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Experimental Investigation on Influence of Process Parameters on Properties of Powder Synthesized Aluminium Metal Matrix Composites by Taguchi's Analysis

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The ever increasing fuel price created urgency for weight reduction of products in automotive and aerospace industries. Requirement of better mechanical properties, quality, improved wear resistance, lower coefficient of thermal expansion leads to the development of aluminum composites of lighter weight. The properties of the aluminium metal matrix composites are greatly influenced by the process parameters of the production methods. In this paper, aluminium metal matrix composite with reinforcement of 10% by weight proportion of silicon carbide is prepared by powder metallurgy process. The process parameters such as compaction pressure (100-130 MPa), sintering temperature (300-600°C) and sintering time (120-300 min) are considered. Properties such as compression strength, sliding wear resistance, micro abrasive wear and coefficient of thermal expansion of aluminum metal matrix composite are measured. Taguchi's experimental design is adopted for laying out the experimental conditions and Principal component analysis approach is used to identify the optimum and significant parameters which provide the preferable properties of the composite. It is found that sintering temperature (300-600°C) is significant parameter influencing the measured properties of aluminium metal matrix composites.

Keywords: *Aluminium metal matrix composite, Powder metallurgy, Process parameters, Taguchi's Analysis.*

1. Introduction

Newer materials with high strength, reduced weight, better thermal stability and quick preparation at nominal cost are needed to meet the demands of design engineers[1]. To meet this challenge of various combinations of material properties, composites have been a solution. Required combination of material properties, which is not possible in monolithic materials are obtained by composite materials. Factors affecting the characteristics of the composites depend upon the properties of matrix material and reinforcement material, size and distribution of reinforcement material and its geometry, nature of interface between matrix material and reinforcement material, orientation of the individual constituents in the isotropy system[2]. Alloying the aluminium increases the strength of naturally soft metal higher than the strength of mild steel. Toughness at low temperatures makes the aluminium alloys more suitable for cryogenic applications[3]. Aluminium metal matrix composites are fabricated with different ceramic reinforcements like silicon nitride Si_3N_4[4], Al_2O_3[5], B_4C[6], TiC[7] and the most commonly used particle is SiC[8]. The material loss mechanism was significantly higher in the case of erosion-corrosion tests, while studying the corrosion behavior of Al (6061)-B_4C-Graphite[9]. Aluminium with silicon carbide reinforced composites having low density and high strength are highly suitable for the industrial applications[10]. Addition of quartz particles having high strength and hardness when combined with aluminium increases the toughness and formability[11]. Aluminium metal matrix composites can be used as an alternate material for copper and aluminium cores in printing wire boards, commercial automotive parts[12]. The wear behavior of the Al 6061 alloy composite with Si_3N_4 and SiC as reinforcement is studied and concluded that dispersion of silicon carbide is the major reason for the improved interfacial characteristics and wear properties[13]. Addition of SiC in aluminium may increase the properties of the composite such as yield strength, young's modulus and wear resistance[14]. Silicon carbide proves to be a better reinforcement among various commercially available materials because of its higher strength, lower coefficient of thermal expansion and better wear resistance at higher working temperatures[15]. Wear rate of cast aluminum, Al and silicon carbide composite, Al, SiC and graphite composites increased with increasing load and decreased with the increasing speed[16]. The wear rate of the magnesium matrix composites when tested under nano- and micro-graphite lubrication conditions showed very little variation over the entire range of loads (15 to 60N) and sliding speeds (1.25 to 3.15 m/s)[17]. Hardness is increased by 35% due to the addition of TiC reinforcement in the composite with Al-Cu alloy and yield strength and ultimate tensile strength were increased by 15% and 24% respectively[18].

Powder metallurgy process is the most suitable method to fabricate metal matrix composites in which ceramic particle

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reinforcements are combined with the metal matrix by solid state blending of the powders. Powder metallurgy process consists of two major steps namely powder preparation and powder compaction. Powder preparation methods used in the industry are atomization, splat cooling or centrifugal disintegration. The foremost purpose of compaction is to prepare a pressed part with required strength to withstand the proceeding operations. The pressed part is called as green compact. Compaction of powder can be taken place either in raised temperature or in ambient temperature named accordingly as hot compaction or cold compaction. The green compacts are sintered and the secondary operations such as machining and forming are carried out to obtain the final powder metallurgy parts.

Green density of the Aluminium alloy with fly ash compacts (weight fraction in the range of 5 – 30%) prepared by compaction at the pressure range of 63 – 316 MPa increases by increasing the compaction pressure and it decreases with the higher percentage of fly ash[19]. The results of the dry sliding wear tests for Al 6061 composite with natural graphite as reinforcement by powder metallurgy route reveal that wear rate increases with the increase in volume of the reinforcement material[20]. There is an improvement in wear resistance in copper graphite composite due to the self-lubricating action of graphite[21]. Milling time and percentage of graphite plays an important role in the mechanical properties like hardness and tensile strength of Al 7075 alloy reinforced with metalized graphite nano particles[22]. Ceramic reinforcements to reduce the coefficient of thermal expansion and to increase the mechanical properties like hardness, stiffness and specific strength of the composites[23]. Addition of MgO will improve densification at lower sintering temperature of aluminium oxide and silicon carbide composite prepared by powder metallurgy[24]. Compression test results for Al reinforced $Zr_{57}Ti_8Nb_{2.5}Cu_{13.9}Ni_{11.1}Al_{7.5}$ glassy powder show that strength of the composite increases to 250MPa when compared to pure Al[25]. X-ray micro tomography of AA2124 with nickel shows that good correlation between the simulations of elasto plastic response of the material with the experimental results[26]. A least square method was developed for understanding the workability limit of the powder metallurgy parts[27]. Effect of silicon carbide on the particle cracking and ductility were studied on the composite prepared by powder metallurgy process[28]. Design of experiments approach using Taguchi method is employed to analyze the dry sliding wear behavior of aluminium/fly ash/graphite hybrid composites[29]. Taguchi method with grey relational analysis was utilized for optimization of the machining parameters of Al356/SiC-mica composites[30].

Even a lot of researches have been carried out in the preparation of aluminium composites by powder metallurgy route, by varying the composition and weight percentage of reinforcements, the analysis of the process parameters involved in the powder metallurgy technique has not been addressed so far.

This paper aims at experimental investigation of the effect of process parameters on properties of powder synthesized aluminium metal matrix composites by Taguchi's analysis.

2. Experimentation and Testing

In powder metallurgy route, the various process parameters involved are powder size, compaction pressure, sintering temperature, sintering time, green density of the powder and the lubricants used in the mixture. The compaction pressure applied on the die will have a great influence on the properties of the resultant products. Similarly the sintering temperature and sintering time for which the component should be maintained at the sintering temperature also play a vital role in the mechanical properties of the composite[31]. The powder metallurgy process parameters taken into account in this paper are compaction pressure, sintering temperature and sintering time.

Design of experiments is carried out using these parameters and their levels are shown in Table 1. Taguchi's orthogonal array (OA16) experimental design consisting of 16 combinations of compaction pressure, sintering temperature and sintering time is considered for this paper. According to design catalogue of Taguchi, three factors without interaction are considered at four finite levels. Based on the above parameters and levels, the operating conditions for powder metallurgy process is found out and is shown in Table 2.

Table 1. Experimental design of composite preparation for powder metallurgy process.

Experimental Factors	Level 1	Level 2	Level 3	Level 4
Compaction Pressure (MPa)	100	110	120	130
Sintering Temperature(°C)	300	400	500	600
Sintering Time (min)	120	180	240	300

Table 2. Designed operating conditions for powder metallurgy process.

Specimen No.	Designed Operating condition		
	Compaction Pressure (MPa)	Sintering Temperature(°C)	Sintering Time (min)
S1	100	300	120
S2	100	400	180
S3	100	500	240
S4	100	600	300
S5	110	300	180
S6	110	400	120
S7	110	500	300
S8	110	600	240
S9	120	300	240
S10	120	400	300
S11	120	500	120
S12	120	600	180
S13	130	300	300
S14	130	400	240
S15	130	500	180
S16	130	600	120

2.1 Preparation of aluminium metal composite by powder metallurgy process

Ready to use atomized aluminium powder of 200 mesh size is used as the base metal for composite preparation. The chemical composition of aluminium powder is shown in Table 3. Properties of silicon carbide are exhibited in Table 4. The powders of aluminium and silicon carbide are weighed using an electronic balance with an accuracy of ± 0.1 mg. The weighed powders to get a mixture of Al-10%SiC are placed in a cylindrical container. Air tight plastic containers are used for avoiding the oxidation of aluminium powders with atmosphere. The cold compaction dies used for specimen preparation are shown in Figure 1. A hydraulic press of capacity 40T as shown in Figure 2 is used for compaction.

Dies to press the blended powders are made from Oil Hardened Non distorting Steel (OHNS). The dies are prepared for the following dimensions.

- Die of Inner diameter of 15mm and length 22 mm for preparing compression strength test specimen.
- Die of Inner diameter of 10 mm and length of 27 mm for obtaining sliding wear resistance test specimen.
- Die of Inner diameter of 24 mm and 14 mm thickness for preparing specimens for micro abrasive wear testing.
- Die of nner diameter of 10mm and 47 mm length for preparing specimen for dilatometer testing of coefficient of thermal expansion.

Initially the die is filled with the required quantity of powder mixture which is blended already and tapped evenly in all directions to make the powder mixture to occupy completely inside the die. The filled powder mixture in the die is compressed uniaxially for 60 seconds at the designed compaction pressures. Compaction of the composite material is carried out at room temperature. Special care is taken while removing the green compacts. The green compacts obtained from consolidation process are sintered in muffle furnace. In this paper, sintering process is conducted in ambient atmosphere for designed temperature and time period.

2.2 Testing of properties

The properties of the composite materials such as compression strength, sliding wear resistance, micro abrasive wear and coefficient of thermal expansion are measured.

Table 3. Chemical composition of Aluminium Powder**.**

Element	Si	Fe	Cu	Mn	Mg	Zn	Ni	Sn	Al
Weight %	12	1.3	3.5	0.5	0.3	1	0.5	0.2	80.7

Table 4. Properties of silicon carbide.

Properties	Values
Density	3220 kg/m^3
Melting point	2973 ºC
Coefficient of thermal expansion	4 µm/mºC
Thermal conductivity	126 W/mK
Young's modulus	410 GPa

The compression strength is measured using compression testing machine (PCTE UTM 4131). The machine has data acquisition system auto instrument series 2005 to acquire data from the load cell and the displacement measuring device. The compressive strength tests are conducted on these samples according to the ASTM – E9-95. The specimen dimensions are of diameter 15 mm and length 20 mm.

The wear tests are conducted as per ASTM G99. The specimen dimensions are of diameter 10 mm and length of 25 mm. The wear rate is measured with the help of pin

Figure 1. Cold compaction dies used to prepare powder metallurgy specimen

Figure 2. Hydraulic press of capacity 40T

on disc wear testing machine (Model: Wear and Friction Monitor TR20, DUCOM) as dry test at 400 rpm, 20 N for 475 seconds. Micro abrasive wear is measured in terms of wear volume.

Micro-abrasion wear volume is measured with a micro-abrasion tester (Wear and Friction Tech Ltd., Chennai) as dry test for 300 seconds, 6 N and 200 rpm. The specimens are prepared for 24 mm diameter and 12 mm thickness. The testing ball is made of high carbon high chromium steel of 25 mm diameter.

Coefficient of thermal expansion of the prepared specimen is measured by hytherm computerized dilatometer between the temperature range of 27°C to 500 °C. The dimensions of the specimen are 10mm Diameter and 45 mm length.

3. Results Analysis and Discussion

Principal Component Analysis (PCA) method is applicable to solve a multi response optimization problem with uncorrelated quality attributes. The response correlations that exist between the responses are eliminated by PCA to evaluate uncorrelated quality indices called principal components. The data is reduced to minimum number of dimensions without any information loss.

The procedure followed in PCA is:

- Step 1: Data Collection. Experimental test results are collected by measuring the properties of the composite specimens and shown in Table 5.
- Step 2: Data Normalization. The normalization of data provides fair information for determining the optimal levels of parameters. The original data are converted to a range of 0 and 1 with 1 counting the best performance and 0 the worst.

Higher the better is chosen for compression strength:

$$Xi*\left(k\right)=\frac{X\left(k\right)}{maxXi\left(k\right)} \tag{1}$$

Lower the better is chosen for Sliding wear resistance, Micro abrasion wear volume, coefficient of thermal expansion:

$$Xi*\left(k\right)=\frac{minXi\left(k\right)}{Xi\left(k\right)} \tag{2}$$

where, i = 1, 2, m;
j = 1, 2, n;
m is the number of experimental runs in Taguchi's OA design;
n is the number of quality characteristics;
Xi (k) is the normalized data of the k^{th} element in the i^{th} sequence.

Experimental data are normalized and shown in Table 6.

- Step 3: Determination of correlation coefficient array
- Step 4: Calculation of Eigen vectors and Eigen values
- Step 5: Evaluation of Principal Components (PC).

In order to eliminate response correlations, PCA has been applied to derive two independent quality indices called principal components. The independent quality indices are denoted as PC1, PC2, PC3 and PC4. Table 6 shows the values of these independent principal components for 16 experimental runs.

Signal to Noise ratio is used for obtaining the maximum value of Multi Performance Index (MPI). "Larger the better" is selected as the quality characteristic. The process parameters of production method in the preparation process of composite materials having greater influence in the performance characteristics are determined by Analysis of Variance (ANOVA). In this study, Minitab Software Version 18 is used for developing general linear model ANOVA. General linear model ANOVA identifies the optimum process parameters for the given experimental responses. The results obtained using Minitab 18 software is shown in Table 7.

From compaction pressure (CP), Sintering Temperature (ST), Sintering Time (ST1) plot for S/N ratio as shown in Figure 3 and Table 8 it is observed that the optimal process parameters for the powder metallurgy process in the preparation

Table 5. Measured Properties of composite specimen – Compression strength, Sliding wear resistance, wear volume and coefficient of thermal expansion.

Specimen No.	Designed Operating condition			Compression strength (MPa)	Sliding wear resistance ($\times10^{-3}mm^3/m$)	Wear volume (mm^3)	Coefficient of thermal expansion (1/K)
	Compaction Pressure (MPa)	Sintering Temperature (°C)	Sintering Time (min)				
S1	100	300	120	128.97	121.21	0.044839	2.30E-05
S2	100	400	180	173.47	15.33	0.074253	2.36E-05
S3	100	500	240	234.76	37.54	0.099645	2.19E-05
S4	100	600	300	279.36	38.54	0.030598	2.17E-05
S5	110	300	180	138.4	22.05	0.091017	2.42E-05
S6	110	400	120	170.7	74.57	0.053585	2.47E-05
S7	110	500	300	209.9	5.72	0.074253	2.20E-05
S8	110	600	240	240.09	47.09	0.038651	2.18E-05
S9	120	300	240	177.44	2	0.042437	2.46E-05
S10	120	400	300	183.31	59.7	0.060941	2.21E-05
S11	120	500	120	173.44	0.59	0.050838	2.22E-05
S12	120	600	180	290.57	71.07	0.092414	2.16E-05
S13	130	300	300	139.96	24.37	0.022871	2.43E-05
S14	130	400	240	200.06	34.29	0.037209	2.27E-05
S15	130	500	180	170.35	49.43	0.073658	2.20E-05
S16	130	600	120	247.53	91.46	0.074253	2.25E-05

Table 6. Calculation of normalized data, Principal Components, MPI and S/N ratio.

Specimen No.	Normalized data				Principal component				MPI	S/N ratio
	Sliding wear resistance (mm^3/m)	Compression strength (MPa)	Wear volume (mm^3)	Coefficient of thermal expansion (1/K)	PC 1	PC 2	PC 3	PC 4		
S1	0.004868	0.443852	0.510069	0.93913	0.256	-0.204	0.077	-0.377	-0.062	-22.49
S2	0.038487	0.596999	0.308014	0.915254	0.268	0.111	-0.116	-0.019	0.061	-26.85
S3	0.015717	0.807929	0.229525	0.986301	0.259	-0.054	-0.165	0.241	0.07025	-21.07
S4	0.015309	0.961421	0.747467	0.995392	0.253	-0.214	0.242	0.198	0.11975	-21.60
S5	0.026757	0.476305	0.251283	0.892562	0.262	-0.171	-0.161	-0.157	-0.05675	-27.71
S6	0.007912	0.587466	0.426817	0.874494	0.27	-0.041	0.033	-0.063	0.04975	-24.32
S7	0.103147	0.722373	0.308014	0.981818	0.263	-0.256	-0.167	0.103	-0.01425	-20.61
S8	0.012529	0.826272	0.591731	0.990826	0.266	-0.074	0.126	0.106	0.106	-19.36
S9	0.295	0.610662	0.53894	0.878049	0.266	0.11	-0.028	-0.212	0.034	-20.61
S10	0.009883	0.630863	0.375297	0.977376	0.27	-0.015	-0.058	-0.047	0.0375	-19.74
S11	1	0.596896	0.44988	0.972973	-0.022	-0.176	-0.725	-0.411	-0.3335	-22.59
S12	0.008302	1	0.247484	1	0.25	0.036	-0.132	0.421	0.14375	-29.07
S13	0.02421	0.481674	1	0.888889	0.186	-0.093	0.475	-0.472	0.024	-23.49
S14	0.017206	0.688509	0.614663	0.951542	0.264	0.119	0.167	-0.07	0.12	-24.85
S15	0.011936	0.586261	0.310503	0.981818	0.267	0.838	-0.118	-0.081	0.2265	-26.07
S16	0.006451	0.851877	0.308014	0.96	0.261	-0.163	-0.091	0.287	0.0735	-25.60

Table 7. Analysis of variance for principal components.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Compaction Pressure (MPa)	3	0.01513	0.01513	0.005042	0.77	0.0553
Sintering Temperature (min)	3	0.03192	0.03192	0.010641	1.62	0.0284
Sintering Time (°C)	3	0.01685	0.01685	0.005616	0.85	0.0413
Error	6	0.03942	0.03942	0.006570		
Total	15	0.10332				

S = 0.0986 R-Sq = 97.85% R-Sq (adj) = 96.43%

Table 8. Response table for means.

Level	Compaction Pressure (MPa)	Sintering Temperature (°C)	Sintering Time (min)
1	0.07825	0.04419	0.12969
2	0.05669	0.06706	0.12200
3	0.13719	0.16113	0.08256
4	0.11100	0.11075	0.04888
Delta	0.08050	0.11694	0.08081
Rank	**3**	**1**	**2**

of pure aluminium metal with 10% SiC composite are Compaction pressure of 120MPa, Sintering temperature of 600°C, sintering time of 180 minutes. After applying the optimal setting of process parameters, confirmation test was carried out to validate the analysis. The improvement of the compression strength from the initial condition to the multi optimal condition is about 9% and reduced sliding wear, micro abrasive wear approximately 10% and coefficient of thermal expansion approximately 6% from individual optimal condition. Sintering temperature is the most significant factor in improving the mechanical properties in powder metallurgy process.

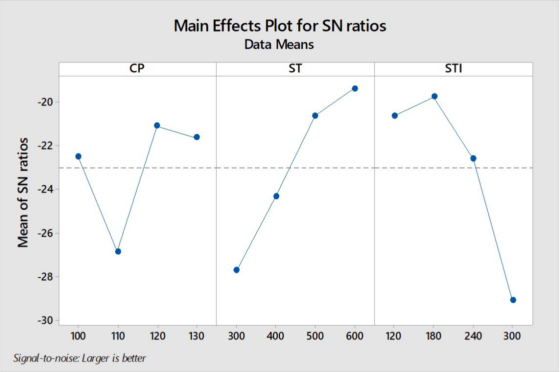

Figure 3. Mean effects plot for SN ratio

4. CONCLUSION

Aluminium metal matrix composite is prepared with 10% SiC by weight by powder metallurgy process considering compaction pressure, sintering temperature and sintering time as process paremeters under various experimental conditions designed by Taguchi's orthogonal array. The results are analyzed using Taguchi's method along with Principal

Component Analysis. From the analysis of test results, it is observed that at significant level of 5%, the process parameter namely sintering temperature is the significant parameter on Compression strength, Sliding wear resistance , Micro abrasive wear volume and coefficient of thermal expansion for the powder metallurgy process. The other process parameters such as compaction pressure and sintering time are found to be insignificant from ANOVA for the above mentioned four properties.

5. References

1. Huda MD, Hashmi MSJ, El-Baradie MA. MMCs: materials, manufacturing and mechanical properties. Key Eng Mater. 1995;104:37-64.
2. Samuel AM, Samuel FH. Foundry aspects of particulate reinforced aluminum MMCs: factors controlling composite quality. Key Eng Mater. 1995;104:65-98.
3. Nieh TG, Xia K, Langdon TG. Mechanical properties of discontinuous SiC reinforced aluminum composites at elevated temperatures. J Eng Mater Technol. 1988;110:77-82.
4. Arik H. Effect of mechanical alloying process on mechanical properties of α-Si3N4 reinforced aluminum-based composite materials. Mater Des. 2008;29:1856-61.
5. Canakci A, Varol T, Ozsahin S. Prediction of effect of volume fraction, compact pressure and milling time on properties of Al-Al_2O_3 MMCs using neural networks. Met Mater Int. 2013;19:519-26.
6. Baradeswaran A, Elayaperumal A, Issac RF. A statistical analysis of optimization of wear behaviour of Al-Al_2O_3 composites using Taguchi technique. Procedia Eng. 2013;64:973-82.
7. Kumar A, Mahapatra MM, Jha PK. Fabrication and characterizations of mechanical properties of Al-4.5% Cu/10TiC composite by in-situ method. J Miner Mater Charact Eng. 2012;11:1075.
8. Ozan S, Guleryuz LF, Uzunsoy D, Ipek R. Characterisation of magnesium matrix composite reinforced with SiC particulates manufactured by powder metallurgy method. Int J Surface Sci Eng. 2012;14:148-56.
9. Muthazhagan C, Gnanavelbabu A, Rajkumar K, Bhaskar GB. Corrosion behavior of aluminium-boron carbide-graphite composites. Appl Mech Mater. 2014;591:51-4.
10. Zafarani HR, Hassani A, Bagherpour E. Achieving a desirable combination of strength and workability in Al/SiC composites by AHP selection method. J Alloys Compd. 2014;589:295-300.
11. Friend CM. Fatigue and fracture behavior of aluminum-B4C particulate composite. Mater Sci. 1987;22:3005-15.
12. Hunt WH Jr, Herling DR. Aluminium metal matrix composites. Adv Mater Process. 2004;39-42.
13. Basavarajappa S, Chandramohan G. Dry sliding wear behavior of hybrid metal matrix composites. Mater Sci. 2005;11:253-7.
14. Ramesh CS, Keshavamurthy R, Channabasappa BH, Pramod S. Friction & wear behavior of Ni-P coated Si_3N_4 reinforced Al6061 composites. Tribol Int. 2010;43:623-34.
15. Tan MJ, Koh LH, Murakoshi Y, Sano T. Processing and high temperature characteristics of AL-Li/SiCp composites. Mater Sci Forum. 1994;170:519-24.
16. Kheder ARI, Marahleh GS, Al-Jamea DMK. Strengthening of aluminum by SiC, Al_2O_3 and MgO. Jordan Journal of Mechanical & Industrial Engineering. 2011;5(6):533-44.
17. Basavarajappa S, Chandramohan G, David JP. Some studies on drilling of hybrid metal matrix composites based on Taguchi techniques. J Mater Process Technol. 2008;196:332-8.
18. Das L, Aggarwal M, Rajkumar K, Aravindan S, Gupta S. Tribological properties of magnesium nano-alumina composites under nano-graphite lubrication. Tribol Trans. 2012;55(3):334-44.
19. Kumar A, Mahapatra MM, Jha PK. Modeling the abrasive wear characteristics of in-situ synthesized Al-4.5% Cu/TiC composites. Wear. 2013;306:170-8.
20. Hrairi M, Ahmed M, Nimir Y. Compaction of fly ash–aluminum alloy composites and evaluation of their mechanical and acoustic properties. Adv Powder Technol. 2009;20:548-53.
21. Jha AK, Prasad SV, Upadhyaya GS. Sintered 6061 aluminium alloy-solid lubricant particle composites: sliding wear and mechanisms of lubrication. Wear. 1989;133:163-72.
22. Rajkumar K, Aravindan S, Kulkarni MS. Wear and life characteristics of microwave-sintered copper-graphite composite. J Mater Eng Perform. 2012;21(11):2389-97.
23. Arpon R, Molina JM, Saravanan RAC, Garcia-Cordovilla C, Louis E, Narciso J. Thermal expansion behavior of Aluminum/SiC composites with bimodal particle distributions. Acta Mater. 2003;51:3145-56.
24. Gustafsson S, Falk LK, Lidén E, Carlström LE. Pressure less sintered Al2O3–SiC nanocomposites. Ceramics International E. 2008;34(7):1609-15.
25. Scudino S, Liu G, Prashanth KG, Bartusch B, Surreddi KB, Murty BS, et al. Mechanical properties of Al-based metal matrix composites reinforced with Zr-based glassy particles produced by powder metallurgy. Acta Mater. 2009;57:2029-39.
26. Watson IG, Lee PD, Dashwood RJ, Young P. Simulation of the mechanical properties of an aluminum matrix composite using X-ray microtomography. Metall Mater Trans, A Phys Metall Mater Sci. 2006;37:551-8.
27. Nath D, Rohatgi PK. Fluidity of mica particles dispersed aluminum alloys. J Mater Sci. 1980;15:2777-84.
28. Mazen AA, Emara MM. Effect of particle cracking on the strength and ductility of Al-SiCp powder metallurgy metal matrix composites. J Mater Eng Perform. 2004;13:39-46.
29. Indumati BD, Purohit GK. Study of mechanical behavior of metal matrix composites using design of experiments. Journal of Advances in Production Engineering and Management. 2011;2011(6):303-9.
30. Rajmohan T, Palanikumar K, Kathirvel M. Optimization of machining parameters in drilling hybrid aluminium metal matrix composites. Trans Nonferrous Met Soc China. 2012;22:1286-97.
31. Liu J, Khan U, Coleman J, Fernandez B, Rodriguez P, Naher S, et al. Graphene oxide and graphene nanosheet reinforced aluminium matrix composites: powder synthesis and prepared composite characteristic. Mater Des. 2016;94:87-94.