Optimization of Natural Hydroxyapatite/SS316L Feedstock for Highest Green Density in Metal Injection Molding by using Taguchi Method

M.H.I.Ibrahim, mdhalim@uthm.edu.my, Advanced Manufacturing & Material Center (AMMC) Universiti Tun Hussein Onn Malaysia, Fakulti Kejuruteraan Mekanikal & Pembuatan,(FKMP) Batu Pahat, Malaysia, N.Mustafa, Advanced Manufacturing & Material Center (AMMC), Fakulti Kejuruteraan Mekanikal & Pembuatan,(FKMP) Universiti Tun Hussein Onn Malaysia,Batu Pahat, Malaysia. nj.wawa@gmail.com,A.M.Amin, Advanced Manufacturing & Material Center (AMMC), Fakulti Kejuruteraan Mekanikal & Pembuatan,(FKMP)Universiti Tun Hussein Onn Malaysia,Batu Pahat, Malaysia, azriszul@uthm.edu.my, R.Asmawi, Advanced Manufacturing & Material Center (AMMC), Fakulti Kejuruteraan Mekanikal & Pembuatan,(FKMP),Universiti Tun Hussein Onn Malaysia,Batu Pahat, Malaysia, roslias@uthm.edu.my

Abstract-- **The developments of Metal injection molding (MIM) process are based on combination of powder metallurgy and plastic injection molding approach but applicable to metals and ceramic .The mixture between metal and binder are called as feedstock. The feedstock is shaping by using metal injection molding technique to produce green parts. Thus this paper concentrates on Taguchi method as a tool in determining the optimum density for Metal Injection Molding (MIM) parameters. In this paper combination of stainless steel 316L (SS316L)/ Natural hydroxyapatite (NHAP) with D_{50} = 6.553 µm was used with 40 wt % Low Density; Polyethylene and 60 %wt Palm Stearin as a binder system. The feedstock of 63 wt % powder loading consist of 90 % wt of SS316 L and 10 wt % NHAP were optimized with 4 significant injection parameter such as Injection temperature (A), Mold temperature (B), Pressure (C) and Speed (D) were selected throughout screening process. An orthogonal array of L_9 $(3)^4$ was conducted. Confirmation test will be done base on Signal-to-Noise (S/N) ratio. The optimum injection parameters for highest green density were found at A_2, B_2, C_2 and D_2. The confirmation experiment result is 13.3146 dB and has archived the minimum requirement of optimum performance.**

Index Term-- **Density; Tilapia Fish Bones; Natural Hydroxyapatite; SS316L; Taguchi Method**

I. INTRODUCTION

Metal injection molding are widely known as preferred technique that can produce metal and ceramic in small and intricate part geometry with more economically and large volume of production There are four major sequential process in MIM which is includes of mixing, molding, debinding and sintering [1]- [5]. Stainless steel is one of metal powder that used as metallic implant material in medical implant application. This selection is due to great mechanical properties of SS316L such as fracture toughness, fatigue strength and cost effectiveness [6], [7]. Moreover the selected of SS316 L water atomized are due to their special characterization in MIM such as high packing densities and non spherical particle shape and resulted to the higher interparticle friction [8]

Hydroxyapatites widely use in medical implant due to their similarity properties to bone structure and teeth based on the chemical and structural point of view, HA with the stoichiometric formula Ca10(PO4)6(OH2) and a Ca/P molar ratio=1.67, are most similar to the inorganic part of bones and teeth. Both dense and porous HA have been vigorously investigated as implant materials for orthopaedic and dental applications, showing excellent bioactivity, osteoconductivity, and osteoinductivity[9]. Metal injection molding is significant method to produce sample of SS316l/ NHAP composites and proven by previous researcher such as [7] ,[10] ,[11] but they employed the synthetic HA. Moreover, the application of MIM technology to stainless steel part gives the superiority to metal industry in term of casting process to complex part geometry and the most important issue it could achievable high final density [12].

The terms of green part are represents to the sample that have been produced through MIM process. The green part properties have to be evaluating in terms of density, strength and defect [13]. Regarding to this concern, an optimization of injection molding parameter could be increased or decreased the quality into an acceptable range [13].

Taguchi method by implement the Design Experiment (DOE) are one of the techniques that provide a systematic and efficient methodology in finding the optimum combination input parameter of process[15] ,[16]. Furthermore, this technique also preferred for product design and process optimization worldwide. Taguchi Method has a several advantages which is includes simplification of experimental plan and feasibility study of interaction between different parameters. These facts regarding to this technique are supported by [17]. Taguchi Methods also known as the greatest method in order to optimize the design, performance and costing issue. Taguchi method is most important technique in order to optimize the green part in metal injection molding [18]. There are several injection parameters were optimized in determination the highest green density which is injection pressure (A), injection parameter (B), mold temperature (C), injection time (D) and holding time (E) and the finding proves that Taguchi Method could be the best methods in order to solve the problem with a minimum number of trials [13]. Other researcher that used Taguchi method as a tool in injection molding optimization parameter are [19]. and [20] focused on optimization of sintering parameter for highest strength by using L_9 3^4 Orthogonal array.

Thus in this paper, NHAP that derived from Tilapia fish bone used to apply as powder in metal injection molding with the combination of metal powder SS316 L and Low density Polyethelene (LDPE) and Palm Stearin as binder system. The optimization of injection parameter to achieve highest density for green part will be investigated using design of experiment (DOE) at which injection molding parameter are optimized using (L934) Taguchi Orthagonal Array

II. Materials And Methods

A. Materials

Table I and Fig 1 exhibit the combination characteristic of SS316L water atomized powder (Epson Atmix Corp) with irregular shapes as it is compatible with water leaching and high corrosion resistance that were used as a metal powder. While NHAP from Tilapia Fish bones applied as a ceramic powder. The NHAP powder was derived from Tilapia Fish bones by calcination process. Moreover, an established binder system in MIM which is Low Density Polyethylene (LDPE) and Palm stearin (PS) acted as temporary vehicles for feedstock homogeneity and packing powder into desired shaped before sintering stages [21]. The binder properties had shown in Table II. Based on fig.5 it can be seen the component of binder system were act as packing agent for the green part.

TABLE I: COMBINATION OF (SS316L) AND NHAP CHARACTERISTIC

Characteristic	Details
Identification	SS31L PF-10F / $Ca_{10}(PO_4)_6(OH_2)$
Powder source	Epson Atomix Corp / Tilapia Fish bones
Tap density g/m^3	4.06
True pynometer density g/m^3	8.0471/ 3.156
Powder size	D10 = 2.06 µm D50 = 6.553 µm D90 = 17.712 µm

TABLE II: BINDER PROPERTIES

Binder	Type	Desig-nation	Compo-sition %	Melting Temperature ˚C	Density gcm^{-3}
Palm Stearin	Primary	PS	60	70	0.891
Low Density Polyethelene	Secondary	LDPE	40	111.5	0.92

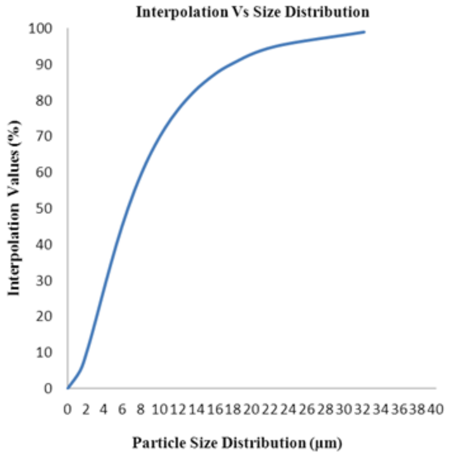

Fig. 1. Graph Interpolation vs. Particle Size Distribution for SS316L/NHAP

B. Feedstock Composition

The feedstock preparations start with mixing the NHAP/SS316L powder and binder system with suitable volume ratio by using plastograph brabinder. Mixing

temperature for this process were depends on the secondary binder system temperature which is higher compare to highest melting point and lower than the lowest degradation temperature [21] Hence, for this research, Palm Stearin (PS) and LDPE was selected as a primary and secondary binder system and the mixing temperature was set up to 150˚C by referring the melting point of LDPE occurs at 111.5˚C The NHAP powder, metal powder (SS316L) and binder system were weighted in order to carry out the mixing process. The selected ratio between NHAP powder and SS316L which is consist of 90 % SS316L and 10% NHAP with 63 Vol % powder loading. While the ratio for binder systems are 60% of Palm Stearin, 40% LDPE in terms of volume fraction. The critical powder loading for SS316L/NHAP mixture is 68.189 Vol %. The optimal powder loading is around 2% -5% lower than critical powder volume concentration (CPVC) [1],[22]. Fig.2 presented the Critical Powder Volume Concentration for SS316L/NHAP mixture. Thus, this paper focused on 63 Vol % powder loading where as still consider within optimal powder loading [13], [15] Fig.3 and fig.4 exhibit the mixing process and the feedstock.

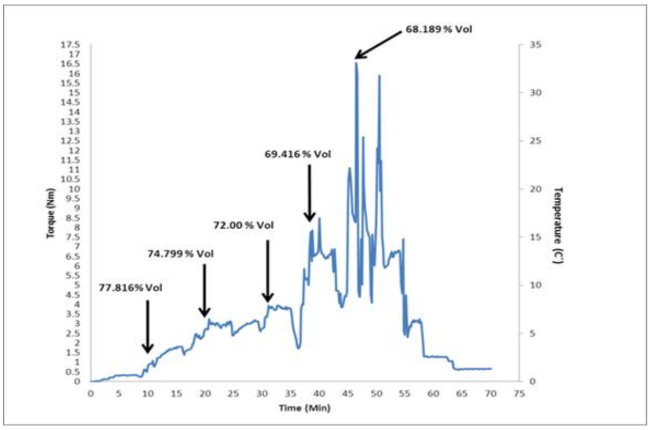

Fig. 2. Critical Powder Volume Concentration for SS316L/NHAP mixture

Fig. 3. Mixing Process

Fig. 4. Feedstock

C. Taguchi Method

In MIM , an optimization of Injection molding process known as an imperative step in order to improve the density and quality of green part. In this paper, L_9 $(3)^4$ Orthogonal Array (OA) was used as an optimization tool which is means by three level designs of experiment with 4 parameter and conducted in 9 trial. Orthogonal arrays can be utilizes as plans of multifactor experiments. The columns represents to the factors, while, the entries in the represents to the test levels of the factors and the rows correspond to the test runs [23].

The chosen injection parameters are injection temperature, mold temperature, pressure and speed based on the most significant parameter via screening trial by using classical analysis of variance (ANOVA). Since the entire control factors are orthogonal, so interactions effects are not studied [24], [25]. Table III demonstrates the three level of injection parameter design while fig.5 and fig.6 showed the injection Molding Machine and sample of green part while fig.7 SEM of green part.

TABLE III
THREE LEVEL OF INJECTION PARAMETER DESIGN

Indicator	Parameter	0	1	2
A	Injection Temperature (˚C)	165	170	175
B	Mold Temperature (˚C)	40	45	50
C	Injection Pressure (%)	55	60	65
D	Speed (%)	55	60	65

Fig. 5. Nissei 21 Horizontal screw injection molding machine

Fig. 6. Sample of Green Part

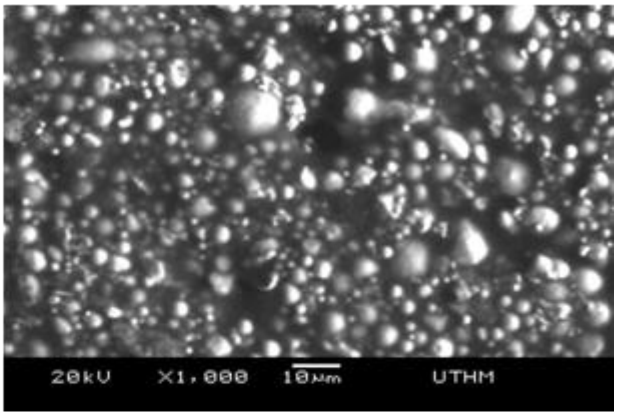

Fig. 7. SEM of Green Part

D. *Density Determination (MPIF42)*

Fig. 8. Mettler Toledo XS 64

Density of green part was measured using the Archimedes water immersion method as recommended in Metal Powder Industries Federation Standard 42 (MPIF 42) [26] ,[4]. The measurements of density test begun by fill the beaker with distilled water and suspend the universal holder for solids from the bracket prepared for non-floating samples. At the mean time, the temperature of distilled water was recorded. Then, the sample were put in the pan and weighed in air and removed it. Afterwards, put the sample in the basket, to ensures that no air bubbles adhere to the sample. Wait until the balance has reached stability and note the displayed weight of sample. Lastly, the density result will be printed by using mini printer provided [21] Fig.8 presented Mettler Toledo XS 64 apparatus for density testing method.

III. RESULTS AND DISSCUSSION

The density measurement was evaluated in order to identify the performance and attain the better quality of green part.

In Taguchi Method the terms of Signal refer to desirables value (mean) for the output characteristic where as Noise can be viewed as the undesirables value (S.D) of output characteristic [13], [27]. The functions of S/N ratios approach is to measure the quality characteristic diverge from the desired value [28]. Furthermore, S/N ratios offer as alternately to transform the experimental outcomes into a value for the evaluation characteristic in the optimum parameter analysis [27], [29]. Thus, in this paper, the selection of S/N ratios characteristic for density evaluation was the larger the better signal type. The data is interprets in S/N ratio attempt to obtain the optimal performance of green part [13] S/N ratios could be defined as (1)

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n}\frac{1}{y_{ij}^{2}}\right) \qquad (1)$$

Where Yij = the amount of score for the green density
n= the total number of shots for each trial

In Taguchi Method, optimizations refer to determination of best level for control factors. In other words best levels of control factors are get the best out of the S/N ratios value. Due to this, the experiments in define the best levels are based on Orthogonal Array (OA) which is the number of experiments which may cause to increase the time and cost can be reduced by using Taguchi technique [29]. Table IV expresses the Taguchi's $L_9(3)^4$ orthogonal arrays demonstrate the value of experimental trials (density) and quality characteristic

TABLE IV
TAGUCHI'S $L_9(3)^4$ ORTHOGONAL ARRAYS DEMONSTRATE THE VALUE OF EXPERIMENTAL TRIALS (DENSITY) AND QUALITY CHARACTERISTIC

	Factors					S/N ratio : Larger is Better
Trial	A	B	C	D		S/N ratios
1	0	0	0	0		12.4208
2	0	1	1	1		12.6006
3	0	2	2	2		13.3324
4	1	0	1	2		12.8659
5	1	1	2	0		13.3427
6	1	2	0	1		13.3077
7	2	0	2	1		13.1187
8	2	1	0	2		13.2031
9	2	2	1	0		13.2676
					$\sum$	117.4595
					$\bar{T}$	13.0511

The graph of main effect plot (Data Means) for S/N ratios were demonstrates in fig.9. The highest peak for each parameter A, B, C and D represents the optimum configuration parameter for injection molding process to obtain the highest density of green part which is A_2, B_2, C_2 and

D_2 without considering any interaction. In better explanation it reflect to Injection Temperature 175 ˚C, Mold Temperature 50 ˚C, Pressure 65 % and Speed 65 % .The main effects plot is developed from Table IV above by using the mean of S/N ratio. The mean S/N value will be calculated refer (2) below:

$$= \left(\frac{12.4208+12.6006+12.8659+13.3427+12.3077+13.1187+13.2301+13.2676}{9} \right) \quad (2)$$

= 13.0511

The significance of injection parameter for green density was consider by measured the variances sensitivity between highest and lowest value of S/N ratio for each factor [25] as presented in Table V. In detail explanation, Mold Temperature expresses as the most contribute factor for green density is where as placed in first rank with 0.50 dB delta value. The mold temperature could enhance the speedy freezing on the mold walls and lead cracking problem, Due to this concern, heating the mold is necessary [1] . The second rank is Injection temperature 0.42 dB delta value. Fundamentally the injection temperature of the feedstock must be high enough since it will offer smooth flow of the feedstock and could overcome the early freezing means it relates to viscosity of feedstock before it fill up the cavity. The range of injection temperature for typical molding parameter is 100 to 200 C [1], [24]. The third rank is pressure with 0.35 dB delta values and the fourth rank is speed with 0.12 dB value. Pressure also affected in increased the density of green part but must concern on chance of powder binder separation. The moderate speed usually used in order to produce a quality green part. Even though in this paper the optimum configuration parameter for injection molding was in highest level but still in acceptable ranges for molding parameters and green part are free form defects

TABLE V
RESPONSE TABLE FOR S/N VALUES

Level	Injection Temperature	Mold Temperature	Pressure	Speed
	Larger Is Better			
0	12.78	12.80	12.98	13.01
1	13.17	13.05	12.91	13.01
2	13.20	13.30	13.26	13.13
Delta	0.42	0.50	0.35	0.12
Rank	2	1	3	4

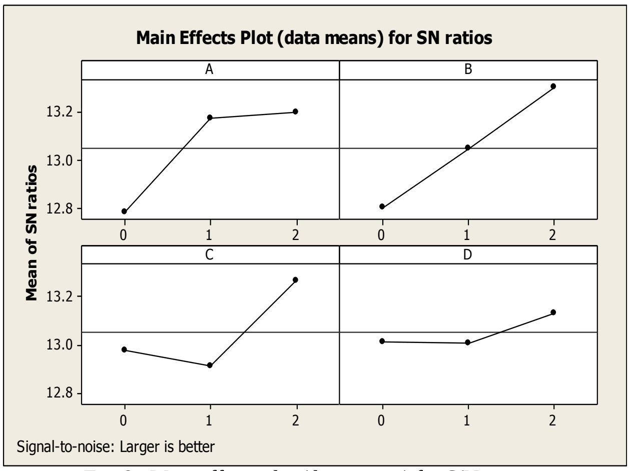

Fig. 9. Main effects plot (data means) for S/N ratio

Analysis of Variance (ANOVA) was used as tool in order to provide a measure of confidence. ANOVA was known as the technique that determines the variance of the data instead of analyzed the data. Moreover, ANOVA also used to strengthen the significant of each parameter involved in this study [14]. Due to this, the confidence measurement is based on the variance of each parameter [13]. In simplest explanation, The ANOVA calculates quantities such as variance (V), sum of squares (SS), percentage of contribution and Degree of freedom (DOF) as shown in Table VI.

TABLE VI
ANOVA TABLE

	DOF	SS	Variance	F	Pure SS	% Contribution
A	2	0.243953	0.121977	756.078	0.243631	33.25334
B	2	0.296572	0.148286	919.157	0.296249	40.43523
C	2	0.166429	0.083215	515.809	0.166106	22.67198
D	2	0.022793	0.011396	70.640	0.02247	3.066937
e	18	0.002904	0.000161			0.572515
total	26	0.732651				100

Moreover, the analysis was proceeded to calculate the confident of interval (C.I) of optimum parameter. The Confident interval was calculated based on (3) below [30]:

$$CL = \pm\sqrt{\frac{(f_1 f_2 \times (ve)}{n_e}} \quad (3)$$

Where as, Fα (f_1, f_2) is the variance ratio for DOF of f_1 and f_2 at level of significance α. The confidence level is (1-α), f_1 is the DOF of mean (usually equal to 1) and f_2 is the DOF of the error. Variance for error terms is Ve and number of equivalent replication is given as ratio of number of trials (1+DOF of all factors used in the estimate).

The confident interval will indicate the maximum and minimum levels of the optimum performance ($A_2B_2C_2D_2$). Table VII presented the expected result of optimum performance for density of SS316L/NHAP green part.

TABLE VII
ESTIMATE OF PERFORMANCE AS THE OPTIMUM PARAMETER
(CHARACTERISTIC: LARGER IS BETTER)

$\overline{A_2}\ \ \overline{B_2}\ \overline{C_2}\ \overline{D_2}$

Optimum Performance Calculation:

$$\bar{T} + (\overline{A_2} - \bar{T}) + (\overline{B_2} - \bar{T})) + (\overline{C_2} - \bar{T}) + (\overline{D_2} - \bar{T})$$

13.0511+ (13.1964 - 13.0511)+(13.3026 -13.0511)+ (13.2646-13.0511)+(13.1337-13.0511)
= 13.7411

Current grand average performance	13.0511
Confident interval at the 90% confidence level	±0.5604
Expected result at optimum performance, µ	13.1807 <µ <14.2475 dB

The confirmation experiment was conducted to predict the quality characteristics based on optimum performance calculation. The confirmation experiment result is 13.3146 dB and has archived the minimum requirement of optimum performance. In other words, the expected result at optimum performance is 13.1807 <µ <14.2475 dB. Table VIII presented result for confirmation experiment

TABLE VIII
CONFIRMATION EXPERIMENT

REP 1	4.6956
REP 2	4.7787
REP 3	4.5617
REP4	4.5549
REP 5	4.6599
REP 6	4.5569
REP 7	4.7461
REP 8	4.5811
REP 9	4.5569
REP 10	4.6312
S/N Ratio larger is better	13.3146 dB

IV. CONCLUSION

The development of SS316l/NHAP composite as a feedstock in MIM was successfully injected. The injection parameters were optimized by using Taguchi Method. Taguchi Method were classified as among the best optimization technique due to cost reduction in MIM.hence, The optimum parameter for highest density is A_2, B_2, C_2 and D_2 represents to Injection Temperature 175 ˚C, Mold Temperature 50 ˚C, Pressure 65 % and Speed 65 %. The confirmation experiment result is 13.3146 dB and has archived the minimum requirement of optimum performance. The density of green part were important since higher density also leads to the overall improvement of mechanical properties

ACKNOWLEDGMENT

The researchers wish to thanks to Advanced Manufacturing and Material Center (AMMC), Universiti Tun Hussein Onn Malaysia and Ministry of Higher Education Learning (Mybrain15, My PhD) for financial support in this research.

REFERENCES

[1] German .R and Bose, Injection Molding of Metals and Ceramics. Powder Industries Federation U.S.A, 1997

[2] N.H.Loh , S.B. Tor, K.A. Kor , Production of Metal Composite part by powder injection molding, Journal of Material Processing Technology, 2001, 108 (398-407)

[3] Yimin Li, Liujun Li, K.A. Khalil, Effect of powder loading on metal injection molding stainless steels, Journal of Materials Processing Technology 2007 ,183 432–439

[4] Khairur Rijal Jamaludin, Norhamidi Muhamad, Sufizar Ahmad, Mohd Halim Irwan Ibrahim, Nor Hafiez Mohd Nor And Yusof Daud, Injection Moulding Temperature And Powder Loading Influence To The Metal Injection Moulding (Mim) Green Compact Scientific Research And Essays Vol. 6(21), 2011, Pp. 4532-4538,

[5] Tirumani S. Shivashankar, Ravi K. Enneti , Seong-Jin Park , Randall M. German , Sundar V. Atre , The effects of material attributes on powder–binder separation phenomena in powder injection molding, Powder Technology 243 ,2013, 79–84

[6] Fatima Zivic , Miroslav Babic, Nenad Grujovic, Slobodan Mitrovic, Dragan Adamovic, Influence of loose PMMA bone cement particles on the corrosion assisted wear of the orthopedic AISI 316LVM stainless steel during reciprocating sliding, Wear 300 ,2013, 65–77

[7] Ramli. Mohd Ikram, Sulong. Abu Bakar. Arifin. Amir, Muchtar. Andanastuti, Muhammad. Norhamidi, Powder Injection Molding of SS316L / HA Composite : Rheological Properties and Mechanical Properties of the Green Part, Journal of Applied Sciences Research,2012, 8(11): 5317-5321

[8] Kipphut, C.M. and German, R.M , Powder selection for shape retention in Powder injection Molding, International Journal of Powder Metallurgy , 1991, 27(2), 117-124

[9] M. Boutinguiza a, J. Pou, R. Comesana a, F. Lusquinos , A. de Carlos, B. Leon, Biological hydroxyapatite obtained from fish bones, Materials Science and Engineering ,2012, C 32, 478–486

[10] Arifin, Amir, Sulong, Abu Bakar, Muhamad, Norhamidi, Syarif, Junaidi, Ramli, Mohd Ikram, Powder injection molding of HA/Ti6Al4V Composite using palm stearin as based binder for implant material, Materials and Design 65,2015 , 1028–1034 Contents.

[11] Thian, E S, Loh, N H, Khor. KA, Tor. SB, Ti-6A1-4V / HA composite feedstock for injection moldingMaterials Letters 56, 2002, 522–53

[12] M. A. Omar, I. Subuki, N. S. Abdullah, N. Mohd Zainon and N. Roslani, Processing of Water-atomised 316L Stainless Steel Powder Using Metal-injection Processes, Journal of Engineering Science, 2012, Vol. 8, 1–13,

[13] M.H.I. Ibrahim, N. Muhamad, A.B. Sulong, K.R. Jamaludin, S. Ahmad and N.H.M. Nor ,Optimization of Micro Metal Injection Molding For Highest Green Strength by Using Taguchi Method International Journal of Mechanical and Materials Engineering (IJMME), 2010, Vol. 5 No.2, 282-289

[14] M.H.I. Ibrahim, N. Muhamad, A.B. Sulong, K.R. Jamaludin, N.H.M. Nor and Sufizar Ahmad, Optimization of Micro Metal Injection Molding with Multiple Performance Characteristics using Grey Relational Grade ,Chiang Mai J. Sci. 2011; 38(2) : 231-241

[15] A.M Amin, M.H.I Ibrahim, R. Asmawi, N. Mustafa, M.Y Hashim, Green Density Optimisation With Sustainable Sewage Fat As Binder Components In SS316l Feedstock Of Metal Injection Moulding Process (Mim) By Taguchi Method, Applied Mechanics and Materials ,2015, Vols 773-774 ,pp 173-177

[16] T. Muthuramalingama & B Mohan, Taguchi-grey relational based multi response optimization of electrical process parameters in electrical discharge machining Indian Journal of Engineering & Materials Science Vol. 20, December 2013, pp. 471-475

[17] S. Kamaruddin, Zahid A. Khan, K. S. Wan, The Use Of The Taguchi Method In Determining The Optimum Plastic Injection Moulding Parameters For The Production Of A Consumer Product, Jurnal Mekanikal Disember 2004, Bil.18 , 98 – 110

[18] W.H.Yang, Y.S Tarng Design Optimization of Cutting parameters for Turning Operations based on Taguchi Methods Jurnal of Material Processing Technology 84, 1997, P 122-129

[19] B. Berginc,, Z. Kampuš , B. Šuštaršič , The use of the Taguchi approach to determine the influence of injection-moulding parameters on the properties of green parts, Journal of Achievements in Materials and Manufacturing Engineering, Volume 15 Issue 1-2 March-April (2006)

[20] N.H. Mohamad Nor, N. Muhamad, A.K.A Mohd Ihsan, K.R. Jamaludin, Sintering Parameter Optimization of Ti-6Al-4V Metal Injection Molding for Highest Strength Using Palm Stearin Binder, Procedia Engineering 68 , 2013, 359 – 364

[21] Z.Y. Liu , N.H. Loh , S.B. Tor , K.A. Khor , Y. Murakoshi , R. Maeda, Binder system for micro powder injection molding, Materials Letters 48 ,2001, 31–38

[22] M.H.I.Ibrahim, N.Mustafa, A.M.Amin,R.Asmawi, Processability Study of Natural Hydroxyapatite and SS316L Via Metal Injection Molding, International Symposium on Technology Management and Emerging Technologies (ISTMET), 2015,p 335-339

[23] Raghu N. Kacker, Eric S. Lagergren, and James J. Filliben , Taguchi's Orthogonal Arrays Are Classical Designs of Experiments, Journal of Research of the National Institute of Standards and Technology. 96,1991, 577

[24] Phadke, M. S, Quality Engineering Using Robust Design. AT & T Bell Laboratories. Pearson Education,2008

[25] Sri Yulis M. Amin, Norhamidi Muhamad, Khairur Rijal Jamaludin, Optimization of Injection Molding Parameters for WC-Co Feedstocks, Jurnal Teknologi (Sciences & Engineering) 63:1 ,2013, 51–54

[26] Metal Powder Industries Federation Standard 42 Determination of Compacted or Sintered Powder Metallurgy Products

[27] Jamaludin, K. R. ,Muhamad, N. ,Ab. Rahman, M., Amin, S. Y. M, Murtadhahadi, Ismail, M. H. Injection molding parameter optimization using the taguchi method for highest green strength for bimodal powder mixture with SS316L in PEG and PMMA. World Congress on Powder Metallurgy & Particulate Materials, 2008

[28] N.H.M. Nor, N.Muhammad, M.H.I.Ibrahim, K.R.Jamaludin. Optimization of injection molding parameter of TI-6AL-4V powder mix with Palm Stearin and Polyethylene for the highest green strength by using taguchi method, International Journal of Mechanical and Materials Engineering (IJMME),2011, Vol.6 ,No.1, 126-132

[29] H. Oktem, T. Erzurumlu, I. Uzman, "Application of Taguchi optimization technique in determining plastic injection molding process parameters for a thin-shell part", Materials and Design. 2007, vol. 28, pp 1271-1278.

[30] Roy, R.K. Design of Experiments Using the Taguchi Approach. John Willey & Sons. New York, 2001.