Journal of Material Science and Mechanical Engineering (JMSME)
Print ISSN: 2393-9095; Online ISSN: 2393-9109; Volume 2, Number 5; April-June, 2015 pp. 365-369

http://www.krishisanskriti.org/jmsme.html

Development of Low Cost Orthopedic Implants using Mg-HA by Powder Metallurgy Process

P. Bharath[1], V.G. Sridhar[2] and Sreekanth Dondapati[3]

[1]*M.Tech CAD/CAM SMBS VIT University Chennai Campus*
[2,3]*SMBS VIT University Chennai Campus*
E-mail: [3]bharathpappu01@gmail.com

Abstract—*Mg-based implants can be used as an alternative over Fe-based and Zn-based implants. However, the extensive applications of Mg-based alloys are still inhibited mainly by their high degradation rates and consequent loss in mechanical integrity. Consequently, extensive studies have been conducted to develop Mg-based alloys with superior mechanical and corrosion performance. In this research project an attempt is made to optimize the process parameters for developing Mg-HA composites by powder metallurgy route using Taguchi method. However, development of magnesium based composites by powder metallurgy process is a challenge. Therefore the objective is to characterize the Mg-HA composite formed with optimized parameters and is tested for their mechanical, physical and biological properties. The results obtained shows that the Mg-HA can be used as a alternative material to Titanium and Stainless Steel implants.*

1. INTRODUCTION

The development and growth of new and advanced materials are the key aspects for progressive growth in the quality of human life. There are many opportunities for the metallurgist to explore and develop new materials, alloys and their processing techniques. Recently lightweight metallic materials are receiving much more attention towards weight reduction associated with the ongoing research in biomedical applications.

In recent years much progress has been made on the magnesium alloys as “smart” implants in biomedical applications [1-3]. The first and foremost requirement for the choice of the biomaterial is its acceptability by the human body. The implanted material should not cause any adverse affects like allergy, inflammation and toxicity either immediately after surgery or under post operative conditions. The success of the biomaterial or an implant is highly dependent on the following major factors: The properties (mechanical, chemical and biological), biocompatibility of the implant and implant flexibility for placing during surgery[4].

Biomaterials has got an immense importance for mankind as the very existence and longevity of some of the less fortune human beings, who requires biomedical implants like aged population and also with the congenital heart diseases[5-7]. The field of biomaterials is a old process used by Egyptians and Romans 4000 years back to make linen for sutures, gold and iron for dental applications and wood for the replacement for corrosion materials. Nylon, Teflon, Silicone, stainless steel and Titanium were some of the other materials which were put in use in World War-II. Now we have many materials which will have better diagnostic tools and advancements in the knowledge on materials as well as surgical procedures [8, 9]. A biomaterial should remain intact for a longer period without fail. The biomaterials now used will be selected based on the major factors given.

Magnesium and its alloys are the best choice for biocompatible implant materials especially for orthopedic implants. Magnesium is the sixth most abundant element in the earth’s crust (2%). Magnesium is the lightest structural material having density 1.74g/cc which is ~35% to ~75% lighter than aluminum and iron respectively. The mechanical properties of magnesium are closer to that of bone which effectively reduces stress shielding effect when compared with other metallic implants [10, 11]. Pure magnesium will have higher corrosion rates in physiological environment and corrosion products releases hydrogen which can be reduced by alloying magnesium with other materials which are bio compatible like Hydroxyapatite (HA), Manganese (Mn), Titanium oxide, Calcium, Zinc(Zn) etc.

The process of manufacturing of shaped components or semi finished components from metal powder is called as powder metallurgy. This technique combines unique technical features with cost effectiveness and generally used to produce sintered hard materials known as carbides [12-14]. Powder metallurgy is generally used for iron based components. Powders used can be elemental, pre-alloyed, partially alloyed. In this technique we will get the near net shape of the component and does not require secondary operations.

The components prepared through compaction are called “Green compacts” which is sintered at a temperature of 0.7 to 0.9% of the base metal powder [15].

Taguchi method is one of the efficient problems solving tool, which is used to improve the performance of the process, product, design and significant slash in time and cost. Taguchi method combines both the experimental design theory and quality loss function to carry out robust design process and for solving many complex problems in manufacturing industries. This method uses the optimum process parameters that are intensive to the variation in noise factors. Number of experiments increases with the increase in the process parameters. To solve this Taguchi is a special parameter of the orthogonal array.

Taguchi has three categories of quality in the analysis of S/N ratio. They are

- The lower - the best
- The nominal –the best
- The larger – the better

In this analysis we are using the larger the better because we are making the implant which should be strong.

2. EXPERIMENTAL SETUP

2.1 Material selection

For the development of the implant for orthopedic applications we selected magnesium as the base material due to its distinct properties and it is one of the human acceptable materials. Table 1 shows the properties of magnesium.

Table 1: Properties of Magnesium

Density	1.74g/cc
Melting point	650ºC
Boiling point	1107ºC

In this research we made the compacts in the die made of HCHCR material and the setup is shown in Fig. 1.

Fig. 1: Experimental setup of the compaction die

2.2 Taguchi method analysis

Taguchi method is one of the statistical Design of Experiments (DOE) to optimize the process parameters like Material composition, Sintering Temperature, Sintering time. In this analysis L9 (3^3) orthogonal array is used. L9 (3^3) means it will investigate 3 levels with 3 factors. Table-2 gives the levels and factors used for preparing the samples. Table-3 gives the experimental data that are taken for the analysis.

Composition of the compacts prepared

- Alloy-1 Mg+1%Mn+2%Zn+1%HA
- Alloy-2 Mg+1%Mn+2%Zn+3%HA
- Alloy-3 Mg+1%Mn+2%Zn+5%HA

Table 2: Critical Parameters and Levels

LEVELS	1	2	3
Material composition (HA%)	1	3	5
Sintering Temperature (ºC)	350	400	450
Sintering Time(Minutes)	30	45	60

Table 3: Experimental Data

Sample number	HA%	Sintering Temp. (ºC)	Sintering time (minutes)
1	1	350	30
2	1	400	45
3	1	450	60
4	3	350	45
5	3	400	60
6	3	450	30
7	5	350	60
8	5	400	30
9	5	450	45

2.3 Pre-processing of hybrid reinforcement

The pre-processing of hybrid reinforcements was carried out using ball milling by solid state processing technique. In addition to the magnesium metal powder other reinforcements (Mn, Zn, HA) were also blended for 5 hours (10 balls) with 10% toluene as control agent. The ball to powder ratio was kept at 20:1 and the speed of the milling machine was set at 250rpm during the blending and ball milling process.

2.4 Primary Processing

Fig. 2: Sintered Compacts

In this stage the blended powder is compacted in the compaction die and then it is sintered in the muffle furnace by following the parameters obtained from Taguchi analysis. The compaction was done at 100KN in UTM then Green compacts were sintered in muffle furnace. Fig. 2 shows sintered compacts. Table-4 gives the values of different tests conducted on the samples.

Table 4: Experimental Observations

Sample number	Hardness (Rockwell)	Tensile Strength (N/mm2)	Bending Strength (N/mm2)
1	67.3	185.37	109.69
2	68.7	198.61	135.99
3	56.1	169.76	147.38
4	51.4	150.17	94.52
5	69.2	212.95	180.59
6	55.8	155.47	153.21
7	61.2	228.57	142.27
8	49.7	196.22	119.51
9	61.7	206.81	158.96

3. RESULTS AND DISCUSSION

3.1 Bend test

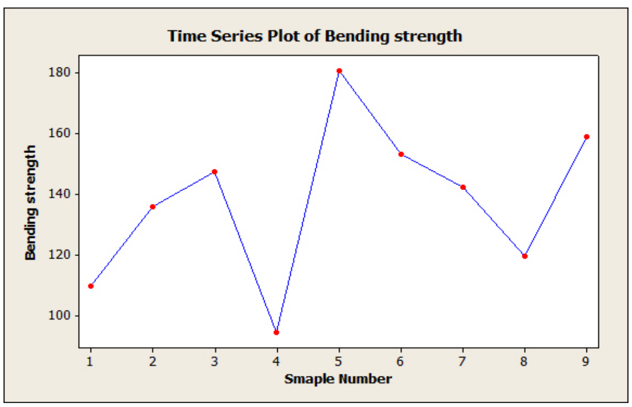


Fig. 3 Time series plot of Bending Strength

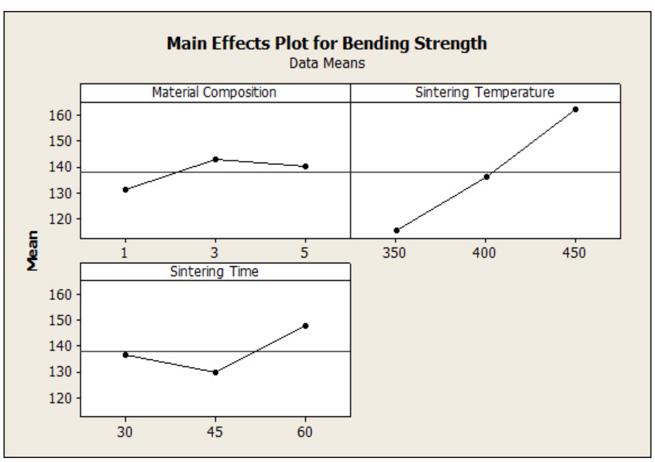


Fig. 4: Main Effects for Bending Strength

3.2 Tensile test

This test is used to determine the modulus of elasticity (E), Ultimate tensile strength (UTS). The tensile test was conducted on UTM and the results were recorded for further tests. By all the parameters what we considered we get specimen-5 will have highest tensile strength (212.95N/mm^2). The tensile strength of all the specimens is shown in and Fig. 5 shows distribution of stress for different specimens and Fig. 6 shows the time series plot.

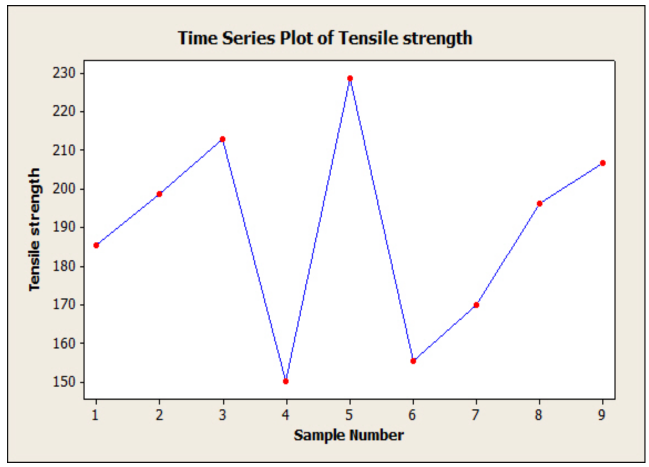


Fig. 5: Time series plot of Tensile Strength

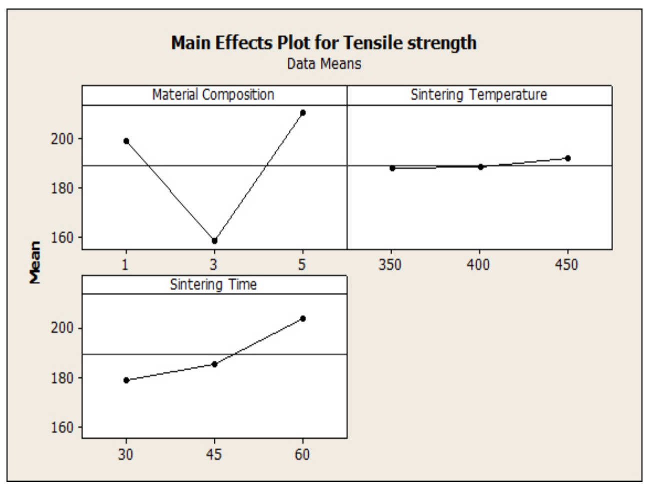


Fig. 6: Main Effects for Tensile Strength

3.3 Hardness

Hardness can be defined as the resistance of the metal to plastic deformation usually by indentation. Hardness test is done on the sintered sample using Rockwell hardness testing machine by applying a load of 100Kgf. In this paper specimen-7 gives greater hardness 69.7R_c and the hardness of all the samples are shown in Fig. 7 and main effects is shown in Fig. 8.

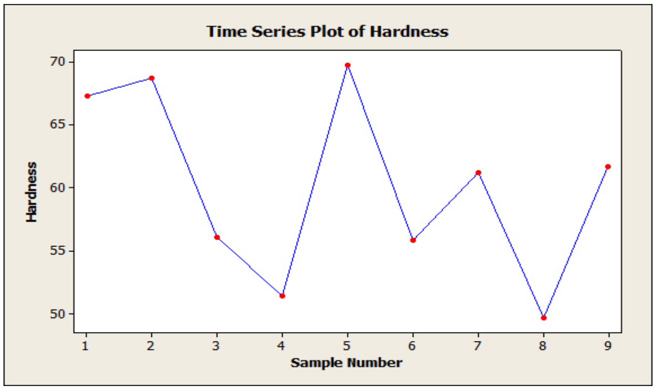


Fig. 7: Time series plot of Hardness

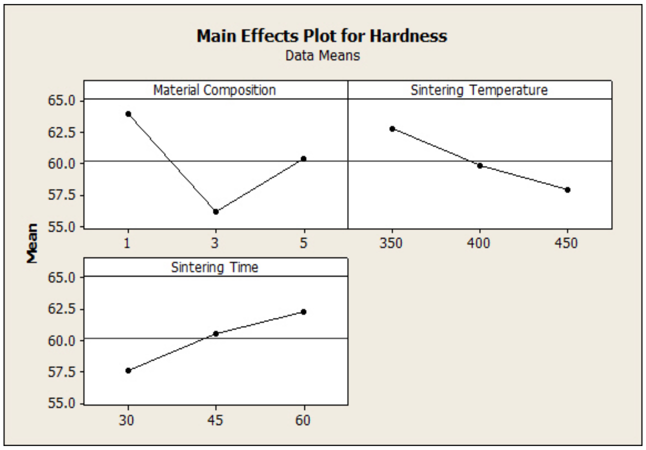
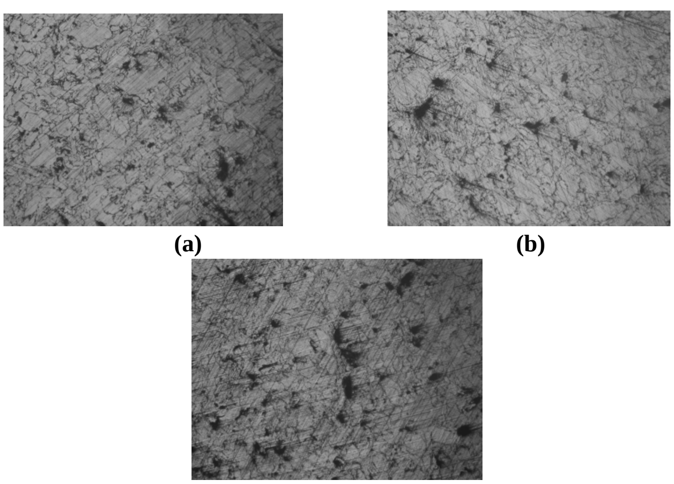


Fig. 8: Main Effects for Hardness

3.4 Micro structural study

Fig. 9 shows the micro structure of 1%HA, 3%HA, 5%HA respectively. It is evident that the HA particles are properly incorporated in the magnesium matrix without any separate interface.



(c)

Fig. 9: Micro structure of Magnesium alloy with 1%HA,(b) 3%HA, (c) 5% HA

4. CONCLUSION

From the present work following conclusions were drawn

- Mg-HA composites were successfully fabricated using powder metallurgy technique.
- Optimum process parameters for Mg-HA powder metallurgy composites were found to be 3% HA, sintering temperature is 400ºC and sintering time is 60 minutes.
- The sample fabricated with optimal parameters has better mechanical properties.
- The mechanical properties of the specimens under optimized conditions are :

Hardness	-	$69.7R_c$,
Tensile strength	-	$196.22N/mm^2$,
Bend strength	-	$180.59N/mm^2$

From this research study it can be concluded that Mg-HA composites are found to be a best suitable orthopedic implant.

REFERENCES

[1] Chen.Y, Zhigang.X, Smith.C, Sankar.J. "Recent advances on the development of magnesium alloys for biodegradable implants", *Acta Biomaterialia*, vol.10, 2014, pp 4561–4573.

[2] Geetha.M, Durgalakshmi.D, Asokamani.R. "Biomedical Implants: Corrosion and its Prevention - A Review", *Recent Patents on Corrosion Science*, vol.2, 2014,pp 40-54.

[3] Zomorodian,M.P.G, MouraT.S, Fernandes J.C.S., Fernandes M.H., Montemor M.F. "Corrosion resistance of a composite polymeric coating applied on biodegradable AZ31 magnesium alloy", *Acta Biomaterialia*, vol. 9,2013, pp 8660–8670.

[4] Kyriacos. A. "Biodegradable Scaffolds for Use in Orthopedic Tissue Engineering", *IEEE*, 1994, pp 541-544.

[5] Hisao.W. "Trend of Research and development for Magnesium Alloys", *Science & Technology Trends*, vol.18, Jan 2006,pp 84-97.

[6] Cha.P, Hyung H.S, Yang G.F, Kim Y.C, Ki-H.H, Seung. C.L.J, Young J, Pyeong J.A, Young Y.K, Sung. Y.C, Young J.B, Kang-S.L, Seok J.Y, Hyun K.S, "Biodegradability engineering of biodegradable Mg alloys: Tailoring the electrochemical properties and microstructure of constituent phases", *scientific reports*, vol.3, 2013pp1-6.

[7] Zhang B.P, Wang Y, Geng L, "Research on Mg-Zn-Ca Alloy as Degradable Biomaterial", *Biomaterials – Physics and Chemistry*, 183-204.

[8] Colleen J.B, "Magnesium Powder Metallurgy: Process and Materials Opportunities", *Journal of Materials Engineering and Performance*, Vol.17, June 2008,pp 297-301.

[9] Hiroyuki W, Toshiji M, Mamoru M, Kenji H, "High-strain-rate super plasticity at low temperature in a ZK61 magnesium alloy produced by powder metallurgy", *Scripta Materialia*, Vol. 41, 1999,pp 209–213.

[10] Pereda M.D, Alonso C, Burgos L.A, Valle J.A.D, Ruano O.A, Perez P, Fernández M.A.L, "Corrosion inhibition of powder metallurgy Mg by fluoride treatments", *Acta Biomaterialia* ,vol.6 , 2010, pp 1772–1782.

[11] Huaye Z, Yong H, Ailing F, “Preparation, mechanical properties and in vitro biodegradation of porous magnesium scaffolds”, *Materials Science and Engineering*, vol. 28, 2008, pp 1462–1466.
[12] Bamberger M, Levi G, Vander J.B.S, “Precipitation Hardening in Mg-Ca-Zn Alloys”, *Metallurgical and Materials Transactions A*, vol.37A, February 2006, pp 481-487.
[13] Zijian L , Xunan G , Siquan L , Yufeng Z, “The development of binary Mg-Ca alloys for use as biodegradable materials within bone”, *Biomaterials*, vol.29, 2008, pp 1329-1344.
[14] Shaoxiang Z, Xiaonong Z, Changli Z, Jianan L, Yang S, Chaoying X.,H.T, Yan Z, Yaohua H, Yao J, Yujun B, “Research on an Mg–Zn alloy as a degradable biomaterial”, *Acta Biomaterialia* ,vol.6 , 2010, pp 626–640.
[15] Zheng Y.F, Gu X.N, Xi Y.L, Chai D.L, “In vitro degradation and cytotoxicity of Mg/Ca composites produced by powder metallurgy”, *Acta Biomaterialia* ,vol.6, 2010, pp1783–1791.