Optimisation the Sintering of Al-MMCs by PM approach and advancement in the tribological properties of Al composites

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Abstract:

The aluminium Metal matrix composites (MMCs) have extensively used in industrial applications due to the lighter weight with high specific strength, good thermal behaviour and high stiffness. But the Processing of aluminium at high temperature is very difficult and complex task due to its reactive nature. In the present work AMCs with graphite, SiC, Mg and zinc along with fly-ash as reinforcements fabricated using PM approach. Sintering carried out using powder silicon dioxide in place of inert gas or vacuum chamber with designed arrangements. Characterisation of composites carried out using hardness testing, wear rate and measurement of friction coefficient. Present way of sintering give more effective results than conventional methods along with considerable reduction in manufacturing cost. Effect of varying sintering time, sintering temperature and compaction pressure observed using taguchi approach on output properties of produced. Composite with 800 kN at 660ºC for 3 of sintering has better hardness compared with all composites. But with 800 kN at 690ºC for 4.5 hours of sintering have better wear behaviour compared with all composites.

Keywords:

Composite, Taguchi' approach, Al MMCs, Sintering and Fly-ash

Introduction:

There is uncountable number of materials and different properties can be produced by combining different materials using particular parameters and fabrication methods. Where high strength and wear resistant materials are required there aluminium ceramic composites gives outstanding results [1, 2].

All the factors make differences in the output product in material science. But due to the reactive nature of aluminium Sintering is the most difficult task as it gets oxidised at higher temperature immediately. Some different methods for sintering of aluminium used by some researchers in different papers like spark plasma sintering, protective ceramic or aluminium coating and microwave sintering.[3-8] In this research work sintering carried in muffle furnace using special approach with silica and flux. It may be a revolutionary technique for the future industry. As it reduces the considerable manufacturing cost and overcomes the major barrier of the usage of MMCs.

This study is based on the fabrication of aluminium composites. As already proved graphite enhances the wear resistance and improves the fatigue behaviour [9-19]. On adding 5% graphite in the aluminium it gives better wear behaviour than the 10% or more due to softness of graphite [14]. Optimal composition of used materials selected by previous research data and with experimental trials to improve the strength and wear resistance. Silicon carbide and fly-ash is selected along with other reinforcements to make the better combination of materials to get achievable properties of produced composite.

In the reference paper the effect of particle size of the fly-ash also analysed using stir casting route of fabrication with average particle size of 4-25, 45-50 and 75-100 µm by examination of compressive strength, tensile strength, hardness and ductility. [14] In this it proved that with the increase in particle size of reinforced fly-ash compressive strength, tensile strength, hardness of Al alloys or composites decreases. And by increasing the weight fractions of the fly ash the ultimate tensile strength, compressive strength, hardness increases but ductility of the composite decreases. On adding ceramics as reinforcement up to15% properties get improved while beyond this limit the toughness, tensile strength and compressive strength deceases and hardness, brittleness increases.

In this research the composites using particle size of 200 mesh of fly-ash as reinforcement and 400 mesh of aluminium as matrix fabricated with particular proportion of different contents to optimise the AMC's. Experimental work carried to reduce the complexities in the fabrication of aluminium composites. The powder metallurgy route used to fabricate the composite as PM is the most effective and efficient way to produce particular metal matrix composite especially with complex shapes, with better surface finish and structural properties. The influencing parameters selected for this research work with powder metallurgy are Particle size, Pressing and Sintering.

Experimental procedure:

Materials design:

The fabrication of composite produced with Fly-ash, Silicon carbide, magnesium, Zinc and graphite as Reinforcements and Aluminium as matrix. 99% pure aluminium in powder form with 400 mesh size of particles collected from "Swastik metals Pvt ltd, kokar. The Fly-ash used brought from thermal power plant, Goindwal sahib. The elemental composition of fly-ash used investigated by Energy dispersive X-Ray fluorescence spectroscopy and given in table 2. Also particle size of 200 meshes taken for reinforcement materials. The particle size of the reinforced fly-ash is obtained by sieve analysis setup with no. of pans having standard sizes. The setup is vibrated for about 15 minutes as to be the separation of fly-ash powder A/c to the particle size. The volume percentage of different materials in used composition to the study given in table 1.

Table 1: Material Composition in volume (%)

Materials	Al	SiC	Mg	Graphite	Zinc	Fly-ash	P.F (CNSL)
Vol (%)	74	5	5	5	5	6	3% (of total mixture)

Table 2: Composition of Fly-ash

Component	**Percentage**
Alumina	28.98%
Silicon dioxide	53.96%
Calcium oxide	0.20%
Carbon	1.06%

The optical photographs of the powders of aluminium and fly-ash at the magnification of 1000 times given below

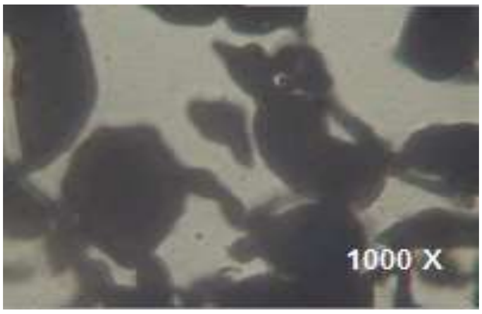

Figure 1: Optical photograph of Al

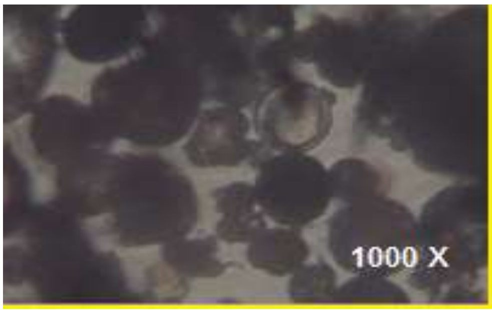

Figure 2: Optical photograph of Fly-ash

Design of Experiments:

Number of factors influences the study of materials. In this study fabrication of the composite done by controlling compaction load, sintering temperature and sintering time with three levels of each. To selection for optimal combinations of the values for selected parameters, taguchi technique with L9 orthogonal array used to perform the experiment. Evaluated detailed factorial format of Experiment is given in table 3.

Table 3: Factorial format with taguchi approach

Sample no.	**Parametric values for Jobs\ samples [Load (kN) + S. temp (^{0}C) + S. time (Hours)]**
1	600+ 630+ 3
2	600+ 660+ 4.5
3	600+ 690+ 6
4	700 + 630+ 4.5
5	700+ 660+ 6
6	700+ 690+ 3
7	800+ 630+ 6
8	800+ 660+ 3
9	800+ 690+ 4.5

Sample making:

Mixing: The different powders in definite proportion mixed using attrition mill (Ball type) (Make: Rathpon engineering) for about 2 hours and at 250 rpm to get the uniform distribution of the powders. In attrition mill due to vibration and other stresses the cold welding of the particles comes into consideration which helps to get the uniform distribution of the particles. Like graphite is solid lubricant and SiC enhances the wear of counterparts etc. The particular patterns used to mix the powder materials according to the behaviour of the materials to get the better results. The powders heated before mixing and after mixing at 200^0 C for about 60 minutes to remove the moisture content and other impurities.

Compaction: Samples prepared with "Hydraulic compression moulding machine" as shown in figure 3 (At "Lovely Professional University", Punjab) at three different loads 600 kN, 700 kN, and 800 kN. High speed alloy steel, die steel and tool steel used to make the parts of "Die" for making green compacts and graphite used as solid lubricants for die walls. The samples of 50 mm diameter and 7 mm height prepared to perform various tests.

Figure 3: Manufactured DIE and Compression moulding Machine

Sintering: The green compacts heated at 200^o C for about one hour to proper evaporation of adhesives and outsourcing of flue gasses. Sintering carried out in muffle furnace at different temperatures (630, 660 and 690 degree Celsius) using powder silicon dioxide and flux by layers to prevent from the oxidation. The silica present around the sample also caused to uniform distribution of heat to the sample and results to better quality material with more effective mechanical and elastic properties. Prepared sample for testing shown in figure 4 & 5.

Figure 4: Sample prepared

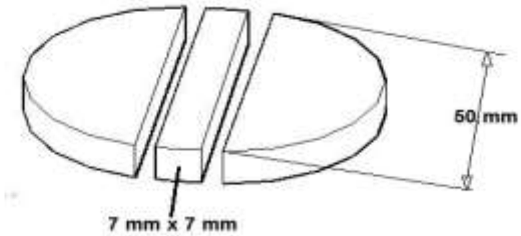

Figure 5: Pins prepared to wear test

Machining: Pins for wear and hardness tests of size 50 x 7 x 7 mm cut from prepared samples using wire cutting (CNC EDM wire cut – ultra cut S2 by "ELECTRONICA") machine at "CIPET", Amritsar.

Results and Analysis:

In this research the effect of selected different parameters evaluated on the hardness and wear behaviour of final composite. Rockwell hardness testing machine used to check the hardness of samples at B scale with 100 kg load and 1/16" steel ball indenter at "NIT, Jalandhar". Pin on disc apparatus at "NIT Jalandhar" used to calculate the wear rate and co-efficient of friction for fabricated material 98.10 N Load, disc speed of 500 r.p.m and for 10 minutes of running time.

The resultant equations given in table 6 formulated in terms of coded factors by using "Design Expert" software. These equations may use to predictions about response for the given levels of each factor.

Table 4: Results of output parameters for different samples

Sample no.	HRB	Wear rate	Co-efficient of friction	Specific wear rate (mm^3/N-km)
1	62	1.93	0.015	0.0197
2	70	1.61	0.016	0.0164
3	66	1.46	0.04	0.015
4	68	0.83	0.014	0.009
5	74	0.45	0.022	0.005
6	72	0.31	0.051	0.0032
7	83	0.78	0.025	0.008
8	88	0.26	0.042	0.003
9	86	0.21	0.057	0.0021

Table 5: Coded equations for different response variables:

HRB = +74.33-8.33*A[1]-3.00*A[2]-3.33*B[1]+3.00*B[2]-0.33*C[1]+0.33*C[2]
WR = +0.87+0.80*A[1]-0.34*A[2]+0.31*B[1]-0.098*B[2]-0.038*C[1]+0.012*C[2]
COF = +0.031-7.667E-003*A[1]-2.333E-003*A[2]-0.013*B[1]-4.667E-003*B[2]+4.667E-003*C[1]-2.333E-003*C[2]

Effect of processing parameters on response variables:

With increase of pressure the output behaviour gets improved due to the proper bonding of the particles and breaking of the oxidation layer present at molecules of aluminium due to passivity at high pressure.

With increase in temperature up to the melting point of the aluminium the hardness increases but beyond MP the hardness decreases and the wear rate and thermal conductivity increases even at slight above melting point.

Up to 4.5 hours of sintering the hardness increases but after that decreases and wear rate increases continuously with increase in time. Thermal conductivity first decreases but from 4.5 to 6 hours it gets increases. This behaviour shown by the material may due to the generation of the residual stresses by heating for longer period of time.

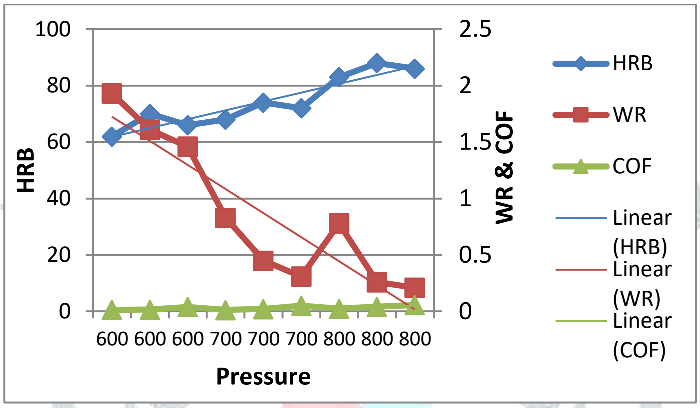

Figure 6: Effect of Pressure on response variables

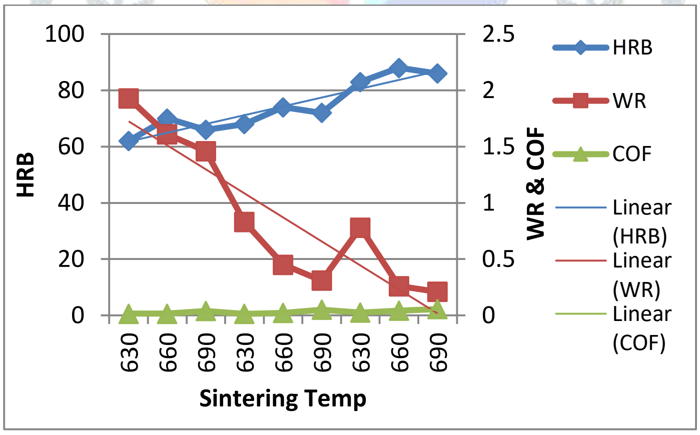

Figure 7: Effect of Sintering Temperature on response variables

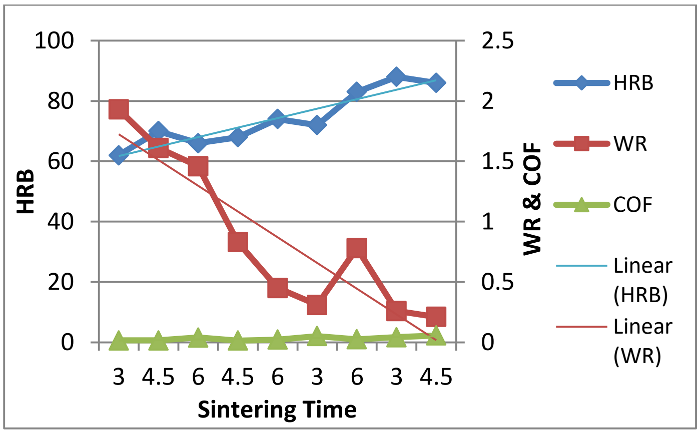

Figure 8: Effect of Sintering Time on response variables

Conclusions:

The composition of SiC, graphite, zinc, Mg and fly-ash in used proportion with Aluminium gives better output of the resultant properties and strength. On increase in pressure the hardness, thermal conductivity and microstructure improves and wear rate reduces considerably. On increase in the sintering temperature properties get improved but hardness increases up to melting temperature but then decreases but estimates to increases in the elastic and tensile properties along with toughness. By increase in the time of the sintering the properties are improved at temperature below than curing point of matrix but at high temperature the properties gets reduced with increase in the time of heating due to the residual stresses generated in the composite and also the distortion of the molecules of the base materials. So 3 or less than 3 hours is sufficient time to get better output properties. The best combination of the selected parameters is at 800 kN pressure and at 690 ^oC for 4.5 hours. Even highest value of the hardness got with 800 kN pressure, 660 ^oC and for 3 hours.

Future scope:

- Different heat treatments can perform to get further refined results as per requirements.
- Further study can be carried out with the different types of fly-ash.
- In Future, study can also carried by multiple sintering and multiple pressing.
- Other properties can check on this material to identify applications in particular areas.

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