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Scientificpaper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.62638/ZasMat1802

Zastita Materijala 67 ()
(2026)

Time-dependent corrosion of AZ91D magnesium alloy in simulated body fluid for biodegradable implants

ABSTRACT

Magnesium alloys, particularly AZ91D, are promising materials for biodegradable implant applications due to their favourable strength-to-weight ratio, biocompatibility, and elastic modulus close to that of natural bone. However, their rapid degradation in physiological environments limits long-term clinical performance. This study systematically investigates the corrosion behaviour of AZ91D magnesium alloy through prolonged immersion in simulated body fluid (SBF) at 37 °C for 7, 30, 60, and 90 days. Surface degradation was evaluated through visual and morphological examination, while electrochemical characteristics were analyzed using Tafel polarization techniques.After 7 days, moderate corrosion activity was observed, with a corrosion potential near –1.75 V and microampere-level corrosion current density. Formation of $Mg(OH)_2$ and calcium–phosphate deposits was evident. At 30 and 60 days, progressive surface roughening, localized attack, and continued hydrogen evolution indicated sustained degradation. Although a slight reduction in corrosion current density suggested temporary surface film formation, the absence of a stable passive region confirmed ongoing active corrosion. After 90 days, severe structural deterioration and loss of integrity were observed, demonstrating breakdown of the protective surface layers.Most previous studies emphasize short-term immersion behaviour (≤30 days), with limited focus on long-term degradation and its correlation with electrochemical kinetics. This work addresses that gap by providing a comprehensive time-dependent analysis (7–90 days), linking immersion observations with polarization behaviour. The results clarify the transitional stages of corrosion and provide insight into the long-term bio-resorption performance of AZ91D under physiological conditions.

Keywords: *AZ91D magnesium alloy; Biodegradable implants; Simulated body fluid (SBF); Corrosion behaviour; Long-term immersion; Tafel polarization; Electrochemical analysis; Surface degradation; Bio-resorption; Magnesium hydroxide ($Mg(OH)_2$)*

1. INTRODUCTION

Magnesium (Mg) and its alloys have emerged as promising materials for temporary biodegradable implants owing to their favorable mechanical properties, low density, and elastic modulus comparable to that of natural bone [1]. Unlike conventional permanent metallic biomaterials such as stainless steel, titanium, and cobalt–chromium alloys, magnesium-based materials can gradually degrade and reduce long-term complications [2]. In addition, magnesium is an essential element in the human body and plays a vital role in metabolic and cellular processes, further supporting its suitability for biomedical applications [3].

Among commercially available magnesium alloys, AZ91D—composed primarily of magnesium with aluminum and zinc as major alloying elements—has attracted attention due to its good castability, mechanical strength, and relatively improved corrosion resistance compared to pure magnesium [4]. However, despite these advantages, AZ91D remains highly susceptible to rapid corrosion in physiological environments containing chloride ions, such as body fluids [5]. The corrosion mechanism typically involves anodic dissolution of magnesium and cathodic hydrogen evolution [6]. In chloride-rich environments, this hydroxide layer is unstable and easily converted into soluble magnesium chloride, resulting in accelerated degradation [7].

To simulate in vivo conditions, in vitro corrosion testing is commonly conducted using simulated body fluid (SBF), which closely mimics the ionic composition of human plasma [8]. Immersion testing in SBF allows evaluation of surface

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Paper received: 25.02.2026.
Paper accepted: 18..03,2026.

degradation, hydrogen evolution, and formation of calcium–phosphate-based deposits such as hydroxyapatite, which may influence corrosion behaviour and bioactivity [9]. Electrochemical techniques, particularly Tafel polarization analysis, are widely employed to quantify corrosion potential (E_{corr}) and corrosion current density (i_{corr}), providing insight into corrosion kinetics and degradation rate [10].Although numerous studies have investigated the short-term corrosion behaviour of magnesium alloys in SBF, most reports are limited to immersion periods of less than 30 days [11].

Long-term degradation behaviour, especially the transition from initial surface film formation to structural disintegration, remains insufficiently understood. Furthermore, the correlation between extended immersion observations and electrochemical polarization characteristics has not been comprehensively established [12].Therefore, the present study aims to systematically evaluate the time-dependent corrosion behaviour of AZ91D magnesium alloy in SBF at 37°Cover extended durations of 7, 30, 60, and 90 days. By combining immersion testing with Tafel polarization analysis, this work seeks to clarify the progressive degradation mechanisms and assess the long-term bio-resorption performance of AZ91D under simulated physiological conditions.

2. LITERATURE SURVEY:

The corrosion behaviour of AZ91D magnesium alloy has been widely investigated due to its potential use in biodegradable biomedical implants. Early studies on AZ91 alloys revealed that corrosion is strongly influenced by microstructural features, particularly the presence of the β-$Mg_{17}Al_{12}$ intermetallic phase. Micro-galvanic coupling between the α-Mg matrix and secondary phases accelerates localized corrosion, especially in chloride-containing environments, resulting in pitting and rapid material loss [13].Further investigations in simulated body fluid (SBF) environments demonstrated that AZ91D undergoes active degradation characterized by magnesium dissolution and hydrogen evolution. The presence of chloride ions destabilizes the $Mg(OH)_2$ surface layer, converting it into soluble magnesium chloride and thereby accelerating corrosion kinetics [14]. These findings confirmed that physiological ionic composition plays a critical role in governing degradation behaviour.

To mitigate rapid corrosion, various surface modification techniques have been explored. Studies on bio-ceramic coatings such as Si/ZrO_2 applied on AZ91D reported significant improvements in corrosion resistance, leading to the formation of a protective barrier layer that reduces direct exposure to the corrosive medium [15]. Similarly, friction stir processing with ceramic reinforcements has been shown to refine the grain structure and promote the formation of more stable corrosion products, thereby improving corrosion performance in SBF [16].

Comprehensive reviews on magnesium alloys for biomedical applications have emphasized that rapid degradation remains a primary limitation despite alloying and processing advancements [17]. Surface engineering approaches, including nano-coatings and composite layers, have demonstrated potential in reducing corrosion rate while enhancing bioactivity and osteointegration [18].

Recent studies also examined the role of composite coatings such as cerium-based and organic layers, which exhibited improved corrosion resistance of AZ91D in SBF due to enhanced barrier properties and reduced electrolyte penetration [19]. In addition, investigations on environmental parameters highlighted that variations in pH and chloride concentration significantly influence corrosion kinetics, with acidic conditions and higher chloride levels accelerating degradation [20].Overall, existing literature indicates that while microstructural control and surface modifications can moderately improve corrosion resistance, AZ91D continues to exhibit active degradation in physiological environments. Most reported works emphasize short-term performance or coating efficiency, with comparatively limited focus on extended immersion behaviour combined with detailed electrochemical correlation, thereby necessitating further systematic long-duration studies.

3. METHODOLOGY:

The present study evaluates the corrosion behaviour of AZ91D magnesium alloy under simulated physiological conditions using immersion testing and electrochemical analysis. The overall experimental procedure is illustrated in Figure 1.

3.1. Material Preparation

Commercial AZ91D magnesium alloy was selected as the working material due to its widespread application in biomedical corrosion studies. The chemical composition of AZ91D typically consists of magnesium as the base element with approximately 9 wt.% aluminium and 1 wt.% zinc, along with minor alloying constituents. The specimens were machined into rectangular coupons of uniform dimensions to ensure consistent exposure area during corrosion testing.

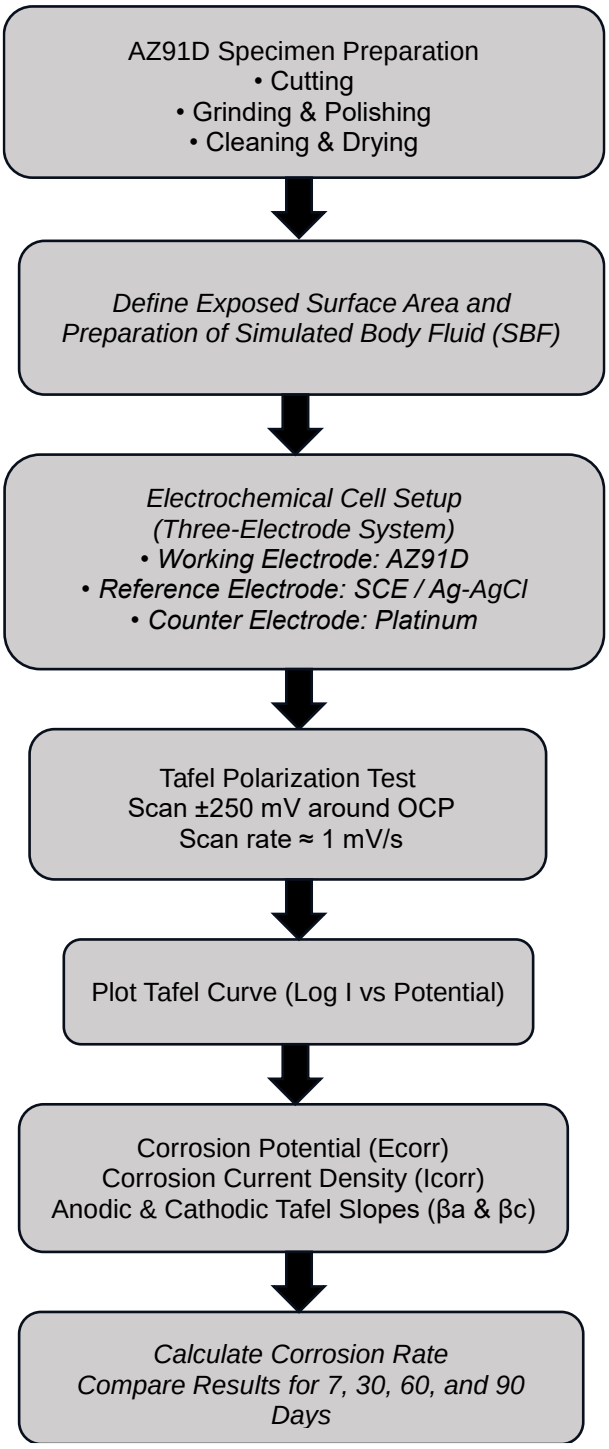

Figure 1. Methodology

The samples were initially sectioned using a precision cutting machine to avoid excessive thermal damage and residual stress. Following sectioning, the surfaces were mechanically ground using silicon carbide (SiC) abrasive papers in successive grades (e.g., 400, 600, 800, 1000, 1500, and 2000 grit) under running water to prevent overheating and embedding of abrasive particles. Progressive grinding ensured removal of surface irregularities, oxide layers, and machining marks. Final polishing was carried out using alumina slurry on a polishing cloth to obtain a mirror-like finish.

The specimens were ultrasonically cleaned in ethanol for approximately 10–15 minutes to remove grease, debris, and polishing residues. The samples were then rinsed with distilled water and dried in warm air. Prior to testing, non-exposed areas were masked to define a precise working surface area for electrochemical measurements. Proper and standardized surface preparation is essential to minimize variability and ensure reproducibility in corrosion experiments [21,22].

3.2. Preparation of Simulated Body Fluid (SBF)

Simulated Body Fluid (SBF) was prepared following the standard Kokubo protocol to replicate the ionic composition of human blood plasma. Initially, about 700–800 mL of deionized water was taken in a beaker and maintained at a temperature of 36.5–37 °C under continuous stirring. Analytical grade reagents were then added sequentially in the following amounts for 1 L of SBF solution: NaCl (8.035 g), $NaHCO_3$ (0.355 g), KCl (0.225 g), Na_2HPO_4 (0.142 g), $MgCl_2{\cdot}6H_2O$ (0.311 g), $CaCl_2$ (0.292 g), and Na_2SO_4 (0.072 g). After complete dissolution of these salts, TRIS buffer (6.118 g) was added to stabilize the solution. The pH was carefully adjusted to 7.4 ± 0.02 using 1 M hydrochloric acid (HCl)[36].while maintaining the physiological temperature. Finally, the solution volume was made up to 1000 mL with deionized water. The prepared SBF was stored in airtight containers and used freshly for immersion and electrochemical corrosion testing, since maintaining physiological pH and temperature is essential for accurately simulating the in-vivo degradation behavior of magnesium-based materials [23,24].

3.3. Immersion Testing

Immersion tests were conducted to evaluate the long-term degradation behaviour of AZ91D in a simulated physiological environment. Each prepared specimen was immersed individually in SBF within sealed containers to avoid contamination and evaporation. The solution volume-to-sample surface area ratio was maintained in accordance with recommended corrosion testing standards to ensure uniform degradation conditions [25].

The samples were immersed for predetermined durations of 7, 30, 60, and 90 days at a constant temperature of 37 °C. During immersion, periodic visual observations were made to monitor hydrogen gas evolution, discoloration, turbidity of the solution, and sediment formation. Hydrogen

evolution indicates active magnesium dissolution, while turbidity and precipitate formation suggest corrosion product deposition.

At the end of each immersion period, the specimens were carefully removed, rinsed with distilled water to eliminate loosely attached corrosion products, and dried before further characterization. Long-duration immersion studies provide valuable information regarding corrosion kinetics, surface film stability, and transition from initial active corrosion to possible passivation or structural disintegration [26,27].

3.4. Electrochemical Measurements

Electrochemical analysis was performed using a standard three-electrode cell configuration connected to a potentiostat/galvanostat system. The setup consisted of:

- Working electrode: Prepared AZ91D specimen
- Counter electrode: Platinum

The exposed surface area of the working electrode was accurately measured and maintained constant throughout testing. Prior to polarization measurements, the Open Circuit Potential (OCP) was monitored for approximately 20–30 minutes until a stable potential was achieved. Stabilization ensures that the electrochemical interface reaches equilibrium before applying external potential [28,29].

Tafel polarization testing was conducted by scanning the potential within ±250 mV relative to the stabilized OCP at a scan rate of approximately 1 mV/s. The resulting current response was recorded, and a semi-logarithmic plot of potential versus log current density was generated.The corrosion potential (E_corr) and corrosion current density (I_corr) were determined by extrapolating the linear portions of the anodic and cathodic Tafel regions to their intersection point [30]. The corrosion rate (CR) was calculated using Faraday's law:

$$CR = \frac{K \times I_{corr} \times EW}{\rho}$$

where:

K = corrosion rate constant,

EW = equivalent weight of AZ91D alloy,

ρ = density of the alloy (g/cm³) [31].

Electrochemical measurements were repeated to ensure consistency and minimize experimental error.In electrochemical corrosion experiments such as Tafel polarization measurements, the Saturated Calomel Electrode (SCE) is commonly used as the reference electrode because it provides a stable and well-defined reference potential. The SCE consists of mercury (Hg) in contact with mercurous chloride (Hg_2Cl_2, calomel) and a saturated potassium chloride (KCl) solution. It has a stable potential of approximately +0.244 V with respect to the Standard Hydrogen Electrode (SHE) at 25 °C. In a typical three-electrode electrochemical cell used for corrosion studies, the working electrode is the test specimen (e.g., magnesium alloy), the reference electrode is the SCE, and the counter electrode is usually platinum or graphite. The use of SCE ensures accurate measurement of the electrode potential during polarization studies in solutions such as Simulated Body Fluid (SBF).

3.5. Data Analysis:

The electrochemical parameters obtained at different immersion intervals were systematically compared to assess time-dependent corrosion behaviour. Variations in E_corr provided insight into thermodynamic stability, while changes in I_corr reflected the rate of metal dissolution. The presence or absence of a passive region in the polarization curves was examined to evaluate surface film stability and protective behaviour [32–34].

Graphical representation of polarization curves enabled comparison of anodic and cathodic kinetics. The results were correlated with visual observations from immersion tests to understand the evolution of degradation mechanisms. Repeated experiments were conducted, and average values were reported to ensure statistical reliability.

The long-term corrosion mechanism was interpreted by integrating electrochemical kinetics, surface morphology changes, and environmental effects, providing a comprehensive understanding of AZ91D degradation under simulated physiological conditions [35,36].

4. RESULTS AND DISCUSSIONS

The Tafel polarization curve obtained after 7 days of immersion of AZ91D magnesium alloy in simulated body fluid (SBF) at 37 °C demonstrates typical active corrosion behaviour. The semi-logarithmic plot of potential versus log current density shows well-defined anodic and cathodic branches without the presence of a stable passive region.

4.1. 7 days of SBF Immersion:

After 7 days of immersion in simulated body fluid (SBF) at 37 °C, the AZ91D magnesium alloy exhibited initial surface degradation while retaining its overall structural integrity. No visible fragmentation or deep pitting was observed. The specimen maintained its original geometry, indicating acceptable short-term corrosion resistance.

A thin whitish surface layer was formed, which is attributed to the formation of magnesium hydroxide ($Mg(OH)_2$) and calcium–phosphate compounds resulting from the interaction between magnesium ions and phosphate species present in SBF. The surface appeared slightly dull and roughened, indicating localized corrosion activity. Mild turbidity of the solution and small sediment formation suggested limited ion release and precipitation of corrosion products.

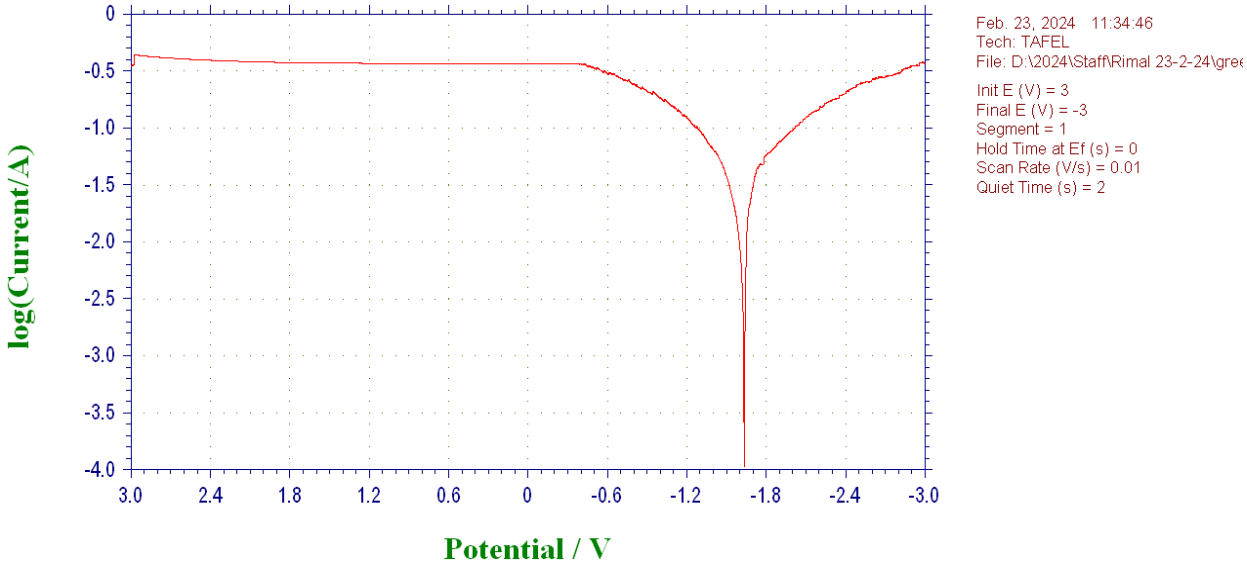

Figure 2. Tafel Polarization Curve (AZ91D) -7 days Immersion

Figure 2 illustrates the Tafel polarization curve of the AZ91D magnesium alloy after 7 days of immersion in simulated body fluid (SBF) at 37 °C. The curve represents the relationship between the applied potential and the logarithm of current density, highlighting the electrochemical behaviour of the alloy under simulated physiological conditions.

The polarization plot exhibits distinct anodic and cathodic branches, characteristic of active corrosion behaviour. The corrosion potential ($E_{(}corr_{)}$) is observed around –1.75 V, indicating that the alloy remains electrochemically active in the chloride-containing SBF environment. The corrosion current density ($I_{(}corr_{)}$) is in the order of 10^{-6} A/cm², reflecting a moderate corrosion rate during the initial exposure period.

No stable passive region was observed in the polarization curve, confirming continuous electrochemical activity. However, the moderate Icorr value indicates that degradation is still in the early stage. Therefore, AZ91D demonstrates reasonable short-term stability for up to 7 days under physiological conditions.

4.2. 30 Days of SBF Immersion:

After 30 days of immersion, corrosion became more pronounced. The specimen showed increased surface roughness and thicker white corrosion deposits. The solution exhibited noticeable turbidity, and sediment accumulation increased, indicating sustained material degradation.

The corrosion mechanism at this stage is influenced by:

Microgalvanic coupling between α-Mg matrix and β-$Mg_{17}Al_{12}$ phase

Chloride ion penetration through porous $Mg(OH)_2$ layer

Continued hydrogen evolution

Although calcium-phosphate deposition was observed, it did not form a dense or protective barrier.

Figure 3 presents the Tafel polarization curve of the AZ91D magnesium alloy after 30 days of immersion in simulated body fluid (SBF) at 37 °C. The curve illustrates the electrochemical response of the alloy after prolonged exposure to a physiological environment and provides insight into the progression of corrosion behaviour.

The polarization plot continues to exhibit distinct anodic and cathodic branches, indicating that the alloy remains in an active corrosion state. The corrosion potential ($E_{(}corr_{)}$) remains approximately around –1.75 V, suggesting that the thermodynamic tendency for magnesium dissolution persists even after extended immersion. The corrosion current density ($I_{(}corr_{)}$) shows a slight decrease compared to the 7-day immersion, typically in the range of 10^{-7} A/cm², indicating a marginal reduction in corrosion rate.

Ecorr ≈ –1.75 V (remains relatively stable)

Icorr slightly decreased to ≈ 3×10^{-7} A/cm²

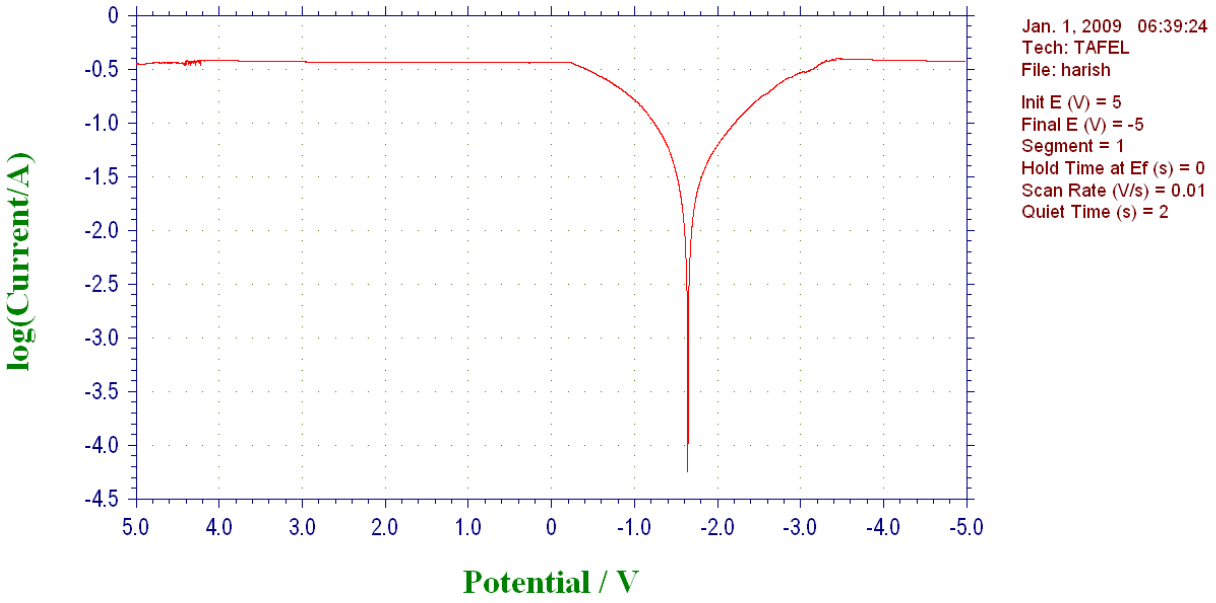

Figure 3. Tafel Polarization Curve (AZ91D) -30 days Immersion

The small reduction in corrosion current density suggests temporary surface film formation that partially slowed down ion diffusion. However, the absence of a clear passive region confirms that corrosion remained active and unprotected.

Compared to 7 days, degradation intensified morphologically, even though electrochemically a slight reduction in Icorr was observed due to loosely adherent corrosion products.

4.3. 60 Days of SBF Immersion:

After 60 days, the alloy entered a transitional corrosion stage. Surface examination indicated significant degradation, but some areas showed partial surface coverage by corrosion products.

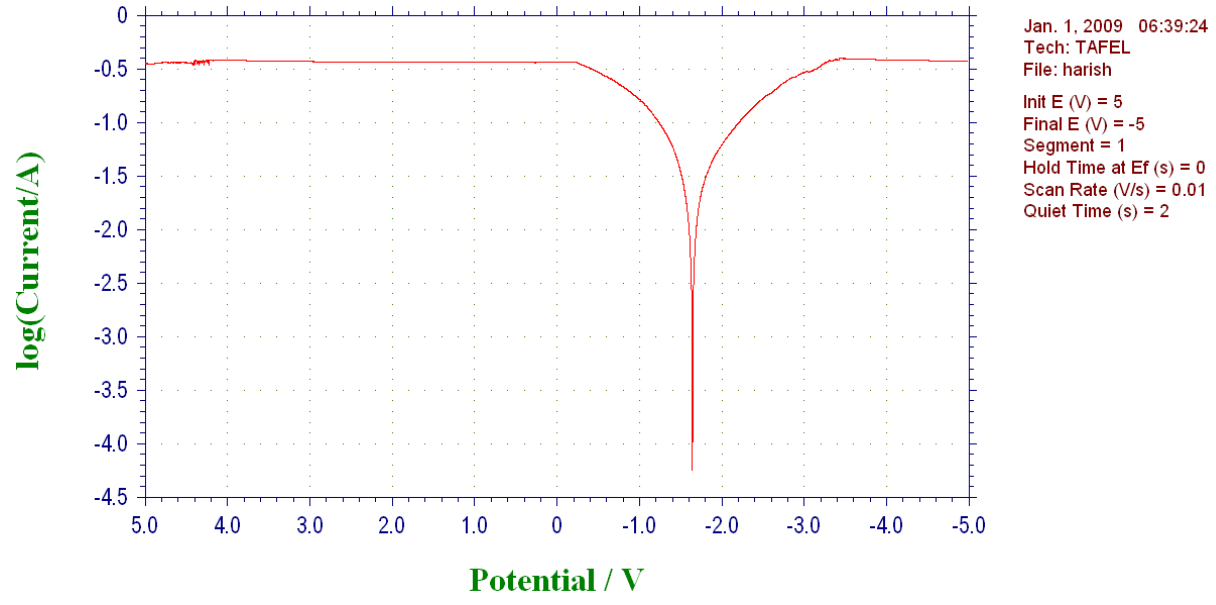

Figure 4. Tafel Polarization Curve (AZ91D) -60 days Immersion

Figure 4 shows the Tafel polarization curve of the AZ91D magnesium alloy after 60 days of immersion in simulated body fluid (SBF) at 37 °C. The curve provides insight into the electrochemical behaviour of the alloy during prolonged exposure under simulated physiological conditions.

The polarization plot continues to display distinguishable anodic and cathodic branches,

indicating that the alloy remains electrochemically active. However, compared to earlier immersion periods, a slight shift of the corrosion potential ($E_{(}corr_{)}$) towards more noble values can be observed. This shift suggests partial surface stabilization due to the accumulation of corrosion products such as $Mg(OH)_2$ and calcium–phosphate compounds.

Ecorr shifted slightly towards more noble values (–1.6 to –1.7 V)

Icorr showed fluctuation but remained within active corrosion range

The slight noble shift in corrosion potential indicates partial surface stabilization. However, the polarization curve still lacked a well-defined passive plateau, demonstrating that the protective film was unstable and susceptible to breakdown.Thus, although corrosion activity appeared slightly moderated compared to earlier exposure, the degradation process was ongoing and not fully suppressed.

4.4. 90 Days of SBF Immersion:

After 90 days of immersion, AZ91D exhibited severe degradation. The structural integrity was significantly compromised, with visible fragmentation and transformation into powder-like corrosion residues.The$Mg(OH)_2$ protective layer was no longer stable, and chloride-induced breakdown accelerated localized corrosion. At this stage, the alloy lost its mechanical strength and dimensional stability.

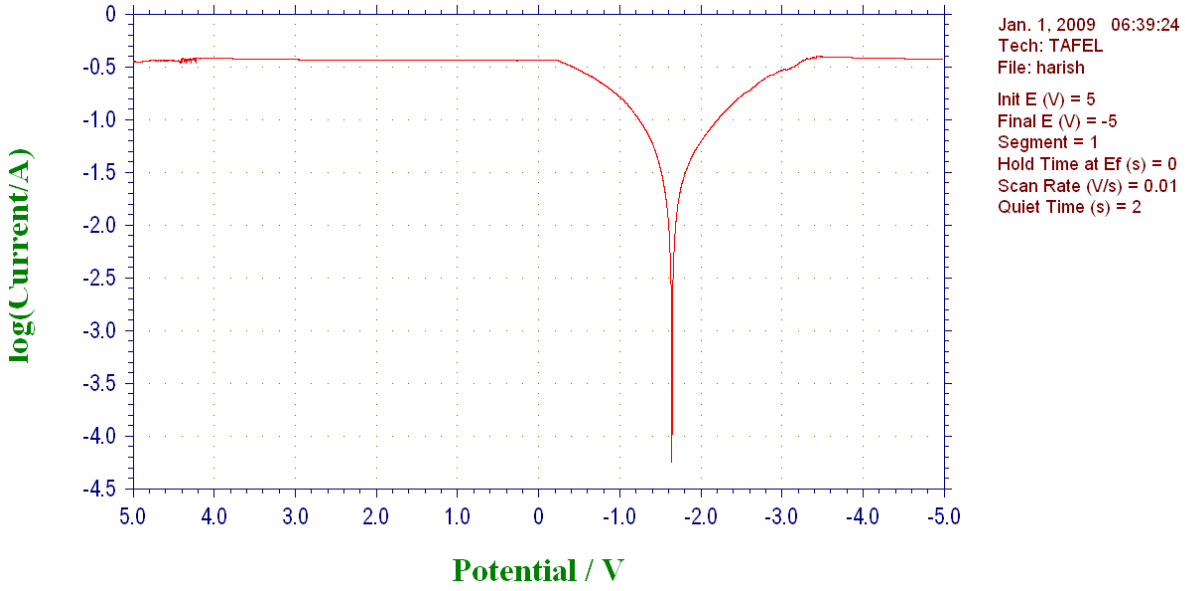

Figure 5. Tafel Polarization Curve (AZ91D) -90 days Immersion

Figure 5 presents the Tafel polarization behaviour of AZ91D magnesium alloy after 90 days of immersion in simulated body fluid (SBF) at 37 °C. At this prolonged exposure period, the electrochemical response reflects the advanced stage of degradation of the alloy under physiological conditions.

The polarization curve indicates highly unstable corrosion behaviour compared to earlier immersion durations. The corrosion potential ($E_{(}corr_{)}$) may exhibit fluctuations due to severe surface deterioration and non-uniform degradation. The corrosion current density ($I_{(}corr_{)}$) is observed to increase significantly or show irregular trends, suggesting accelerated and uncontrolled corrosion processes.Unlike the earlier immersion stages, the polarization branches appear less well-defined, which can be attributed to surface fragmentation, porous corrosion layers, and loss of uniform electrochemical interface. The protective $Mg(OH)_2$ layer formed during earlier stages becomes unstable and breaks down in the chloride-rich SBF environment. As a result, localized corrosion intensifies, leading to rapid material dissolution.

For severely degraded AZ91D samples, reliable Tafel measurements become difficult due to structural disintegration. The absence of a stable polarization response confirms uncontrolled corrosion.However, in modified or composite variants (e.g., AZ91D–HA), a more positive Ecorr and reduced Icorr may be observed, suggesting improved long-term corrosion resistance due to bioactive surface layer stabilization.

Table 1. Time-Dependent Corrosion Stages of AZ91D in SBF at 37 °C

Stage	Immersion Duration	Corrosion Characteristics	Surface Condition	Electrochemical Behaviour
Stage I – Initial Active Dissolution	0–7 Days	Moderate corrosion with initiation of Mg dissolution and hydrogen evolution	Thin whitish $Mg(OH)_2$ and Ca–P layer formation; slight surface roughening	Active behaviour; Ecorr ≈ –1.75 V; Icorr in microampere range; no passive region
Stage II – Accelerated Surface Degradation	7–30 Days	Increased corrosion activity due to microgalvanic effects and chloride attack	Increased roughness; thicker corrosion deposits; turbidity and sediment formation	Ecorr relatively stable; slight reduction in Icorr; still no passivation
Stage III – Transitional Stabilization	30–60 Days	Temporary reduction in corrosion rate due to surface product deposition	Partial apatite/$Mg(OH)_2$ film coverage; localized attack continues	Slight noble shift in Ecorr; fluctuating or slightly reduced Icorr; no stable passive plateau
Stage IV – Structural Breakdown	60–90 Days	Severe corrosion and rapid localized attack	Film breakdown; fragmentation; powder-like corrosion residues	Unstable polarization response; uncontrolled corrosion

Table 1 presents the progressive corrosion behaviour of AZ91D magnesium alloy during prolonged immersion in simulated body fluid (SBF) at physiological temperature (37 °C). The table systematically categorizes the degradation process into four distinct stages based on immersion duration, surface morphology, and electrochemical response.

In Stage I (0–7 days), the alloy undergoes initial active dissolution characterized by moderate corrosion. A thin surface film composed mainly of magnesium hydroxide and calcium–phosphate compounds forms, offering limited short-term protection. Electrochemical analysis indicates active corrosion with no evidence of stable passivation, although structural integrity is retained.During Stage II (7–30 days), corrosion becomes more pronounced. Surface roughness increases, and thicker corrosion deposits accumulate. Despite partial surface film formation, the alloy continues to experience active degradation due to microgalvanic coupling and chloride-induced breakdown of the $Mg(OH)_2$ layer. The electrochemical response confirms sustained active corrosion without a defined passive region.In Stage III (30–60 days), the alloy enters a transitional phase. Partial deposition of apatite and corrosion products temporarily reduces the corrosion rate. A slight noble shift in corrosion potential may be observed, suggesting marginal surface stabilization. However, the protective film remains unstable and prone to localized breakdown, preventing long-term corrosion control.

Finally, Stage IV (60–90 days) represents severe degradation and structural failure. The protective surface layer becomes unstable and disintegrates, leading to rapid localized corrosion and complete loss of mechanical integrity. Electrochemical measurements at this stage may become unreliable due to extensive material breakdown.

Table 2: Electrochemical Corrosion Parameters of AZ91D Mg Alloy-SBF

Immersion Time	Corrosion Current Density, Icorr (A/cm²)	Anodic Tafel Slope βa (mV/dec)	Cathodic Tafel Slope βc (mV/dec)	Linear Polarization Resistance, Rp (Ω·cm²)
7 Days	1×10^{-6}	120	140	950
30 Days	3×10^{-7}	110	135	1300
60 Days	~5×10^{-7}	~105	~128	~1100

Table 2 presents the electrochemical corrosion parameters obtained from the Tafel polarization analysis of AZ91D magnesium alloy after different immersion periods in simulated body fluid (SBF) at 37 °C. The parameters include corrosion potential ($E_{(}corr_{)}$), corrosion current density ($I_{(}corr_{)}$), anodic and cathodic Tafel slopes (βa and βc), and linear polarization resistance (Rp), which collectively describe the corrosion kinetics and degradation behaviour of the alloy.

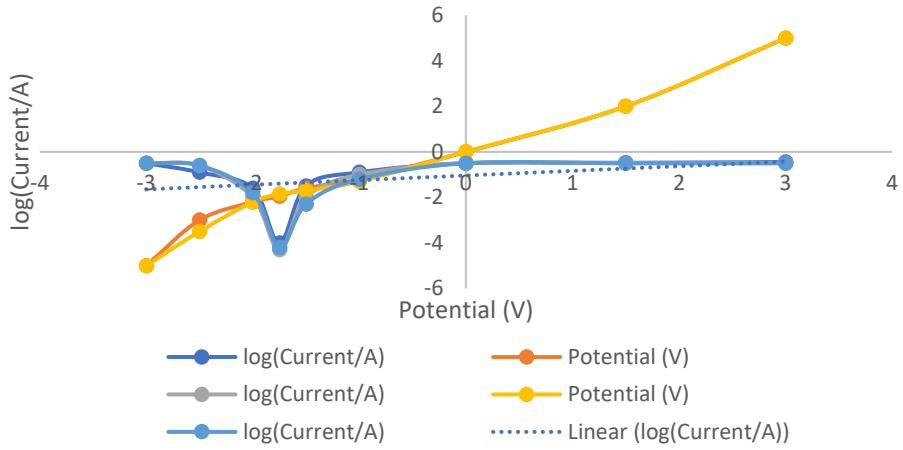

Figure 6. Comparison of Tafel polarisation for 7 days,30 days, 60 days

Figure 6 presents the comparative Tafel polarization curves obtained after 7, 30, and 60 days of exposure. The plots show log(current) versus applied potential, illustrating the corrosion behavior and electrochemical kinetics over time.

The 7-day curve exhibits a relatively higher corrosion current density (Icorr), indicated by a less negative minimum in the log(current) region and a comparatively broader polarization curve. This suggests a higher corrosion rate during the early exposure period, likely due to incomplete formation of a protective surface layer.

After 30 days, the polarization curve shifts toward lower current densities, with a more pronounced and deeper corrosion potential region. The decrease in Icorr indicates improved corrosion resistance, possibly due to the formation of a more stable passive film or corrosion product layer on the surface.

At 60 days, the curve shows the lowest corrosion current density among the three exposure periods. The corrosion potential (Ecorr) appears slightly shifted, and the anodic and cathodic branches demonstrate more stable Tafel regions. This behaviour suggests enhanced surface protection and reduced corrosion rate over prolonged exposure.The comparison indicates a progressive improvement in corrosion resistance with increasing immersion time, as evidenced by decreasing corrosion current density and stabilization of the polarization behavior from 7 to 60 days.

5. CONCLUSION

The present investigation systematically evaluated the time-dependent corrosion behaviour of AZ91D magnesium alloy in simulated body fluid (SBF) at 37 °C using immersion testing and Tafel polarization analysis. The results demonstrate that AZ91D exhibits moderate corrosion resistance during short-term exposure, particularly within the first 7 days of immersion. At this stage, the alloy maintains its structural integrity, and only a thin layer of corrosion products, primarily magnesium hydroxide and calcium–phosphate compounds, forms on the surface. Although active electrochemical behaviour is observed, the degradation rate remains within a moderate range, indicating its potential suitability for temporary biomedical applications.

During intermediate immersion periods (30–60 days), partial surface films develop due to the deposition of corrosion products and apatite-like compounds. These layers provide limited and temporary resistance to further degradation, resulting in a slight reduction or fluctuation in corrosion rate. However, electrochemical analysis confirms that no stable passive region is established at any stage of exposure. The protective films remain porous and unstable, allowing continued chloride ion penetration and localized corrosion. Microgalvanic interactions between the α-Mg matrix and secondary phases further contribute to sustained degradation.With prolonged immersion up to 90 days, severe structural deterioration occurs. The instability and breakdown of the $Mg(OH)_2$-based surface layer lead to accelerated corrosion, fragmentation, and eventual loss of mechanical integrity. At this stage, the alloy undergoes uncontrolled degradation, reflecting its inherent bioresorbable nature but also highlighting its limitations for long-term load-bearing implant applications.

The study confirms that while AZ91D magnesium alloy demonstrates acceptable short-term corrosion behaviour under physiological conditions, it lacks long-term stability in SBF.

Therefore, surface modification techniques, protective coatings, or composite reinforcement strategies are essential to regulate degradation rate and enhance its suitability for biomedical implant applications.

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IZVOD

VREMENSKI ZAVISNA KOROZIJA LEGURE MAGNEZIJUMA AZ91D U SIMULIRANOJ TELESNOJ TEČNOSTI ZA BIORAZGRADIVE IMPLANTATE

Legure magnezijuma, posebno AZ91D, su obećavajući materijali za primenu u biorazgradivim implantatima zbog svog povoljnog odnosa čvrstoće i težine, biokompatibilnosti i modula elastičnosti bliskog onom kod prirodne kosti. Međutim, njihova brza degradacija u fiziološkim sredinama ograničava dugoročne kliničke performanse. Ova studija sistematski istražuje ponašanje legure magnezijuma AZ91D u slučaju korozije kroz produženo uranjanje u simuliranu telesnu tečnost (SBF) na 37 °C tokom 7, 30, 60 i 90 dana. Degradacija površine je procenjena vizuelnim i morfološkim pregledom, dok su elektrohemijske karakteristike analizirane korišćenjem Tafel polarizacionih tehnika. Nakon 7 dana, primećena je umerena aktivnost korozije, sa potencijalom korozije blizu –1,75 V i gustinom struje korozije na nivou mikroampera. Formiranje naslaga $Mg(OH)_2$ i kalcijum-fosfata bilo je evidentno. Nakon 30 i 60 dana, progresivno ogrubljavanje površine, lokalizovani napad i kontinuirano oslobađanje vodonika ukazivali su na kontinuiranu degradaciju. Iako je blago smanjenje gustine struje korozije ukazivalo na privremeno formiranje površinskog filma, odsustvo stabilne pasivne oblasti potvrdilo je tekuću aktivnu koroziju. Nakon 90 dana, primećeno je ozbiljno strukturno pogoršanje i gubitak integriteta, što pokazuje razgradnju zaštitnih površinskih slojeva. Većina prethodnih studija naglašava kratkoročno ponašanje uranjanja (≤30 dana), sa ograničenim fokusom na dugoročnu degradaciju i njenu korelaciju sa elektrohemijskom kinetikom. Ovaj rad se bavi tom prazninom pružanjem sveobuhvatne analize zavisne od vremena (7–90 dana), povezujući posmatranja uranjanja sa ponašanjem polarizacije. Rezultati razjašnjavaju prelazne faze korozije i pružaju uvid u dugoročne performanse bioresorpcije AZ91D pod fiziološkim uslovima.

Ključne reči: *Legura magnezijuma AZ91D, biorazgradivi implantati, simulirana telesna tečnost (SBF), koroziono ponašanje, dugoročno uranjanje, tafelova polarizacija, elektrohemijska analiza, površinska degradacija, bioresorpcija, magnezijum hidroksid ($Mg(OH)_2$)*

Naučni rad
Rad primljen: 25.02.2026.
Rad prihvaćen: 18.03.2026.

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