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Optimization Of Magnetorheological Fluid Blended With TiO_2 Nanoparticles Using MCDM Technique

* [1]Bhavana Mariyappalavar, [2]Suhas Deshmukh, [3]S. Notla

[1,3] Assistant Professor, College of Military Engineering, Pune

[2]Associate Professor, Government College of Engineering, Karad

ABSTRACT

This research investigates the influence of Titanium Oxide nanoparticles as an additive into the magnetorheological fluid experimentally. The optimization parameters were considered based on their significance in achieving the magnetorheological effect such as density, sedimentation rate, shear stress, viscosity so as to enhance the stability of magnetorheological fluid and to achieve better damping in case of magnetorheological damper. Different volume percentage of Titanium Oxide nanoparticles viz;0.2%,0.4%,0.6%. have been blended with the magnetorheological fluid and the developed composites have been ranked using most preferred MCDM technique, TOPSIS. The experimental results revealed that 0.2 weight %TiO_2 (Titanium Oxide) indicates highest relative closeness and ranking.

Keywords – TiO_2, nanoparticle, TOPSIS, magnetorheological fluid, MR Damper

1.INTRODUCTION

Magnetorheological fluid belongs to class of controllable smart material having fascinating performance with reversible rheological properties on application and reversal of applied magnetic field [1][2]. Magnetorheological fluids(MR fluids) are suspensions of carbonyl iron micron-sized particles in carrier liquid like oil or water. In practice, in the absence of magnetic field, MR fluids are free flowing liquids having consistency like motor oil. On application of magnetic field, the apparent viscosity increases, in case of MR fluid. It is an excellent option to improve the comfort of four-wheeler through damping the unwanted vibrations in a smart way than the traditional methods of damping [3].It is characterized by ability to revert from liquid to viscous fluid which enables the fluid to absorb the shock.The application of certain magnetic field strength results in chain clusters formed by magnetic particles in the direction of external field[4][5]. The molecules of the fluid get align in straight line due to the application of current [6]. The magnetorheological (MR) fluids have attracted attention in the different applications in engineering in case of active vibration control like brakes, dampers and isolators [7]. M. Chand et.al. explained that this wonderful quality of MR Fluid makes it attractive for research in automobile, medical, chemical sector to researchers [8].

MR fluid containing micron-sized magnetic particles deals with the settling issue while working in actual practice in various applications. The addition of particles modifies the physical, rheological, mechanical properties, etc. [9]. Redispersion in the suspension and maintaining the homogeneity of the MR fluid becomes major challenge. To address this issue, the addition of nano particles has been adopted by researchers to improve the quality of MR fluid and make it more useful[10]. The yield stress, sedimentation rate and viscosity prove to be the influencing parameters in case of magnetorheological fluid. W. Zhu et.al. concluded that the magnetorheological effect of MR fluid declines because of the sedimentation [11]. Sedimentation occurs due to the density difference between carrier liquid and magnetic particles [12]. To work on these drawbacks and to increase its wide use in different fields, additives or nanoparticles are added in certain percentage in MR fluid & a versatile, more useful blend is prepared which is effective in terms of lower sedimentation, higher shear stress and better viscosity [13][14][15][16]. Addition of nano particles greatly reduces the settling rate of MR fluid [17][18].In this research work, Magneto rheological damper has been focused and research and experiment have been conducted to find the best blend of magnetorheological fluid with TiO_2(Titanium Oxide) nano particles as it is proved to improve the damping force in case of magnetorheological damper.TiO_2 nanoparticles of size 10mm – 20mm are added in different percentage and their rheological & physical properties have been studied based on the five criterions used for the optimization viz; density, sedimentation rate, shear stress, viscosityand magnetic flux density.

I. Emovon et.al. explained that multi criteria decision making technique is preferred in the selection of the best alternative among the available options. The alternatives are assessed considering the different criterion [19]. The various methods in Multicriteria decision-making technique are a scientific tool preferred by researchers while assessing the available alternatives [20][21]. The commonly adopted MCDM methods by researchers in the available literature are TOPSIS, WASPAS, AHP, CODAS, ARAS, ELECTRE, VIKOR etc. [22][23][24]. In this technique, the distance of number of alternatives are measured from positive ideal solution as well as the distance from negative ideal solution also measured to finalize the best alternative [25][26][27][28][29].

2. Preparation of blend

2.1 Selection of nanoparticle and preparation of sample

Selection of nanoparticle - P. S. Paul, J. A. Iasanth et.al.in their research proved that to get better damping capability TiO_2 nanoparticles magnetized with direct current at higher amplitudes offers better viscosity and reduces temperature in the MR fluid [31]. Different weight percent of TiO_2 nanoparticles added to MR fluid and have been checked through conducting trials to check viscosity on Brooklyn LVDVE Viscometer at different spindle speed and by setting different rpm. After addition of different weight percent of TiO_2 nano particles and it is concluded that addition of more than 10 weight % TiO_2 lowers the viscosity of magnetorheological fluid. Therefore, 0.2 weight%,0.4 weight % & 0.6 weight % TiO_2 nanoparticle have been added to magnetorheological fluid for sample preparation.

Preparation of sample -To prepare sample, firstly MR fluid and TiO_2 nanoparticles were weighted. In the present research, TiO_2 nanoparticles mixed with MR fluid stirred for 15 minutes. Then to make uniform mixture, ultrasonic bath sonicator has been used.15 minutes time limit were set and fabricated samples were sonicated for the set time. Then samples were tested for physical and rheological properties. Designation and composition for the fabricated composites have been indicated in Table no.1.For each composition, 3 samples have been prepared and they have been tested.

Table No. 1 Developed Composites

Composite Designation	MR Fluid+ TiO_2 Composition (Weight%)
S0	100 wt % MR Fluid +0 wt % TiO_2 particles
S1	99.8wt % MR Fluid +0.2% TiO_2 particles
S2	99.6wt %MR Fluid+0.4% TiO_2 particles
S3	99.4 wt. %MR Fluid+0.6wt % TiO_2 particles

The developed composites are designated by S0, S1, S2, S3 out of which S0 composite represents 100 weights% quantity of magnetorheological fluid with addition of 0 weight % TiO_2 nanoparticles. S1 represents 99.8 weight% MR fluid and 0.2 weight% TiO_2 particles, S2 represents 99.6 weight % MR fluid and 0.4 weight % TiO_2 particles, S3 represents 99.4 weight %MR fluid added with 0.6 weight percent TiO_2 particles.

2.2 Property Testing

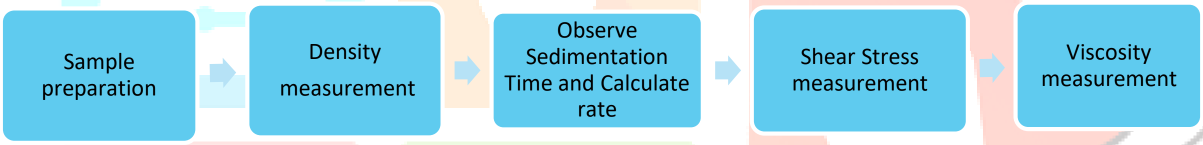

Fig.No.1 Property Testing Sequence

Density(D)- Density has been measured according to ASTM D 4052-96 for the fabricated blend of TiO_2 & magnetorheological fluid. Density of each sample checked with the help of density bottle. Difference in the weight of empty density bottle(W1) and density bottle filled with fabricated blend (W2) noted and the obtained value divided by the volume of the blend contained in the density bottle gives the density of sample.

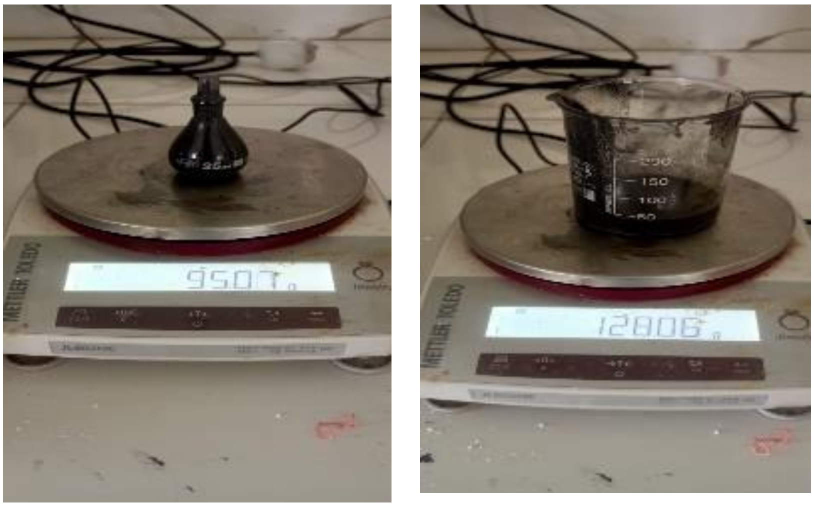

Fig.No.2 Density Measurement

Sedimentation Rate (SR)- Sedimentation is one of the properties of magnetorheological fluid on which the stability of fluid performance is depend upon. The measurement of sedimentation was carried out by visual inspection. The changes in the boundary position between clear and muddy carrier oil were observed. Samples were filled into the glass vials and observed for 4 days. Observations have been noted after every 10 hours. In this way, in total for 80 hours readings have been noted and the changes in the levels of fluid blend are observed for three samples of each composition of newly fabricated blends. Sedimentation ratio (R_s) calculated based on the height of clear fluid and height of muddy fluid. Based on the collected data for 80 hours, the sedimentation ratio is calculated. The equation to calculate the sedimentation ratio is as stated below.

$$R_s\ \% = \frac{V_a}{V_b} \times 100$$

where: R_s [%]–sedimentation ratio, V_a– length of the clear part, V_b–length of the turbid part.

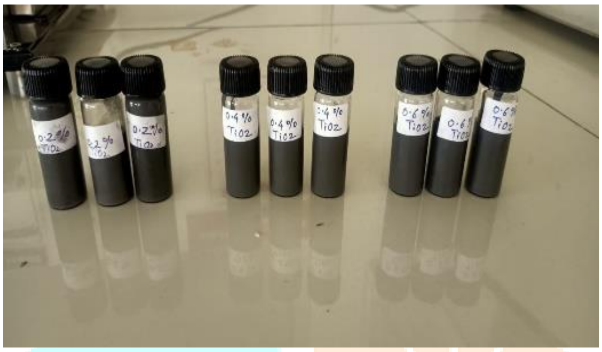

Fig.No.3 Prepared Samples

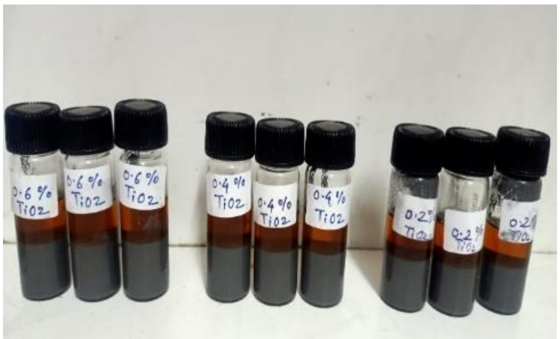

Fig.No.4 Sedimentation Test Photos- After 80 Hrs.

Sedimentation Readings

S1 Composition								
Time(hrs)	10	20	30	40	50	60	70	80
Va	32	29	25	22	20	19	18	16
Rs	86.48	78.37	67.56	59.45	54.05	51.35	48.64	43.24

S2 Composition								
Time(hrs)	10	20	30	40	50	60	70	80
Va	31	26	24	22	21	20	19	19
Rs	83.78	70.27	64.86	59.45	56.75	54.05	51.35	51.35

S3 Composition								
Time(hrs)	10	20	30	40	50	60	70	80
Va	31	27	25	24	22	21	20	20
Rs	83.78	72.97	67.56	64.86	59.45	56.75	54.05	54.05

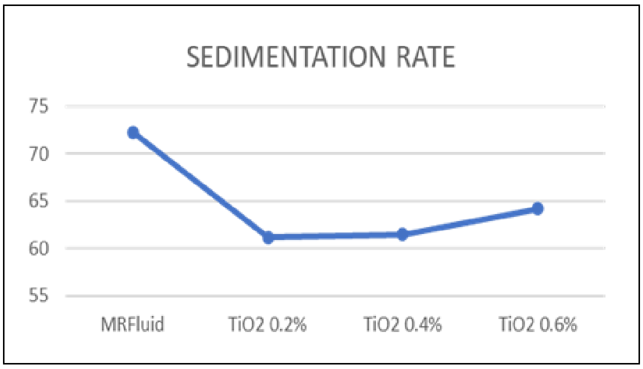

Fig.No.5 Sedimentation Rate

Rheological characteristics- Shear stress (SS), viscosity (VS) and Magnetic flux density (MFD) were measured for all the samples. Anton Paar - Physica MCR-301 magneto rheometer has been utilised to determine the rheological properties of the MR fluids. The measuring system used is PP 20. Air type bearing is used in the system. Measurements like Shear Stress, Viscosity and Magnetic Flux density were measured. Tests were programmed to study the behaviour of the samples applying magnetic field keeping magnetic flux sweep up to maximum of 0.92 T, at a constant shear rate of 100 1/s. Table no.4 indicates the physical and rheological test results.

Table No. 4 Experimental Results of physical and rheological properties

Composites	D	SR	SS	VS	MFD
S0	1.88	72.29	45	0.113	0.82
S1	2.56	61.14	61.39	615.77	0.83
S2	2.76	61.44	62.64	628.31	0.86
S3	2.95	64.18	63.34	635.26	0.92

The density of S1, S2, S3 is found increased than S0 i.e., pure MR fluid due to the addition of nanoparticles.

The sedimentation rate for S0 composition is higher than remaining three compositions and found decreased in S1, S2, S3 which indicated the better stability of the developed composites.

Shear stress for the fabricated blends shows increased values of stress which assures better MR effect and hence better damping. Viscosity increased greatly with addition of TiO_2 which is useful for achieving for better damping force.

Magnetic flux density slightly varied for the different compositions. It is seen from the observed values of different parameters

The selection criteria for the depicted parameters are indicated in table no 5.

Table No. 5 Selection Criterion of parameters

Attributes/Criterion/parameters	Selection Criterion of parameters
Density(D)	Lower the better
Sedimentation Rate (SR)	Lower the better
Shear Stress (SS)	Larger the better
Viscosity (VS)	Larger the better
Magnetic Flux Density (MFD)	Larger the better

3. Optimization Methodology -TOPSIS (Technique for order performance by similarity to ideal solution)

The method stresses that chosen option should have least distance from best possible option and most distance from the worst possible option. As discussed earlier, TOPSIS is very useful and versatile MCDM method to select the best alternative from the available one. By applying this technique, the minimum distance from the ideal solution along with the farthest distance from the least important solution is achieved. To start with the procedure, decision matrix having no. of alternatives say ‘m’ and no. of criteria’s ‘n’ is to be formed according to the TOPSIS procedure. The various compositions of magnetorheological fluid with different weight percentages of Titanium Oxide nanoparticles are selected as the different alternatives as indicated in table1. Different parameters used are density, sedimentation rate, shear stress, viscosity and magnetic flux density. Table 2 indicates the rheological test results. The selection criteria for the depicted parameters are indicated in table 3.

The values obtained through conducting the experiments on the selected parameters have been used in forming the decision matrix as indicated in Table 4.

The different procedural steps used in TOPSIS method have been described below[4].

a. Preparation of normalized decision matrix. The equation used is as given below-

$$Smn = \frac{Ymn}{\sqrt{\sum_{m=1}^{k} Y_{mn}^{2}}} m = 1 \ldots\ldots k, n = 1, \ldots. q \quad (1)$$

After completing the normalized decision matrix, assign weights to each attribute.

b. Formulate the weighted normalized matrix -

$$Wmn = Rw \times Smn \quad (2)$$

Rw indicates the nth attributes relative weight.

Also $\sum_{n=1}^{q} Wn = 1$.

c. Find out positive and negative ideal solutions.

$$B^{+} = \{W_1^{+}, W_2^{+}, \ldots\ldots W_n^{+}\} = \{(\max W_{mn} \mid n \in K_b)\ (\min W_{mn} \mid n \in K_l) \quad (3)$$
$$B^{-} = \{W_1^{-}, W_2^{-}, \ldots\ldots W_n^{-}\} = \{(\min W_{mn} \mid n \in K_b)\ (\max W_{mn} \mid n \in K_l) \quad (4)$$

Here, K_l=Lower the better, K_h=Higher the better

d. Obtain the separation measures for each alternative.

$$S_m^{+} = \sqrt{\sum_{n=1}^{a} (Wmn - W_n^{+})2}, m=1, 2\ldots\ldots k \quad (5)$$

$$S_m^{-} = \sqrt{\sum_{n=1}^{a} (Wmn - W_n^{-})2}, m=1, 2\ldots\ldots k \quad (6)$$

e. Determination of the relative closeness value

$$QC_m = \frac{S_m^{-}}{S_m^{+} + S_m^{-}}, m=1, 2\ldots\ldots\ldots k \; 0<QC_m<1 \quad (7)$$

Large value of QC_m indicates better alternative.

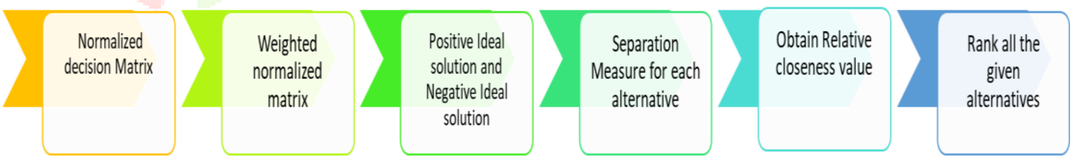

Fig.No.6 Steps involved in TOPSIS

The values obtained through conducting the experiments on the selected parameters have been used in forming the decision matrix as indicated in Table no 4.

Table No. 6 Decision Matrix

Composite No.	D	SR	SS	VS	MFD
S0	1.88	72.29	45	0.113	0.82
S1	2.56	61.14	61.39	615.77	0.83
S2	2.76	61.44	62.64	628.31	0.86
S3	2.95	64.18	63.34	635.26	0.92

The first step in applying the Topsis method is preparation of the decision matrix which is formed based on the values obtained in the testing of physical and rheological characteristics experimentally as discussed earlier.

Table No.7 Normalized Matrix

Composite No	D	SR	SS	VS	MFD
S0	0.3658	0.5567	0.3840	0.000104	0.4780
S1	0.4981	0.4708	0.5239	0.567463	0.4809
S2	0.5370	0.4732	0.5345	0.57902	0.5037
S3	0.5740	0.4943	0.5405	0.585424	0.5351

After preparing the decision matrix, normalized matrix has been formed using eq. (1).

Table No. 8 Weighted Normalized Matrix

Composites	D	SR	SS	VS	MFD
S0	0.073168	0.111354	0.07681	2.08E-05	0.09561
S1	0.099633	0.094179	0.104785	0.113493	0.096193
S2	0.107416	0.094641	0.106919	0.115804	0.100741
S3	0.114811	0.098862	0.108114	0.117085	0.107037

The weighted normalized matrix being prepared by multiplying the values of normalized matrix with associated weights which is 0.2 with the help of equation no. (2) and the mentioned values in the table are obtained for the fabricated blends.

Table No 9 Positive and Negative Ideal Solution

V+	0.073168	0.094179	0.108114	0.117085	0.107037
V-	0.114811	0.111354	0.08528	0.113493	0.09561

Using equation, (3) and (4) lower the better and higher the better values have been found out. The positive and negative ideal solution is found out based on the criteria values approaching closer value as positive and farthest value as negative solution.

Table No.10 Separation Measures

Composites	Sm+	Sn-
S0	0.122921	0.121168
S1	0.029016	0.030102
S2	0.034869	0.028877
S3	0.041905	0.028651

The separation measures values have been calculated with the help of eqs. (5) & (6) respectively.

Table No. 11 Relative Closeness Value & Ranking of Composites

Composites	Relative Closeness Value	Ranking of Composites
S0	0.496	2
S1	0.519	1
S2	0.453	3
S3	0.406	4

With the help of equation no. (7), the relative closeness value is calculated. It indicates the closeness with the ideal solution. From the table it can be seen that S1 i.e. (99.8%MRF +0.2% TiO_2) has been Ranked 1. The value of relative closeness obtained for S1is 0.519 which is highest compared to other alternatives. Remaining rankings are as follows: Rank 2 (S0: 100 %MRF + 0 wt.% TiO_2), Rank 3 (S2: 99.6 %MRF + 0.4 wt.% TiO_2), Rank 4 (S3: 99.4 % MRF + 0.6 wt.% TiO_2). The graph of relative closeness value for the fabricated composites has been as shown in the figure.

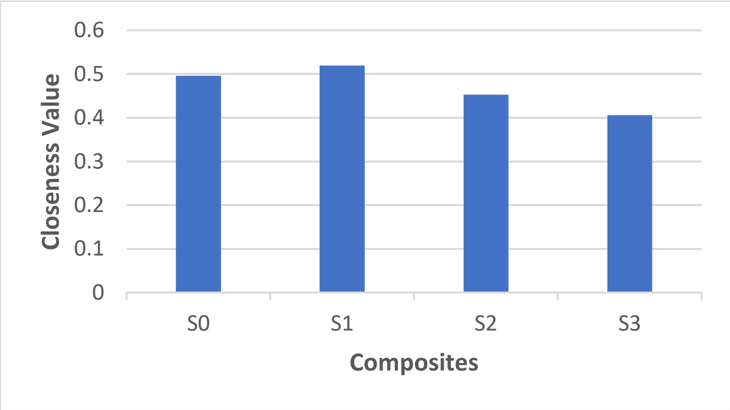

Fig.No.7 Ranking of Composites

3. RESULTS & DISCUSSION

As discussed previously in the TOPSIS procedure, the first step in the process, the decision matrix is prepared based on the experimental outcomes. It has been depicted in table 4. Then normalized matrix is formed with the help of eq. (1). It is indicated in table no 5. After preparing the normalization matrix, the weighted normalized matrix is prepared. To obtain the weighted normalized matrix, values of normalized matrix have been multiplied with associated weights which is 0.2. It is indicated in table no.6. Next step is the determination of ideal values of positive solutions and negative solutions. After this step, the separation measures values are calculated with the help of eqs. (5) & (6) respectively. With the help of equation no. (7), the relative closeness value is calculated. It indicates the closeness with the ideal solution. All the obtained values of Separation measure are shown in table 8. Relative closeness values and rankings of the composites are shown in table 9. The actual ranking of the composites has achieved by arranging the relative closeness values in descending order. The higher the relative closeness, the best is the composition. Following the complete procedure, it is found that, S1 i.e. (99.8%MRF +0.2% TiO_2) is Ranked 1. The value of relative closeness obtained for S1 is 0.519 which is highest compared to other alternatives. Remaining rankings are as follows: Rank 2 (S0: 100 %MRF + 0 wt.% TiO_2), Rank 3 (S2: 99.6 %MRF + 0.4 wt.% TiO_2), Rank 4 (S3: 99.4 % MRF + 0.6 wt.% TiO_2).

4. CONCLUSION

The analysis of performance of Titanium Oxide infused in Magnetorheological fluid offers below mentioned conclusions:

1: It offers the technique of finding the best composite from the various developed compositions with the help of TOPSIS.

2: It has been found that the composition of Titanium Oxide with magnetorheological fluid shows optimum results with 0.2 weight % TiO_2 added to 99.8 weight % MRF in the Magnetorheological fluid. This composition shows the better results compared to other alternatives.

3: Optimum properties of S1 composition consisting of 0.2 weight% TiO_2 +99.8% MRF shows the best composition offering less sedimentation and density values as well as increased shear stress and viscosity compared to remaining compositions which are the desirable properties of magnetorheological fluid in engineering based application.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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