Optimization of Tribological Properties During Powder Metallurgy Operation of AL- SI Alloy with Varying Percentage of Tin and Zinc using MCDM Approach MOORA and WASPAS

[1]Bhumika Peshwani , [2]Aashish Jaiswal, [3]Santanu Chakraborty, [4]B. B. Pradhan

[1,2,3,4]Mechanical Engineering Department. Sikkim Manipal Institute of Technology, Sikkim Manipal University, Majitar, East Sikkim, 737136.
Email: santanu_chak@rediffmail.com

Abstract : Aluminium, a metal known for its versatile nature including light weight, high strength to weight ratio, different mechanical properties etc.In the present work optimization of tribological properties of aluminium silicon alloys were studies by varying the percentage of tin and zinc during powder metallurgy operation.The tribological properties considered were fractional porosity, hardness and wearness.The readings were obtained by considering three response parameter such as total fractional porosity, average hardness and wear rate. The optimized alloy percentage was found by the application of MCDM approach MOORA and WASPAS.

Keywords : Aluminium-Silicon alloy, Composition Analysis, MCDM, MOORA, Powder metallurgy, Tribological properties, WASPAS.

I. INTRODUCTION

The benefits of aluminium like being a light metal having corrosion resistance, high reflectivity, good conductor of heat and electricity, on toxic, low density, high strength and easily recyclable making it advantageous for use over other metals. The aluminium alloys are widely used today after steel in use as structural metals making it most versatile, economical and attractive metallic material.Aluminium alloys for sheet products are identified by a 4-digit numerical system. The alloys containing major percentage of magnesium, manganese, iron, copper, silicon, zinc, tin etc. are conveniently divided into 8 groups based on their principle alloying elements as shown in the mentioned table1 below. During the calculation for overall assessment value, the average hardness (HR_B) was considered to be the beneficial criterion while the rest two,i.e. fractional porosity and the wear rate to be the non-beneficial one. **Aman**[1]et al used WASPAS method to study the tribological properties of Al-Si alloy by varying percentage of tin and zinc and obtained the optimized result.**Chakraborty**[2] explored the application of MCDM approach WASPAS as a multi criteria decision making tool for selecting result using five real time manufacturing related problems.**Chakraborty**[3]et al applied WASPAS method for optimizing tool in Non-Traditional Machining Process. **Madic**[4] studied MCDM approach WASPAS for selecting the suitable machining process and the relative significance was determined considering the pair wise comparison matrix. **Chakraborty**[5]explored an effective MCDM method for solving eight manufacturing decision making problems and also studied the effect of λ on ranking performance of WASPAS.**Majumder and Saha**[6]considered MCDM approach MOORA coupled with PCA for finding the optimal combination of input and output responses for turning ASTM A588 mild steel.**Patel and Maniya**[7]applied hybrid method AHP and MOORA for obtaining optimum machining parameter of EN 31 alloy steel suggesting MOORA to be satisfactory and results.**Kalirasu**[8] et al studied the machinability performance of jute and polyester composites using AWJM and obtained the optimum condition using MOORA.

TABLE 1 : Different alloy groups and its specifications:

Alloy Group	Principal Alloying Group	Characteristics	Applications
1xxx	Unalloyed Aluminium	Purity of 99% or more	Rotor manufactures
2xxx	Copper	Copper heat treatable alloy, increases strength and hardness	Used in electrical industry
3xxx	Manganese	90% of all shaped casted products	Architectural application and various products
4xxx	Silicon	Low melting point alloys, increases strength to weight ratio etc.	Welding rods, automobile parts
5xxx	Magnesium	Good corrosion resistance and weldability	Marine industry
6xxx	Magnesium and silicon	Heat treatable alloys	Architectural extrusions
7xxx	Zinc	Heat treatable alloys	Aircraft structural components

			and other high strength application
8xxx	Other elements	May contains appreciable amount of tin, lithium or iron	
9xxx		Reserved for future use	

II. EXPERIMIENTAL CONDITIONS

During the formation of powder of metals for powder metallurgy operation the mixing was done by ball milling type mixing method in which the metal balls of ball bearing were rotated using lathe chuck for proper mixing. The powder was compacted in universal testing machine (UTM) between the pressure range of 40kN to 50kN; lubrication (lubricants used here were graphite and stearic acid) was provided to reduce friction between powder being pressed and die-wall. After this, the heat treatment process sintering was done at 650^{o}C in vacuum furnace. For the experimental Purpose, the composition of tin and zinc were varied, keeping the composition of Al, Si, Cu, and Mg same for calculating the value of output parameters i.e. fractional porosity, average hardness and wear rate.

TABLE 2 : Varying percentage of tin and zinc.

SAMPLE	TIN(Sn)%	ZINC(Zn)%
1	5.4	0
2	4.8	0.6
3	4.2	1.2
4	3.6	1.8
5	3	2.4
6	2.4	3
7	1.8	3.6
8	1.2	4.2
9	0	5.4

III. CALCULATION USING INPUT PARAMETERS.

TABLE 3: Measurement of composition on density

Alloy Specimen	Mean Dia.(mm) $[\{d_1+d_2+d_3\}/3]$	Mean Length (mm) $[\{l_1+l_2+l_3\}/3]$	Mean Mass (gm.) $[\{m_1+m_2+m_3\}/3]$	Volume (mm^3) $[\pi*\{d/2\}^2*l]$	Mean Density (gm/cm^3) $[\{\rho_1+\rho_2+\rho_3\}/3]$
Alloy 1	25	90	104.40	44178.647	2.363
Alloy 2	25	90	103.22	44178.647	2.336
Alloy 3	25	90	102.98	44178.647	2.331
Alloy 4	25	90	102.81	44178.647	2.327
Alloy 5	25	90	102.63	44178.647	2.323
Alloy 6	25	90	103.46	44178.647	2.341
Alloy 7	25	90	103.88	44178.647	2.351
Alloy 8	25	90	104.21	44178.647	2.358
Alloy 9	25	90	104.56	44178.647	2.366

TOTAL FRACTIONAL POROSITY (γ)

Porosity or void fraction or simply fractional porosity is the measure of fraction of volume of voids over the total volume. It is found that even after sintering, it is impossible to produce a component of powder metallurgy without voids or pores. The amount of voids or pores in the sintered components may be evaluated from total fractional porosity measurement i.e.**γ** and is given by:

$$\gamma = 1 - (\gamma_p/\gamma_s)$$

Where, **γ**=fractional porosity of powder metallurgy components.

$\gamma_p = M_p/V_p$= density of sintered component.

$\gamma_s = x_i * y_i =$ density of solid materials.

M_p=mass of sintered components.

V_p=volume of sintered components.

X_i=mass fraction of the individual alloying element present in the alloy.

Y_i=density of the individuals alloying elements.

TABLE 4 : Measurement of fractional porosity

ALLOY SPECIMEN	TOTAL FRACTIONAL POROSITY (γ).
Alloy 1	0.145
Alloy 2	0.191
Alloy 3	0.201
Alloy 4	0.22
Alloy 5	0.210
Alloy 6	0.195
Alloy 7	0.20
Alloy 8	0.22
Alloy 9	0.215

MEASUREMENT OF COMPOSITION ON HARDNESS

The hardness of the powder metallurgy component was measured in which the applied load was 100kgf and indenter used was 1/16" hardened steel. The alloy samples were tested and the average hardness was shown below:-

TABLE 5: Measurement of average hardness

Alloy Specimen	Average Hardness(HR_B)
Alloy 1	55.78
Alloy 2	52.33
Alloy 3	56.78
Alloy 4	57.55
Alloy 5	54.66
Alloy 6	56.66
Alloy 7	58.89
Alloy 8	58.22
Alloy 9	62.33

It was found that by varying the percentage of tin and zinc altered the hardness of alloy as the hardness first increases then decreases and then after a continuous increment was seen. Thus, the optimal percentage of tin and zinc can improve the hardness of the alloy.

MEASUREMENT OF COMPOSITION ON WEARING PROPERTY

The tribological behaviour of knowing the wear rate in the present work is done by the wear friction test; in which a hardened steel disc of 100 mm diameter and 8 mm thick is rotated through a reduction gear box, thus creating friction between the load specimens and rotating disc. In this work, the wear rate is calculated by height loss (inμm) by varying the sliding speed at 600 rpm to 800rpm and applied load by 40N to 60N. The wear rate so found is shown below:

$W_r=[(M_i-M_f)/\{t^*(\pi DN/1000)\}]$

Where,M_i=initial mass(gms)

M_f=finial mass (gms)

t=time of rotation (in mins)

D =track diameter (in mm)

N =revolutions per minutes (rpm)

W_t=wear rate (gm/m rotation)

TABLE 6 : Measurement of wearing

RPM	LOAD(N)	WEAR RATE(μm)								
		Alloy 1	**Alloy2**	**Alloy3**	**Alloy4**	**Alloy5**	**Alloy6**	**Alloy7**	**Alloy8**	**Alloy9**
600	40	71	63	58	46	42	37	31	26	21
	60	309	253	179	130	122	113	105	99	93
800	40	74	78	81	87	95	103	112	117	123
	60	330	336	341	345	353	359	364	369	371

Thus from the readings it can be concluded that wear rate increases at the higher rpm and vice-versa.

4. METHODOLOGY

This paper represents the MCDM approach MOORA and WASPAS for parametric optimization of selection of best alloy sample with varying sample of tin and zinc during powder metallurgy operation. The steps involved are as follows:

A. MOORA (Multi Objective Optimizationon the Basis of Ratio Analysis)

MOORA is a one folded method applied to and extended in many decision making problems. It is basically used for optimizing two or more conflicting objectives subjected to certain restraints. This method was given by Brauers and Zavadskas in 2006, and suggested it to be sensible enough in problem solving assessment as it exactly matches the result with what the past researchers have derived. The accompanying steps are as follows:-

Step1:PROBLEM DETERMINATION

In this step the required alternatives and their characteristics are classified.

Step2:FORMATION OF DECISION MATRICES

Here, the decision matrix is prepared depicting the performance characteristics with respect to different variables.

$$R = \begin{bmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & \cdots & x_{mn} \end{bmatrix}.$$

Here, x_{ij} = performance measure of i^{th} alternative on j^{th} attribute,

m=number of alternatives, and

n=number of attributes.

Step3:NORMALIZATION OF PERFORMANCE MEASURES

In this step, the decision matrix is normalized, for making it dimensionless for comparison between every component. It is important to specify whether the beneficial or non-beneficial criterion does not impact in decision matrix normalization. The normalization of matrix is equal to the ratio of performance measures of individual alternative per criterion to square root of sum of squares of individual alternative per criterion, and can be represented as follows:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}}.$$

Here, x_{ij}^{*} =normalized value of i^{th} alternative on j^{th} criterion which lies between 0 and 1.

Step 4: EVALUATION OF OVERALL ASSESSMENT VALUES

Here, the beneficial and the non-beneficial criterion are added and subtracted respectively of the normalized performance measures and is given by:-

$$z_i = \sum_{j=1}^{g} x_{ij}^{*} - \sum_{j=g+1}^{n} x_{ij}^{*} .$$

To give preference to an objective, as few attributes were more influential than others, they could be multiplied by its corresponding weight. Thus, overall assessment value is given by:-

$$z_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{n} w_j\, x_{ij}^{*},$$

Where, w_j = weight of j^{th} criterion.

Step5:-ASSIGNING RANKING TO OVERALL ASSESSMENT

The assessment values are sorted in descending order in this step for choosing the best and the worst alternatives. Thus, the highest assessment is the best alternative while the lowest value is the worst.

TABLE 7 : The following table shows the fractional porosity, average hardness, and wear rate

Alloy Specimen	Tin (Sn) Mass%	Zinc (Zn) Mass%	Fractional Porosity (γ)	Avg. Hardness (HR_B)	x
Alloy 1	5.4	0	0.145	55.78	330
Alloy 2	4.8	0.6	0.191	52.33	336
Alloy 3	4.2	1.2	0.201	56.78	341
Alloy 4	3.6	1.8	0.22	57.55	345
Alloy 5	3.0	2.4	0.210	54.66	353
Alloy 6	2.4	3.0	0.195	56.66	359
Alloy 7	1.8	3.6	0.20	58.89	364
Alloy 8	1.2	4.2	0.22	58.22	369
Alloy 9	0	5.4	0.215	62.33	371

NOTE: x= Wear (μm) at 800 RPM with 60 N.

TABLE 8 : Normalized values of the decision matrix through MOORA

Alloy Specimen	Decision Matrix			Normalized Values		
	Total Fractional Porosity	Avg.Hardness	x	Total Fractional Porosity	Avg. Hardness	x
Alloy 1	0.145	55.78	330	0.240647079	0.325722926	0.312254524
Alloy 2	0.191	52.33	336	0.316990291	0.305576922	0.317931879
Alloy 3	0.201	56.78	341	0.333586641	0.331562347	0.322663008
Alloy 4	0.22	57.55	345	0.365119706	0.336058702	0.326447911
Alloy 5	0.21	54.66	353	0.348523356	0.319182774	0.334017718
Alloy 6	0.195	56.66	359	0.323628831	0.330861617	0.339695073
Alloy 7	0.2	58.89	364	0.331927006	0.343883527	0.344426202
Alloy 8	0.22	58.22	369	0.365119706	0.339971114	0.349157331
Alloy 9	0.215	62.33	371	0.356821531	0.363971136	0.351049783

NOTE: Wear Rate (μm) at 800 RPM with 60 N

TABLE 9: Overall assessment values and ranking

Alloy Specimen	Total Fractional Porosity	Avg. Hardness	X	Z_i	Z_i considering weight w_j=(1/3)	Ranking
Alloy 1	0.240647079	0.325722926	0.312254524	-0.227178677	-0.075726226	1
Alloy 2	0.316990291	0.305576922	0.317931879	-0.329345247	-0.109781749	3
Alloy 3	0.333586641	0.331562347	0.322663008	-0.324687301	-0.1082291	2
Alloy 4	0.365119706	0.336058702	0.326447911	-0.355508916	-0.118502972	6
Alloy 5	0.348523356	0.319182774	0.334017718	-0.3633583	-0.121119433	8

Alloy 6	0.323628831	0.330861617	0.339695073	-0.332462286	-0.110820762	4
Alloy 7	0.331927006	0.343883527	0.344426202	-0.332469681	-0.110823227	5
Alloy 8	0.365119706	0.339971114	0.349157331	-0.374305923	-0.124768641	9
Alloy 9	0.356821531	0.363971136	0.351049783	-0.343900178	-0.114633393	7

NOTE: Wear Rate (µm) at 800 RPM with 60 N

B. WASPAS (WeightedAggregated Sum Product Assessment).

WASPAS is a **MCDM** approach and a combination of **WSM** and **WPM** model i.e.

WASPAS = WSM (WEIGHTED SUM MODEL) + WPM (WEIGHTED PRODUCT MODEL).

This method is used when decisions are to be taken between multi criterions as in manufacturing decision making, material selection etc. The following steps can be used for implementing the WASPAS method:-

Step1:-FORMATION OF DECISION MATRIX

In this step a decision matrix is created $Y=(y_{ij})_{m*n}$

Where; yij=performance of i^{th} alternative with respect to j^{th} criterion.

m=no. of alternatives

n=no. of evaluation criteria

Step2:- NORMALIZATION OF PERFORMANCE MEASURES

The normalization is done for making every components (here fractional porosity, wear rate and hardness) dimensionless so that every components can be compared. Normalization can be done by the following equations:-

For maximising the performance measures:

$\bar{y}_{ij}=\frac{y_{ij}}{\max_i y_{ij}}$ for beneficial criteria.

For minimising the performance measures:

$\bar{y}_{ij}=\frac{\min_i y_{ij}}{y_{ij}}$ for non beneficial criteria.

Step3:-APPLYING WSM AND WPM FOR FINDING IMPORTANCE OF ITH ALTERNATIVE

From WSM and WPM, the relative importance of i^{th} alternative is given by:-

$$R_i^{(1)} = \sum_{j=1}^{n} \bar{y}_{ij} w_j$$

$R_i^{(2)} = \prod_{j=1}^{n} (\bar{y}_{ij})^{w_j}$, respectively.

Thus the collective weight from both the methods i.e WSM and WPM can be given by:-

$$R_i = 0.5R_i^{(1)} + 0.5R_i^{(2)} = 0.5\sum_{j=1}^{n} \bar{y}_{ij} w_j + 0.5\prod_{j=1}^{n} (\bar{y}_{ij})^{w_j}$$

Where w_j is weight of j^{th} criterion=1/3; as fractional porosity **(γ)**,average hardness **(HR_B)**, and wear rate **(WR)** have equal weightage.

For finding the optimum value the ranking is to be done and it is made possible by the R_i values. The highest R_i corresponds to the best optimized alternative.

TABLE 10 : The following table shows the fractional porosity, average hardness, and wear rate.

ALLOY SPECIMEN	TIN(Sn) Mass%	ZINC(Zn) Mass%	FRACTIONAL POROSITY(γ)	AVERAGE HARDNESS(HR_B)	X
Alloy 1	5.4	0	0.145	55.78	330
Alloy 2	4.8	0.6	0.191	52.33	336
Alloy 3	4.2	1.2	0.201	56.78	341
Alloy 4	3.6	1.8	0.22	57.55	345
Alloy 5	3.0	2.4	0.210	54.66	353
Alloy 6	2.4	3.0	0.195	56.66	359
Alloy 7	1.8	3.6	0.20	58.89	364
Alloy 8	1.2	4.2	0.22	58.22	369
Alloy 9	0	5.4	0.215	62.33	371

NOTE: Wear Rate (µm) at 800 RPM with 60 N

TABLE 11 : Normalization of decision matrix through WASPAS.

ALLOY SPECIMEN	DECISION MATRIX			NORMALIZED VALUES		
	FRACTIONAL POROSITY(γ)	AVERAGE HARDNESS(HR_B)	X	FRACTIONAL POROSITY(γ)	AVERAGE HARDNESS(HR_B)	x
Alloy 1	0.145	55.78	330	1	0.8949	1
Alloy 2	0.191	52.33	336	0.7592	0.8396	0.9821
Alloy 3	0.201	56.78	341	0.7214	0.9111	0.9677

Alloy 4	0.22	57.55	345	0.6591	0.9233	0.9565
Alloy 5	0.210	54.66	353	0.6905	0.8769	0.9348
Alloy 6	0.195	56.66	359	0.7436	0.9090	0.9192
Alloy 7	0.20	58.89	364	0.7250	0.9448	0.9066
Alloy 8	0.22	58.22	369	0.6591	0.9341	0.8943
Alloy 9	0.215	62.33	371	0.6744	1	0.8895

TABLE 12 : Relative importance of i^{th} alternative.

ALLOY SPECIMEN	γ	HR_B	X	$R_i^{(1)}$	$R_i^{(2)}$	R_i	Ranking
Alloy 1	1	0.8949	1	0.964966667	0.963662227	0.964314447	1
Alloy 2	0.7592	0.8396	0.9821	0.8603	0.855450294	0.857875147	3
Alloy 3	0.7214	0.9111	0.9677	0.866733333	0.859991797	0.863362565	2
Alloy 4	0.6591	0.9233	0.9565	0.8463	0.834948535	0.840624268	7
Alloy 5	0.6905	0.8769	0.9348	0.834066667	0.827200558	0.830633613	8
Alloy 6	0.7436	0.9090	0.9192	0.857266667	0.853305268	0.855285967	5
Alloy 7	0.7250	0.9448	0.9066	0.8588	0.853161407	0.855980704	4
Alloy 8	0.6591	0.9341	0.8943	0.829166667	0.819613881	0.824390274	9
Alloy 9	0.6744	1	0.8895	0.854633333	0.84337587	0.849004602	6

5. CONCLUSIONS.

In this paper, the applicability and usefulness of hybrid MCDM approach MOORA and WASPAS was used as a decision making tool for optimizing the best alloy percentage during powder metallurgy operation; and it was observed that the results obtained from both the methods concluded alloy 1(having 5.4%tin and 0%zinc) to be the best optimized composition. The application of MOORA and WASPAS as a hybrid approach prove them to be a one folded method, computationally easy and compatible in result with what past researchers have derived. Thus, accustomization of these methods can be done for any decision making problems.

6. REFERENCES.

[1] Aman, Arindam Bharadwaj, Satyam Singh, Dhritiman Das and Santanu Chakraborty Study and Optimization of the mechanical and tribological properties of Al-Si alloy with varying percentage of Tin and Zinc,ICMMRE 2017.

[2] Shankar chakraborty, Application of the WASPAS method as the multi criterion decision making tool.

[3] Shankar Chakraborty, Orchi Bhattacharyya, Edmunds kazimieras zavadskas, jurgita Antucheviciene , Application of WASPAS method as an optimization tool in nontraditional machining process, Information technology and control-2015.

[4] Madic M., Gecevska V., Radovanovic M.,Petkovic D. Muti criteria economic analysis of machining processes using the WASPAS method, journal of production engineering, vol.17,2014.

[5] Shankar chakraborty, Edmunds kazimieras zavadskas,Application of WASPAS method in manufacturing decision making, journal of informatica, vol.25 (2014), page (1-20).

[6] Himadri Majumdar and Abhijit Saha, Application of MCDM based hybrid optimization tool during turning of ASTM A588, dsl-2017-22 page (143-156).

[7] Jaksan Patel and Kalpesh D.Maniya Application of AHP-MOORA method to select wire cut electrical discharge machining process parameter to cut EN31 alloys steel with brass wire, Materials today vol.2 (2015), page (2496-2503).

[8] Kalirasu S, Rajini N, Rajesh S, Winowlin Jappes J T, and Karuppasamy K Machining performance of jute/polyester composite with AWJM, journal of material science (2017), page (1-40).

◈◈◈