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Multi-objective Optimization Using Grey Relational Analysis in Selection of Nano Hybrid Sintered Composites for Drone Propeller Mount Application

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Abstract – The objective of the study is to select a material for the propeller mount of a drone. Propeller mount is used to hold the propeller and motor firmly. Hence the material should possess good strength and wear properties. The existing material used in propeller mount is Aluminium made through the casting method. In this study, the Aluminium (Al) matrix with nano boron nitride (BN) and nano titanium di oxide (TiO_2) reinforcements are used for fabrication of specimens through powder metallurgy route. The best specimen is chosen using multi-objective optimization grey relational analysis method. Based on the study, S2 (97.5 wt% Al + 1.25 wt% BN + 1.25 wt% TiO_2) specimen is selected for fabrication of propeller mount in the drone.

Key Words: Multi-Objective Optimization, Powder metallurgy, Mechanical Properties, Tribology, Drone, Propeller Mount

1. INTRODUCTION

In recent years, the need of aluminium and its composites is increasing demand for its high strength and low weight ratio. The BN is a solid lubricant, addition of BN less wt% as reinforcement will improve the mechanical and tribological properties of the material. Generally, the BN has a low thermal coefficient of expansion and good thermal conductivity. The TiO_2 is used as filler material, and the addition of lesser wt% as reinforcement will improve mechanical properties of the material. TiO_2 possesses small bulk density, larger surface area, and excellent photocatalyst properties.[1-39]

The powder metallurgy process significantly reduces the metal removal process. It reduces the porosity and flow lines by conforming uniform amount and weight throughout the process. As constant density is allowed throughout the process it avoids defects and contamination.[1-39]

Multi-objective optimization using grey relational analysis (GRA) tool which does not required complex formulation and results could be obtained in short period of time. GRA method is most satisfying method than other methods for optimizing the response parameters.[40-47]

2. EXPERIMENTAL WORK

The specimens are prepared using the powder metallurgy route. Aluminium metal powder is used as the matrix and Nano BN and Nano TiO_2 are used as reinforcements. The material specification is represented in Table-1. In ball milling process, matrix and reinforcements were blended for 2 hrs.

Table -1: Material Composition

Specimen	Material Composition
S1	97.5 wt % Al+ 1.0 wt% BN + 1.5 wt% TiO_2
S2	97.5 wt % Al+ 1.25 wt% BN + 1.25 wt% TiO_2
S3	97.5 wt % Al+ 1.5 wt% BN + 1.0 wt% TiO_2

During the ball milling process, the matrix and reinforcements are bonded by impact and attrition principle. The blended powder is pressed to desired shape using hydraulic press in compaction process. The compacted specimens were sintered in sintering furnace which causes the diffusion of atoms in the specimens. The way in which atoms travels from high to low potential chemical gradient is the sintering mechanism.

Fig -1: Fabrication of composites

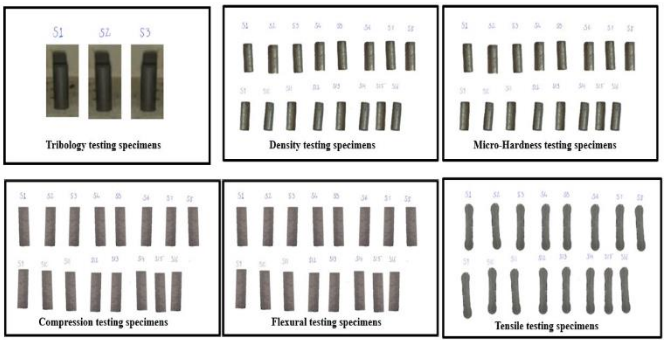

Fig -2: Testing Specimens

It also strengthens the specimens. The fabrication of specimens is represented in Fig-1. The list of specimens used for various testing is represented in Fig-2.

The following tests were conducted, Tensile test as per ASTM E8 standard, Compression test as per ASTM B331 standard, Flexural test as per ASTM B528 standard, Microhardness test as per ASTM E384 standard, Density analysis as per ASTM B962-17 standard and tribology pin on disc as per ASTM G99 standard. The testing machines are represented in Fig-3. The testing results are tabulated in Table-2.

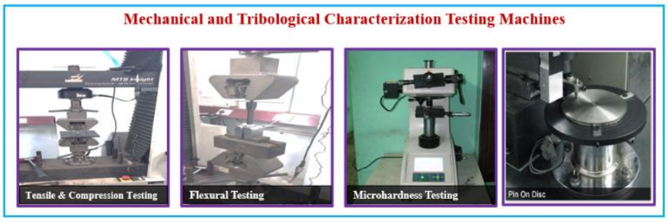

Fig -3: Characterization testing Machines

3. RESULTS AND DISCUSSION

Table-2 represents the list of objectives used in multi objective optimization using grey relational method. For each sample (S1, S2,S3) there are 7 objectives.

Table -2: List of Objectives for Optimization

S.NO	OBJECTIVES	SPECIMENS		
		S1	S2	S3
1	Tensile Strength (MPa)	97.81	97.65	97.32
2	Compressive Strength (MPa)	94.32	102.33	86.21
3	Flexural Strength (MPa)	221.7	211.1	199.8
4	Micro-Hardness (H.V)	35.7	36.2	35.9
5	Density (g/cm^3)	2.645	2.638	2.648
6	SWR*10^{-9} (m^3/Nm)	0.00051	0.00042	0.00049
7	CoF (No Unit)	0.7109	0.5824	0.821

The mechanical properties such as tensile strength, compressive strength, flexural strength and hardness of the specimens needs to be higher in value to withstand higher loads, hence the above properties should be higher the better. The density should be lower in value, so the weight of the specimen will be reduced, hence lower the better criterion is chosen for the density. The specific wear rate and coefficient of friction should be lower in values, so the weight loss in specimen due to speed and load could be reduced. And the frictional force of the specimen will be reduced. Hence the SWR and CoF chosen as lower the better criterion. The list of Input criteria is represented in Table-3.

Table -3: Input Criteria

S.NO	OBJECTIVES	INPUT CRITERIA
1	Tensile Strength (MPa)	HTB
2	Compressive Strength (MPa)	HTB
3	Flexural Strength (MPa)	HTB
4	Micro-Hardness (H.V)	HTB
5	Density (g/cm^3)	LTB
6	SWR*10^{-9} (m^3/Nm)	LTB
7	CoF (No Unit)	LTB

HTB - Higher The Better, LTB - Lower The Better

The first stage in grey relational analysis is to normalize the measured outputs (objectives) function individually. Since the aim is to minimize the density, SWR and CoF 'lower the better' normalization equation is selected and it is represented as

$$Y_{ij} = \frac{(max(Z_{ij}) - Z_{ij})}{(\max(Z_{ij}) - \min(Z_{ij}))} \qquad \text{Eq.(1)}$$

The mechanical properties are chosen for the 'higher the better' normalization equation and it is represented as

$$Y_{ij} = \frac{(Z_{ij} - \min(Z_{ij}))}{(\max(Z_{ij}) - \min(Z_{ij}))} \qquad \text{Eq.(2)}$$

The measured outputs (objectives) are normalized (i.e converted in the range of 0-1) using the Eq. (1) and (2). The normalized values of all the objectives of each specimen are represented in Table -4.

Table -4: Normalized Values

S.NO	OBJECTIVES	SPECIMENS				
		S1	S2	S3	Min.Value	Max.Value
1	Tensile Strength (MPa)	1	0.673	0	0	1
2	Compressive Strength (MPa)	0.503	1	0	0	1
3	Flexural Strength (MPa)	1	0.516	0	0	1
4	Micro-Hardness (H.V)	0	1	0.4	0	1
5	Density (g/cm^3)	0.3	1	0	0	1
6	SWR*10^{-9} (m^3/Nm)	0	1	0.255	0	1
7	CoF (No Unit)	0.461	1	0	0	1

The deviation sequence is the difference between the maximum value of each objective (Table-4) and the corresponding normalized value of each specimen (Table-4). The deviation sequence values are represented in Table -5.

Table -5: Deviation Sequence

S.NO	OBJECTIVES	SPECIMENS				
		S1	S2	S3	Min.Value	Max.Value
1	Tensile Strength (MPa)	0	0.327	1	0	1
2	Compressive Strength (MPa)	0.497	0	1	0	1
3	Flexural Strength (MPa)	0	0.484	1	0	1
4	Micro-Hardness (H.V)	1	0	0.6	0	1
5	Density (g/cm^3)	0.7	0	1	0	1
6	SWR*10^{-9} (m^3/Nm)	1	0	0.745	0	1
7	CoF (No Unit)	0.539	0	1	0	1

The grey relational coefficient is calculated using the equation given below,

$$GRC_{ij} = \frac{(\delta_{min} - \gamma\delta_{max})}{(\delta_{ij} - \delta_{max})} \qquad \text{Eq.(3)}$$

The γ is the distinguishing coefficient ($\gamma \in [0,1]$). It is used to adjust the difference of the relational coefficient. For this study γ is considered as 0.5. The grey relational coefficient value of each specimen and the sum is represented in Table -6.

Table -6: Grey Relational Coefficient

S.NO	OBJECTIVES	SPECIMENS		
		S1	S2	S3
1	Tensile Strength (MPa)	1	0.605	0.333
2	Compressive Strength (MPa)	0.502	1	0.333
3	Flexural Strength (MPa)	1	0.502	0.333
4	Micro-Hardness (H.V)	0.412	1	0.333
5	Density (g/cm^3)	0.625	0.333	1
6	SWR*10^{-9} (m^3/Nm)	0.333	1	0.402
7	CoF (No Unit)	0.481	1	0.333
	TOTAL	4.353	5.44	3.067

The grey relational grade is the ranking method, in which the highest grey relational coefficient value is considered as best combination which satisfies the input criteria set by the user. In this study, the S2 specimen possesses the highest grey relational coefficient value of 5.44. The ranking of all specimens is listed in Table -7.

Table -7: Grey Relational Grade

S.NO	SPECIMENS	GRC	GRG	RANK
1	S1	4.353	0.622	2
2	S2	5.44	0.777	1
3	S3	3.067	0.438	3

4. CONCLUSIONS

The experimental work and the multi-objective optimization using GRA method was performed and the following findings and observations are observed.

- The optimum composition of this metal matrix composites during the tensile loading is found to be in specimen S1 (97.5 wt% aluminium with 1.0 wt% nano BN and 1.5 wt% nano TiO_2 reinforcement) composition.
- The optimum composition of this metal matrix composites during the compression loading is found to be in specimen S2 (97.5 wt% aluminium with 1.25 wt% nano BN and 1.25 wt% nano TiO_2 reinforcement) composition.
- The optimum composition of this metal matrix composites during the flexural loading is found to be in specimen S1 (97.5 wt% aluminium with 1.0 wt% nano BN and 1.5 wt% nano TiO_2 reinforcement) composition.
- The optimum composition of this metal matrix composites during the microhardness testing is found to be in specimen S2 (97.5 wt% aluminium with 1.25 wt% nano BN and 1.25 wt% nano TiO_2 reinforcement) composition.
- The optimum composition of this metal matrix composites during the tribology testing is found to be in specimen S2 (97.5 wt% aluminium with 1.25 wt% nano BN and 1.25 wt% nano TiO2 reinforcement) composition
- The optimum composition of this metal matrix composites during the Multi-objective optimization is found to be in specimen S2 (97.5 wt% aluminium with 1.25 wt% nano BN and 1.25 wt% nano TiO_2 reinforcement) composition.

The S2 (97.5 wt% aluminium with 1.25 wt% nano BN and 1.25 wt% nano TiO_2 reinforcement) specimen is selected for fabrication of propeller mount and testing its aerodynamic performance.

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