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Tailored Reinforcement Strategies for Next-Generation Magnesium Matrix Composites

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Abstract: The low density, light weight structural and qualities of magnesium metal matrix composites have made them a major player in a large number of applications, including chemical, biomedical, automobiles and aeronautical engineering. The present literature review on magnesium-magnesium metal composites (Mg-MMCs) covers topics such as processing methods, tribological properties, characterization and mechanical behaviour. This work also provides an explanation of the Zinc, CNT, hydroxyapatite, Carbon-based materials, bioglass, SiC, Al_2O_3, graphene and TiO_2 and Fe_3O_4 reinforced Mg-MMC articulates. Thus, for a variety of innovative techniques, compressive strength, hardness, tensile strength behaviour, tribological characteristics such as rate of wear and corrosive efficiency was examined. The observation indicates that the substance's durability and hardness are increased by the ceramic reinforcement. The ductility was still reduced, however the TiO_2-based metallic reinforcement can improve strength and ductility of Mg-MMCs.

Keywords: Composites; Magnesium; Characterization, light weight

1. INTRODUCTION

Bone breaks are a typical result of injuries or infections, like osteoporosis. About one-third of bone cracks detailed in a year require interior fixation plates to assist with working with recuperating. During recuperating, screws metal plates and metal plates help in adjusting and balancing out the cracked bone pieces. Decision of metal relies upon its erosion opposition, bioinertness, strength and biocompatibility (Chaya, 2016). Metallic inserts are liked for load bearing muscular applications over ceramic and polymer-based inserts because of their higher strength, exhaustion opposition, and crack sturdiness. The ordinary materials accessible in the muscular business for extremely durable inner break obsession are titanium and its compounds, 316L hardened steel, and cobalt–chromium composites (Krishnakumar, 2021).

These inserts are described as “highly durable” because the embed flops inside the patient’s body post-break has sufficiently recuperated. These metal materials are considered to be the best quality, but they have their limitations as well. Releasing toxic metallic particles from existing structural metal biomaterials due to wear is an important issue and can lead to adjacent tissue necrosis (Hanawa, 2012) These inserts are likewise connected with long haul intricacies, like obstruction with skeletal development, tissue bothering and contamination, also surrounding bones starts weakening (Allen et al., 1997. Chaya, 2016).

Moreover, as of now accessible long-lasting fixation plates have higher versatile modulus in contrast with normal bone (Heiden et al., 2015). The bungle of flexible moduli between normal bone and super durable embed raises the chance of the pressure protecting peculiarity, which unfavorably influences the bone redesigning process at the crack site and prompts break shakiness (Staiger et al., 2006).

Hence, an optional evacuation medical procedure is required once the fracture is healed. Be that as it may, second a medical procedure frequently prompts new tissue harm, expanded contamination risk, high therapy cost, and languishing. This prompts the improvement of a degradable crack obsession gadget that will give break security all through the recuperating period and normally debase once the mending is finished. Not at all like super durable inserts, degradable inserts can keep a harmony among strength and corruption (Dutta et al., 2020).

Consequently, degradable inserts relieve long haul intricacies and dispose of the prerequisite briefly medical procedure. As of now, degradable crack fixation plates are made of polymeric materials, like poly lactic corrosive (PLA), which experiences mediocre mechanical properties (Nagels et al., 2003). Along these lines, broad examination is centered around creating degradable metals for break obsession gadgets. Recently, magnesium-based break fixation plates are particularized due to their higher strength and excellent mechanical properties such as Young’ modulus and the

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compressive yield strength comparable to the natural bone (Tan et al., 2013, Huang et al., 2020).

Magnesium is the fourth most plentiful cation in the human body, and most of physiological magnesium is put away in bone. Magnesium likewise fundamentally affects human digestion, and it shows stimulatory consequences for new bone development (Y. Ren et al., 2018). Moreover, corruption of magnesium-based inserts in physiological arrangement prompts a dissolvable, nontoxic oxide that can be discharged effectively without bringing on any difficulties.

Thus, magnesium-based fixation plates may be employed as biodegradable muscular inserts (for non-load-bearing applications), such as maxillofacial plate screws and impedance screws. It is also presumed that these plates would provide sufficient mechanical strength at the fracture site while the new bone tissue heals and will subsequently be resorbed by normal tissue. Throughout recent many years, broad examination has zeroed in on creating Mg-based biomaterial (Saris et al., 2000, Naujokat et al., 2020). However, the concern of whether magnesium is suitable for crack obsession devices was raised by its mechanical characteristics and bad degradation. Several approaches, such as composite readiness with appropriate bioactive fortifications, alloying, or surface enhancements, have been used to assess the problems of consumption and low yield strength of pure magnesium. Composite advancement is gaining attention among them. Fostering the required biodegradable magnesium-based composite requires a thorough understanding of the handling techniques and supporting materials.

In this way, we expect to give a far reaching portrayal of a few bioactive and bioactive fortifications that are utilized to plan Mg composites alongside the composite handling strategies. Researchers focus on how support determination and composite planning affect the mechanical, consumption, and organic properties of magnesium-based composite biomaterials (Kannan et al., 2008).

Material plan and handling methods assume a significant part in the improvement of Mg-based degradable MMCs. The essential necessity for Mg-based degradable MMCs is to give adequate mechanical dependability during the break mending period and afterward corrupt bit by bit without bringing on any antagonistic host reaction. The fast corruption of Mg amalgams attributable to their entomb galvanic erosion during in vivo study could cause loss of their mechanical trustworthiness, prompting prior embed disappointment. Besides, uncontrolled debasement of Mg-based inserts brings about over the top hydrogen gas development around the embed locales, which shapes a gas pocket and diminishes the embed's biocompatibility (Dutta et al., 2020). Accordingly, it is basic to control the erosion rate as well as the mechanical properties of Mg-based inserts for their effective execution.

The mechanical properties and consumption opposition of Mg-based MMCs can be constrained by choosing fitting fortifications (M Staiger et al., 2006). Coming up next are the particular choice rules for fortifications to be utilized in Mg-based MMCs: 1. Reinforcement should be biodegradable in order to eliminate osteolysis caused by degradation products.2. For quick bone crack healing, the reinforcement of the biodegradable products needs to be biocompatible and preferably osteogenic. 3. The reinforcement to increase the Mg composite's resistance to corrosion and provide embed-related crack soundness. 4. In order to provide adequate mechanical security at the body's break point, reinforcing works to improve the mechanical characteristics of magnesium composite.

2. REVIEW OF LITERATURE ON MAGNESIUM BASED COMPOSITES

The literature review part contains the detail study about the metal matrix composites of magnesium alloy in the chronological order (2015-2025).

Khalajabadi et. al. (2015) reported that composites made of magnesium and hydroxyapatite have demonstrated promise for use as biodegradable metal matrix composite implants. The substantial aggregation of HA particles has limited the mechanical characteristics and corrosion resistance of magnesium-hydroxyapatite composites. In this study, different amounts of hydroxyapatite (HA) and magnesium oxide (MgO) nanopowders were added to pure magnesium to improve the bio-corrosion properties of a Mg/HA-based composite. The Mg/HA/MgO nanocomposites were then made using a blend-cold press-sinter powder metallurgy (PM) technique, which produced better results than the magnesium-hydroxyapatite composites.

Dezfuli et al. (2017) created Mg-matrix composites using bredigite as the reinforcing component and outperformed Mg in terms of degradation resistance. On the mechanical behaviour of the composites before and after deterioration, the impacts of the materials processing method and process parameters were not yet known. This study focused on the mechanical properties of magnesium-bredigite composites both before and after degradation. It was found that by optimizing the Pressure Assisted Sintering (PAS) process parameters, low-porosity Mg-bredigite composites with strong interfaces between uniformly distributed bredigite particles and the Mg matrix could be created.

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Vahid et.al. (2017) presented that pure magnesium (Mg) implants don't perform well mechanically, especially when used in load-bearing applications. In comparison to unreinforced metals, Particulate-Reinforced Mg Composites are known as Promising Materials to Provide Higher Strength Implants. The current research uses biocompatible tantalum (Ta) and niobium (Nb) particles as reinforcement to create magnesium-niobium and magnesium-tantalum composites using a powder metallurgy method including ball milling. The effects of Nb and Ta contents on the microstructure and mechanical properties of the Mg matrix were investigated. There was no intermetallic formation, a uniform distribution of reinforcements, and a respectable level of integrity in the magnesium matrix. The amount of reinforcement used affects the compressive mechanical properties of composites. The perfect composition with the proper strength, hardness, and ductility is suggested, as are the ideal parameters to produce biocompatible magnesium composites.

Munir et.al. (2019) created graphene nanoplatelets (GNPs)-reinforced magnesium (Mg) metal matrix composites (MMCs) using powder metallurgy (PM). High-energy ball-milling techniques were used to distribute GNPs with varying concentrations (0.1, 0.2, and 0.3 weight percent), layer thicknesses (5 nm and 9 nm), and particle sizes (15 µm and 5 µm) into magnesium powder. Transmission electron microscopy (TEM), scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD), Raman spectroscopy (RS), and compression tests were used to analyze the mechanical characteristics and microstructure of the produced composites. Hydrogen evolution measurements and electrochemical tests were used to assess the corrosion resistance. Osteoblast-like SaOS2 cells were used to evaluate the cytotoxicity of Mg-GNPs composites. The findings demonstrate that GNPs are a great option for reinforcing magnesium matrices in the production of biodegradable magnesium-based composite implants. Through synergistic strengthening processes, the addition of GNP improved the mechanical characteristics of magnesium.

Ghasali et.al. (2019) demonstrated the consumption behavior and in vitro bioactivity of two types of permeable Mg-metal lattice nano-composites that were separately constructed using Si_3N_4 particles and Al_2O_3 stubbles. Using ethanol media and high-energy ball processing, 10 weight percent of the support was combined with magnesium for ten minutes. At the final stage of drying on a radiator/stirrer at 70 °C, 10 ml of ethylene glycol was added to the processed blend. The powder mixtures were uniaxially crushed at 300 MPa after being blended for 12 hours to produce bar-molded green samples. A graphite bed was not absorbed during the 650 °C microwave sintering process. Using the Archimedes rule, porosity of about half was calculated for both sintered composites. As a result of the reaction between Mg and Al_2O_3, the XRD analyses revealed Mg_2Al_3 and MgO stages.

Jayasathyakawin et al. (2020) studied that the potential application of Magnesium matrix composites is in the field of aerospace, orthopedic application and defence organization due to its low density, good physical and mechanical properties. The phrase "powder metallurgy" (PM) refers to a variety of processes that use metal powder to create components. Biocomposite based on magnesium (Mg) is utilized in biomedical applications such hip joints, dental implants, cardiovascular stents, and bone fixation. PM is the best technique among the others for creating magnesium matrix composites for use in biomedical applications. The significance, creation, and characteristics of magnesium matrix composites for biomedical applications were discussed by the authors. The mechanical characteristics of the generated magnesium matrix composites revealed that they would be a good option for biodegradable implants.

Radha and Sreekant (2020) discovered that the magnesium composites' biocompatibility and biodegradability make them stand out for utilization in biomedical applications. Because of its similar synthetic and crystallographic structures to bone, hydroxyapatite (HA) is recognized as being extremely bioactive. In order to combine the benefits of both Mg and HA, HA is acknowledged as an anticipated clay material for the production of Mg-based composites. However, generally speaking, the network combination is more resilient to consumption attacks than the composites. Therefore, Sn is used as an alloying component in the current work to evaluate its effect on the mechanical and consumption features of Mg/HA composites. Leading the pressure and tiny hardness tests allowed for the evaluation of mechanical properties. Straight polarization, Tafel, and electrochemical impedance spectroscopy (EIS) techniques were used to focus on the erosion characteristics of as-projected composites. The results of XRD and SEM-EDS revealed that the main established periods of as-projected Mg/HA composites were α-Mg and HA; nevertheless, in Mg-Sn/HA composites, the stage Mg_2Sn was observed accompanying fine dispersion of HA particles.

Tan et al. (2021) found that biodegradable magnesium (Mg) alloys have not yet been successfully used in clinical settings for implant applications, partly because of their quick corrosion after the first implant period in the physiological environment. The best method for overcoming the high rate of corrosion and enhancing the biomedical performance of magnesium alloys is still surface modification. Despite a great deal of research on surface alterations, there are still issues with the methods used today. Additionally, layered

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double hydroxide (LDH) films are a possible next-generation coating for implant applications due to their biodegradability and biocompatibility. This review details the recent development of LDH and its composite coatings on Mg alloys as a potential protective coating for implant applications. The synthesis parameters affecting the structural and morphological properties of LDH films are discussed. The state-of-the-art of LDH and its composite coatings for corrosion mitigation are also assessed. The current difficulties, restrictions, and potential uses of LDH as a multipurpose coating on magnesium alloys for biodegradable implant applications round up this review.

Dubey et al. (2021) revealed that the best reinforcement for adjusting the debasement energy of magnesium-based temporary muscle inserts is hydroxyapatite. However, a major obstacle to their combination has been the negligible cooperation between hydroxyapatite and magnesium during the sintering process because to the huge difference in their liquefying temperatures. By making it transparent with the Mg matrix, doping pure HA with Mg2+ and Zn2+ particles could be an acceptable arrangement. Additionally, such doping results in a science that is more similar to the typical apatite seen in human bone. In this review, flash plasma sintering is used to blend and build up doped hydroxyapatite (CoHA) with Mg2+ and Zn2+ particles to achieve high thickness in magnesium-based composites. This study sheds light on the possibility for creating and developing M3Z-CoHA composites for temporary orthopedic implants.

Sun et al. (2022) created a unique matrix composition of Mg-10Li-3Al (wt.%, LA103) reinforced with ex situ micron TiB2 particles. This material could be prepared under stir casting circumstances with good dispersion thanks to the ball milling and cold pressing pretreatment of the reinforcements. The microstructure and mechanical characteristics of the composites made using various pretreatment techniques were thoroughly examined. Because highly wettable core-shell units formed in the melt, the TiB2 particles in the Al-TiB2/LA103 composite utilizing the pretreatment technique were dispersed throughout the microstructure. TiB2's potent grain refining impact was primarily responsible for the composites' strengthening effect. With the traditional stir casting technique, this result demonstrated a balance between high specific modulus (36.1 GPa·cm3·g-1) and elongation (8.4%), which is highly applicable.

Tuminoh et al. (2022) discovered that throughout the past ten years, magnesium alloys have been regarded as absorbable metals for biomedical applications, and some of them have been used in clinical settings as temporary bone implants. However, their strength and degradability continue to restrict their broad application. Adding carbon nanofibers to magnesium alloys to create composites is one method of improvement. The goal of this effort is to create carbon nanofiber-reinforced magnesium-zinc (Mg–Zn/CNF) composites that are biocompatible and have the best strength and degradability. A response surface method was used to determine their optimum process parameters (composition, compaction pressure, and sintering temperature), and analyse the resulting properties (elastic modulus, hardness, weight loss, and cytocompatibility). Future researchers who are eager to find ways to create Mg–Zn/CNF composites with excellent mechanical properties, corrosion resistance, and biocompatibility can also use this study as a starting point.

Verma and Ogata (2023) investigated that Magnesium (Mg) and its alloys have been shown to be favorable for orthopedic and cardiovascular medical device fabrication applications; however, in the context of a living organism, they naturally degrade biologically when placed with an aqueous solution of the substances and/or water-saturated tissue. Magnesium's low corrosion resistance reduces the implants' mechanical qualities and increases their harmful effects on bone metabolism. The protective polymeric deposit coatings are a promising way to increase the corrosion resistance of magnesium alloys without altering their characteristics. Additionally, biopolymers have been employed as a composite component to improve the mechanical and biocompatible properties of magnesium-based materials. Their favorable mechanical and thermomotive qualities, along with their biocompatibility, may aid clinicians in resolving current orthopedic-related problems.

Sundram et al. (2023)) revealed that because magnesium oxide (MgO) is a biocompatible and biodegradable metal, researchers are interested in using it to replace standard 316L stainless steel in the biomedical industry. Using the bottom pour stir casting technique, MgO and Tricalcium Phosphate (TCP) were combined in different ways to create MgO composites. Sample 1 was a MgO alloy, Sample 2 was a MgO with 5 weight percent TCP, and Sample 3 was a MgO with 10 weight percent TCP. All three samples were manufactured at 9600C and extruded as rods. Rods were divided into billets for microstructure study, hardness testing, and scanning electron microscopy, and the outcomes were compared. Sample 3 of the three composites—90 weight percent MgO and 10 weight percent TCP—performs better than the other samples and alloy. The microstructure and hardness value of magnesium composites containing 10% TCP were improved, suggesting that they could be utilized as biodegradable materials in the biomedical industry.

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Saberi et al. (2024) Investigated that magnesium (Mg) is a desirable material for orthopedic applications because of its density and elastic modulus, which are similar to those of the body's natural bones, as well as its biodegradability and good tensile strength. However, it has significant drawbacks, such as a rapid rate of deterioration and consequent loss of mechanical capabilities when exposed to the biological environment over extended periods of time.

Also, among its other weaknesses, it can be mentioned that it does not deal with bacterial biofilms. It has been discovered that creating composites by combining their different components might be an effective method of enhancing their qualities. Magnesium oxide nanoparticles (MgO NPs) are a good option for reinforcement in composites because of their unique physicochemical and biological characteristics, which include biocompatibility, biodegradability, high bioactivity, significant antibacterial properties, and good mechanical properties. However, a hurdle in their application is the lack of a thorough understanding of how well Mg NPs work as Mg matrix reinforcements in the disciplines of biology, corrosion, and mechanics. This article highlights the key findings of recent studies on the mechanical, corrosion, and biological performance of Mg/MgO composites while introducing the role of MgO NPs in medical domains.

Nikem et al. (2025) examined the creation and improvement of magnesium matrix composites (Mg-MMCs) for use in biomedical applications, emphasizing the incorporation of ceramic reinforcements to promote biocompatibility, corrosion resistance, and mechanical qualities. The study tackles the drawbacks of conventional internal fixation devices composed of titanium or stainless steel alloys, which frequently necessitate removal procedures and present hazards like corrosion and stress shielding. The study investigates whether Mg-MMCs can function as efficient biodegradable substitutes for biological equipment such as load-bearing implants.

Motaharinia et al. (2025) discovered a variety of manufacturing processes used to produce metallic scaffolds, with an emphasis on those composed of alloys based on magnesium. Both contemporary fabrication approaches based on additive manufacturing and conventional production processes, such as the directional solidification of metal-gas eutectic technology, pattern casting, and methods utilizing space holders. Mg-based scaffolds in terms of their mechanical characteristics, microstructure specifications, corrosion and degradation behavior, antibacterial activity, and biocompatibility (in vitro and in vivo).

Although a great deal of research has been done to optimize the manufacturing parameters and qualities of Mg-based scaffolds for use in biomedical applications, particularly for bone tissue engineering applications, more research is required to fabricate these scaffolds with specific properties, such as high corrosion resistance, good antibacterial properties, osteoconductivity, osteoinductivity, and the ability to elicit a favorable response from osteoblast-like cell lines.

METHODS

3. CONCLUSION

This study looks at the mechanical, tribological, and reinforcing material performance of MMCs. To enhance the engineering use of magnesium alloys, many types of MMCs with different dimensions, configurations, and categories of reinforcement components are manufactured. The primary component influencing the microstructure's composition and mechanical behaviour in accordance with requirements is the correct construction and reinforcing of MMCs. Following this review examination, the following was noted: The GNP reinforcement approach is novel due to its appealing mechanical characteristics. In contrast to CNTs, the TiO_2 and SiC reinforced magnesium alloy-based matrix offers the best relationship to the fibre matrix. As a result, the reinforced MMCs increased in tensile strength, hardness and thermal growth. The CNT-reinforced MMCs also achieved a low mass density and high strength because of the decrease in the coefficient of friction. In contrast to TiO_2 and SiC, light weight MMCs are produced using CNT manufacturing. SiC is used to decrease the corrosion resistance qualities, however other reinforced particles improve the properties. Additionally, by employing novel organic materials like fly ash and other materials, the mechanical and tribological properties are improved in hybrid composites.

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