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Effect of machining on biodegradable magnesium alloys used for tissue engineering

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Abstract

Magnesium alloys have evolved into future biomaterials that are considered biodegradable in nature. These alloys are suitable for the purpose of manufacturing bone scaffolds and implants. The manufacturing process and process parameters have a great influence on the surface and mechanical properties. In the present investigation, the effect of machining process parameters on surface integrity, corrosion behavior and mechanical characterization is analyzed. Magnesium alloys are recommended in these approaches as future biomaterial. The approach was recommended in the future development of biomedical Mg alloys.

Keywords: machining, Magnesium, engineering, biomaterials

1. Introduction

The tissues or bone could be damaged due to the cause of accident or certain diseases. The numbers of surgical procedures are performed to repair or replace these affected tissues and bone. Some examples of the traditionally repairing techniques are all grafting and auto grafting but these techniques could be painful for human as well as longer to heal completely and also sometimes it could not comfortable in the human body [1, 2]. To overcome these problems, an advance field has been introduced and that would be known by Tissue Engineering for replacing and repairing of tissues/bones. The development of Tissue Engineering, the procedure in which the cells are biopsy from the human body and being implemented bio-medically by cell isolation, the cells will grow in a porous biomaterial bone or tissue scaffold, which act as templates for tissue regeneration, to guide the growth of new tissue [3]. While these metallic biomaterials have some short comings [1] decomposition of the material can result in cytotoxicity in vivo, cause local allergic reaction or infection, decrease biochemistry [2]. As well, the unmatched mechanical properties of metallic biomaterials mainly the elastic module of these conventional materials induce stress shielding effect, and increase the chance of secondary bone fracture [3].

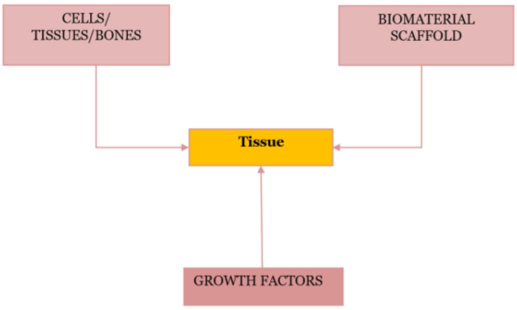


Fig 1: Schematic diagram of Tissue Engineering process.

The damaged tissues/cells/bones were replaced by using porous biocompatible scaffold in tissue engineering [7, 8]. Tissue engineering associations with the principles of materials and cell replacement was to develop temporary tissues and support endogenous regeneration of tissue. The approach was initially considered to report of the critical gap between the increasing number of patients to come list for organ replacement due to last-stage failure and the partial number of donated tissues available for such techniques [9].

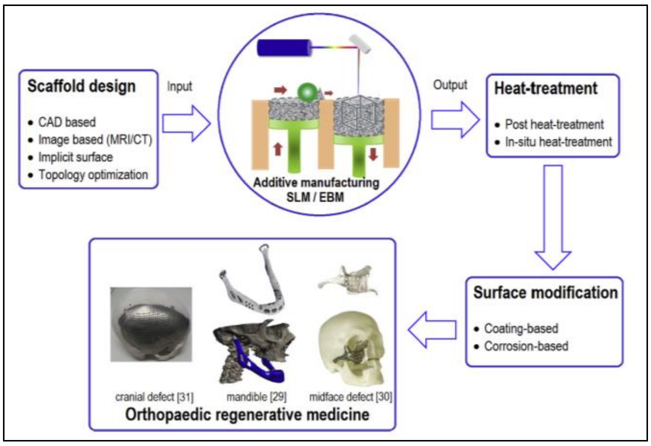


Fig 2: Scaffold cycle diagram for tissue engineering.

The porous structure provides the biological environment to the implant, which plays an important role in the proliferation and growth of cells during implantation, helping in tissue repair and providing mechanical stability [10]. Implant and scaffold materials that must be bioresorbable, biocompatible and have good strength. The modulus of elasticity of the implant material should be close to that of the natural bone [11].

Polyglycolic acid (PGA) and poly lactic acid (PLA) are used as a biodegradable polymer material for implantation and scaffolding. Polymer materials lose their mechanical integrity in a month, which are the main drawbacks of these scaffolds. The loss of mechanical integrity faced due to the rapid degradation rate of polymeric materials in body environment [12]. From the materials science point of view the main groups of biomaterials such as ceramics, composites, metals and polymers are in biomedical field. Ceramics such as calcium phosphate are widely used as a coating material, which is non-toxic in nature, good osteoporosis, and biochemistry [13]. Moreover, they have the high corrosion rate and poor mechanical properties in the acidic environment, which restrict their usage as bone implant in load bearing areas [14].

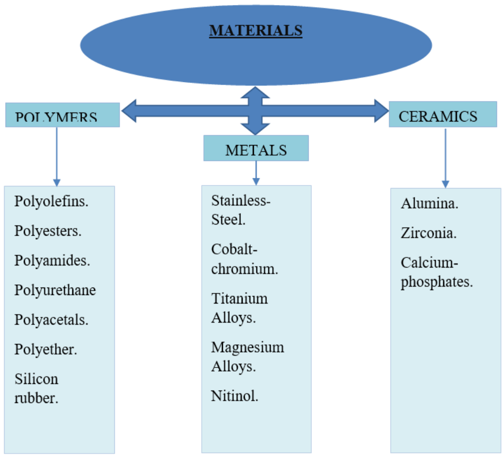


Fig 3: List of materials used in tissue engineering scaffolds.

In the recent investigated, Magnesium, zinc and ferrous alloy consider as smart implant materials among the metallic biodegradable metal implants. The loss of mechanical integrity has before the healing period of host bones are the most significant challenge [15]. Mg- and Fe-based implants exhibit good mechanical properties as hard tissue implants. Ferrous and magnesium based hard tissue implants are exhibited the high mechanical strength. Moreover, very low corrosion rate of Fe-based materials and high corrosion rate of Mg-based materials are limited their use as biodegradable implants. Degradation rate of pure magnesium can be improved as a biodegradable material by surface modification and alloying [16, 18].

For biomedical applications polymeric biomaterials are widely used. The surface properties of polymeric biomaterials can be easily modified. Mechanical and chemical properties of polymers can be change to certain degrees during sterilization. However, polymers limited the applications due to their undesirable mechanical properties [19].

Polymers can be used as scaffold biomaterials due the ease in fabrication of polymeric implants and scaffolds, good biodegradability and biocompatibility of polymers. Main focus of researcher was on polymeric structure for enhancing mechanical properties used in the medical implants [20].

Recently, Magnesium (Mg) has interest for the application of biodegradable scaffolds since it possesses good mechanical strength, low value of elastic modulus, good biocompatibility, bio resorbable and ability to allow osteoblastic activity [21, 22]. Magnesium (Mg) is a metal, which is used for bone applications due to the similarity in properties of Mg (i.e. density (1.74 g/ cm3), Young's modulus 45 GPa) and human bone (i.e. 1.8-2.1 g / cm3 and 40-57 GPa). But they are faced some problems which are mentioned below:

- High Corrosion Rate

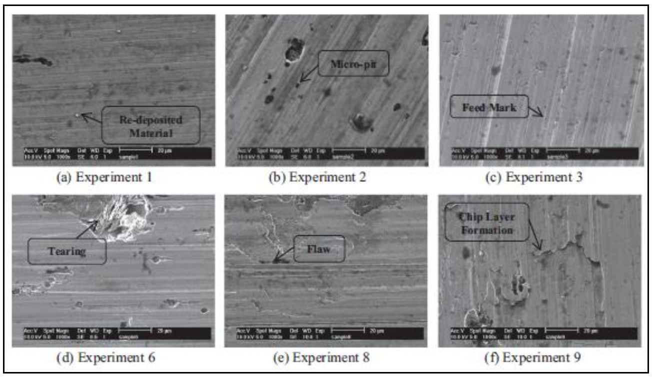
The corrosion rate of Mg based scaffold is high due to this early degradation of the scaffold. Sometime it may be degrading before the bone healing process.

- Hydrogen Evolution

Evolution of hydrogen bubbles during the degradation of Mg scaffold implant. It would reflect the healing process and may lead to tissue damage due to formation of gaps between the implant and the tissue [23, 24]. There are three main groups of Mg alloys. First group including pure Mg, second group consists of aluminium (Al) containing alloys such as AZ91, AZ31 and rare earth elements (RE) such as AE21. Third group made of Al free alloys such as Mg-Ca, WE, Mg-Zn and WZ. Pure Mg results in very high degradation rate and loss of necessary mechanical strength before the healing time [25, 26].

Effect of machining process parameters on response parameters on the biodegradable mg alloys

The grain refinement of ZM21 takes place due to the re-crystallization temperature during the hot rolling [27]. Dekena *et al*. has been observed that corrosion rate and compressive stress in turning sub-surface have been higher than the deep rolling sub surface [28, 29]. The surface integrity of dry and cryogenic AZ31B turning surface with various tool radiuses has been investigated in present research. The machined with the tool larger edge have better surface finishing, nano-crystal grain structure higher compressive residual stress [30]. The influence of turning process parameters in dry and MQL cutting conditions on AZ91D magnesium alloy using uncoated WC tool. Best surface roughness is obtained with lowest feed rate and cutting speed under MQL cutting condition [31]. Shi *et al*. investigated the effect process parameters on surface roughness and cutting force. The production efficiency and surface finishing of AZ91D are improved with lower feed rate and the higher cutting speed of milling machining [32]. The influence of milling process parameters on hardness and surface roughness has been investigated in present research work. The main aim of present work to corrosion resistant of Mg/Mg-based alloys. The tool speed and depth of cut have high most influencing on surface roughness whereas, the feed rate and tool speed most influencing on hardness. M. S. Uddin *et al*. has been investigated the effect of milling process parameters on surface integrity and hardness. The enhanced surface integrity also improved the corrosion resistant of AZ31 Mg alloys [33].



(a) Experiment 1 (b) Experiment 2 (c) Experiment 3
(d) Experiment 6 (e) Experiment 8 (f) Experiment 9

Fig 4: SEM surface micrographs developed after inclined end milling [35]

Masmiati *et al*. conducted study to improve the cutting parameters in inclined end milling to achieve improved microhardness and residual stress integrity of the surfaces. Surface damage such as deformation of the feed mark, tearing surface, formation of the chip layer, micro pits, relocations of the material (chips) to the processed surface and flaws is indicated in the SEM Micrographs in Fig 4 [34]. After study the machined surface inclination angle was found to have a great impact on residual stress and micro-hartness in the direction of feed. The machined angle of inclination of the surface also increased the microhardness. Nevertheless, the residual stress showed other effects, which increased the residual stress when the machined surface angle was inclined. Cutting speed and axial cutting depth seems to have less impact on residual stress and microhardness and surface integrity was mildly affected by feed rates [35].

Klocke *et al* investigated the effect of EDM processes on biocompatibility of WE43. EDM processes improve the biocompatibility of biodegradable Mg alloy [36]. Xu *et al*. has been investigated the effect of multi cut with high speed wire electrical discharge machine (WEDM-HS) on AZ91D biodegradable Mg alloy. The water contact angle of WEDM-HS machining is higher. WEDM-HS machining has been decreased micro-pits and micro-cracks, therefore, improved the surface integrity [37]. Abdul-Rani *et al*. has been investigated the influence of PM-EDM process parameters on surface roughness. Pulse on time and pulse off time most significant factor which most affected the surface roughness. Zn mixed dielectric improve the surface roughness and machined surface quality of AZ31 Mg alloy [38]. The effect of micro-WEDM process parameters on AZ31 biodegradable Mg alloy by using tungsten wire as a electrode. Surface integrity of AZ31 biodegradable Mg alloy has been improved while using tungsten coated electrode [39]. Razak *et al*. analysed the effect of Zinc powder mixed electric discharge machining (PM-EDM) on corrosion rate of AZ31 Mg alloy. Zn particles deposited on the surface during the erosion process and improve the surface integrity and the corrosion resistant [40]. Mostafapor *et al* were analysed the effect of WEDM process parameters on MRR, kerfs width and surface roughness of AZ91 Mg alloy. High MRR and kerfs width were notice due to the low melting point of material. Whereas the good surface roughness are observed on the same material. It was also noticed that content of Zn, Cu and O are increased whereas the Mg and Al content were decreased [41].

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