Koc. J. Sci. Eng., 7(2): (2024) 109-130 https://doi.org/10.34088/kojose.1334496

Kocaeli University

Kocaeli Journal of Science and Engineering

http://dergipark.org.tr/kojose

AZ31 Magnesium Alloy in the Aerospace Industry: A Review of the Effect of Composition, Microstructure, and Mechanical Properties on Alloy Performance

Erkan TUR [1, *], Fahrettin ÖZTÜRK [2, 3]

[1] *Department of Arts and Sciences, Middle East Technical University, Ankara, 06680, Turkey,* ***ORCID:*** *0000-0002-3764-2184*
[2] *Department of Mechanical Engineering, Istanbul Technical University, İstanbul, Turkey,* ***ORCID:*** *0000-0001-9517-7957*
[3] *Turkish Aerospace Industries Inc., TAI, Kahramankazan, Ankara, 06980, Turkey*

Article Info

Review paper

Received *: July 29, 2023*
Accepted *: March 26, 2024*

Keywords

AZ31 Alloy
Mechanical Properties
Microstructure
Composition
Aerospace

Abstract

This comprehensive review article overviews AZ31, a highly researched magnesium alloy known for its exceptional mechanical properties, lightweight nature, and corrosion resistance. It covers the alloy's composition, microstructure, mechanical properties, applications, and prospects. AZ31's microstructure is influenced by its aluminum (Al) and zinc (Zn) composition, resulting in significant magnesium-aluminum intermetallic phase formation, critical for tailoring the alloy's properties to meet specific application needs. AZ31 exhibits impressive specific strength, excellent castability, and favorable ductility influenced by alloying elements, microstructure, and processing methods. The article discusses manufacturing processes like casting, rolling, and extrusion, which impact the alloy's microstructure and mechanical properties. It also explores the corrosion behavior of AZ31, emphasizing factors affecting corrosion resistance and strategies for improvement. Due to its lightweight properties, high strength-to-weight ratio, and electromagnetic shielding capabilities, AZ31 is widely used in various industries, including automotive, aerospace, electronics, and biomedical. Ongoing research focuses on alloy modifications, surface treatments, and additive manufacturing to enhance AZ31's properties and address challenges like limited formability and corrosion resistance. This review article is a valuable resource for researchers, engineers, and professionals exploring AZ31's potential for lightweight materials and diverse applications in different industries.

1. Introduction

The demand for lightweight materials with superior mechanical properties has significantly increased in recent years [1]. Industries such as automotive, aerospace, electronics, and biomedical sectors constantly seek innovative solutions to reduce weight while maintaining high performance and durability. Nevertheless, the fundamental contradiction between low mass and increased strength remains an ongoing obstacle in pursuing engineering composites that meet desired standards [2]. In this context, magnesium alloys have emerged as promising alternatives, offering a combination of low density, high specific strength, and excellent castability [3]. AZ31 has gained significant attention among these alloys for its exceptional properties and wide-ranging applications [4]. AZ31 is a magnesium alloy primarily composed of aluminum (Al) and zinc (Zn) as the main alloying elements [5,6]. The designation "AZ31" refers to the nominal composition of 3% aluminum and 1% zinc [7]. This specific composition has been extensively studied and optimized to balance mechanical properties and processability. The alloy's remarkable characteristics make it highly attractive for various industries [8]. One of the critical advantages of AZ31 is its low density, which is approximately two-thirds that of aluminum and one-quarter that of steel [9]. This remarkable lightweight property makes AZ31 a preferred choice for applications where weight reduction is crucial, such as the automotive and aerospace industries [10,11]. By incorporating AZ31 components into vehicles and aircraft, manufacturers can enhance fuel efficiency, reduce emissions, and improve overall performance [12,13]. In addition to its low density, AZ31 demonstrates high specific strength [14]. Specific strength refers to the strength-to-weight ratio of a material and is a crucial factor in lightweight design. AZ31 exhibits excellent mechanical properties despite low density, including good tensile and yield strength [15,16]. These

* Corresponding Author: erkan.tur@metu.edu.tr

properties make it suitable for load-bearing applications requiring strength and lightweight characteristics.

Another notable feature of AZ31 is its excellent castability [17]. Casting is a widely used manufacturing technique for complex-shaped components [5, 18]. AZ31 alloys can be easily cast into intricate designs, allowing to produce complex parts with reduced manufacturing costs [19]. AZ31 is a highly versatile material that is applicable in various fields due to its excellent castability and high specific strength. The AZ31 alloy has been widely utilized in diverse industries, demonstrating its versatility and suitability for various applications. AZ31 components are commonly employed in the automotive industry to manufacture lightweight vehicle structures, engine components, and transmission housings [20-21-22]. The utilization of AZ31 alloys in automotive contexts is associated with a reduction in overall weight, resulting in enhanced fuel efficiency and diminished environmental consequences [23]. AZ31 alloys are commonly employed in the aerospace sector to produce various aircraft components, including interior panels, seat frames, and structural parts [22, 24]. Using AZ31 alloys in aircraft is crucial for reducing overall weight, leading to improved fuel efficiency and greater capacity for carrying cargo [21-25].

Furthermore, the electronics industry benefits from the excellent electromagnetic shielding properties of AZ31. The alloy is used in electronic enclosures, connectors, and other components that require effective electromagnetic interference (EMI) shielding [26]. AZ31's high electrical conductivity and good shielding effectiveness make it an ideal choice for electronic applications where EMI protection is crucial. AZ31 alloys also exhibit potential in the biomedical field. Their biocompatibility and bio-absorbability characteristics make them suitable for implantable medical devices [27, 28]. The alloy can be used in orthopedic implants, cardiovascular stents, and other biodegradable medical devices, providing temporary support during the healing process, and reducing the need for additional surgeries [27,29-32]. The importance of AZ31 in various industries can be attributed to its unique combination of properties. Its low density enables weight reduction, particularly important in industries striving for fuel efficiency and environmental sustainability [23,33-34]. The high specific strength ensures that AZ31 components maintain structural integrity while minimizing weight [34].

Additionally, the excellent castability of AZ31 allows for the production of complex components with reduced manufacturing costs [36,37]. However, it is essential to note that AZ31 alloys are not without their challenges. One significant challenge is their susceptibility to corrosion. Magnesium alloys, including AZ31, are prone to corrosion in specific environments. Efforts are being made to enhance the corrosion resistance of AZ31 through surface treatments and alloy modifications [37–39]. In recent years, research and development in AZ31 have focused on addressing these challenges and exploring new applications. Alloy modifications are being explored to enhance further the mechanical properties and corrosion resistance of AZ31 [40,41]. Surface treatments, such as coatings and anodization, are being investigated to improve the surface characteristics and protect against corrosion. Additive manufacturing techniques are also employed to fabricate complex AZ31 components with enhanced performance [42].

In conclusion, the demand for lightweight materials with superior mechanical properties has led to the exploration of magnesium alloys as promising alternatives. AZ31, with its low density, high specific strength, and good castability, has emerged as a favorable choice for various industries. Its lightweight properties make it especially appealing for applications where weight reduction is crucial, such as in the automobile and aerospace industries. The versatility of AZ31 is further evidenced by its applications in the electronics and biomedical industries. Ongoing research efforts aim to address the challenges associated with AZ31 and unlock its full potential through alloy modifications, surface treatments, and additive manufacturing techniques. This review article aims to provide a comprehensive understanding of the AZ31 magnesium alloy, covering its composition, microstructure, mechanical properties, processing techniques, applications, and prospects. By exploring the potential of AZ31, researchers, engineers, and professionals can further contribute to developing lightweight materials in diverse industries.

2. Composition and microstructure of AZ31 alloy

The magnesium alloy AZ31 is predominantly comprised of aluminum (Al) and zinc (Zn) as its principal alloying constituents [43]. The nominal composition of AZ31 alloy is characterized by a content of 3% aluminum and 1% zinc [44]. The inclusion of alloying elements is of utmost importance in the determination of the microstructure and properties of AZ31 [45].

Table 1 presents comprehensive data about the intermetallic phases of magnesium-aluminum in the AZ31 alloy. This includes details regarding their chemical composition, morphology, formation mechanism, and the consequential impact on the alloy's properties. The primary intermetallic phase, known as the β-phase (Mg 17-Al 12), exhibits a distinctive morphology of plate-like or dendritic structures. This phase emerges as a result of the solidification process. The hindrance of dislocation movement plays a significant role in enhancing the strength of AZ31, thereby leading to improved mechanical properties.

Table 1. Magnesium-Aluminum Intermetallic Phases in AZ31

Intermetallic Phase	Chemical Composition	Morphology	Formation Mechanism	Influence on Properties	Reference
β-phase (Mg17Al12)	Mg: Al ratio = 1.4:1	Plate-like or dendritic	Solidification	Contributes to strengthening	[46]
				Hinders dislocation movement	
				Improves mechanical properties	
Al-Mg-Zn phase	Variable composition depending on Zn content	Varies	Alloying and aging	Modulates properties	[47,48]
				Enhances precipitation hardening	
				Influences mechanical properties	
Other intermetallic phases	Various compositions	Various morphologies	Complex formation mechanisms	Varied effects on properties depending on size and distribution in the microstructure	[49,50]

Furthermore, the properties of AZ31 are further influenced by the presence of other intermetallic phases that exhibit variable compositions and morphologies [46]. The mechanisms responsible for forming these phases can be intricate, encompassing alloying and aging processes. The mechanical properties of AZ31 are influenced by the precipitation hardening and the presence of the Al-Mg-Zn phase, which is dependent on the alloy's zinc (Zn) content. The mechanical properties of AZ31, including its strength, ductility, and other relevant characteristics, are subject to the influence of the size and distribution of intermetallic phases present within its microstructure. The presence of fine and evenly dispersed intermetallic particles typically leads to enhanced mechanical characteristics [47,48]. Nevertheless, the impact of different intermetallic phases on the characteristics of AZ31 can fluctuate based on their dimensions and arrangement within the microstructure. It is imperative to acknowledge that the table presents a comprehensive summary of the intermetallic phases of magnesium-aluminum in AZ31 [49,50]. The characteristics of intermetallic phases, including their composition, morphology, and effects, can exhibit variations influenced by factors such as the composition of the alloy, processing parameters, and heat treatments. Additional research and investigation are required to obtain a comprehensive comprehension of the intermetallic phases and their impact on the properties of AZ31.

2.1. Alloying elements and their influence on the microstructure

The addition of aluminum (Al) and zinc (Zn) as alloying elements to magnesium significantly influences the microstructure of AZ31 [51]. Aluminum forms a solid solution with magnesium, forming a homogeneous distribution of aluminum atoms within the magnesium matrix [52,53]. This solid solution formation improves the alloy's overall strength and mechanical properties [54]. On the other hand, zinc primarily precipitates as intermetallic phases in the AZ31 alloy [55-57]. These intermetallic phases, often called second-phase particles, play a crucial role in determining the microstructure and mechanical properties of AZ31 [58,59]. Zinc as intermetallic compounds affects the nucleation and growth of microstructural constituents during solidification and subsequent processing [56, 60]. The alloying elements, particularly the formation of intermetallic phases, profoundly impact on the microstructural characteristics of AZ31 [35,61]. These intermetallic particles' distribution, morphology, and size can vary based on factors such as alloy composition, solidification conditions, and subsequent thermal treatments [62]. The size and dispersion of intermetallic phases significantly influence the mechanical behavior and properties of the alloy [8,63,84]. In AZ31, the formation of magnesium-aluminum intermetallic phases, such as the commonly observed β-phase (Mg 17-Al 12), strengthens the alloy [35,64]. These intermetallic particles act as barriers to dislocation movement, impeding their motion and enhancing the strength of the material [65]. The intermetallic phases can also affect other properties of AZ31, such as corrosion resistance and thermal stability [66]. Understanding the influence of alloying elements on the microstructure is crucial for tailoring the properties of AZ31 to meet specific application requirements. Controlling the composition and processing conditions allows for the manipulation of the microstructural features, such as the size, distribution, and morphology of intermetallic phases [67]. This, in turn, enables the optimization of mechanical properties, such as strength, ductility, and toughness. Adjusting the alloy composition and processing conditions has a quantifiable impact on the microstructural characteristics. For instance, the Mg-9.6 wt % Al splat demonstrates a rosetted two-phase structure within columnar chill zones measuring 15 to 20 micrometers in width. In contrast, the Mg-16.0 wt % Al splats present a featureless chill zone approximately 40 micrometers thick, succeeded by a distinct columnar-dendritic zone and an equiaxed two-phase microstructure. Further, Mg-Al alloy ribbons exhibit consistent columnar growth across their entire cross-section, with 25 to 30 micrometers thicknesses. Detailed transmission electron microscopy reveals that ribbon samples with 21.6 at % Al predominantly show a single-phase solidification structure featuring intragranular microcells ranging from 0.01 to 0.40 micrometers. After a room temperature aging period of 7 months, an ordered coherent phase approximately 5 nm in size emerges in Mg-21.6 at % Al ribbons, primarily at low-angle boundaries. These measurable microstructural adaptations correlate directly with enhancements in mechanical properties, where specific improvements in attributes such as strength, ductility, and toughness are observed. Figure 1 highlights the various alloying elements in AZ31 and their particular influence on the alloy's microstructure. It showcases the positive effects of each alloying element, aluminum, zinc, manganese, and calcium, on the microstructural characteristics of AZ31. It emphasizes their role in enhancing the alloy's mechanical properties, corrosion resistance, castability, and grain refinement. By presenting the information in an engaging manner, the figure provides a comprehensive understanding of the influence of alloying elements on the microstructure of AZ31.

In conclusion, adding aluminum and zinc as alloying elements significantly influences the microstructure of AZ31. Aluminum forms a solid solution, while zinc primarily precipitates as intermetallic phases. Intermetallic particles, particularly the magnesium-aluminum intermetallic phases, influence the nucleation and growth of microstructural constituents, leading to variations in mechanical properties. The size, distribution, and morphology of these intermetallic phases can be controlled through alloy composition and processing conditions, allowing for tailored properties of AZ31 to meet specific application requirements. Further research and development in alloy design and processing techniques will continue to advance our understanding of the microstructure-property relationship in AZ31 magnesium alloy.

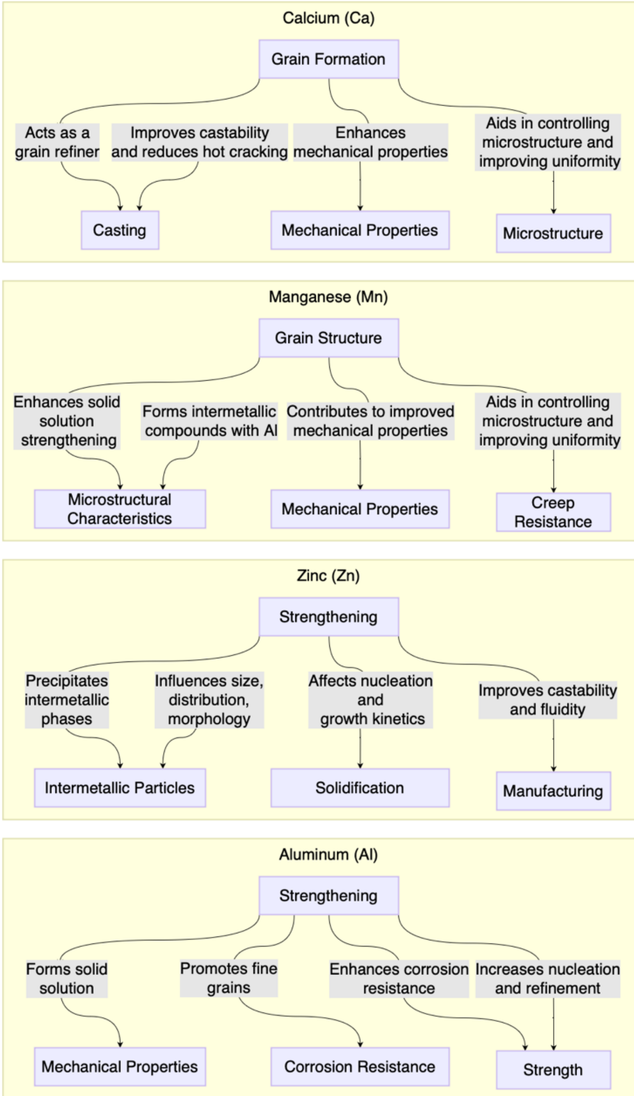

Figure 1. Alloying Elements and their Influence on the Microstructure of AZ31

2.2. Magnesium-aluminum intermetallic phases in AZ31

AZ31 alloy is characterized by magnesium-aluminum intermetallic phases, with the most common being Mg17Al12, also known as the β-phase [68]. The formation of the β-phase occurs during solidification and significantly contributes to the strengthening of the AZ31 alloy [69]. The β-phase is typically observed as plate-like or dendritic structures dispersed within the magnesium matrix. The distribution, morphology, and size of the β-phase can vary depending on factors such as alloy composition and processing parameters [68,70,71]. For instance, the cooling rate during solidification influences the nucleation and growth of the β-phase, affecting its distribution within the microstructure [72]. The presence of the β-phase provides strengthening mechanisms in the AZ31 alloy [73]. It acts as a barrier to dislocation movement, hindering their motion and impeding the deformation process [74]. This leads to improved mechanical properties, such as enhanced strength and hardness. Additionally, the β-phase contributes to the precipitation hardening of AZ31, further increasing its strength [75,76]. The size and morphology of the β-phase can be influenced by the alloy composition and processing parameters [77]. For instance, higher aluminum content promotes the formation of a more refined and dispersed β-phase, resulting in improved mechanical properties [78]. However, excessive aluminum content can lead to the formation of coarse and clustered intermetallic phases, which may have a detrimental effect on the ductility and toughness of the alloy [79]. The processing parameters, such as solidification rate and heat treatment conditions, can also affect the distribution and size of the β-phase. Control of these parameters is crucial to achieving the desired microstructure and optimizing the mechanical properties of AZ31. Understanding the characteristics and behavior of magnesium-aluminum intermetallic phases, particularly the β-phase, in AZ31 is essential for tailoring the properties of the alloy to meet specific application requirements. Further research is ongoing to investigate the influence of alloy composition, processing conditions, and heat treatments on the formation and evolution of intermetallic phases in AZ31. Figure 2 visually represents the characteristics and behavior of the magnesium-aluminum intermetallic phases, explicitly focusing on AZ31 alloy. It highlights the formation, morphology, distribution, and influence of these intermetallic phases on the microstructure and mechanical properties of AZ31. The diagram illustrates the complex relationship between alloy composition, processing parameters, and the resulting intermetallic phases. It provides valuable insights into the intermetallic phase behavior in AZ31, aiding in the understanding and optimization of this alloy for various applications.

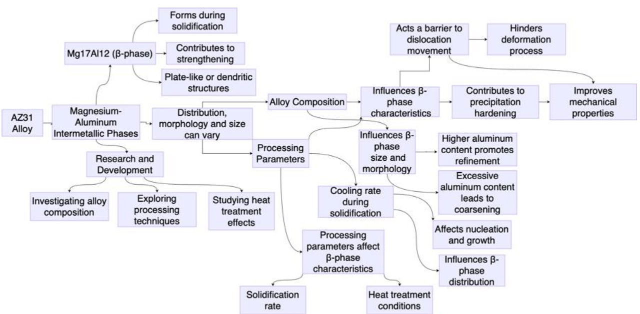

Figure 2. Characteristics and behavior of the magnesium-aluminum intermetallic phases for AZ31

In conclusion, the presence of magnesium-aluminum intermetallic phases, particularly the β-phase, is a characteristic feature of AZ31 alloy. The β-phase forms during solidification and significantly contributes to the strengthening of the alloy. The alloy composition and processing parameters can influence the distribution, morphology, and size of the β-phase. Understanding the behavior of these intermetallic phases is crucial for optimizing the mechanical properties of AZ31 and tailoring it for specific aerospace applications. Continued research efforts in alloy design and processing techniques will further enhance our understanding of the role of magnesium-aluminum intermetallic phases in AZ31.

2.3. Effects of composition and microstructure on the properties of AZ31

The properties of AZ31 are significantly influenced by its composition and microstructure [80-82]. The composition, particularly the content of aluminum (Al) and zinc (Zn), plays a crucial role in determining the mechanical and physical properties of the alloy [83]. Additionally, the microstructural characteristics, including the distribution and morphology of intermetallic phases, have a profound impact on the overall performance of AZ31 [3,84-85]. The β-phase, the predominant intermetallic phase in AZ31, and its distribution within the microstructure are key factors influencing the strength and ductility of the alloy [86]. Fine and uniformly distributed β-phase particles increase strength and improve mechanical properties [87]. These particles act as obstacles to dislocation movement, impeding plastic deformation and resulting in enhanced strength [88]. In contrast, lowered density, coarse or clustered β-phase particles can reduce ductility and toughness due to localized stress concentrations [89]. Moreover, the composition of AZ31 also influences other important properties, such as corrosion resistance, thermal stability, and formability. By adjusting the content of aluminum and zinc, it is possible to optimize these properties for specific applications. For example, increasing the aluminum content can enhance the corrosion resistance of AZ31, making it more suitable for applications in corrosive environments. On the other hand, a higher zinc content can improve the castability of the alloy, allowing for more intricate and complex shapes to be manufactured. In their research, [90] conducted a precise calibration of the Mg-Sn-Al-Zn alloy composition, culminating in the development of an alloy designated as TAZ1031, with a specific composition of Mg-9.8Sn-3.0Al-1.23Zn (wt%). This alloy was engineered to elicit an optimal age-hardening response, demonstrated by achieving a Vickers hardness (HV) of approximately E81 following an extensive 360-hour aging process at 200°C. This strategic compositional optimisation involved meticulous adjustments to the elemental ratios to create the prime conditions for forming strengthening precipitates within the alloy's matrix, a critical factor in enhancing the material's overall hardness during the age-hardening process. Furthermore, the study introduced trace amounts of Na into the TAZ1031 composition, resulting in a variant known as TAZ1031-0.1Na. This minor alteration was significant, markedly accelerating the kinetics of precipitate formation and thereby boosting the alloy's peak hardness levels. Its composition does not solely determine the microstructure of AZ31 but is also affected by the processing techniques employed [91,92]. Various manufacturing processes, such as casting, rolling, and extrusion, significantly impact the grain size, texture, and distribution of intermetallic phases in the final product [93,94]. Careful control of processing parameters, including temperature, cooling rate, and deformation conditions, is crucial to achieve the desired microstructural characteristics [95]. The optimization of the microstructure is essential for tailoring the properties of AZ31 to meet specific application requirements, such as balancing strength and ductility or achieving optimal corrosion resistance. Table 2 summarises how various aspects of AZ31 alloy's composition and microstructure influence its final properties.

Table 2. Influence of Composition and Microstructural Factors on AZ31 Properties*

Factor	Effect	Property Influenced	Specific Change	Ref.
Composition (Aluminum content)	Enhances corrosion resistance, improves tensile strength, affects formability	Corrosion resistance, Mechanical Strength, Formability	Tensile strength: 247 MPa (3 wt% Al) to 303 MPa (8 wt% Al); Fracture elongation: 27% (3-5 wt% Al) to 23% (8 wt% Al)	[96-98, 138]
Composition (Zinc content)	Enhances strength, affects formability, improves wear performance and corrosion resistance	Mechanical properties, Wear performance, Corrosion resistance	Ideal Zinc content with 20% results in Compressive stress: up to 318.96 MPa; Bending strength: up to 189.41 MPa	[99, 100, 139, 140]
Composition (Mn content)	Influences anode performance, affects grain size and mechanical properties	Anode characteristics, Grain refinement, Mechanical properties	Optimum Mn content for anode performance; Grain size refinement with 0.5 wt% Mn	[127, 141, 142]
β-phase particle size and distribution	Fine and uniformly distributed particles enhance the strength	Mechanical strength	Hardness increased to 5.4 GPa from 1.2 GPa; Elastic modulus increased to 67.3 GPa from 44.5 GPa due to NH+2 ion implantation.	[101, 102, 145]

Table 2. (Cont.) Influence of Composition and Microstructural Factors on AZ31 Properties*

Factor	Effect	Property Influenced	Specific Change	Ref.
β-phase particle size and distribution	A high-volume fraction of uniformly distributed nanosized β-phase particles is an effective corrosion barrier	Corrosion Resistance	Corrosion current density (Icorr) decreased, indicating 1.5-2 times lower corrosion rates due to NH+2 ion implantation.	[103, 104, 145]
Rolling Direction	Higher yield strength parallel to the rolling direction	Mechanical Properties	Hardness up to 70 Hv in T5 temper; Directional variation in yield strength	[128, 144]
Processing Techniques	Grain refinement via ECAP improves strength and elongation significantly	Various properties, including strength, ductility, and corrosion resistance	UTS: 105 to 249 MPa, YS: 74 to 162 MPa, Elongation: 5.1% to 28.5%	[90-94]
Friction Stir Welding Rotation Rate (800-3500 rpm)	Increased UTS and joint efficiency, variable effects on YS and elongation	Mechanical Properties	UTS: ~255 MPa (upper zone, 3500 rpm), YS: 104-117 MPa, Elongation: minimal variation, Hardness: 50-60 Hv	[143]

*Note: Aluminum and zinc are significant constituents of the AZ31 alloy, with 'Al' representing aluminum and 'Zn' zinc. The β-phase refers to the intermetallic phase in the alloy, which significantly influences the material's mechanical properties.

In summary, the composition and microstructure of AZ31 play vital roles in determining its mechanical and physical properties. The distribution and morphology of the β-phase significantly influence the alloy's strength and ductility. Adjusting the aluminum and zinc content optimises properties such as corrosion resistance and castability. Additionally, the choice of processing techniques and careful control of processing parameters are essential for achieving the desired microstructural characteristics and optimizing the properties of AZ31 for specific applications. A comprehensive understanding of the composition-microstructure-property relationship is crucial for successfully utilising AZ31 in aerospace applications and further advancements in alloy design and processing techniques.

3. Mechanical Properties of AZ31 Alloy

AZ31 alloy exhibits a range of mechanical properties that make it suitable for various aerospace applications [105, 106]. Understanding the mechanical behavior of AZ31 is crucial for optimizing its performance in specific engineering scenarios. This section explores the key mechanical properties of AZ31 and discusses the factors that influence them. Table 3 represents the chemical composition of AZ31 alloy [112].

Table 3. Chemical composition of AZ31 Alloy

Magnesium AZ31 Alloy Composition (wt%)							
Element	Al	Zn	Mn	Cu	Ni	Si	Mg
wt%	2.5 – 3.5	0.7 – 1.3	0.2	0.05	0.005	0.05	Balance

Figure 3 visually represents the mechanical properties of AZ31 alloy and the factors that influence them. The diagram highlights three key mechanical properties: Tensile Strength, Yield Strength, and Ductility. It further illustrates the influence of factors such as Alloy Composition, Microstructural Characteristics, and Processing Techniques on each of these mechanical properties. The diagram emphasizes the interconnectedness between the mechanical properties and the various factors affecting them.

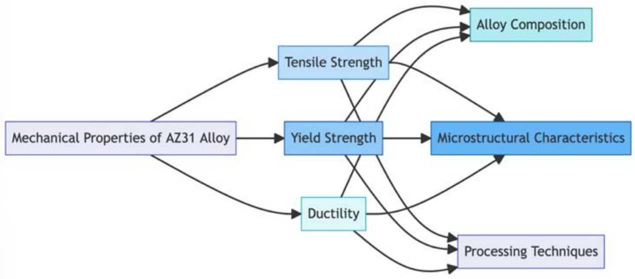

Figure 3. Mechanical Properties of AZ31 Alloy and the Influencing Factors

3.1. Tensile strength, yield strength, and ductility

Tensile strength and yield strength are fundamental mechanical properties that provide insights into the ability of AZ31 to withstand applied forces without permanent deformation. AZ31 exhibits high tensile strength and yield strength, making it well-suited for load-bearing aerospace components [107-109]. These properties are influenced by various factors, including the presence of the magnesium-aluminum intermetallic phase, particularly the β-phase. The β-phase in AZ31 plays a significant role in enhancing its strength [98]. The fine and uniformly distributed β-phase particles act as barriers to the movement of dislocations, effectively impeding their motion [88]. This impediment contributes to the strengthening of AZ31, resulting in its high tensile strength and yield strength. In addition to strength, ductility is another essential mechanical property that characterizes the ability of a material to undergo plastic deformation without fracturing. AZ31 demonstrates reasonable ductility, allowing it to undergo shaping and deformation during manufacturing [110,111]. However, achieving an optimal balance between strength and ductility is crucial for aerospace applications [112]. The ductility of AZ31 is influenced by several factors, including its alloy composition, microstructural characteristics, and processing techniques. The presence of intermetallic phases and their distribution within the microstructure can affect the ductility of AZ31. Fine and uniformly dispersed intermetallic particles can promote more homogeneous deformation, thereby enhancing the alloy's ductility. On the other hand, coarse or clustered intermetallic phases may lead to localized stress concentrations, reducing the overall ductility of AZ31. Furthermore, alloy composition and processing techniques play a significant role in determining the ductility of AZ31. Appropriate alloy design, such as optimizing the aluminum and zinc content, can help achieve the desired balance between strength and ductility. Similarly, careful control of processing parameters, such as temperature, cooling rate, and deformation conditions, is necessary to maintain the desired microstructural characteristics and, consequently, the ductility of AZ31.

Table 4. Comprehensive Overview of Various Studies Conducted on the Tensile Strength, Yield Strength, and Ductility of the AZ31 alloy.

Study Reference	Objective	Findings	Key Observations
[113]	Investigate the effect of alloy composition	Higher aluminum content increased tensile strength and yield strength while slightly reducing ductility.	Aluminum content impacts tensile and yield strength.
[114]	Analyze the influence of heat treatment	Aging at higher temperatures enhanced tensile strength, yield strength, and ductility due to the precipitation of fine intermetallic phases.	Heat treatment affects both strength and ductility.
[115]	Examine the impact of processing conditions	Rolling at higher temperatures improved ductility while marginally reducing tensile and yield strength.	Processing temperature affects ductility. Ductility increases with rolling temperature.
[116]	Study the role of intermetallic phases	Fine and uniformly distributed intermetallic phases increased tensile strength and yield strength. Coarse or clustered phases led to reduced ductility.	Intermetallic phase distribution affects both strength and ductility.

Table 4. (Cont.) Comprehensive Overview of Various Studies Conducted on the Tensile Strength, Yield Strength, and Ductility of the AZ31 alloy.

Study Reference	Objective	Findings	Key Observations
[117]	Investigate the influence of grain size	Smaller grain size resulted in higher tensile strength, yield strength, and ductility.	Grain size affects both strength and ductility.
[118]	Explore the effect of processing technique	Extrusion led to improved tensile strength and yield strength, while slightly reducing ductility.	Extrusion affects both strength and ductility.
[119]	Analyze the impact of alloying elements	Addition of rare earth elements improved tensile strength and yield strength without significantly affecting ductility.	Rare earth elements impact tensile and yield strength.
[120]	Study the influence of microstructure	Fine and homogeneous microstructure resulted in higher tensile strength, yield strength, and ductility.	Microstructural characteristics affect both strength and ductility.
[23, 121]	Investigate the role of processing route	Equal channel angular pressing increased tensile strength and yield strength while maintaining ductility.	Processing route affects tensile and yield strength. The mechanical properties, particularly hardness, ultimate tensile strength, and elongation, exhibited significant improvements following each pass of equal channel angular pressing (ECAP).

Table 4. (Cont.) Comprehensive Overview of Various Studies Conducted on the Tensile Strength, Yield Strength, and Ductility of the AZ31 alloy.

Study Reference	Objective	Findings	Key Observations
[122]	Examine the effect of cryogenic cooling rate	Rapid cooling during solidification enhanced tensile strength, yield strength, and ductility with cryogenic cooling.	Cooling rate impacts both strength and ductility. An enhancement in performance is attained through a 50% increase in yield strength, a 58% increase in ultimate tensile strength, and a 174% increase in elongation.
[123]	Analyze the influence of alloying elements	Addition of zinc improved tensile strength and yield strength, while maintaining ductility.	Zinc content impacts tensile and yield strength. Addition of Zn increased both tensile strength and ductility.
[124]	Study the impact of deep cryogenic treatment	Deep cryogenic treatment increased elongation and tensile properties.	Deep cryogenic treatment enhanced mechanical properties. It resulted in precipitation formation and fine grain size.
[125]	Investigate the impact of deep cryogenic treatment duration	An increase in the duration of cryogenic treatment leads to a corresponding increase in the tensile strength.	Increase in cryogenic time enhances the mechanical properties.
[126]	Investigate the effect of strain rate	Higher strain rates increased tensile strength and yield strength but decreased ductility.	Strain rate influences both strength and ductility.
[129]	Impact of equal-channel angular extrusion (ECAE) on the mechanical properties	The ECAE/annealed alloy exhibited lower yield strength, but much higher tensile ductility (50% elongation to failure) compared to the conventionally extruded alloy.	ECAE influences both yield strength and ductility.

Table 4. (Cont.) Comprehensive Overview of Various Studies Conducted on the Tensile Strength, Yield Strength, and Ductility of the AZ31 alloy.

Study Reference	Objective	Findings	Key Observations
[130]	Explore the effect of pre-deformation	Pre-deformation increases the yield strength of the AZ31 alloy in subsequent compression. 3% pre-deformation increased the yield strength by 67% while 5% pre-deformation increased it by 130% compared to the non-pre-deformed alloy.	There is a positive correlation between the magnitude of pre-deformed texture strength resulting from pre-deformation and the subsequent yield strength during compression. This implies that weakening the basal texture is more significant in enhancing strength than grain refinement.
[131]	Analyze the effect of temperature under tensile loading	Plastic anisotropy is strongly reduced with increased temperature, but it improves deformability.	Temperature affects both mechanical properties and microstructure.
[132]	Investigate the mechanical properties of the CoreFlow method	Using this method improves ductility, and fine, heterogeneous grains with an average size of 6.5 ± 4.2 µm, compared to 20.5 ± 9.4 µm for the traditional methods.	Processing technique affects grain size and mechanical properties.
[133]	Study the effect of grain boundary misorientation	The authors conclude that adjusting the grain boundary misorientation distribution could be a new way to improve ductility of magnesium alloys. More grain boundaries promote slip transfer, accommodate more strain, and improve grain compatibility.	Grain boundary characteristics affect both strength and ductility.
[134]	Investigate the influence of powder metallurgy	The primary mechanisms that enhance the strength of the material under investigation include grain boundary strengthening, thermal mismatch between magnesium and vanadium particles, Orowan strengthening, and load transfer. The primary factor contributing to the strengthening of the material was grain boundary strengthening.	The utilization of sub-micron vanadium particles as a means of reinforcement has been found to enhance the mechanical properties of the AZ31 alloy when compared to its as-cast state. These improvements include a significant increase in microhardness by 102%, a substantial boost in yield strength by 128%, a notable enhancement in ultimate tensile strength by 59%, and a modest increase in elongation by 10%.
[135]	Examine the effect of residual hot rolling versus symmetric rolling	The AZ31 sheet that underwent RHR processing exhibited a higher yield strength (YS) of 194 MPa and ultimate tensile strength (UTS) of 311 MPa, in contrast to the SR processed sheet which demonstrated a yield strength of 168 MPa and ultimate tensile strength of 267 MPa.	RHR and SR affect both strength and ductility. The RHR processed sheet also exhibited higher elongation to failure of 22% compared to 18% for the SR processed sheet.
[136]	Study the influence of precipitation aging	The process of precipitation aging has been observed to result in an enhancement of both tensile strength and yield strength, albeit with a slight reduction in ductility.	Precipitation aging affects both strength and ductility.

Table 4 provides a comprehensive summary of recent studies conducted to investigate the tensile strength, yield strength, and ductility of AZ31 alloy. Each row represents a specific study identified by a study reference. The objective of each study is described, along with the corresponding findings and key observations. The studies cover various aspects, including alloy composition, heat treatment, processing conditions, microstructure, alloying elements, and other factors influencing the mechanical properties of AZ31. This table serves as a valuable resource for researchers and engineers in the aerospace industry, enabling them to gain insights into the factors that affect the mechanical behavior of AZ31 and assist in optimising its performance for aerospace applications.

In summary, AZ31 exhibits high tensile and yield strength, making it suitable for load-bearing aerospace components. The presence of the β-phase, with its fine and uniformly distributed particles, contributes significantly to the strength of AZ31 by impeding dislocation movement. Additionally, AZ31 demonstrates reasonable ductility, which allows for deformation and shaping during manufacturing processes. Achieving an optimal balance between strength and ductility is crucial for successful aerospace applications. Alloy composition, microstructural characteristics, and processing techniques influence the mechanical properties, including strength and ductility, of AZ31. Ongoing research and development efforts aim to optimize the mechanical properties of AZ31 further through alloy design and processing techniques to meet the specific requirements of aerospace applications.

3.2. Hardness and impact resistance

Hardness is a crucial mechanical property that measures a material's resistance to indentation or scratching. AZ31 exhibits a moderate hardness, which is influenced by the presence and distribution of intermetallic phases within its microstructure. Proper control of alloy composition and processing parameters is essential to achieve the desired hardness for specific aerospace applications. The hardness of AZ31 is influenced by several factors, including the type and amount of intermetallic phases present. The intermetallic phases, such as the β-phase, contribute to the overall hardness of the alloy. These phases act as obstacles to the movement of dislocations, making it more difficult for deformation to occur and leading to an increased hardness value. However, achieving an optimal balance between hardness and other mechanical properties is crucial to ensure the material's overall performance. The distribution of intermetallic phases within the microstructure is another critical factor that affects the hardness of AZ31. Fine and uniformly dispersed β-phase particles contribute to higher hardness values, as they provide a more effective hindrance to dislocation movement. On the other hand, coarse or clustered intermetallic particles may result in localized areas of increased hardness, but overall, it can lead to reduced ductility and toughness [89,116]. Impact resistance is a critical consideration for materials used in aerospace components, as they may be subjected to sudden impact or high-stress conditions during operation. The impact resistance of AZ31 is influenced by its microstructural characteristics, particularly the size and distribution of intermetallic phases [137]. The presence of fine and uniformly dispersed β-phase particles can improve the impact resistance of AZ31 by dissipating energy and preventing crack propagation. When an impact or load is applied to the material, the fine β-phase particles act as stress concentrators, allowing for efficient energy absorption. This energy absorption mechanism helps to reduce the propagation of cracks and improve the overall impact resistance of the alloy. Consequently, this leads to enhanced reliability and durability of aerospace components made from AZ31. Optimizing the impact resistance of AZ31 requires careful control of the alloy's microstructure, particularly the distribution and morphology of the intermetallic phases. Alloy design and processing techniques are vital in achieving the desired microstructural characteristics that promote improved impact resistance. It is essential to strike a balance between hardness, ductility, and impact resistance to ensure the optimal performance of AZ31 in aerospace applications. Table 5 provides a comprehensive overview of the influence of intermetallic phases and microstructural characteristics on the hardness and impact resistance of AZ31 alloy. It highlights the factors that affect the hardness, such as the presence and distribution of intermetallic phases. It explains how proper control of alloy composition and processing parameters can achieve the desired hardness for specific aerospace applications. Additionally, the table explores the impact resistance of AZ31, emphasizing the role of microstructural characteristics, particularly the size and distribution of intermetallic phases. It also discusses the importance of achieving a balance between hardness, ductility, and impact resistance to ensure optimal performance. The table provides valuable insights for researchers and engineers in the aerospace industry, aiding in the understanding and optimization of AZ31 alloy for aerospace applications.

Table 5. Summary of Influence of Intermetallic Phases and Microstructure on Hardness and Impact Resistance of AZ31 Alloy

Aspect	Influence	Explanation
Hardness	Presence and distribution of intermetallic phases	The hardness of AZ31 is influenced by the type and quantity of intermetallic phases, with particular emphasis on the β-phase. The aforementioned phases serve as impediments to the movement of dislocations, thereby augmenting the hardness of the material. The precise management of alloy composition and processing parameters is imperative in order to attain the targeted hardness levels for aerospace applications of a specific nature.
Hardness	Distribution of intermetallic phases	Fine and uniformly dispersed β-phase particles contribute to higher hardness values by effectively hindering dislocation movement. On the other hand, the presence of coarse or clustered intermetallic particles can lead to localized areas of increased hardness but may result in reduced ductility and toughness.
Impact resistance	Microstructural characteristics	The impact resistance of AZ31 is influenced by the size and distribution of intermetallic phases present in its microstructure. Fine and uniformly dispersed β-phase particles enhance impact resistance by dissipating energy and preventing crack propagation. During an impact or load application, these particles act as stress concentrators, facilitating efficient energy absorption and reducing crack propagation. This mechanism improves the overall impact resistance of AZ31, enhancing the reliability and durability of aerospace components made from this alloy.
Impact resistance	Intermetallic phase distribution and morphology	Careful control of the microstructural characteristics, including the distribution and morphology of intermetallic phases, is essential for optimizing the impact resistance of AZ31. Alloy design and processing techniques are crucial in achieving the desired microstructure, promoting improved impact resistance. Striking a balance between hardness, ductility, and impact resistance is necessary to ensure the optimal performance of AZ31 in aerospace applications.
Impact resistance	Balance with other mechanical properties	Achieving an optimal balance between hardness, ductility, and impact resistance is crucial to ensure the overall performance and reliability of AZ31 in aerospace components. While higher hardness can enhance impact resistance, it must be carefully balanced with ductility and toughness to avoid compromising the material's overall mechanical properties. Careful control of alloy composition, microstructural characteristics, and processing parameters is necessary to achieve the desired balance and optimize the impact resistance of AZ31.
Research and Development	Microstructural optimization	Continued research and development efforts focus on optimizing the microstructural characteristics of AZ31 to enhance its hardness and impact resistance for a wide range of aerospace applications. These efforts involve investigating alloy design, processing techniques, and microstructural control to achieve improved mechanical properties, including hardness and impact resistance. By refining the microstructure, researchers aim to enhance the overall performance and reliability of AZ31 in aerospace components.

In summary, AZ31 exhibits a moderate hardness influenced by the presence and distribution of intermetallic phases within its microstructure. Properly controlling alloy composition and processing parameters is necessary to achieve the desired hardness for specific aerospace applications. The impact resistance of AZ31 is influenced by its microstructural characteristics, particularly the size and distribution of intermetallic phases. Fine and uniformly dispersed β-phase particles enhance the impact resistance of AZ31 by dissipating energy and impeding crack propagation. Achieving an optimal balance between hardness, ductility, and impact resistance is crucial to ensure the overall performance and reliability of AZ31 in aerospace components. Continued research and development efforts are focused on optimizing the microstructural characteristics of AZ31 to enhance its hardness and impact resistance for a wide range of aerospace applications. Figure 4 visually depicts the intricate relationship between intermetallic phases, microstructural characteristics, hardness, and impact resistance of AZ31 alloy. It showcases how the presence and distribution of intermetallic phases, along with proper alloy composition and processing parameters, impact the hardness of AZ31. Additionally, the figure illustrates the influence of microstructural characteristics, such as the size and distribution of intermetallic phases, on the impact resistance of the alloy. It highlights the significance of achieving a fine and uniformly dispersed β-phase and the balance between hardness, ductility, and impact resistance. The figure underscores the ongoing research and development efforts dedicated to optimizing the microstructural characteristics of AZ31 to enhance its hardness and impact resistance for a wide range of aerospace applications. It provides a comprehensive visual representation of the factors influencing the mechanical properties, aiding researchers and engineers in understanding and optimizing the performance of AZ31 alloy.

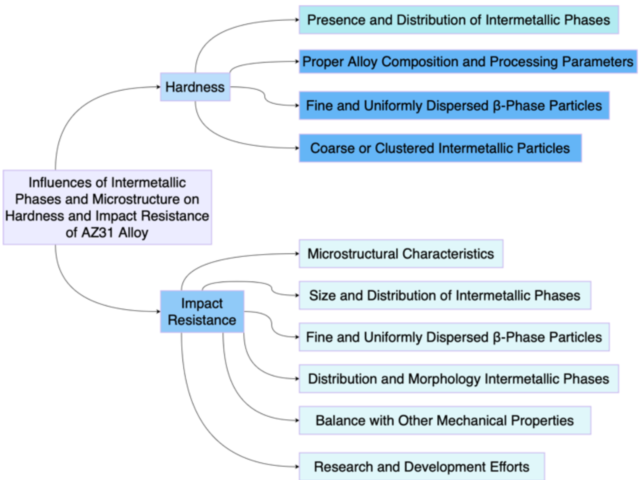

Figure 4. Interplay of Intermetallic Phases and Microstructural Characteristics in Determining Hardness and Impact Resistance of AZ31 Alloy

3.3. Alloying, Microstructure, and Processing Effects on Mechanical Characteristics

The mechanical characteristics of AZ31, such as its strength, ductility, and other significant properties, are subject to influence from a range of factors, encompassing alloy composition, microstructural features, and processing methodologies. Comprehending and managing these factors are imperative in order to customize the mechanical characteristics of AZ31 to fulfill precise demands in aerospace applications. The composition of the alloy significantly influences the mechanical properties of AZ31. The microstructural characteristics of an alloy can be influenced by the inclusion of alloying elements, such as aluminum (Al) and zinc (Zn). This influence can be observed in the distribution and morphology of intermetallic phases [47,48]. The presence of well-distributed intermetallic particles in an alloy has been observed to improve its mechanical properties significantly. This is primarily attributed to the hindrance of dislocation motion and the resulting strengthening effect. The influence of the β-phase, which is the predominant intermetallic phase in AZ31, has a notable impact on the strength and mechanical properties of the alloy [46]. By modifying the alloy composition, it is possible to optimize the distribution and size of intermetallic phases in order to finely adjust the mechanical properties of AZ31. The mechanical properties of AZ31 are significantly influenced by various processing techniques, including casting, rolling, and extrusion. These techniques influence the microstructure by impacting the grains' dimensions, the crystal lattice's orientation, and the arrangement of intermetallic phases. It is imperative to exercise meticulous control over processing parameters, including temperature, cooling rate, and deformation conditions, in order to effectively enhance the microstructural properties and, consequently, the mechanical performance of AZ31. Employing suitable heat treatment techniques can result in the refinement of the grain structure and facilitate the development of a more homogeneous dispersion of intermetallic phases, thereby enhancing the mechanical properties. Casting processes, such as sand casting and permanent mold casting, are frequently employed in the aerospace industry to manufacture intricate aerospace components with complex geometries. The cooling rate significantly influences the microstructural characteristics of the cast AZ31 alloy during solidification. The process of rapid cooling has the potential to yield a microstructure that is both fine and homogeneous, thereby enhancing the mechanical properties of the material. On the other hand, the deceleration of cooling rates can result in the creation of more extensive intermetallic phases and a coarser microstructure, which may potentially undermine the mechanical properties. The production of AZ31 sheets and profiles involves the utilization of rolling and extrusion processes, respectively. These processes result in plastic deformation, which impacts various factors such as the size of grains, the orientation of crystallographic texture, and the dispersion of intermetallic phases. The precise management of rolling or extrusion parameters, including reduction ratio and annealing conditions, plays a vital role in attaining the intended microstructural attributes and maximizing the mechanical properties of AZ31.

Overall, alloy composition, microstructural characteristics, and processing techniques significantly influence the mechanical properties of AZ31. The presence of alloying elements and the distribution of intermetallic phases play a vital role in enhancing the mechanical properties of AZ31. Additionally, controlling the microstructure through appropriate processing techniques, such as casting, rolling, and extrusion, allows for tailoring the mechanical properties to meet specific aerospace requirements. Continued research and development efforts focused on alloy design, microstructural control, and processing optimization will further advance our understanding and utilization of AZ31 in the aerospace industry.

4. Ongoing Research and Future Prospects

4.1. Current Research Efforts in Advancing AZ31 Properties for Aerospace

Current research efforts are focused on advancing the properties of AZ31 alloy to enhance its suitability for aerospace applications further. Researchers are exploring various approaches to improve the mechanical, thermal, and corrosion resistance properties of AZ31. Alloy modification techniques, such as the addition of trace elements or alloying with other elements, are being investigated to tailor the microstructure and enhance specific properties. Moreover, researchers are optimizing processing techniques to achieve finer grain sizes, improved texture, and better control over intermetallic phase distribution. This research aims to enhance the strength, ductility, fatigue resistance, and overall performance of AZ31 in aerospace environments.

4.2. Exploration of Novel Alloys and Composites Based on AZ31

In addition to the advancement of AZ31 properties, researchers are exploring the development of novel alloys and composites based on the AZ31 matrix. By incorporating various reinforcing materials, such as nanoparticles, fibers, or laminates, into the AZ31 matrix, researchers aim to create hybrid materials with superior mechanical properties. These efforts involve the evaluation of different reinforcement architectures, volume fractions, and interfacial bonding mechanisms. The development of such AZ31-based composites holds great potential for achieving enhanced strength, stiffness, and damage tolerance while maintaining the advantageous characteristics of AZ31 alloy.

4.3. Emerging Trends and Future Prospects for AZ31 in the Aerospace Industry

AZ31 alloy has already demonstrated its suitability for a wide range of aerospace applications. However, ongoing research and emerging trends indicate a promising future for AZ31 in the aerospace industry. With continued advancements in alloy design, processing techniques, and composite development, AZ31 is expected to exhibit even better mechanical properties, corrosion resistance, thermal stability, and formability. Moreover, the use of AZ31-based materials is being explored in critical aerospace components, such as engine parts, structural components, and aerospace fasteners, which require high strength, lightweight, and excellent fatigue resistance. Furthermore, AZ31's excellent recyclability and sustainability make it an attractive choice for environmentally conscious aerospace manufacturing. Overall, the prospects for AZ31 in the aerospace industry look promising, and further research and development efforts will continue to push the boundaries of its applications and performance. Figure 5 illustrates the interconnection between current research efforts in advancing AZ31 properties for aerospace, the exploration of novel alloys and composites based on AZ31, and the emerging trends and prospects for AZ31 in the aerospace industry.

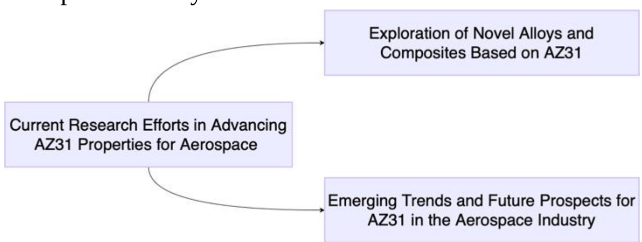

Figure 5. Interconnected Research and Prospects for AZ31 in Aerospace Applications

5. Conclusion

5.1. Summary of the Key Findings and Contributions of AZ31 in the Aerospace Industry

In conclusion, AZ31 alloy has proven to be a versatile and potentially helpful material in the aerospace industry. Aerospace components can benefit significantly from their low density, high specific strength, outstanding castability, and superior corrosion resistance. The mechanical characteristics and overall performance of AZ31 in the aerospace industry have been improved thanks to the research and development efforts in understanding the influence of alloy composition, microstructure, and processing techniques. The presence of magnesium-aluminum intermetallic phases, such as the β-phase, has been found to influence the strength and toughness of the alloy significantly. Control of cooling rates during solidification and optimization of heat treatment processes have been crucial in achieving desired microstructural characteristics and mechanical properties. The casting, rolling, and extrusion techniques have enabled the production of complex-shaped components, sheets, and profiles, respectively, with improved mechanical properties. Moreover, ongoing research in alloy modification and composite development based on AZ31 matrix shows great potential for further enhancing the material's properties and expanding its applications in aerospace.

5.2. Prospects for Ongoing Development and Utilization in Aerospace Materials

The potential for further development and applications of AZ31 in aerospace materials is promising. Continued research and innovation in alloy design, processing techniques, and composite development will lead to improved performance and expanded application areas. Advancements in alloy modification techniques, such as the addition of trace elements and alloying with other elements, will allow tailoring of AZ31's microstructure and properties to meet specific aerospace requirements. Further optimization of processing parameters, including rolling, extrusion, and heat treatment, will enable the production of AZ31 with finer microstructures, enhanced texture, and controlled distribution of intermetallic phases. Exploring novel alloys and composites based on the AZ31 matrix, incorporating reinforcing materials, will open up new possibilities for achieving superior mechanical properties and multifunctional characteristics. Additionally, the recyclability and sustainability of AZ31 make it an attractive choice for eco-friendly aerospace manufacturing practices.

In conclusion, AZ31 alloy has significantly contributed to the aerospace industry with its unique properties and excellent performance. The ongoing research and development efforts and the potential for further advancements position AZ31 as a promising material for future aerospace applications. Continued exploration of its properties, optimization of manufacturing processes, and development of novel alloys and composites will further propel the utilization of AZ31 in the aerospace materials landscape.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ambekar, Rushikesh S., Kushwaha, B., Sharma, P., Bosia, F., Fraldi, M., Pugno, N.M., Tiwary, C.S., 2021. Topologically engineered 3D printed architectures with superior mechanical strength. Materials Today, **48**, pp. 72-94.

[2] Zhang, Z., Mu, Z., Wang, Y., Song, W., Yu, H., Zhang, S., Li, Y., Niu, S., Han, Z., Ren, L., 2023. Lightweight Structural Biomaterials with Excellent Mechanical Performance: A Review. Biomimetics, **8(2)**, pp. 153.

[3] Baral, S.K., Thawre, M.M., Sunil, B.R. and Dumpala, R., 2023. A review on developing high-performance ZE41 magnesium alloy by using bulk deformation and surface modification methods. Journal of Magnesium and Alloys, **11(3)**, pp.776-800.

[4] Ding, Qingli., 2023, "Microstructural, Corrosion And Mechanical Characterization of Friction-Stir Welded Joints Between Aluminum and Magnesium Alloys." Phd Diss., Worcester Polytechnic Institute.

[5] Ezhilmaran, V., Anand, P.S.P., Kannan, S., Sivashanmugam, N., Jayakrishna, K., Kalusuraman, G., 2023. Review of bioresorbable AZ91, AZ31 and Mg–Zn–Ca implants and their manufacturing methods. Materials Science and Technology, **39(8)**, pp. 901-925.

[6] Pan, S.Q., Zhang, F., Wen, C. and Zeng, R.C., 2023. Advances in Mg–Al-layered double hydroxide steam coatings on Mg alloys: a review. Journal of Magnesium and Alloys, **11(5)**, pp.1505-1518.

[7] Kwon, D., Pham, H.V., Song, P., Moon, S., 2023. Corrosion Behavior of the AZ31 Mg Alloy in Neutral Aqueous Solutions Containing Various Anions. Metals, **13(5)**, p. 962.

[8] Singh, V.P., Kumar, D. and Kuriachen, B., 2023. Effect of low welding and rotational speed on microstructure and mechanical behaviour of friction

stir welded AZ31-AA6061-T6. Transactions of the Indian Institute of Metals, **76(9)**, pp.2483-2491.

[9] Fang, X., Zhou, C., Lin, J. and Li, W., 2023. Research on deformation mechanism of AZ31 magnesium alloy during uniaxial compression. Materials Science and Technology, **39(16)**, pp.2398-2408.

[10] Drunka, R., Iesalniece, P., Steins, I., Grase, L., Eiduks, T.V., Savkovs, K. and Blumbergs, I., 2023. Complex coating system for improving corrosion resistance of AZ31 magnesium alloy. Paper presented at Journal of Physics: Conference Series (Vol. 2423, No. 1, p. 012020). IOP Publishing.

[11] Zakaria, M.S., Mustapha, M., Azmi, A.I. and Khor, C.Y., 2023. Chip morphology and surface integrity in turning AZ31 magnesium alloy under dry machining and submerged convective cooling. Metals, **13(3)**, p.619.

[12] Liu, B., Yang, J., Zhang, X., Yang, Q., Zhang, J. and Li, X., 2023. Development and application of magnesium alloy parts for automotive OEMs: A review. Journal of Magnesium and Alloys, **11(1)**, pp.15-47.

[13] Siengchin, S., 2023. A review on lightweight materials for defence applications: Present and future developments. Defence Technology, **24**, pp.1-17.

[14] Shen, T., Liu, H., Zhang, J., Ma, M., Wu, Z., Liu, L. and Lu, L., 2023. The improvement on mechanical anisotropy of AZ31 magnesium alloy sheets by multi cross-rolling process. Journal of Alloys and Compounds, **963**, pp.171252.

[15] Zhang, M., Yang, K., Wei, G., Xie, W., Yang, Y., Li, B., Chen, H. and Yang, Q., 2023. AZ31/GNP magnesium composites with excellent comprehensive mechanical properties prepared by friction stir processing and rolling. Journal of Materials Research and Technology, **25**, pp.3078-3092.

[16] Wang, S., Zhang, K., Ouyang, S., Du, C., Wu, X., Tang, A., She, J. and Pan, F., 2023. Grain refinement and mechanical properties of AZ31 alloy processed by pre-die forging extrusion at different temperatures. Journal of Materials Engineering and Performance, **32(23)**, pp.10877-10884.

[17] Sai Divya, P.V., Penumakala, P.K., Kalyan, K.G.V. and Nallathambi, A.K., 2023. Analysis of hot tensile behaviour and prediction of thermal stresses during processing of AZ31 magnesium alloy. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, **237(6)**, pp.1445-1462.

[18] Lehmhus, D., 2024. Advances in Metal Casting technology: A Review of State of the Art, Challenges and Trends—Part II: Technologies New and Revived. Metals, **14(3)**, p.334.

[19] Yusuke, K., Bandara, A., Soga, N., Kan, K., Koike, A. and Aoki, T., 2023. Investigation of industrial die-cast Al-alloys using X-ray micro-computed tomography and machine learning approach for CT segmentation. Production Engineering, **17(2)**, pp.291-305.

[20] Mégret, A., Prince, L., Olivier, M.G. and Vitry, V., 2023. Tribo-and Tribocorrosion Properties of Magnesium AZ31 Alloy. Coatings, **13(2)**, p.448.

[21] ABOSHBA, FADELL SAID AHMED., 2022, "ANALYSIS OF THE PUNCHING PROCESS OF AZ31 MG ALLOY SHEET WITH EXPERIMENTAL AND SIMULATION STUDIES." PhD diss.,.

[22] Lokesh Kumar, R., Yashwanth Kumar, B.G., Vaira Vignesh, R., Kaasi Viswanath, J., Muralimanokar, M., Memon, S. and Govindaraju, M., 2022. Microstructure, tribology, and corrosion characteristics of hot-rolled AZ31 magnesium alloy. In Advances in Processing of Lightweight Metal Alloys and Composites: Microstructural Characterization and Property Correlation (pp. 299-326). Singapore: Springer Nature Singapore.

[23] Huang, S.J., Kannaiyan, S., Sarkar, M. and Mose, M.P., 2023. Enhancement of Mechanical Behaviors and Microstructure Evolution of Nano-Nb2O5/AZ31 Composite Processed via Equal-Channel Angular Pressing (ECAP). Journal of Composites Science, **7(6)**, p.230.

[24] Yang, J., Zhu, Z., Han, S., Gu, Y., Zhu, Z. and Zhang, H., 2024. Evolution, limitations, advantages, and future challenges of magnesium alloys as materials for aerospace applications. Journal of Alloys and Compounds, p.176707.

[25] Gołąbczak, M., Święcik, R., Gołąbczak, A., Nouveau, C., Jacquet, P., & Blanc, C., 2018,. Investigations of surface layer temperature and morphology of hard machinable materials used in aircraft industry during abrasive electrodischarge grinding process: Untersuchungen zur Oberflächentemperatur und Morphologie beim elektrolytischen Erosionsschleifen von schwer zerspanbaren Werkstoffen aus der Luftfahrtindustrie. *Materialwissenschaft und Werkstofftechnik*, ***49*(5)**, 568-576.

[26] Li, D., Slater, C., Cai, H., Hou, X., Li, Y. and Wang, Q., 2023. Joining technologies for aluminium castings—A review. Coatings, **13(5)**, p.958.

[27] Chen, Z., Zhang, Z., Ouyang, Y., Chen, Y., Yin, X., Liu, Y., Ying, H. and Yang, W., 2023. Electrospinning polycaprolactone/collagen fiber coatings for enhancing the corrosion resistance and biocompatibility of AZ31 Mg alloys. Colloids and Surfaces A: Physicochemical and Engineering Aspects, **662**, pp.131041.

[28] Zhang, Zihao, Xiaoyu Wang, Hengtong Xia, Hongyuan Li, Zhihao Chen, and Wenzhong Yang., 2023, "Electrical-responsive biocompatible coatings for highly corrosion-resistance and self-healing performance on AZ31 Mg alloy." *Journal of Industrial and Engineering Chemistry* **121**, pp. 179-189.

[29] Vahedi, S., Aghdam, R.M., Sohi, M.H. and Rezayan, A.H., 2023. Characteristics of electrospun chitosan/carbon nanotube coatings deposited on AZ31 magnesium alloy. Journal of Materials Science: Materials in Medicine, **34(1)**, p.8.

[30] Akbarzadeh, F.Z., Sarraf, M., Ghomi, E.R., Kumar, V.V., Salehi, M., Ramakrishna, S. and Bae, S., 2024. A state-of-the-art review on recent advances in the fabrication and characteristics of magnesium-based alloys in biomedical applications. Journal of Magnesium and Alloys, **12(7)**, 2569-2591.

[31] Kumar, V., Ramesha, C.M., Sharanraj, V., Sadashiva, M. and Kavya, K., 2023. In-vitro biocompatibility study and comparison of magnesium AZ31 and PEEK 450G biomaterials used as cardiovascular stent implants. Journal of Mines, Metals and Fuels, **12**, pp.67-72.

[32] Pang, Shuoshuo, Wenxiang Zhao, Tianyang Qiu, Weiliang Liu, Li Jiao, and Xibin Wang., 2023, "Study on surface quality and mechanical properties of micro-milling WE43 magnesium alloy cardiovascular stent." *Journal of Manufacturing Processes* **101**, pp. 1080-1090.

[33] Kayode, O. and Akinlabi, E.T., 2019. An overview on joining of aluminium and magnesium alloys using friction stir welding (FSW) for automotive lightweight applications. Materials Research Express, **6(11)**, p.112005.

[34] Zakaria, Muhammad Syamil, Mazli Mustapha, Azwan Iskandar Azmi, Azlan Ahmad, Mohd Danish, and Saeed Rubaiee., 2022, "Machinability investigations of AZ31 magnesium alloy via submerged convective cooling in turning process." *Journal of Materials Research and Technology* **19**: pp. 3685-3698.

[35] Dhanaji, T.U., Dassani, S., Somasundaram, M., Muthuchamy, A. and Raja Annamalai, A., 2023. Microstructural, Mechanical, and Corrosion Properties of AZXX Magnesium Alloy: A Review of Processing Methods. Crystals, **13(2)**, p.344.

[36] Cao, Q., Qi, B., Zeng, C., Zhang, R., He, B., Qi, Z., Wang, F., Wang, H. and Cong, B., 2022. Achieving equiaxed microstructure and isotropic mechanical properties of additively manufactured AZ31 magnesium alloy via ultrasonic frequency pulsed arc. Journal of Alloys and Compounds, **909**, pp.164742.

[37] Zeng, Z., Salehi, M., Kopp, A., Xu, S., Esmaily, M. and Birbilis, N., 2022. Recent progress and perspectives in additive manufacturing of magnesium alloys. Journal of Magnesium and Alloys, **10(6)**, pp.1511-1541.

[38] Beura, V., Zhang, D., Overman, N., Darsell, J., Herling, D.R., Solanki, K. and Joshi, V.V., 2022. Enhanced mechanical behavior and corrosion resistance of AZ31 magnesium alloy through a novel solid-phase processing. Corrosion Science, **197**, p.110074.

[39] Zhang, A.M., Liu, C., Sui, P.S., Sun, C., Cui, L.Y., Kannan, M.B. and Zeng, R.C., 2023. Corrosion resistance and mechanisms of smart micro-arc oxidation/epoxy resin coatings on AZ31 Mg alloy: Strategic positioning of nanocontainers. Journal of Magnesium and Alloys, **11(12)**, pp.4562-4574.

[40] Fajardo, S., Miguélez, L., Arenas, M.A., de Damborenea, J., Llorente, I. and Feliu, S., 2022. Corrosion resistance of pulsed laser modified AZ31 Mg alloy surfaces. Journal of Magnesium and Alloys, **10(3)**, pp.756-768.

[41] Qiu, W., Xie, W., Li, Q.F., Huang, W.Y., Zhou, L.B., Chen, W., Chen, J., Ren, Y.J., Yao, M.H., Xiong, A.H. and Zeng, Z.R., 2023. Effect of vanadium nitride (VN) particles on microstructure and mechanical properties of extruded AZ31 Mg alloy. Acta Metallurgica Sinica (English Letters), **36(2)**, pp.237-250.

[42] Zhang, X., Shi, H., Wang, X., Zhang, S., Luan, P., Hu, X. and Xu, C., 2023. Processing, microstructure, and mechanical behavior of AZ31 magnesium alloy fabricated by electron beam additive manufacturing. Journal of Alloys and Compounds, **938**, p.168567.

[43] Kwon, D., Pham, H.V., Song, P. and Moon, S., 2023. Corrosion and Formation of Surface Films on AZ31 Mg Alloy in Aqueous Solution Containing Sulfate Ions with Different pHs. Metals, **13(7)**, p.1150.

[44] Selvan, A.T. and Palani, S., 2023, May. Prediction of mechanical strength of magnesium alloy AZ31 with calcium addition using a neural network based model. Presented in Journal of Physics: Conference Series (Vol. 2484, No. 1, p. 012015). IOP Publishing.

[45] Chowdhury, S.H., Chen, D.L., Bhole, S.D., Cao, X. and Wanjara, P., 2013. Friction stir welded AZ31 magnesium alloy: microstructure, texture, and tensile properties. Metallurgical and materials transactions A, **44(1)**, pp.323-336.

[46] Chatterton, Mark., 2015, "Thermo-Mechanical Deformation Processing of Advanced Magnesium Alloys." PhD diss., The University of Manchester (United Kingdom).

[47] Schneider, K., McKay, B.J. and Nadendla, B., 2018. Influence of zinc on intermetallic phase selection in Al-Mg compound castings. Presented in Proceedings of the 16th International Aluminium Alloys Conference (ICAA16) (pp. 1-8).

[48] Wang, Z.L., Wei, Z.J., Wang, H.W. and Cao, L., 2006. Effects of high pressure on microstructure and phase of Al–Mg–Zn alloy. International Journal of Cast Metals Research, **19(5)**, pp.269-273.

[49] Elthalabawy, W. and Khan, T., 2011. Liquid phase bonding of 316L stainless steel to AZ31 magnesium alloy. Journal of Materials Science & Technology, **27(1)**, pp.22-28.

[50] Shang, L., Jung, I.H., Yue, S., Verma, R. and Essadiqi, E., 2010. An investigation of formation of second phases in microalloyed, AZ31 Mg alloys with Ca, Sr and Ce. Journal of Alloys and Compounds, **492(1-2)**, pp.173-183.

[51] Anbuchezhiyan, G., Mubarak, N.M., Karri, R.R. and Khalid, M., 2022. A synergistic effect on enriching the Mg–Al–Zn alloy-based hybrid composite properties. Scientific reports, **12(1)**, p.20053.

[52] Gao, L., Li, F., Wang, Y., Xiao, X.M. and Da Huo, P., 2022. Fabrication and Interface Structural Behavior of Mg/Al Thickness-Oriented Bonding Sheet via Direct Extrusion. Metals and Materials International, pp.1-11.

[53] Sun, A., Sui, X., Li, H. and Wang, Q., 2015. Interface microstructure and mechanical properties of zinc–aluminum thermal diffusion coating on AZ31 magnesium alloy. Materials & Design, **67**, pp.280-284.

[54] Sahu, P.K., Das, J., Chen, G., Liu, Q., Pal, S., Zeng, S. and Shi, Q., 2020. Friction stir selective alloying of different Al% particulate reinforced to AZ31 Mg for enhanced mechanical and metallurgical properties. Materials Science and Engineering: A, **774**, p.138889.

[55] Liu, F., Zhang, Z. and Liu, L., 2012. Microstructure evolution of Al/Mg butt joints welded by gas tungsten arc with Zn filler metal. Materials Characterization, **69**, pp.84-89.

[56] Dewangan, S.K., Banjare, P.N., Tripathi, M.K. and Manoj, M.K., 2023. Effect of vertical and horizontal zinc interlayer on material flow, microstructure, and mechanical properties of dissimilar FSW of Al 7075 and Mg AZ31 alloys. The International Journal of Advanced Manufacturing Technology, **126(9)**, pp.4453-4474.

[57] Zeng, Z., Jiang, P., Hou, R., Wang, L., Zhu, S. and Guan, S., 2023. Enhanced Corrosion Resistance and Mechanical Properties of Mg-Zn Alloy via Micro-alloying of Ge. JOM, **75(7)**, pp.2326-2337.

[58] Qiu, W., Xie, W., Li, Q.F., Huang, W.Y., Zhou, L.B., Chen, W., Chen, J., Ren, Y.J., Yao, M.H., Xiong, A.H. and Zeng, Z.R., 2023. Effect of vanadium nitride (VN) particles on microstructure and mechanical properties of extruded AZ31 Mg alloy. Acta Metallurgica Sinica (English Letters), **36(2)**, pp.237-250.

[59] Zhang, H., Li, H., Li, R., Liu, B., Wu, R., Zhao, D. and Li, S., 2023. Effect of Initial Microstructure Prior to Extrusion on the Microstructure and Mechanical Properties of Extruded AZ80 Alloy with a Low Temperature and a Low Ratio. Chinese Journal of Mechanical Engineering, **36(1)**, p.72.

[60] Springer, H., Szczepaniak, A. and Raabe, D., 2015. On the role of zinc on the formation and growth of intermetallic phases during interdiffusion between steel and aluminium alloys. Acta Materialia, **96**, pp.203-211.

[61] Yang, Q., Wu, X. and Qiu, X., 2023. Microstructural characteristics of high-pressure die casting with high strength–ductility synergy properties: a review. Materials, **16(5)**, p.1954.

[62] Kocaman, E., 2023. Effect of Al5Ti1B and Al8B on the microstructure, wear and corrosion behavior of CuZn19Al6 bronze alloy. Materials Today Communications, **36**, p.106551.

[63] Ghiasvand, A., Ranjbarnodeh, E. and Mirsalehi, S.E., 2023. The microstructure and mechanical properties of single-pass and double-pass lap joint of Al 5754H-11 and Mg AZ31-O alloys by friction stir welding. Journal of Materials Research and Technology, **23**, pp.6023-6038.

[64] Yang, Y., Deng, Y., Zhang, R., Su, Y., Liu, S., Gourlay, C.M. and Zeng, G., 2023. Influence of β-Mg17Al12 and Al-Mn intermetallic compounds on the corrosion behaviour of cast and solution treated Mg-Al-Zn-Mn alloys. Corrosion Science, **222**, p.111363.

[65] Majidabad, M.A., Eftekhari, M. and Faraji, G., 2023. Characterization of Mg–9Al–1Zn-0.2 Mn alloy tubes processed by a new modified tube cyclic expansion extrusion (M-TCEE) process. Journal of Materials Research and Technology, **24**, pp.7989-8001.

[66] Li, L., Huang, Z., Chen, L., Jing, J., Hou, H. and Zhao, Y., 2023. Changing the second phase distribution shape and improving the corrosion resistance of Mg-6.7 Y-2.5 Zn alloy by addition of trace Ta. Corrosion Science, **221**, p.111341.

[67] Hermann, F., Sommer, F., Jones, H. and Edyvean, R.G.J., 1989. Corrosion inhibition in magnesium-aluminium-based alloys induced by rapid solidification processing. Journal of materials science, **24**, pp.2369-2379.

[68] Pardo, A., Merino, M.C., Coy, A.E., Arrabal, R., Viejo, F. and Matykina, E., 2008. Corrosion behaviour of magnesium/aluminium alloys in 3.5 wt.% NaCl. Corrosion Science, **50(3)**, pp.823-834.

[69] Sharahi, H.J., Pouranvari, M. and Movahedi, M., 2020. Strengthening and ductilization mechanisms of friction stir processed cast Mg–Al–Zn alloy. Materials Science and Engineering: A, **781**, p.139249.

[70] Liu, S., Yang, W., Shi, X., Li, B., Duan, S., Guo, H. and Guo, J., 2019. Influence of laser process parameters on the densification, microstructure, and mechanical properties of a selective laser melted AZ61 magnesium alloy. Journal of Alloys and Compounds, **808**, p.151160.

[71] Desai, A., Khatri, B., Rana, H., Patel, V. and Badheka, V., 2023. Numerical and experimental investigation on AZ91 friction stir welding joints: mechanics, properties. Materials Science and Technology, **39(17)**, pp.2767-2781.

[72] Chen, Y., Liu, G.H., Wang, Y. and Wang, Z.D., 2023. Solidification microstructure of Ti-43Al alloy by twin-roll strip casting. China Foundry, **20(2)**, pp.99-107.

[73] Zhou, J., Yang, H., Jiang, B., He, C., Dong, Z., Liu, L., Luo, X., Liu, Y., Huang, D., Xu, J. and Huang, G., 2023. Clarifying the deformation modes and strengthening mechanisms of Mg-11Gd-5Y-2Zn-0.7 Zr with outstanding high-temperature mechanical properties. *Materials Science and Engineering: A*, *866*, p.144638.

[74] Song, X., Fu, X. and Wang, M., 2023. First–principles study of β′ phase in Mg–RE alloys. International Journal of Mechanical Sciences, **243**, p.108045.

[75] Lv, X. and Liu, L., 2024. Microstructure and mechanical performance of AZ31/6061 lap joints welded by laser-TIG hybrid welding with Zn-Al alloy filler metal. Journal of Magnesium and Alloys, **12(8)**, pp.3325-3338.

[76] Xu, B., Sun, J., Yang, Z., Han, J., Fu, Y., Jiang, J. and Ma, A., 2020. A near-isotropic ultrafine-grained Mg-Gd-Ag alloy with high strength-ductility synergy. Journal of Materials Research and Technology, **9(6)**, pp.13616-13624.

[77] Sunil, B.R., Ganesh, K.V., Pavan, P., Vadapalli, G., Swarnalatha, C., Swapna, P., Bindukumar, P. and Reddy, G.P.K., 2016. Effect of aluminum content on machining characteristics of AZ31 and AZ91 magnesium alloys during drilling. Journal of Magnesium and alloys, **4(1)**, pp.15-21.

[78] Liu, Q., Ma, Q.X., Chen, G.Q., Cao, X., Zhang, S., Pan, J.L., Zhang, G. and Shi, Q.Y., 2018. Enhanced corrosion resistance of AZ91 magnesium alloy through refinement and homogenization of surface microstructure by friction stir processing. Corrosion science, **138**, pp.284-296.

[79] Liu, X., Jia, H.L., Wang, C., Wu, X., Zha, M. and Wang, H.Y., 2022. Enhancing mechanical properties of twin-roll cast Al–Mg–Si–Fe alloys by regulating Fe-bearing phases and macro-segregation. Materials Science and Engineering: A, **831**, p.142256.

[80] Ma, D., Xu, C., Qi, Y., Sui, S., Tian, J., Tu, T., Guo, C., Wu, X., Zhang, Z., Remennik, S. and Shechtman, D., 2023. Achieving fully equiaxed grain microstructure and isotropic mechanical properties in wire arc additive-manufactured Mg-Y-Nd-Zr alloys. Journal of Alloys and Compounds, **962**, p.171041.

[81] Wang, W., Zhang, J., Li, J., Chen, X., Liu, S., Huang, G., Chen, X., Zheng, K., Jiang, B. and Pan, F., 2023. Influence of different extrusion methods on the microstructure, texture evolution and mechanical property of Tip/AZ31 composite. Materials Science and Engineering: A, **862**, p.144377.

[82] Wang, Z., Wang, J., Lin, X., Zhang, T., Dang, C., Wang, Y., Huang, W. and Pan, F., 2023. Solidification texture dependence of the anisotropy of mechanical properties and damping capacities of an AZ31 Mg-based alloy fabricated via wire-arc additive manufacturing. Journal of Materials Research and Technology, **25**, pp.2589-2601.

[83] Sahu, P.K., Das, J. and Shi, Q., 2023. Effect of Alloying Foil on the Friction Stir Weld Quality of Mg Alloy Joints. Metallography, Microstructure, and Analysis, **12(4)**, pp.672-682.

[84] Sun, M., Niknejad, S.T., Zhang, G., Lee, M.K., Wu, L. and Zhou, Y., 2015. Microstructure and mechanical properties of resistance spot welded AZ31/AA5754 using a nickel interlayer. Materials & Design, **87**, pp.905-913.

[85] Zhong, Q., Pan, D., Zuo, S., Li, X., Luo, H. and Lin, Y., 2021. Fabrication of MgZn intermetallic layer with high hardness and corrosion resistance on AZ31 alloy. Materials Characterization, **179**, p.111365.

[86] Huang, S.J. and Abbas, A., 2020. Effects of tungsten disulfide on microstructure and mechanical properties of AZ91 magnesium alloy manufactured by stir casting. *Journal of Alloys and Compounds*, **817**, p.153321.

[87] Xiao, B.L., Yang, Q., Yang, J., Wang, W.G., Xie, G.M. and Ma, Z.Y., 2011. Enhanced mechanical properties of Mg–Gd–Y–Zr casting via friction stir processing. Journal of Alloys and Compounds, **509(6)**, pp.2879-2884.

[88] Hamu, G.B., Eliezer, D. and Wagner, L., 2009. The relation between severe plastic deformation microstructure and corrosion behavior of AZ31 magnesium alloy. Journal of alloys and compounds, **468(1-2)**, pp.222-229.

[89] Yu, Z., Xu, C., Meng, J., Zhang, X. and Kamado, S., 2018. Microstructure evolution and mechanical properties of as-extruded Mg-Gd-Y-Zr alloy with Zn and Nd additions. Materials Science and Engineering: A, **713**, pp.234-243.

[90] Elsayed, F.R., Sasaki, T.T., Ohkubo, T., Takahashi, H., Xu, S.W., Kamado, S. and Hono, K., 2013. Effect of extrusion conditions on microstructure and mechanical properties of microalloyed Mg–Sn–Al–Zn alloys. Materials Science and Engineering: A, **588**, pp.318-328.

[91] Tong, W.E.N., Liu, S.Y., Shi, C.H.E.N., Liu, L.T. and Chen, Y.A.N.G., 2015. Influence of high frequency vibration on microstructure and mechanical properties of TIG welding joints of AZ31 magnesium alloy. Transactions of Nonferrous Metals Society of China, **25(2)**, pp.397-404.

[92] Chen, Y., Wang, Q., Peng, J., Zhai, C. and Ding, W., 2007. Effects of extrusion ratio on the microstructure and mechanical properties of AZ31 Mg alloy. Journal of materials processing technology, **182(1-3)**, pp.281-285.

[93] Zhi, C., Lei, J., Xing, H., Huang, Z., Xu, H., Jia, W. and Ma, L., 2023. Tensile fracture prediction of AZ31 cast-rolled sheet based on hot working map. Journal of Materials Research and Technology, **23**, pp.3272-3283.

[94] Ye, P., Yang, C., Li, Z., Bao, S., Sun, Y., Ding, W. and Chen, Y., 2023. Texture and High Yield Strength of Rapidly Solidified AZ31 Magnesium Alloy Extruded at 250° C. Materials, **16(8)**, p.2946.

[95] Zulkfli, Z., Hamedon, Z. and Fatchurrohman, N., 2023. Surface Modification on Magnesium Alloys' Hardness and Microstructure Using Friction Stir Processing–A Review. *Jurnal Teknologi*, **13(1)**, pp.39-45.

[96] Song, G.L. and Xu, Z., 2010. The surface, microstructure and corrosion of magnesium alloy AZ31 sheet. *Electrochimica Acta*, ***55*(13)**, pp.4148-4161.

[97] Li, M., Chen, J., Sun, J., Hao, L., Wu, D., Wang, J. and Ke, W., 2023. Varied corrosion evolution behavior of pure Mg, AZ31 and AZ91 magnesium alloys in phosphate buffer solution. Anti-Corrosion Methods and Materials, **70(4)**, pp.166-172.

[98] Cheng, Y.L., Qin, T.W., Wang, H.M. and Zhang, Z., 2009. Comparison of corrosion behaviors of AZ31, AZ91, AM60 and ZK60 magnesium alloys. Transactions of Nonferrous Metals Society of China, **19(3)**, pp.517-524.

[99] Kaliyaperumal, G., Elango, S., Ramalingam, P.S., Devi, G.R., Thangamani, P., Venkatesh, R., Kishan, S.A., Kumar, R.K. and De Poures, M.V., 2023. Experimental study and TiC interfacial action on microstructural and mechanical properties of AZ31 alloy composite made by stir casting route. *Materials Today: Proceedings*.

[100] Osipenko, M.A., Kasach, A.A., Adamiec, J., Zimowska, M., Kurilo, I.I. and Kharytonau, D.S., 2023. Corrosion inhibition of magnesium alloy AZ31 in chloride-containing solutions by aqueous permanganate. Journal of Solid State Electrochemistry, **27(7)**, pp.1847-1860.

[101] Ma, Z.Y., Pilchak, A.L., Juhas, M.C. and Williams, J.C., 2008. Microstructural refinement and property enhancement of cast light alloys via friction stir processing. Scripta Materialia, **58(5)**, pp.361-366.

[102] Minárik, P., Zimina, M., Čížek, J., Stráska, J., Krajňák, T., Cieslar, M., Vlasák, T., Bohlen, J., Kurz, G. and Letzig, D., 2019. Increased structural stability in twin-roll cast AZ31 magnesium alloy processed by equal channel angular pressing. Materials Characterization, **153**, pp.199-207.

[103] Kim, H.S. and Kim, W.J., 2013. Enhanced corrosion resistance of ultrafine-grained AZ61 alloy containing very fine particles of Mg17Al12 phase. Corrosion Science, **75**, pp.228-238.

[104] Zang, Q., Chen, H., Zhang, J., Wang, L., Chen, S. and Jin, Y., 2021. Microstructure, mechanical properties and corrosion resistance of AZ31/GNPs composites prepared by friction stir processing. Journal of Materials Research and Technology, **14**, pp.195-201.

[105] Lei, X., Liu, T., Chen, J., Miao, B. and Zeng, W., 2011. Microstructure and mechanical properties of magnesium alloy AZ31 processed by compound channel extrusion. Materials transactions, **52(6)**, pp.1082-1087.

[106] Śliwa, R.E., Balawender, T., Hadasik, E., Kuc, D., Gontarz, A., Korbel, A. and Bochniak, W., 2017. Metal forming of lightweight magnesium alloys for aviation applications. Archives of Metallurgy and Materials, **62(3)**, pp.1559-1566.

[107] Zhang, H., Huang, G., Roven, H.J., Wang, L. and Pan, F., 2013. Influence of different rolling routes on the microstructure evolution and properties of AZ31 magnesium alloy sheets. Materials & Design, **50**, pp.667-673.

[108] Chino, Y., Kimura, K. and Mabuchi, M., 2009. Deformation characteristics at room temperature under biaxial tensile stress in textured AZ31 Mg alloy sheets. Acta Materialia, **57(5)**, pp.1476-1485.

[109] Zúberová, Z., Kunz, L., Lamark, T.T., Estrin, Y. and Janeček, M., 2007. Fatigue and tensile behavior of cast, hot-rolled, and severely plastically deformed AZ31 magnesium alloy. Metallurgical and Materials Transactions A, **38**, pp.1934-1940.

[110] Su, C.W., Lu, L. and Lai, M.O., 2007. Mechanical behaviour and texture of annealed AZ31 Mg alloy deformed by ECAP. Materials science and technology, **23(3)**, pp.290-296.

[111] Mekonen, M.N., Steglich, D., Bohlen, J., Letzig, D. and Mosler, J., 2012. Mechanical characterization and constitutive modeling of Mg alloy sheets. Materials Science and Engineering: A, **540**, pp.174-186.

[112] Rakshith, M. and Seenuvasaperumal, P., 2021. Review on the effect of different processing techniques on the microstructure and mechanical behaviour of AZ31 Magnesium alloy. Journal of Magnesium and Alloys, **9(5)**, pp.1692-1714.

[113] Marya, M., Hector, L.G., Verma, R. and Tong, W., 2006. Microstructural effects of AZ31 magnesium alloy on its tensile deformation and failure behaviors. *Materials science and engineering: A*, ***418*****(1-2)**, pp.341-356.

[114] Nguyen, Q.B., Tun, K.S., Lim, C.Y.H., Wong, W.L.E. and Gupta, M., 2013. Influence of nano-alumina and sub-micron copper on mechanical properties of magnesium alloy AZ31. *Composites Part B: Engineering*, ***55***, pp.486-491.

[115] An, Z.G., Yan, D., Qie, J.J., Lu, Z.L. and Gao, Z.Y., 2020. Effect of process parameters on formability of a AZ31 magnesium alloy thin-walled cylindrical part formed by multistage warm single-point incremental forming. *Frontiers in Materials*, ***7***, p.151.

[116] Guo, W., Wang, Q., Ye, B. and Zhou, H., 2013. Microstructure and mechanical properties of AZ31 magnesium alloy processed by cyclic closed-die forging. *Journal of Alloys and Compounds*, ***558***, pp.164-171.

[117] Hamad, K. and Ko, Y.G., 2016. A cross-shear deformation for optimizing the strength and ductility of AZ31 magnesium alloys. *Scientific Reports*, ***6*****(1)**, p.29954.

[118] Zhan, M., Li, C., Zhang, W. and Zhang, D. , 2012, 'Processing of AZ31 magnesium alloy by accumulative roll-bonding at gradient temperature', Acta Metallurgica Sinica (English Letters), **25(1)**, pp. 65–75. doi: 10.3724/SP.J.1037.2012.00365.

[119] Masoudpanah, S.M. and Mahmudi, R., 2009. Effects of rare-earth elements and Ca additions on the microstructure and mechanical properties of AZ31 magnesium alloy processed by ECAP. *Materials Science and Engineering: A*, ***526*****(1-2)**, pp.22-30.

[120] Zhang, H., Yan, Q. and Li, L., 2008. Microstructures and tensile properties of AZ31 magnesium alloy by continuous extrusion forming process. *Materials Science and Engineering: A*, ***486*****(1-2)**, pp.295-299.

[121] Suh, J., Victoria-Hernández, J., Letzig, D., Golle, R. and Volk, W., 2016. Effect of processing route on texture and cold formability of AZ31 Mg alloy sheets processed by ECAP. Materials Science and Engineering: A, **669**, pp.159-170.

[122] Li, X., Zhang, M., Fang, X., Li, Z., Jiao, G. and Huang, K., 2023. Improved strength-ductility synergy of directed energy deposited AZ31 magnesium alloy with cryogenic cooling mode. *Virtual and Physical Prototyping*, ***18*****(1)**, p.e2170252.

[123] Yuan, M., He, C., Song, Y., Lei, B., Qian, X., Dong, Z., Zhao, J., Yang, H., Chai, Y., Jiang, B. and Pan, F., 2022. Effects of Zn addition on the microstructure and mechanical properties of as-extruded Mg-2Al-0.5 Ca alloy. *Metals*, ***12*****(2)**, p.221.

[124] Pan, Y., Wang, J., Cui, H., Feng, R., Gong, B., Zhao, X., Hou, N., Cui, B., Song, Y. and Yang, T., 2020. Effect of deep cryogenic treatment on the microstructure and corrosion behavior of the microarc oxidized Mg-2.0 Zn-0.5 Ca alloy. *Journal of Materials Research and Technology*, ***9*****(3)**, pp.3943-3949.

[125] Dong, N., Sun, L., Ma, H. and Jin, P., 2021. Effects of cryogenic treatment on microstructures and mechanical properties of Mg-2Nd-4Zn alloy. *Materials Letters*, ***305***, p.130699.

[126] Chai, F., Ma, Z., Han, X., Hu, X., Chang, Z. and Zhou, J., 2023. Effect of strain rates on mechanical behavior, microstructure evolution and failure mechanism of extruded-annealed AZ91 magnesium alloy under room-temperature tension. Journal of Materials Research and Technology, **27**, pp.4644-4656.

[127] Savaedi, Z., Motallebi, R., Mirzadeh, H., Aghdam, R.M. and Mahmudi, R., 2023. Superplasticity of fine-grained magnesium alloys for biomedical applications: A comprehensive review. *Current Opinion in Solid State and Materials Science*, ***27*****(2)**, p.101058.

[128] Wang, C., Ding, H., Wang, B.S., Wang, K., Shi, J.J. and Chen, J.F., 2017. Effects of deformation texture and twins on the corrosion resistance of rolled AZ31 Mg alloy under 5% uniaxial compression. *Acta Metallurgica Sinica (English Letters)*, ***30***, pp.921-930.

[129] Mukai, T., Yamanoi, M., Watanabe, H. and Higashi, K., 2001. Ductility enhancement in AZ31 magnesium alloy by controlling its grain structure. *Scripta materialia*, ***45*****(1)**, pp.89-94.

[130] Li, Y., Yang, B., Han, T., Chu, Z., Tuo, L., Xue, C., Yang, Q., Zhao, X. and Gao, H., 2022. Effect of pre-deformation on microstructure characteristics, texture evolution and deformation mechanism of AZ31 magnesium alloy. *Materials Science and Engineering: A*, ***845***, p.143234.

[131] Dessolier, T., Lhuissier, P., Roussel-Dherbey, F., Charlot, F., Josserond, C., Blandin, J.J. and Martin, G., 2020. Effect of temperature on deformation mechanisms of AZ31 Mg-alloy under tensile loading. *Materials Science and Engineering: A*, ***775***, p.138957.

[132] Zhao, X., Zeng, X., Yuan, L., Gandra, J., Hayat, Q., Bai, M., Rainforth, W.M. and Guan, D., 2023. A novel approach for producing Mg-3Al-1Zn-0.2 Mn alloy wire with a promising combination of strength and ductility using CoreFlowTM. *Scripta Materialia*, ***227***, p.115301.

[133] Sun, J., Liu, J., Chen, Q., Lu, L. and Zhao, Y., 2022. Study of the Effect of Grain-Boundary Misorientation on Slip Transfer in Magnesium Alloy Using a Misorientation Distribution Map. *Crystals*, ***12*****(3)**, p.388.

[134] Sun, S., Deng, N., Zhang, H., He, L., Zhou, H., Han, B., Gao, K. and Wang, X., 2021. Microstructure and mechanical properties of AZ31 magnesium alloy reinforced with novel sub-micron vanadium particles by powder metallurgy. *Journal of Materials Research and Technology*, ***15***, pp.1789-1800.

[135] Liu, Y., Zhao, Y., Wang, L., Jin, X., Sun, C., Wang, X., Wang, G., Dai, S. and Wang, Y., 2021. Microstructure and Mechanical Properties of AZ31 Alloys Processed by Residual Heat Rolling. *Journal of Wuhan University of Technology-Mater. Sci. Ed.*, ***36*****(4)**, pp.588-594.

[136] Wan, Y.J., Zeng, Y., Dou, Y.C., Hu, D.C., Qian, X.Y., Zeng, Q., Sun, K.X. and Quan, G.F., 2022. Improved mechanical properties and strengthening mechanism with the altered precipitate orientation in magnesium alloys. *Journal of Magnesium and Alloys*, ***10*****(5)**, pp.1256-1267.

[137] Kazemi, A., Heidari, A., Amini, K., Aghadavoudi, F. and Loh-Mousavi, M., 2023. The Effect of Surface Mechanical Attrition Treatment Time on Microstructure and Mechanical Properties of AZ31 Mg Alloy. Protection of Metals and Physical Chemistry of Surfaces, **59(3)**, pp.453-460.

[138] Huang, X., Suzuki, K., Chino, Y. and Mabuchi, M., 2015. Influence of aluminum content on the texture and sheet formability of AM series magnesium alloys. Materials Science and Engineering: A, **633**, pp.144-153.

[139] Clinch, M.R., Harris, S.J., Hepples, W., Holroyd, N.J.H., Lawday, M.J. and Noble, B., 2006, July. Influence of zinc to magnesium ratio and total solute content on the strength and toughness of 7xxx series alloys. Presented in Materials science forum (Vol. 519, pp. 339-344). Trans Tech Publications Ltd.

[140] Hu, Y., Guo, X., Qiao, Y., Wang, X. and Lin, Q., 2022. Preparation of medical Mg–Zn alloys and the effect of different zinc contents on the alloy. Journal of Materials Science: Materials in Medicine, **33(1)**, p.9.

[141] Parthiban, G.T., Palaniswamy, N. and Sivan, V., 2009. Effect of manganese addition on anode characteristics of electrolytic magnesium. Anti-Corrosion Methods and Materials, **56(2)**, pp.79-83.

[142] Razzaghi, M., Mirzadeh, H. and Emamy, M., 2019. Mechanical properties of Mg-Al-Mn magnesium alloys with low Al content in the as-cast

and extruded conditions. Materials Research Express, **6(10)**, p.106521.

[143] Yang, J., Wang, D., Xiao, B.L., Ni, D.R. and Ma, Z.Y., 2013. Effects of rotation rates on microstructure, mechanical properties, and fracture behavior of friction stir-welded (FSW) AZ31 magnesium alloy. Metallurgical and Materials Transactions A, **44**, pp.517-530.

[144] Yu, K., Li, W., Wang, R., Wang, B. and Li, C., 2008. Effect of T5 and T6 tempers on a hot-rolled WE43 magnesium alloy. Materials transactions, **49(8)**, pp.1818-1821.

[145] Wei, X., Li, Z., Liu, P., Li, S., Peng, X., Deng, R. and Zhao, Q., 2020. Improvement in corrosion resistance and biocompatibility of AZ31 magnesium alloy by NH2+ ions. Journal of Alloys and Compounds, **824**, p.153832.