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Characterization of Mechanical Properties on Magnesium Hybrid Composites for Bio-Medical Applications

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Abstract: Over the past centuries there is a considerable development in the medical field. There is a lot of development in surgery and prosthetic fields. For this purpose, a lot of materials are used as implants for replacing them in place of damaged parts. These materials are called as biomaterials. It has been observed that one of the most important properties governing the suitability of the material to be a bio implant is 'wear resistance' 'Corrosion Resistance'. This paper explains about mechanical properties on Magnesium

Keywords: Die casting, Biomaterials, Bio-medicals, Hybrid-composites

1. Introduction

A Biomaterial is any material, natural or manmade, that comprises whole or part of a living structure or biomedical device which performs, augments, or replaces a natural function [1-6]. A Biomaterial is a non-viable material used in the medical device, so it's intended to interact with biological systems". Biomaterials as a very old background of the '80s and '90s where in particular centuries some of the implementation and surgical techniques take place as shown in the below dates [7-16]. Where 80's surgical techniques as been used and the early 90's bone plates as used as the fix fractures. And that time the materials like stainless steel, cobalt, chromium alloys as been used before that these materials as not been used then in the 1938 the first hip prosthesis as been done at the same time after 2 years by biomaterials bone repair was implemented in biomaterials and then Mechanical Heart Valve as done in 1952 where that was an artificial heart which works same as a human heart [17-20].

Characteristics of Biomaterials

- It's Multidisciplinary
- It Uses Many Diverse Materials
- The End product is the Development of Devices
- The Magnitude of the Field is Generally Unappreciated

Classification of Biomaterials according to their bioactivity:

(a) Bio-inert Biomaterials: The term bio-inert refers to any material that once placed in the human body has minimal interaction with its surrounding tissue. Examples: stainless steel, titanium, alumina, partially stabilized zirconia, and ultra-high molecular weight polyethylene. Generally, a fibrous capsule might form around bioinert implants hence its functionality relies on tissue integration through the implant.

(b) Bio-active Biomaterials: Bioactive refers to a material, which upon being placed within the human body interacts with the surrounding bone and in some cases, even soft tissue. This occurs through a time-dependent kinetic modification of the surface, triggered by their implantation within the living bone. An ion-exchange reaction between the bioactive implant and surrounding body fluids – results in the formation of a biologically active carbonate apatite (CHAp) layer on the implant that is chemically and crystallographically equivalent to the mineral phase in the bone. Examples: Synthetic hydroxyapatite [Ca10 (PO4)6(OH)2], glass-ceramic A-W and bioglass.

(c) Bio-resorbable Biomaterials: Bioresorbable refers to a material that upon placement within the human body starts to dissolve (resorbed) and slowly replaced by advancing tissue (such as bone). Examples: Tricalcium phosphate [$Ca_3(PO_4)_2$], polylactic–polyglycolic acid copolymers, Calcium oxide, calcium carbonate, and gypsum.

2. Materials Selection

The material selection is carried out by considering various mechanical, physical and chemical properties of the parent material that is to be used for the fabrication of the biomaterials. The materials exhibiting high compressive strength, tensile strength, yield strength and having high density are considered as first-level materials. And the materials exhibiting good hardness, shear modulus, shear strength, and good surface topology are termed as second-level materials. Considering parameters like density, availability, castability, machinability, tribological properties and biocompatibility of the following materials have been selected for the characterization and study of mechanical properties for the biomedical applications.

- Magnesium
- Aluminum
- Zinc

The detailed properties of selected materials are as follows.

Table: 1 Physical values

Parameter	Value
Atomic number	12
Atomic mass	24.305 g.mol^{-1}
Electronegativity (Pauling)	1.2
Density	1.74 g.cm^{-3} at 20 °C
Melting point	650 °C
Boiling point	1107 °C
Vanderwaals radius	0.16 nm
Ionic radius	0.065 nm
Isotopes	5
Electronic shell	[Ne] 3s^2
The energy of first ionization	737.5 kJ.mol^{-1}
The energy of second ionization	1450 kJ.mol^{-1}
Standard potential	- 2.34 V

Physical properties of Mg:

- Melting point: 923 [or 650 °C (1202 °F)] K
- Boiling point: 1363 [or 1090 °C (1994 °F)] K
- Liquid range: 440 K

Expansion and conduction properties Mg:

- Thermal conductivity: 160 W m^{-1} K^{-1}
- Coefficient of linear thermal expansion: 8.2 x10-6 K^{-1}

Bulk properties Mg:

- The density of solid: 1738 kg m^{-3}
- Molar volume: 14.00 cm^3
- The velocity of sound: 4602 m s^{-1}

Elastic properties Mg:

- Young's modulus: 45 GPa
- Rigidity modulus: 17 GPa
- Bulk modulus: 45 GPa
- Poisson's ratio: 0.29 (no units)

The hardness of Mg:

- Mineral hardness: 2.5 (no units)
- Brinell hardness: 260 MN m^{-2}
- Vickers hardness: no data MN m^{-2}

Chemical properties of Al:

- Atomic Number: 13
- Atomic Weight: 26.981539

Physical properties of Al:

- Melting Temperature: 933.47 K
- Boiling Temperature: 2792.15K
- Critical Temperature: 7850 K

Mechanical Properties of Al:

- Density: 2700 kg/m^3
- Modulus of Elasticity: 62.053 GPa
- Poisson Ratio: 0.35
- Thermal Expansion Coefficient: 2.310 /K

Table 2: Chemical properties of Zn:

Name, symbol, number	Zinc, Zn, 30
Chemical series	Transition metals
Group, period, block	12, 4, d
Appearance	Bluish pale gray
Atomic mass	65.409(4) g/mol
Electron configuration	[Ar] 3d10 4s2
Electrons per shell	2, 8, 18, 2

Table 3: Physical properties of Zn:

Parameter	Value
Density	7.14 g.cm^{-3}
Melting point	692.68 K (419.53°C, 787.15°F)
Boiling point	1180 K (907°C, 1665°F)
Heat of fusion	7.32 kJ.mol^{-1}
Heat of vaporization	123.6 kJ.mol^{-1}
Heat capacity	(25°C) 25.390 J.mol^{-1}.K^{-1}

3. Methodology

Rule of mixture: The idea is that by combining two or more distinct materials one can engineer a new material with the desired combination of properties (e.g., light, strong, corrosion-resistant). The idea that a better combination of properties can be achieved is called the principle of combined action or rule of mixture.

Taking the density formula, the basic equation for the rule of the mixture is;

$$V_c = V_{Mg} + V_{Al} + V_{zn}$$

$$\frac{Mc}{\rho c} = \frac{Mmg}{\rho mg} + \frac{Mal}{\rho al} + \frac{Mzn}{\rho zn\text{-}}$$

Die casting: The die is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings are made from non-ferrous metals, specifically zinc, copper, aluminum, magnesium, lead, pewter and tin-based alloys. Depending on the type of metal being cast, a hot- or cold-chamber machine is used. Die has the following specification.

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Fig-1 Muffle furnace.

Fig-2 Die casting.

- The material used: Mild steel
- Type of Die: Split type (using two plates)
- Plate dimensions: 150*120*27mm (for one plate)
- Cavity shape: Round rods of diameter 20mm two holes and 12mm of one hole.

Muffle furnace: Furnace operating temperature is 800°C. And Die temperature should be maintained at 260°c before poring of molten metal into cavity. Fig-1 shows the muffle furnace.

Die casting: Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity. By using muffle furnace melting of selected materials is done according to the following procedure. Weigh the materials according to the calculated weight from rule of mixture, after weighing add the materials into crucible and place it in furnace and switch on the furnace for heating. Set the temperature of the muffler furnace to 800°c. correspondingly put the Die for heating in oven at temperature of 260°c. when the furnace reaches for set temperature pour the molten metal into the Die. And keep the die for cooling at atmospheric temperature and remove the casted pieces from the Die. The complete die casting process is shown in Fig-2.

Machining: Machining is done by using lathe according to ASTM standards.

4. Experimental study:

Tensile test: Tensile test is done according to American society for testing and materials (ASTM). The ASTM standard is E-08. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required.

Compression test: The American society for testing and materials (ASTM) for compression test is E-09. The specimen is subjected to an increasing axial compressive load and strain may be monitored either continuously or in finite increment, and the mechanical properties in compression determined.

Shear test: The American society for testing and materials (ASTM) for bending test is E-143-012. A shear test determines the ability of a material to stand up against perpendicular, or upright, stresses. Such testing can be used for a variety of activities and may involve many different kinds of equipment. Single shear carries all load on one face while double shear carries it on two faces.

5. Result and Discussion

Tensile test: By using a Universal testing machine **(UTM)** the tensile test is conducted, and the following results are obtained.

Table 4: Tensile test results for different samples.

S. No	Composition	Ultimate tensile Load in KN	Ultimate tensile stress in KN/mm^2
1	Magnesium 88.99%, Aluminium 5.66%, Zinc 4.95%. sample 1	13.420	0.211
2	Magnesium 88.99%, Aluminium 5.66%, Zinc 4.95%.,sample 2	10.880	0.171
3	Magnesium 74.85%, Aluminium 6.24%, Zinc 18.46% sample 1	9.460	0.149
5	Magnesium 74.85%, Aluminium 6.24%, Zinc 18.46%sample 2	11.180	0.176
4	Magnesium 83.88%, Aluminium 4.89%, Zinc 10.75% sample 2	10.900	0.171

Compression test: By using a Universal testing machine **(UTM)** the Compression test is conducted, and the following results are obtained.

Table 5: Compression test results for different specimens.

Sl no	composition	Ultimate compressive load In KN	Ultimate compressive stress in KN/mm^2
1	Magnesium 88.99%, Aluminium 5.66%, Zinc 4.95%.	83.440	0.329
2	Magnesium 83.88%, Aluminium 4.89%, Zinc 10.75%	98.32	0.386
3	Magnesium 74.85%, Aluminium 6.24%, Zinc 18.46%	93.020	0.365

Shear test: By using a Universal testing machine (UTM) the Shear test is conducted, and the following results are obtained.

Table 6: Shear test results for different specimens.

S. No	Composition	Type of shear	Ultimate load in KN	Ultimate stress in KN/mm^2	Ultimate shear stress in KN/mm^2
1	Magnesium 88.99%, Aluminium 5.66%, Zinc 4.95%.	Double shear	30.10	0.266	0.133
2	Magnesium 83.88%, Aluminium 4.89%, Zinc 10.75%	Single shear	19.640	0.174	0.087
3	Magnesium 83.88%, Aluminium 4.89%, Zinc 10.75%	Double shear	26.70	0.236	0.118
4	Magnesium 74.85%, Aluminium 6.24%, Zinc 18.46%	Single shear	20.280	0.174	0.090
5	Magnesium 74.85%, Aluminium 6.24%, Zinc 18.46%	Double shear	33.460	0.296	0.148

6. Conclusion

- In tensile test it is seen that when the zinc is added up to 4.95 ultimate tensile load withstanding capacity of the prepared composite is 13.9kN. And as zinc is increased up to 18.46 the tensile load withstanding capacity is reduced to 9.46kN. Hence by the obtained result we can easily interpret that as the composition of zinc increases the material is turning into brittle thereby reducing the tensile properties of the biomaterial.

- In the tensile test results as it is been observed that the material is acting as brittle in nature as there is an increase in the zinc composition. Hence the compression strength of the biomaterial is increased from 83.44kN to 98.32kN as the zinc was increased from 4.95 to 10.75. But beyond the 10% of zinc again the compression strength has been reduced which means that the material has turned to be very highly brittle in nature. This can be concluded as the zinc percentage up to an optimum case i.e upto10% increases the compression strength of the material then it gradually decreases with increase in the reinforcements.

- The maximum shear strength obtained is 20.280kN in terms of single shear and 33.460kN in double shear these results are obtained when the reinforcement i.e zinc is added upto 18.46% which means that as the reinforcement is increasing the shear strength of the material is also increasing.

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