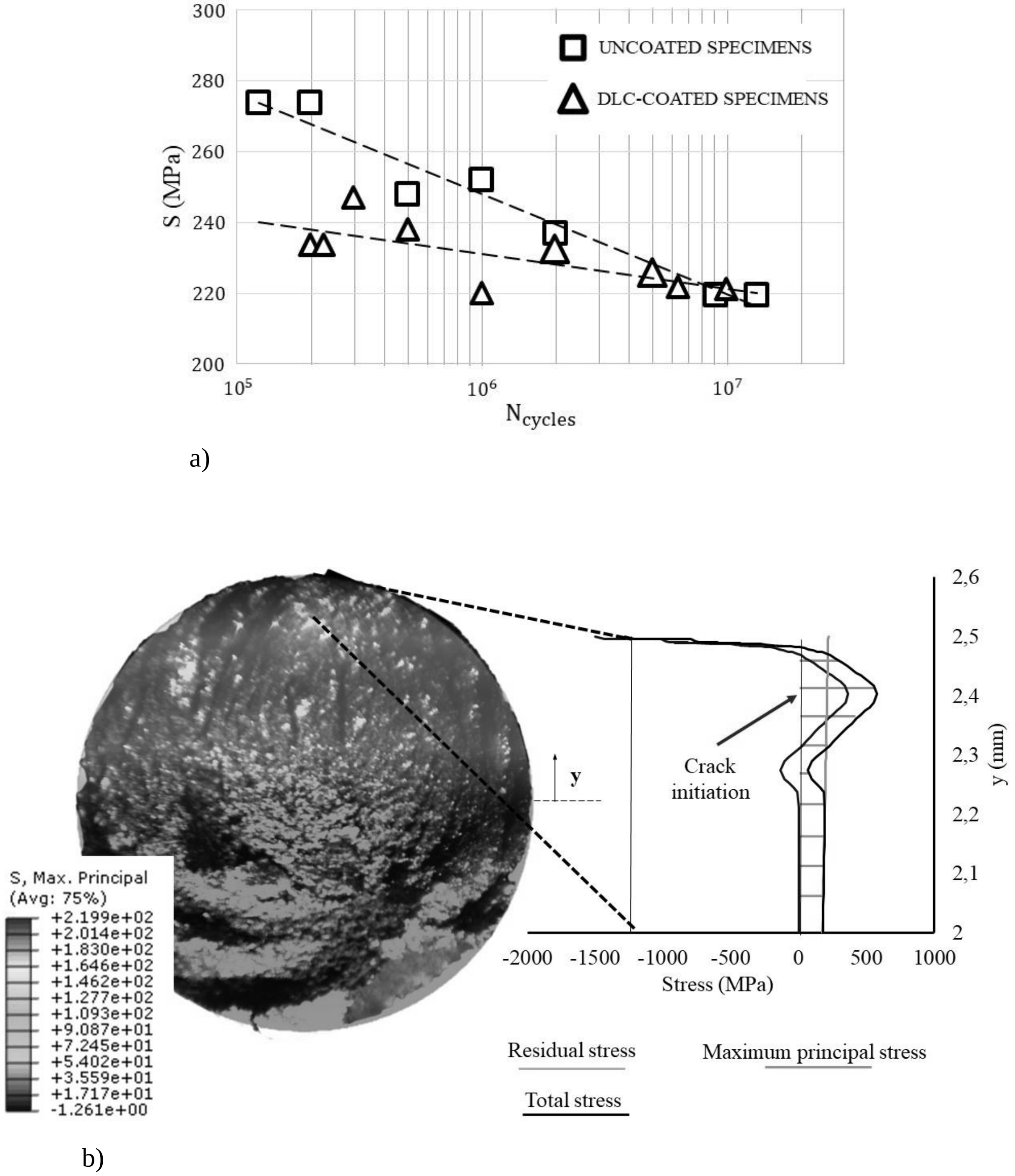


Figure 4. Effect of the deposition of a Diamond-Like Carbon coating on 7075-T6 (adapted from [58, 59]): a) stress vs fatigue life curves for uncoated and coated specimens; b) superposition of the maximum principal stresses (GPa) with the fracture surface of a coated specimen and assessment of the total stresses in the minimum cross section.

High strength low alloy steels have high strengths as a consequence of variations in composition and processing. Fatigue experiments were conducted by Sherman [62] on specific high strength low alloy steels, highlighting their superior fatigue resistance compared to conventional hot rolled low carbon steel at longer lives. Plastic prestrains significantly increased monotonic strength but led to cyclic softening in fatigue, with tensile prestrains adversely affect fatigue resistance. High strength low alloy steel exhibited higher fatigue notch sensitivity than hot rolled low carbon steel, even though its overall notch fatigue resistance remained superior. Nehila and Li [63] evaluated the notch effect on very high cycle fatigue behavior of carburized 17CrNi high-strength steel. A life prediction model, that includes stress ratio and fatigue notch factor, was proposed to predict the fatigue life of the alloy. The results of the theoretical model agreed well with the experimental data. Ślęzak and coauthors [64] explored the fatigue crack initiation and propagation processes in high strength low alloy S960QL steel and its welded joints. Low cycle fatigue tests were conducted and fracture surfaces were analyzed with scanning electron microscopy. Microhardness measurements and residual stress analysis revealed varied hardness distribution, with square joints exhibiting a slightly higher fatigue life compared to single-V joints. Local stress orientation and levels near the fusion line were found to impact fatigue life. The research activity described in [65] assessed the fatigue resistance of high-strength steels and their gas metal arc welded joints using fatigue crack growth tests. Probability methods and two-stage crack growth relationships were employed to build fatigue crack propagation limit curves.

TITANIUM AND TITANIUM ALLOYS

The density of titanium and its alloys is approximately 0,55 times that of steels [66], while the yield strength ranges from 480 MPa to 1725 MPa. The development of a stable protective TiO2 surface layer contributes to an interesting corrosion resistance. Titanium alloys demonstrate good weldability, heat transfer properties, but relatively low thermal conductivity [67]. In spite of the high cost of raw materials and manufacturing processes [68], the fascinating properties of titanium alloys have led to a widespread use in various engineering sectors [66-71] aerospace (e.g. airframe and engine components for aircrafts); marine (e.g. propellers and submarine components); automotive (e.g. suspension and valve components); biomedical (e.g. surgical implants and prosthetic devices); chemical and petrochemical; pulp and paper; energy production and storage (e.g. in heat exchangers, condensers, nuclear power plant condensers).

Commercially pure titanium exhibits two crystallographic structures: the first, existing at room temperature, has a hexagonal close-packed structure and is called the α phase; the second, replacing the first at 883 °C, features a body-centered cubic structure and is known as the β phase. Alloying leads to the formation of a vast selection of alloys with various properties thanks to the introduction of two temperatures: below the first, the alloys exhibit only the α phase, between the first and the second, both the α and β phases are present, and above the second temperature, only the β phase is observed. Impurities can influence mechanical properties. Titanium alloys can be classified based on the phases present [66, 72]. The α alloys contain α-stabilizing elements that inhibit the α-β transformation or increase the temperature at which this transformation occurs; these alloys offer strength, toughness, weldability, and creep resistance but poor forgeability. The α+β alloys have a mixed composition at room temperature; heat treatments and thermomechanical processes can modify their properties. The β alloys are characterized by the presence of β-stabilizing elements which anticipate the α-β transition temperature; they are forgeable and heat-treatable and demonstrate outstanding hardenability.

The Ti-6Al-4V alloy is the most common titanium alloy. It presents both the α and β phases and it is extensively employed in aerospace, naval and automotive industries due to its impressive mechanical properties [73-76].Its biocompatibility extends its utility to biomedical applications [77, 78], even if susceptibility to corrosion fatigue in artificial saliva and fluorine environments has been noted [79]. Ti-6Al-4V resistance to various corrosive environments stems from the quick formation of a thick and stable TiO2 surface layer. However, damage to this oxide layer, induced by factors like low adhesion to the base material, variable loads, and aggressive environments, can compromise these properties [80, 81]. The alloy is also notch-sensitive, with methanol identified as one of the most aggressive environments under static and dynamic loads [82, 83]. Methanol, present in turbojet aircraft engines, poses challenges, which can be mitigated by the presence of water. Hydrochloric acid has also been recognized as an aggressive environment for Ti-6Al-4V [84, 85]. Additionally, fretting corrosion in air and body environments can occur under specific conditions, leading to a poor-quality oxide layer and diminished resistance to corrosion and erosion [86].

Dawson and Pelloux [87] categorized three fatigue behaviors of Ti-6Al-4V based on the environment: in vacuum, air, and solutions with corrosion inhibitors, fatigue failure is independent of frequency of applied load; in methanol, high frequencies of applied load postpone fatigue failure due to less time for environmental attack; in saline solutions and potassium bromide, the frequency and repassivation actions coexist. Even the shape of the applied load influences corrosion resistance: a haversine shape is better than a rectangular one because the tip of the fatigue crack is less exposed to corrosive attacks in a load cycle. The fatigue limit of Ti-6Al-4V in air environments has been observed to be constant after around 100 000 cycles, as reported in [88, 89], indicating a consistent fatigue limit for a significant number of cycles.

The studies presented in [90, 91] and summarized in [92] employed both notched and smooth Ti-6Al-4V specimens to investigate the quasi-static and fatigue behavior of the material in inert conditions such as air and paraffin oil, as well as aggressive and very aggressive like saline and methanol solutions. Air and paraffin oil exhibited similar effects, while the presence of a 3,5 % wt. NaCl solution led to an approximate 20 % reduction of fatigue strength. The surface morphology of specimens exposed to air and saline solutions showed similarities, potentially attributed to the rapid crack propagation inhibiting corrosion. Across all tested environments, a threshold stress concentration factor was identified for stress at failure. Fatigue degradation was noticed for small concentrations of methanol and high concentrations resulted in a significant reduction of fatigue strength. In the case of quasi-static loading, the stress at failure was observed to decrease only for methanol concentrations exceeding 90%.

In [93] quasi-static tests were conducted on Ti-6Al-4V specimens not subjected to solution treatment and over-aging. An analysis of the fracture surfaces of the failed specimens was macroscopically carried out in [94]. The specimens were tested in diverse environmental conditions, including air and paraffin oil (inert environments), and methanol (aggressive environment). The investigation aimed to understand the impact of the presence of different notch geometries in the specimens. The analysis highlighted the effects of aggressive environments and stress gradients induced by the presence of the notches. The combination of aggressive environment and high-stress concentration factors was found to be detrimental. Interestingly, no significant effects of methanol on the structural integrity were observed in smooth specimens. Methanol, however, caused the development of brittle surfaces near the edges, and its presence, in conjunction with high stress gradients, leads to crack nucleation from the notches. The unnotched specimen immersed in paraffin oil during the test revealed the biphasic structure of the alloy. Overall, the alloy exhibited a ductile/brittle behavior contingent upon the specific combination of environment and notch. This behavior was further supported by the observed failure patterns in the experiments. In the inert environment tests, specimens failed without substantial deformation, at stress levels approximately equal to the ultimate tensile strength of the material.

Axial fatigue tests were carried out in [95] on Ti-6Al-4V specimens that had not undergone solution treatment and over-aging. The experiments were carried out in inert environment and various notch depths were tested in the study. The results revealed that specimens with low notch depths in the gauge section of the specimen exhibit limit loads higher than those of specimens with deep notches. Additionally, the nominal stress at failure, referenced to the net area, remained quite constant among the tested specimens.

ALUMINUM AND ITS ALLOYS

Aluminum and its alloys find extensive use across various industries due to high versatility, wide range of mechanical properties that can be achieved, excellent machinability, appreciable corrosion resistance and a density that is about one-third that of steel. Strength of certain aluminum alloys is higher than that of structural steels, others, including pure aluminum, exhibit lower strength and hardness. Key characteristics of aluminum and its alloys include remarkable thermal and electrical conductivity, along with nonferromagnetic and nonpyrophoric properties.

Applications of aluminum and its alloys span a broad spectrum, includingbuilding and construction sectors, automotive industry (e.g. cylinder heads, pistons, transmission housings and bumpers), aeronautical and aviation applications (e.g. airframes, engines, missile bodies, fuel cells and satellite parts), marine industry (e.g. hulls, air ports, furniture, hardware, and fuel tanks), cooking utensils, high-torque electric motors, heat exchangers and evaporators, containers for food and beverages, furniture (e.g. seat frames and armrests), optical and telescopic instruments, sacrificial anodes for the cathodic protection of steel structures and components [96].

Aluminum components can be connected using bolts, rivets and welds, although oxide fragments should be removed because they could reduce ductility and increase the risk of cracking during welding. The high thermal conductivity of aluminum, combined with a high coefficient of thermal expansion, may induce distortions during the welding process.

The Aluminum Association has devised a systematic nomenclature to group wrought alloys into families. According to the nomenclature, 1xxx serie indicates commercial pure aluminum (> 99 %). The second digit (1 to 9) signifies special impurity controls, and the last two digits indicate the minimum percentage of aluminum. These alloys demonstrate exceptional corrosion resistance and workability but lower mechanical properties. In 2xxx, aluminum alloys copper is the primary alloying element, requiring solubilization for property optimization. These alloys exhibit inferior corrosion resistance among aluminum alloys. In 3xxx, manganese is the primary alloying element. These alloys have a resistance approximately 1,2 times that of 1xxx serie. Heat treatment is not permitted. In 4xxx alloys, silicon is the primary alloying element, which is responsible for decreasing the melting range without inducing brittleness. Magnesium is the main alloying element in 5xxx aluminum serie. These alloys offer medium-to-high strength, good work-hardenability, weldability, and resistance to marine environments. In 6xxx aluminum, magnesium and silicon are the primary alloying elements, which provide intermediate strength with good formability, weldability, machinability, and corrosion resistance. 7xxx denotes alloys where zinc is the principle alloying element, with copper, magnesium, chromium, and zirconium also present. These alloys exhibit strength ranging from moderate to very high, and require overaging because their typical high strength penalizes stress corrosion cracking resistance. Finally, the alloys of 8xxx serie contain Tin and lithium.

Except for foundry ingots, temper designation is usually applied to aluminum alloys following a system based on a capital letter that identifies the basic temper and a potential series of digits specifying treatment sequences and variations. Even if the temper is the same, time, temperature, and other heat treatment parameters may differ between alloys [97]. For example, T indicates solution heat-treatment, i.e. stable temper, for alloys with stable resistance within a few weeks of solution treatment and T6 indicates solution heat-treatment and artificial aging that means enhancing mechanical properties through precipitation for grain refinement, solid solution strengthening, precipitation hardening, and dislocation hardening [98].

7075 alloy has the highest strength among aluminum alloys, along with impressive fracture resistance and moderate machinability. However, it is prone to corrosion [80, 99-102], with potential nucleation sites for cracks that coincide with inclusions or intermetallic phases near the surface [103]. This alloy is widely used for structural components requiring high strength, especially in the aeronautical sector. In cases where sustained (residual or applied) tensile stresses are a concern, particularly across the grain transverse direction, opting for a T73 temper is recommended, despite the lower tensile strength that can be obtained [104]. In [105], numerical analyses were conducted to investigate fracture and fatigue behavior in 2024-T3 aluminum alloy. The study adopted the extended finite element method for fracture simulation and combined stress life and fracture mechanics approaches for fatigue failure analysis. A modified elastic-viscoplastic material model was constructed in [106] to accurately reproduce the hysteresis loops observed in aerospace aluminum alloy 7175-T7351 under fatigue at 160°C and 200°C. The temperature values were chosen in order to consider nominal and extreme conditions for aero-engine gearbox components.

COMPOSITE MATERIALS

The use of composite materials has rapidly expanded in the last years reaching various engineering fields. The appeal of such materials lies in the possibility of combining lightness, stiffness, strength, toughness, and corrosion resistance. The adaptable structure of composites allows customization for specific service conditions. Composite materials are formed by a matrix and a reinforcement. The first one can be polymeric, metallic, or ceramic. Common reinforcements include long fibers of carbon or glass, but short fibers or particulate reinforcement are also used. This variability enables composite materials to achieve property combinations that are unachievable in monolithic materials [107].

Experiments and Monte Carlo simulations were used in [108] to study the failure mechanism of reinforced concrete with steel fibres. It was found that failure occurred due to fibre pull-out. Employing a fibre bundle model, the study introduces an inverse procedure for parameter estimation, demonstrating the equivalence of factor analysis and averaging procedures on experimental results. Kastratović et al. [109] determined the mechanical properties of a composite laminate for a light aircraft engine cover combining experimental and numerical approaches. The paper [110] presents a numerical fatigue assessment method for composite plates using continuous strength and stiffness degradation calculation. An integrated experimental and numerical investigation was conducted in [111] on the deformation and fracture in aluminum matrix-carbide particle composites. The finite element method, coupled with constitutive models, was used to explore plastic strain localization in the aluminum matrix and crack origination and growth in ceramic particles under tension and compression.

ADDITIVE MANUFACTURING: A TECHNOLOGY TO PRODUCE LIGHTWEIGHT STRUCTURES AND COMPONENTS

Additive manufacturing is becoming popular in many industrial applications such as aerospace, automobile, biomedical and sports due to the possibility to reach good design flexibility and reduced industrial waste and obtain economical and joint free components [112].

Ti6Al4V titanium alloy has shown adaptability to additive manufacturing for producing components with a favorable strength-to-density ratio. However, the technology’s drawbacks include poor fatigue strength, attributed to characteristic porosity and anisotropy in the processed components [113, 114]. Hot isostatic pressing can induce a fatigue strength comparable to that of cast and wrought material [115].

The microstructure generally plays a significant role [116] and the size of defects is also crucial for the resistance to fatigue loading in corrosive environments of materials [117]. In [112] fracture and fatigue behavior was explored in additively manufactured Ti-6Al-4V alloy. Using the extended finite element method, crack initiation and propagation processes were modelled, providing insights into the influence of microstructural characteristics on fracture and fatigue properties of the alloy. Gupta et al. [118] evaluated the high cycle fatigue performance of a weight-optimized bracket in Ti-6Al-4V made using laser powder bed fusion for aero-engine applications. The fatigue performance of the parts was linked with present defects using a modified Kitagawa-Takahashi diagram.

Khosravani et al. [119] explored the impact of accelerated thermal aging on the mechanical behavior of 3D-printed parts, investigating the effects on structural integrity and fracture behavior. Examining intact and defective specimens with different raster orientations, it was found that a defect perpendicular to the loading direction had a more marked influence on tensile strength than a defect oriented as the loading direction.

Additive manufacturing of composites still requires mechanical tests to understand material behavior under various loads. The study presented in [120] investigated the impact of notches on the mechanical properties of 3D-printed composite materials. Findings revealed that the orientation of laminate layering influences mechanical properties, with notched specimens experiencing higher impact toughness under direct loading compared to those without notches. Gljušćić et al. [121] proposed a modified fused deposition modeling method for selective reinforcement of continuous carbon fiber-reinforced thermoplastic composite.

FROM ADDITIVE MANUFACTURING TO DESIGN OF MATERIALS: METAMATERIALS

Advancements in additive manufacturing techniques have been the basis for the design of metamaterials. These materials exhibit grid-like patterns and their mechanical characteristics are no longer determined exclusively by the composition of the material. Through meticulous design of structures and thanks to the cost-effectiveness of additive manufacturing, we can produce lightweight structures with exceptional energy absorption properties and ability to undergo high elastic deformations. Thanks to these properties, metamaterials are a hot topic for research and industry, with applications in shock absorbers, heat exchangers, and medical implants [122-124]. Lattice structures and triply periodic minimal surface structures are two of the most widespread families of metamaterials.

The paper [123] shows how a wide range of mechanical properties can be obtained in metamaterials by combining different additive manufacturing techniques and materials. Furthermore, bending tests on printed specimens and finite element simulations were used to understand local and global deformation behaviors. The study [124] investigates the impact of process parameters on the mechanical properties of aluminum truss lattice structures produced by selective laser melting. The effect of process parameters on the lattice porosity of the structures, their dimensional accuracy and their structural behavior under compressive loads was studied. The relation between the lattice strut diameter and the process parameters was identified. The work [125] experimentally characterizes lattice structures produced by selective laser melting and electron beam melting. Their compressive behavior was related to the manufacturing technology, material properties and geometry. Additionally, the study provides an equivalent Young’s modulus of lattice specimens which was measured in experiments and compared with numerical results.

Triply periodic minimal surface structures consist of continuous, smooth structures with extended surface areas and continuous inner channels. In [126] different triply periodic minimal surface structures for 316L stainless steel sheets were investigated regarding their compressive behavior. The diamond type structure was found to be the best structure from the experiments. The conducted finite element analyses highlighted a uniform stress distribution in the diamond and gyroid structures, which ensures stable collapse and desired energy absorption. Wang et al. [127] explored the integration of triply periodic minimal surface structures into heat exchanger design, which is strategic for the efficiency and safety of advanced nuclear systems. Using additive manufacturing, various triply periodic minimal surface structures were analyzed for fluid flow and heat transfer. Parametric analysis revealed that heat exchangers with triply periodic minimal surface structures achieve significantly higher heat transfer rates with lower volume than conventional designs. Monkova et al. [128] investigated the impact of volume ratio on the bending properties of AlSi10Mg triply periodic minimal surface structures created by direct laser metal sintering. The structure with 50 % relative weight was found to be brittle, while the one with 30 % relative weight appeared optimal. The study offers insights for defining boundary conditions in simulations of such structures.

CASE STUDIES ON AIRCRAFT AND AUTOMOTIVE SECTORS AND ON TURBO MACHINES

In this section specific case studies were analyzed in aerospace, automotive and turbo machinery sectors, in order to show the engineering challenges.

In [129], the extended finite element method was used to evaluate stress intensity factors for fatigue cracks in a wing-fuselage attachment lug of a light aircraft. The results pointed out the danger of crack appearance, emphasizing the need for safe-life design in attachment lugs for aviation components. In [130], the extended finite element method was used to numerically evaluate the fatigue life of integral skin-stringer panels produced by laser beam welding for aircraft applications. Simulation results, validated with experimental data, revealed significantly longer fatigue life for laser beam welded skin-stringer panels compared to simple flat plates.

The automotive industry has recently witnessed a significant transition towards electrically powered vehicles. Electric traction motors designed for such applications must exhibit high power density and efficiency, as well as reliability. Braut et al. [131] focused on the fatigue life analysis of a permanent magnet synchronous motor rotor for electric traction motors in electric vehicles. A multidisciplinary approach which integrates stresses from structural loading and thermal effects was used to estimate the fatigue life and improving the reliability. Rølvåg et al. The presented method predicts hot spots and durability in a high-performance race engine. The work [133] investigated the influence of elevated temperature on the fatigue strength of autofrettaged components in diesel engine fuel injection systems. The study analyzed cyclic material behavior and simulated elevated temperature effects on autofrettaged and non-autofrettaged components, revealing good agreement with experimental results. To ensure weight reduction in automotive industry, resistance spot welding of two sheets, e.g. aluminum to aluminum, or aluminum to steel, is a challenge. The successful resistance spot welding of three sheets, i.e. 6022 aluminum alloy to high strength low alloy steel and CR780T steel sheets, is reported in [134]. Pastorcic et al. [135] provided a failure and fatigue analysis of a failed coil spring from a vehicle. The fracture was found to be induced by the formation of corrosion pits due to the contact of the coils. Finite element analysis, coupled with strain-life and fatigue damage assessment, was used to predict the spring fatigue life. A damage tolerance framework was proposed in [136] for investigating the fatigue behavior of a high-strength steel trailer structures. The aim of the study is to provide a tool for the design of trailers with improved fatigue performance and reduced weight.

The structural integrity and life of a hydro power plant turbine shaft under static and dynamic loading is studied in [137], using fracture mechanics approaches. Comparing classical engineering approaches with finite element results, it was provided a comprehensive assessment of the shaft integrity. A method for low-cycle fatigue life monitoring of steam turbine rotors is presented in [138]. It is based on the equivalent strain energy density approach. The strain energy correction factor, derived from elastic-plastic finite element analysis, improves the estimation of strain amplitudes and fatigue life. Frank and Weihe [139] investigated the fatigue strength of end stage blades from steam turbines subjected to high centrifugal forces and bending loads. Experimental analyses pointed out two competing damage mechanisms at different locations. Lifetimes obtained with the finite element method were compared to experimental results, providing insights into blade fatigue behavior. The blades of axial turbomachines are subjected to vibrations and fatigue cracking. The paper [140]presents an accelerated fatigue testing procedure for gas turbine compressor blades using the modified Locati method. The study provides a systematic approach to assess the stress vs fatigue life curves of gas turbine components.

CONCLUSIONS

The imperative need to address global warming and environmental pollution underscores the critical role of developing energy-efficient systems. The strategy of reducing the mass of mechanical systems emerges as a promising avenue for achieving energy efficiency, as a consequence of diminished inertia, lower fuel and energy consumption, and enhanced transportation capabilities. A key design principle involves the use of lightweight materials in optimized structures, manufactured through advanced methods such as additive manufacturing. Throughout the design process, attention to ensuring the structural integrity and durability of systems under diverse loading and environmental conditions is paramount. Using results from mathematical models, numerical simulations, and experimental tests, this article proposes a comprehensive assessment framework, highlighting the potentialities, advantages and disadvantages of possible design solutions. The article delves into critical aspects for the integrity and durability of components, such as fatigue, impact damage and coating deposition effects. The important role of the use of metamaterials in increasing system efficiency is highlighted. The conducted exploration of materials, such as steel, titanium, aluminium and composites, allows for a comprehensive evaluation of their applicability in energy-efficient system design. The presented real-world case studies offer practical insights for researchers and engineers, that facilitate informed decision-making in the pursuit of sustainable energy solutions for a greener future.

REFERENCES

[1] Ordoukhanian, E. and Madni, A.M.: *Blended wing body architecting and design: current status and future prospects*.
Procedia Computer Science **28**, 619-625, 2014,
http://dx.doi.org/10.1016/j.procs.2014.03.075,

[2] Lomolino, S.; Tovo, R. and dos Santos, J.: *On the fatigue behaviour and design curves of friction stir butt-welded Al alloys*.
International Journal of Fatigue **27**(3), 305-316, 2005,
http://dx.doi.org/10.1016/j.ijfatigue.2004.06.013,

[3] Hirsch, J.: *Aluminium in innovative light-weight car design*.
Materials Transactions **52**(5), 818-824, 2011,
http://dx.doi.org/10.2320/matertrans.L-MZ201132,

[4] Kumar, M.; Sotirov, N. and Chimani, C.M.: *Investigations on warm forming of AW-7020-T6 alloy sheet*.
Journal of Materials Processing Technology **214**(8), 1769-1776, 2014,
http://dx.doi.org/10.1016/j.jmatprotec.2014.03.024,

[5] Bull, S.J.: *Physical vapour deposition methods for protection against wear*.
In: Mellor, B.G., ed.: *Surface coatings for protection against wear*. Woodhead Publishing Ltd., Abington, 2006,
http://dx.doi.org/10.1533/9781845691561.146,

[6] Goward, G.W.: *Progress in coatings for gas turbine airfoils*.
Surface and Coatings Technology **108-109**, 73-79, 1998,
http://dx.doi.org/10.1016/S0257-8972(98)00667-7,

[7] Galileo, G.: *Discorsi e dimostrazioni matematiche intorno a due nuove scienze (Two new Sciences)*.
Ludovico, ed. Elzeviro, Leida, 1638,

[8] Baragetti, S.: *A theoretical study on nonlinear bending of wires*.
Meccanica **41**, 443-458, 2006,
http://dx.doi.org/10.1007/s11012-006-0002-y,

[9] Baragetti, S.; Terranova, A. and Vimercati, M.: *Friction behaviour evaluation in beryllium-copper threaded connections.*
International Journal of Mechanical Sciences **51**(11-12), 790-796, 2009,
http://dx.doi.org/10.1016/j.ijmecsci.2009.09.004,

[10] Baragetti, S. and Arcieri, E.V.: *Study of Impact Phenomena for the Design of a Mobile Anti-Terror Barrier: Experiments and Finite Element Analyses*.
Engineering Failure Analysis **113**, No. 104564, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104564,

[11] Mlikota, M. and Schmauder, S.: *Numerical determination of component Wöhler curve*.
DVM Bericht/Anwend Werkstoffgesetze Bauteilsimulation **1684**, 111-124, 2017,

[12] Sangid, M.D.: *The physics of fatigue crack initiation*.
International Journal of Fatigue **57**, 58-72, 2013,
http://dx.doi.org/10.1016/j.ijfatigue.2012.10.009,

[13] Polak, J. and Man, J.: *Fatigue crack initiation – the role of point defects*.
International Journal of Fatigue **65**, 18-27, 2014,
http://dx.doi.org/10.1016/j.ijfatigue.2013.10.016,

[14] Ewing, J.A. and Humfrey, J.C.W.: *The fracture of metals under repeated alternations of stress*.
Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character **200**, 241-250, 1903,
http://www.jstor.org/stable/90874,

[15] Santus, C. and Taylor, D.: *Physically short crack propagation in metals during high cycle fatigue*.
International Journal of Fatigue **31**, 1356-1365, 2009,
http://dx.doi.org/10.1016/j.ijfatigue.2009.03.002,

[16] Kujawski, D.: *Correlation of long- and physically short-cracks growth in aluminum alloys*.
Engineering and Fracture Mechanics **68**(12), 1357-1369, 2001,
http://dx.doi.org/10.1016/S0013-7944(01)00029-7,

[17] Klesnil, M. and Lukas, P.: *Fatigue of metallic materials*.
Elsevier, Amsterdam, 1980,

[18] Babić, M.; Verić, O.; Božić, Ž. and Sušić, A.: *Reverse engineering based integrity assessment of a total hip prosthesis*.
Procedia Structural Integrity **13**, 438-443, 2018,
http://dx.doi.org/10.1016/j.prostr.2018.12.073,

[19] Babić, M.; Verić, O.; Božić, Ž. and Sušić, A.: *Fracture analysis of a total hip prosthesis based on reverse engineering*.
Engineering Fracture Mechanics **215**, 261-271, 2019,
http://dx.doi.org/10.1016/j.engfracmech.2019.05.003,

[20] Babić, M.; Verić, O.; Božić, Ž. and Sušić, A.: *Finite element modelling and fatigue life assessment of a cemented total hip prosthesis based on 3D scanning*.
Engineering Failure Analysis, **113**, No. 104536, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104536,

[21] Božić, Ž.; Wolf, H. and Semenski, D.: *Growth of multiple fatigue cracks in plates under cyclic tension*.
Transactions of FAMENA **34**, 1-12, 2010,

[22] Čakmak, D., et al.: *Vibration fatigue study of the helical spring in the base-excited inerter-based isolation system*.
Engineering Failure Analysis **103**, 44-56, 2019,
http://dx.doi.org/10.1016/j.engfailanal.2019.04.064,

[23] Cazin, D.; Braut, S.; Božić Ž. and Žigulić, R.: *Low cycle fatigue life prediction of the demining tiller tool*.
Engineering Failure Analysis **111**, No. 104457, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104457,

[24] Nečemer, B.; Božić, Ž. and Glodež, S.: *Fatigue resistance of the auxetic honeycombs*.
Procedia Structural integrity **46**, 68-73, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.06.012,

[25] Mlikota, M.; Schmauder, S. and Božić, Ž.: *Calculation of the Wöhler (S-N) curve using a two-scale model*.
International Journal of Fatigue **114**, 289-297, 2018,
http://dx.doi.org/10.1016/j.ijfatigue.2018.03.018,

[26] Mlikota, M.; Schmauder, S.; Božić, Ž. and Hummel, M.: *Modelling of overload effects on fatigue crack initiation in case of carbon steel*.
Fatigue and Fracture of Engineering Materials and Structures **40**(8), 1182-1190, 2017,
http://dx.doi.org/10.1111/ffe.12598,

[27] Mlikota, M.; Schmauder, S.; Dogahe, K. and Božić, Ž.: *Influence of local residual stresses on fatigue crack initiation*.
Procedia Structural Integrity **31**, 3-7, 2021,
http://dx.doi.org/10.1016/j.prostr.2021.03.002,

[28] Mlikota, M.; Dogahe, K.; Schmauder, S. and Božić, Ž.: *Influence of the grain size on the fatigue initiation life curve*.
International Journal of Fatigue **158**, No. 106562, 2022,
http://dx.doi.org/10.1016/j.ijfatigue.2021.106562,

[29] Baragetti, S.: *Shot peening optimisation by means of 'DOE': Numerical simulation and choice of treatment parameters*.
International Journal od Materials and Product Engineering **12**, 83-109, 1997,

[30] Nicholas, T.: *Foreign Object Damage*.
In: Nicholas, T., ed.: *High cycle fatigue*. Elsevier Science, Oxford, 2006,
http://dx.doi.org/10.1016/B978-008044691-2/50007-2,

[31] Wang, L.F., et al.: *Fatigue strength improvement in Ti-6Al-4V subjected to foreign object damage by combined treatment of laser shock peening and shot peening*.
International Journal of Fatigue **155**, No. 106581, 2022,
http://dx.doi.org/10.1016/j.ijfatigue.2021.106581,

[32] Zhu, L.; Hu, X.; Jiang, R. Song, Y. and Qu, S.: *Experimental investigation of small fatigue crack growth due to foreign object damage in titanium alloy TC4*,
Materials Science and Engineering: A **739**, 214-224, 2019,
http://dx.doi.org/10.1016/j.msea.2018.10.031,

[33] Ding, J.; Hall, R.F.; Byrne, J. and Tong, J.: *Fatigue crack growth from foreign object damage under combined low and high cycle loading. Part I: Experimental studies*.
International Journal of Fatigue **29**(7), 1339-1359, 2007,
http://dx.doi.org/10.1016/j.ijfatigue.2006.10.020,

[34] Peters, J.O. and Ritchie, R.O.: *Influence of foreign-object damage on crack initiation and early crack growth during high-cycle fatigue of Ti–6Al–4V*.
Engineering Fracture Mechanics **67**(3), 193-207, 2000,
http://dx.doi.org/10.1016/S0013-7944(00)00045-X,

[35] Ruschau, J.; Thompson, S.R. and Nicholas, T.: *High cycle fatigue limit stresses for airfoils subjected to foreign object damage*.
International Journal of Fatigue **25**(9-11), 955-962, 2003,
http://dx.doi.org/10.1016/S0142-1123(03)00135-X,

[36] Martinez, C.M., et al.: *Effects of ballistic impact damage on fatigue crack initiation in Ti–6Al–4V simulated engine blades*.
Materials Science and Engineering A **325**(1-2), 465-477, 2002,
http://dx.doi.org/10.1016/S0921-5093(01)01532-5,

[37] Chen, X.: *Foreign object damage on the leading edge of a thin blade*.
Mechanics of Materials **37**(4), 447-457, 2005,
http://dx.doi.org/10.1016/j.mechmat.2004.03.005,

[38] Nowell, D.; Duó, P. and Stewart, I.F.: *Prediction of fatigue performance in gas turbine blades after foreign object damage*.
International Journal of Fatigue **25**(9-11), 963-969, 2003,
http://dx.doi.org/10.1016/S0142-1123(03)00160-9,

[39] Zhang, H., et al.: *Experimental and analytical modelling on aeroengine blade foreign object damage*.
International Journal of Impact Engineering **183**, No. 104813, 2024,
http://dx.doi.org/10.1016/j.ijimpeng.2023.104813,

[40] Hu, D.Y., et al.: *A life prediction model coupled with residual stress and initial damage on aerofoil specimens subjected to foreign object damage*.
International Journal of Fatigue **154**, No. 106559, 2022,
http://dx.doi.org/10.1016/j.ijfatigue.2021.106559,

[41] Zhang, X.Y., et al.: *Post-impact Fatigue Performance of 2198-T8 Aluminum-Lithium Alloy Sheet with Pre-crack*.
Journal of Testing and Evaluation **51**(6), 4328-4339, 2023,
http://dx.doi.org/10.1520/JTE20220546,

[42] Boyce, B.L., et al.: *The residual stress state due to a spherical hard-body impact*.
Mechanics of Materials **33**(8), 441-454, 2001,
http://dx.doi.org/10.1016/S0167-6636(01)00064-3,

[43] Xu, Y.; Cheng, L.; Shu, C.; Chen, X. and Li, P.: *Foreign object damage performance and constitutive modeling of titanium alloy blade*.
International Journal of Aerospace Engineering **2020**, No. 2739131, 2020,
http://dx.doi.org/10.1155/2020/2739131,

[44] Li, Z.H., et al.: *Effects of foreign object damage on high-cycle fatigue behavior of Inconel Alloy 690TT steam generator tubes*.
Engineering Fracture Mechanics **292**, No. 109660, 2023,
http://dx.doi.org/10.1016/j.engfracmech.2023.109660,

[45] Zhang, H., et al.: *Numerical and theoretical prediction of foreign object damage on AM355 simulated blade validated by ballistic impact tests*.
Thin-Walled Structures **193**, No. 111230, 2023,
http://dx.doi.org/10.1016/j.tws.2023.111230,

[46] Zhang, H.; Hu, D.; Ye, X.; Chen, X. and He, Y.: *Prediction on aeroengine blade foreign object damage validated by air gun tests*.
Engineering Failure Analysis **143**, No. 106919, 2023,
http://dx.doi.org/10.1016/j.engfailanal.2022.106919,

[47] Arcieri, E.V.; Baragetti, S. and Božić, Ž.: *Residual stress modelling and analysis of a 7075-T6 hourglass specimen after foreign object damage*.
Procedia Structural Integrity **46**, 24-29, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.06.005,

[48] Arcieri, E.V.; Baragetti, S. and Božić, Ž.: *Stress assessment and fracture surface analysis in a foreign object damaged 7075-T6 specimen under rotating bending*.
Engineering Failure Analysis **138**, No. 106380, 2022,
http://dx.doi.org/10.1016/j.engfailanal.2022.106380,

[49] Arcieri, E.V.; Baragetti and S. and Božić, Ž.: *Application of design of experiments to foreign object damage on 7075-T6*.
Procedia Structural Integrity **31**, 22-27, 2021,
http://dx.doi.org/10.1016/j.prostr.2021.03.005,

[50] Baragetti, S. and Tordini, F.: *Fatigue resistance of PECVD coated steel alloy*. International Journal of Fatigue **29**(9-11), 1832-1838, 2007, http://dx.doi.org/10.1016/j.ijfatigue.2007.02.008,

[51] Srinivasan, N.; Bhaskar, L.K.; Kumar, R. and Baragetti, S.: *Residual stress gradient and relaxation upon fatigue deformation of diamond-like carbon coated aluminum alloy in air and methanol environments*. Materials and Design **160**, 303-312, 2018, http://dx.doi.org/10.1016/j.matdes.2018.09.022,

[52] Puchi-Cabrera, E.S., et al.: *Fatigue behavior of AA7075-T6 aluminum alloy coated with ZrN by PVD*. International Journal of Fatigue **30**, 1220-1230, 2008, http://dx.doi.org/10.1016/j.ijfatigue.2007.09.001,

[53] Chang, Y.Z., et al.: *Zr-based metallic glass thin film coating for fatigue-properties*. Thin Solid Films **544**, 331-334, 2013, http://dx.doi.org/10.1016/j.tsf.2013.02.104,

[54] Kim, K.R.; Suh, C.M.; Murakami, R.I. and Chung, C.W.: *Effect of intrinsic properties of ceramic coatings on fatigue behavior of Cr–Mo–V steels*. Surface and Coatings Technology **171**(1-3), 15-23, 2003, http://dx.doi.org/10.1016/S0257-8972(03)00229-9,

[55] Gelfi, M.; La Vecchia, G.M.; Lecis, N. and Troglio, S.: *Relationship between through-thickness residual stress of CrN-PVD coatings and fatigue nucleation sites*. Surface and Coatings Technology **192**(2-3), 263-268, 2005, http://dx.doi.org/10.1016/j.surfcoat.2004.05.032,

[56] Baragetti, S.; Gelfi, M.; La Vecchia, G.M. and Lecis, N.: *Fatigue resistance of CrN thin films deposited by arc evaporation process on H11 tool steel and 2205 duplex stainless steel*. Fatigue and Fracture of Engineering Materials and Structures **28**(7), 615-621, 2005, http://dx.doi.org/10.1111/j.1460-2695.2005.00905.x,

[57] Oskouei, R.H. and Ibrahim, R.N.: *Restoring the tensile properties of PVD-TiN coated Al 7075-T6 using a post heat treatment*. Surface and Coatings Technology **205**(15), 3967-3973, 2011, http://dx.doi.org/10.1016/j.surfcoat.2011.02.041,

[58] Baragetti, S.; Borzini, E.; Božić, Ž. and Arcieri, E.V.: *On the fatigue strength of uncoated and DLC coated 7075-T6 aluminum alloy*. Engineering Failure Analysis **102**, 219-225, 2019, http://dx.doi.org/10.1016/j.engfailanal.2019.04.035,

[59] Baragetti, S.; Božić, Ž. and Arcieri, E.V.: *Stress and fracture surface analysis of uncoated and coated 7075-T6 specimens under the rotating bending fatigue loading*. Engineering Failure Analysis **112**, No. 104512, 2020, http://dx.doi.org/10.1016/j.engfailanal.2020.104512,

[60] Radu, D., et al.: *Engineering critical assessment of steel shell structure elements welded joints under high cycle fatigue*. Engineering Failure Analysis **114**, No. 104578, 2020, http://dx.doi.org/10.1016/j.engfailanal.2020.104578,

[61] Voorwald, H.J.C., et al.: *Increasing fatigue resistance of AISI 4340 steel by nitrogen plasma ion-implantation*. Engineering Failure Analysis **104**, 490-499, 2019, http://dx.doi.org/10.1016/j.engfailanal.2019.06.018,

[62] Sherman, A.M.: *Fatigue properties of high strength-low alloy steels*. Metallurgical Transactions A **6**, 1035-1040, 1975, http://dx.doi.org/10.1007/BF02661357,

[63] Nehila, A. and Li, W.: *Effect of notch and stress ratio on Very High Cycle Fatigue characteristics of the carburized 17CrNi high-strength steel and life prediction*.
Procedia Structural Integrity **51**, 152-159, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.10.082,

[64] Ślęzak, T.: *Fatigue Examination of HSLA Steel with Yield Strength of 960 MPa and Its Welded Joints under Strain Mode*.
Metals **10**(2), No. 228, 2020,
http://dx.doi.org/10.3390/met10020228,

[65] Lukács, J.: *Fatigue crack propagation limit curves for high strength steels based on two-stage relationship*.
Engineering Failure Analysis **103**, 431-442, 2019,
http://dx.doi.org/10.1016/j.engfailanal.2019.05.012,

[66] Destefani, J.D.: *Introduction to titanium and titanium alloys*.
In: ASM Hadbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[67] Lampman, S., 1990. *Wrought titanium and titanium alloys*.
In: ASM Hadbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[68] Eylon, D., Newman, J.R., K. Thorne, J.K., 1990. *Titanium and titanium alloy castings*.
In: ASM Hadbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[69] Honnorat, Y.,: *Titanium alloys use in turbojet engines*.
In: Lacombe, P.; Tricot, R. and Beranger, G., eds.: *Proceedings of the sixth world conference on titanium*. Societe Francaise de Metallurgie, 1988,

[70] Kramer, K.-H.: *Titanium applications - a critical review*,
In: Lacombe, P.; Tricot, R. and Beranger, G., eds.: *Proceedings of the sixth world conference on titanium*. Societe Francaise de Metallurgie, 1988,

[71] Fukuhara, Y.: *Nonaerospace applications of titanium*.
In: Lacombe, P.; Tricot, R. and Beranger, G., eds.: *Proceedings of the sixth world conference on titanium*. Societe Francaise de Metallurgie, 1988,

[72] Donachie, M.J.: *Titanium: a technical guide*.
ASM International, Metals Park, 1988,

[73] Boyer, R.R.: *An overview on the use of titanium in the aerospace industry*.
Materials Science and Engineering A **213**(1-2), 103-114, 1996,
http://dx.doi.org/10.1016/0921-5093(96)10233-1,

[74] Lütjering, G. and Williams, J.C.: *Titanium*.
Springer, Berlin, 2007,

[75] Ritchie, R., et al.: *Thresholds for high-cycle fatigue in a turbine engine Ti-6Al-4V alloy*.
International Journal of Fatigue **21**(7), 653-662, 1999,
http://dx.doi.org/10.1016/S0142-1123(99)00024-9,

[76] Knobbe, H.; Koster, P.; Christ, H.-J.; Fritzen, C.-P. and Riedler, M.: *Initiation and propagation of short fatigue cracks in forged Ti–6Al–4V*.
Procedia Engineering **2**, 931-940, 2010,
http://dx.doi.org/10.1016/j.proeng.2010.03.101,

[77] Dimah, M.K.; Devesa Albeza, F.; Amigó Borrás, V. and Igual Muñoz, A.: *Study of the biotribocorrosion behavior of titanium biomedical alloys in simulated body fluids by electrochemical techniques*.
Wear **294-295**, 409-418, 2012,
http://dx.doi.org/10.1016/j.wear.2012.04.014,

[78] Niinomi, M.: *Mechanical properties of biomedical titanium alloys*.
Materials Science and Engineering A **243**, 231-236, 1998,
http://dx.doi.org/10.1016/S0921-5093(97)00806-X,

[79] Zavanelli, R.A.; Pessanha Henriques, G.E.; Ferreira, I. and de Almeida Rollo, J.M.D.: *Corrosion-fatigue life of commercially pure titanium and Ti-6Al-4V alloys in different storage environments*.
Journal of Prosthetic Dentistry **84**(3), 274-279, 2000,
http://dx.doi.org/10.1067/mpr.2000.108758,

[80] Brown, B.F.: *Stress-corrosion cracking in high strength steels and in titanium and aluminum alloys*.
Naval Research Laboratory: Washington, 1972,

[81] Lee, E.U.; Vasudevan, A.K. and Sadananda, K.: *Effects of various environments on fatigue crack growth in Laser formed and IM Ti-6AI-4V alloys*.
International Journal of Fatigue **27**(10-12), 1597-1607, 2005,
http://dx.doi.org/10.1016/j.ijfatigue.2005.07.013,

[82] Johnson, R.E.: *NASA Experiences with Ti-6Al-4V in methanol*.
DMIC Memorandum **228**, 1967,

[83] Johnston, R.L., et al.: *Stress-corrosion cracking of Ti-6Al-4V alloy in methanol*.
NASA Technical Note TN D-3868, 1967,

[84] Chen, C.; Kirkpatrick, H. and Gegel, H.: *Stress corrosion cracking of titanium alloys in methanolic and other media*.
Air Force Materials Laboratory, Wright-Patterson AFB, 1972,

[85] Sanderson, G. and Scully, J.C.: *The stress corrosion of Ti alloys in methanolic solutions*.
Corrosion Science **8**(7), 541-548, 1968,
http://dx.doi.org/10.1016/S0010-938X(68)80008-3,

[86] Zhou, J. and Bahadur, S.: *Erosion-corrosion of Ti-6Al-4V in elevated temperature air environment*.
Wear **186-187**, 332-339, 1995,
http://dx.doi.org/10.1016/0043-1648(95)07161-X,

[87] Dawson, D.B. and Pelloux, R.M.: *Corrosion fatigue crack growth of titanium alloys in aqueous environments*.
Metallurgical Transactions **5**, 723-731, 1974,
http://dx.doi.org/10.1007/BF02644669,

[88] Morrissey, R.J. and Nicholas, T.: *Fatigue strength of Ti–6Al–4V at very long lives*.
International Journal of Fatigue **27**(10-12), 1608-1612, 2005,
http://dx.doi.org/10.1016/j.ijfatigue.2005.07.009,

[89] Sadananda, K.; Sarkar, S.; Kujawski, D. and Vasudevan, A.K.: *A two-parameter analysis of S-N fatigue life using Δσ and σmax*.
International Journal of Fatigue **31**(11-12), 1648-1659, 2009,
http://dx.doi.org/10.1016/j.ijfatigue.2009.03.007,

[90] Baragetti, S.: *Notch corrosion fatigue behavior of Ti-6Al-4V*.
Materials **7**(6), 4349-4366, 2014,
http://dx.doi.org/10.3390/ma7064349,

[91] Baragetti, S.: *Corrosion Fatigue Behaviour of Ti-6Al-4V in Methanol Environment*.
Surface and Interface Analysis **45**(10), 1654-1658, 2013,
http://dx.doi.org/10.1002/sia.5203,

[92] Baragetti, S. and Arcieri, E.V.: *Corrosion Fatigue Behavior of Ti-6Al-4V: Chemical and Mechanical Driving Forces*.
International Journal of Fatigue **112**, 301-307, 2018,
http://dx.doi.org/10.1016/j.ijfatigue.2018.02.033,

[93] Baragetti, S.; Borzini, E. and Arcieri, E.V.: *Effects of environment and stress concentration factor on Ti-6Al-4V specimens subjected to quasi-static loading*.
Procedia Structural Integrity **12**, 173-182, 2018,
http://dx.doi.org/10.1016/j.prostr.2018.11.097,

[94] Baragetti, S.; Borzini, E.; Božić, Ž. and Arcieri, E.V.: *Fracture surfaces of Ti-6Al-4V specimens under quasi-static loading in inert and aggressive environments*. Engineering Failure Analysis **103**, 132-143, 2019, http://dx.doi.org/10.1016/j.engfailanal.2019.04.072,

[95] Arcieri, E.V.; Baragetti, S. and Božić, Ž.: *Limit load of notched Ti-6Al-4V specimens under axial fatigue*. Procedia Structural Integrity **51**, 3-8, 2023. http://dx.doi.org/10.1016/j.prostr.2023.10.059,

[96] Rooy, E.L.: *Introduction to aluminum and aluminum alloys*. In: ASM Handbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[97] Cayless, R.B.C.: *Alloy and temper designation systems for aluminum and aluminum alloys*. In: ASM Handbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[98] Panigrahi, S.K. and Jayaganthan, R.: *Effect of ageing on microstructure and mechanical* properties *of bulk, cryorolled, and room temperature rolled Al Al-7075 alloy*. Journal of Alloys and Compounds **509**(40), 9609-9616, 2011, http://dx.doi.org/10.1016/j.jallcom.2011.07.028,

[99] Starke, E.A. and Staley J.T.: *Application of modern aluminium alloys to aircraft*. Progress in Aerospace Sciences **32**(2-3), 131-172, 1996, http://dx.doi.org/10.1016/0376-0421(95)00004-6,

[100] Wu, S.D.; Cheng, W.Y. and Yang, J.H.C.: *The corrosion protection study on inner surface from welding of aluminum alloy 7075-T6 hydrogen storage bottle*. Journal of Hydrogen Energy **41**(1), 570-596, 2016, http://dx.doi.org/10.1016/j.ijhydene.2015.09.144,

[101] Sankaran, K.K.; Perez, R. and Jata, K.V.: *Effects of pitting corrosion on the fatigue behavior of aluminum alloy 7075-T6: modeling and experimental studies*. Materials Science and Engineering A **297**, 223-229, 2001, http://dx.doi.org/10.1016/S0921-5093(00)01216-8,

[102] Silva, G.; Rivolta, B.; Gerosa, R. and Derudi, U.: *Study of the SCC behavior of 7075 aluminum alloy after one-step aging at 163 °C*. Journal of Materials Engineering and Performance **22**, 210-214, 2013, http://dx.doi.org/10.1007/s11665-012-0221-4,

[103] Leng, L.; Zhang, Z.J.; Duan, Q.Q.; Zhang, P. and Zhang, Z.F.: *Improving the fatigue strength of 7075 alloy through aging*. Materials Science and Engineering A **738**, 24-30, 2018, http://dx.doi.org/10.1016/j.msea.2018.09.047,

[104] VVAA: *Properties of wrought aluminum and aluminum alloys*. In: ASM Hadbook Committee, ed.: *Properties and selection: nonferrous alloys and special-purpose materials*, Vol. 2. ASM International, Metals Park, 1990,

[105] Gairola, S.; Verma, R. and Jayaganthan R.: *Study on fatigue and fracture behavior of Al 2024 alloy through XFEM and stress-life approach*. Procedia Structural Integrity **46**, 182-188, 2023, http://dx.doi.org/10.1016/j.prostr.2023.06.031,

[106] Lam Wing Cheong, M.F.; Rouse, J.P.; Hyde, C.J. and Kennedy, A.R.: *The prediction of isothermal cyclic plasticity in 7175-T7351 aluminium alloy with particular emphasis on thermal ageing effects*. Engineering Failure Analysis **114**, 92-108, 2018, http://dx.doi.org/10.1016/j.ijfatigue.2018.05.010,

[107] Clyne, T.W. and Hull, D.: *An introduction to composite materials*. Cambridge University, 2019,

[108]Kozar, I.; Malic, N.T.; Simonetti, D. and Bozic, Z.: *Stochastic properties of bond-slip parameters at fibre pull-out.*
Engineering Failure Analysis **111**, No. 104478, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104478,

[109]Kastratović, G.: *Composite material selection for aircraft structures based on experimental and numerical evaluation of mechanical properties*.
Procedia Structural integrity **31**, 127-133, 2021,
http://dx.doi.org/10.1016/j.prostr.2021.03.021,

[110]Takacs, L.; Kovacs, L. and Olajos, T.: *Numerical tool with mean-stress correction for fatigue life estimation of composite plates*.
Engineering Failure Analysis **111**, No. 104456, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104456,

[111]Balokhonov, R.; Romanova, V. and Kulkov, A.: *Microstructure-based analysis of deformation and fracture in metal-matrix composite materials*.
Engineering Failure Analysis **110**, No. 104412, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104412,

[112]Verma, R.; Gairola, S.; Kumar, P. and Jayaganthan, R.: *Fracture toughness and fatigue crack growth behaviour of laser powder bed fusion (LPBF) built Ti-6Al-4V alloy through XFEM*.
Procedia Structural Integrity **46**, 175-181, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.06.030,

[113]Leuders, S., et al.: *On the mechanical behaviour of titanium alloy TiAl6V4 manufactured by selective laser melting. Fatigue resistance and crack growth performance*.
International Journal of Fatigue **48**, 300-307, 2013,
http://dx.doi.org/10.1016/j.ijfatigue.2012.11.011,

[114]Van Hooreweder, B., et al.: *On the determination of fatigue properties of Ti-6Al-4V produced by selective laser melting*.
In: Proceedings of the 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials, Honolulu, 2012,

[115]Seifi, M.; Salem, A.; Satko, D.; Shaffer, J. and Lewandoski, J.J.: *Defect distribution and microstructure heterogeneity effects on fracture resistance and fatigue behavior of EBM Ti–6Al–4V*.
International Journal of Fatigue **94**, 263-287, 2017,
http://dx.doi.org/10.1016/j.ijfatigue.2016.06.001,

[116]Nalla, R.K.; Campbell, J.P. and Ritchie, R.O.: *Effects of microstructure on mixedmode, high-cycle fatigue crack-growth thresholds in Ti-6Al-4V alloy*.
Fatigue and Fracture of Engineering Materials and Structures **25**(6), 587-606, 2002,
http://dx.doi.org/10.1046/j.1460-2695.2002.00522.x,

[117]Gangloff, R.P.: *Crack size effects on the chemical driving force for aqueous corrosion* fatigue.
Metallurgical Transactions A **16**, 953-969, 1985,
http://dx.doi.org/10.1007/BF02814848,

[118]Gupta, A.; Bennett, C.J. and Sun, W.: *High cycle fatigue performance evaluation of a laser powder bed fusion manufactured Ti-6Al-4V bracket for aero-engine applications*.
Engineering Failure Analysis **140**, No. 106494, 2022,
http://dx.doi.org/10.1016/j.engfailanal.2022.106494,

[119]Khosravani, M.R.; Božić, Ž.; Zolfagharian, A. and Reinicke. T.: *Failure analysis of 3D-Printed PLA components: Impact of manufacturing defects and thermal ageing*.
Engineering Failure Analysis **136**, No. 106214, 2022,
http://dx.doi.org/10.1016/j.engfailanal.2022.106214,

[120]Vaško, M., et al.: *Influence of notch and load direction on impact toughness of fibre reinforced composites produced by 3D printing*.
Procedia Structural Integrity **51**, 173-178, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.10.085,

[121]Gljušćić, M., et al.: *Application of digital image correlation in behavior modelling of AM CFRTP composites*.
Engineering Failure Analysis **136**, No. 106133, 2022,
http://dx.doi.org/10.1016/j.engfailanal.2022.106133,

[122]Mohsenizadeh, M., et al.*: Additively-manufactured lightweight Metamaterials for energy absorption*.
Materials & Design **139**, 521-530, 2018,
http://dx.doi.org/10.1016/j.matdes.2017.11.037,

[123]Truszkiewicz, E., et al.: *Mechanical behavior of 3D-printed polymeric metamaterials for lightweight applications*.
Journal of Applied Polymer Science **139**(6), No. 51618, 2021,
http://dx.doi.org/10.1002/app.51618,

[124]Großmann, A.; Gosmann, J. and Mittelstedt, C.: *Lightweight lattice structures in selective laser melting: Design, fabrication and mechanical properties*.
Materials Science and Engineering A **766**, No. 138356, 2019,
http://dx.doi.org/10.1016/j.msea.2019.138356,

[125]De Pasquale, G.; Luceri, F. and Riccio, M.: *Experimental characterization of SLM and EBM cubic lattice structures for lightweight applications*.
Experimental Mechanics **59**, 469-482, 2019,
http://dx.doi.org/10.1007/s11340-019-00481-8,

[126]Zhang, L., et al.: *Energy absorption characteristics of metallic triply periodic minimal surface sheet structures under compressive loading*.
Additive Manufacturing **23**, 505-515, 2018,
http://dx.doi.org/10.1016/j.addma.2018.08.007,

[127]Wang, J., et al.: *Assessment of flow and heat transfer of triply periodic minimal surface based heat exchanger*.
Energy **282**, No. 128806, 2023,
http://dx.doi.org/10.1016/j.energy.2023.128806,

[128]Monkova, K., et al.: *Experimental study of the bending behaviour of the Neovius porous structure made additively from aluminium alloy.*
Aerospace **10**(4), No. 361, 2023,
http://dx.doi.org/10.3390/aerospace10040361,

[129]Solob, A.; Grbović, A.; Božić, Ž. and Sedmak, S.A.: *XFEM based analysis of fatigue crack growth in damaged wing-fuselage attachment lug*.
Engineering Failure Analysis **112**, No. 104516, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104516,

[130]Grbović, A., et al.: *Effect of laser beam welded reinforcement on integral skin panel fatigue life*.
Engineering Failure Analysis **101**, 383-393, 2019,
http://dx.doi.org/10.1016/j.engfailanal.2019.03.029,

[131]Braut, S., et al.: *Fatigue life prediction of Electric RaceAbout (ERA) traction motor rotor*.
Procedia Structural integrity **31**, 45-50, 2021,
http://dx.doi.org/10.1016/j.prostr.2021.03.024,

[132]Rølvåg, T., et al.: *Fatigue analysis of high performance race engines*.
Engineering Failure Analysis **112**, No. 104514, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104514,

[133]Vormwald, M., et al.: *Fatigue strength of autofrettaged Diesel injection system components under elevated temperature*.
Engineering Failure Analysis **113**, 428-437, 2018,
http://dx.doi.org/10.1016/j.ijfatigue.2018.01.031,

[134]Shi, L., et al.: *Fatigue behavior of three-sheet aluminum-steel dissimilar resistance spot welds for automotive applications*.
Procedia Structural Integrity **51**, 102-108, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.10.074,

[135]Pastorcic, D.; Vukelic, G. and Bozic, Z.: *Coil spring failure and fatigue analysis*.
Engineering Failure Analysis **99**, 310-318, 2019,
http://dx.doi.org/10.1016/j.engfailanal.2019.02.017,

[136]Huang, P.; Yin, Y.; McNaulty, D. and Yan, W.: *A damage tolerance approach for structural integrity of truck trailers*.
Engineering Failure Analysis **136**, No. 106197, 2022,
http://dx.doi.org/10.1016/j.engfailanal.2022.106197,

[137]Milovanović, N.; Sedmak, A.; Arsic, M.; Sedmak, S.A. and Božić, Ž.: *Structural integrity and life assessment of rotating equipment.*
Engineering Failure Analysis **113**, No. 104561, 2020,
http://dx.doi.org/10.1016/j.engfailanal.2020.104561,

[138]Banaszkiewicz, M.: *The low-cycle fatigue life assessment method for online monitoring of steam turbine rotors*.
International Journal of Fatigue **113**, 311-323, 2018,
http://dx.doi.org/10.1016/j.ijfatigue.2018.02.032,

[139]Frank, L. and Weihe, S.: *Component tests and numerical investigations to determine the lifetime and failure behavior of end stage blades*.
Procedia Structural Integrity **51**, 3-9, 2023,
http://dx.doi.org/10.1016/j.prostr.2023.06.002,

[140]Braut, S.; Tevčić, M.; Butković, M.; Božić, Ž. and Žigulić, R: *Application of modified Locati method in fatigue strength testing of a turbo compressor blade*.
Procedia Structural integrity **31**, 33-37, 2021,
http://dx.doi.org/10.1016/j.prostr.2021.03.007.