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Optimization of magneto-rheological fluids on the volume fraction and viscosity for MR damper application

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ABSTRACT

Magneto-rheological fluid (MR fluid) in squeeze mode able to produce stress resistance up to 80kPa which is exceeded most basic requirement of normal mechanical application. However, to attain the good performance of stress resistance, the composition of MR fluids has to be optimized. The aim of this study is to investigate the optimum volume fraction of carbonyl iron particle (CIP), mineral oil (MO) and fumed silica (FS) for MR damper application. Simultaneously, the appropriate viscosity of MO is also studied. Hence, MR fluid samples with various composition are synthesized and analysed according to combined D-Optimal mixture design (CDMD) design of experiment (DOE). The compression test was conducted to study the compression strength and compression modulus of each samples. The findings indicate that the volume fraction of CIP is the most significant factor to affect the compression stress and compression modulus of MR fluid. Increment of CIP volume fraction from 20vol% to 40vol% increased the compression stress from 0.12MPa to 10.95MPa. Moreover, the compression modulus increased from 0.24MPa to 27.24MPa. This study shows that MR fluid can be produced for MR damper by selecting higher magnetic particles composition. Optimization model produced in this study is crucial for composing aimed squeeze mode MR fluid for MR damper.

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Introduction

MR fluid has become important in automotive technology such as vehicle ride comfort and actuator to stop motion. Extensive researches on the MR fluid preparation have shown that the amendment in one or more constituents will influence the performance of the materials. MR fluids are formerly used in motion damping devices, perhaps the most practical use for MR fluid technology today (Phu & Choi, 2019). Damping mechanisms transfer kinetic energy to thermal energy, dissipating the force exerted on the device. A typical example of a damping mechanism on a car is shown in Figure1.

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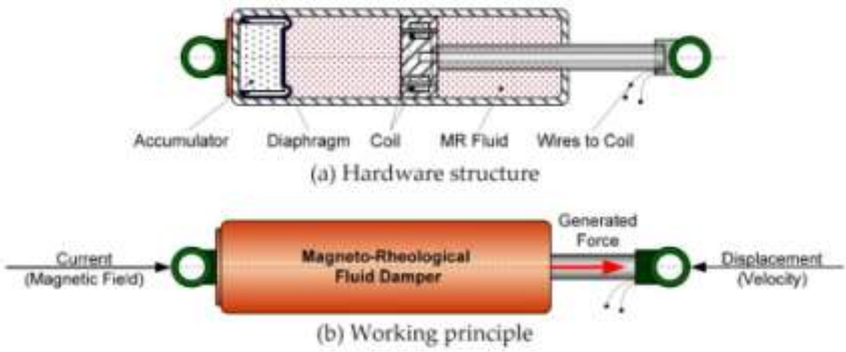

Figure 1. Damping Mechanism on a Car (a) Hardware Structure (b) Working Principle (Truong & Ahn, 2012)

Method

MR fluid consists of three parts: magnetic particles, carrier fluid and additive. Table 1 lists the materials used to synthesize MR fluid in the laboratory.

Table 1. Constituents of MR fluid

Component	Materials Name	Density(g/cm^3)
Magnetic particles	Carbonyl iron particles (CIP)	7.8
Carrier fluid	Mineral oil (MO)	0.833-0.862
Additive	Fumed Silica (FS)	0.037

Constituents were weighed using microgram balance as per required quantity. FS and CIP were mixed up using a spatula. Small amount of dry mixture was added to the mineral oil. They were stirred at low speed (50 to 100 rpm) until all of the dry mixture being used. The mixture was allowed to mix thoroughly with a mechanical stirrer at 800rpm for 20 to 30 minutes to disperse all the particles uniformly and become homogeneous mixture of MR fluid. Total of 16 samples of MR fluid were prepared based on CDMD.

Table 2. CDMD for MR Fluid Formulated With CIP, MO and FS in Various Proportion

SAMPLE	MO Viscosity [cP]	MO [vol%]	CIP [vol%]	FS [vol%]
1	98.1	70	20	10
2	98.1	55	40	5
3	18.5	50	40	10
4	18.5	75	20	5
5	98.1	75	20	5
6	18.5	70	20	10
7	58.3	62.5	30	7.5
8	58.3	75	20	5
9	58.3	50	40	10
10	38.4	56.25	35	8.75
11	18.5	60	30	10
12	98.1	70	20	10
13	98.1	55	40	5
14	18.5	70	20	10
15	18.5	75	20	5
16	98.1	75	20	5

After the preparation of the MR fluid samples in the laboratory, 4 ml for each samples of the fluid were inserted into the support cylinder of the squeeze mode testing rig by using a syringe. The test rig was positioned in the compression test apparatus. Compressions of MR fluid were conducted using a squeeze mode testing rig. The compression tests were assisted by Universal Testing Machine (UTM). The applied magnetic field was achieved by linking the cable of the test rig to a Quantel DC power supply to conduct a 0.8T magnetic field to the test rig. Compression stress and strain data were recorded during compression process. Optimization were analysed according to combined D-Optimal mixture design (CDMD) design of experiment (DOE).

Results and Discussions

Figure 2 shows compression stress versus compression strain for MR fluid samples. From the curves plotted, it can be say that the compression stress for all samples increase as the compression strain increase up to 75%. The compressive stress for all samples were increased with increasing the compressive strain, which similar to shear thickening. The shear thickening behavior of compressed MR fluid was in agreement with previous findings (Brown et al., 2010; Pinto & Meo, 2017).

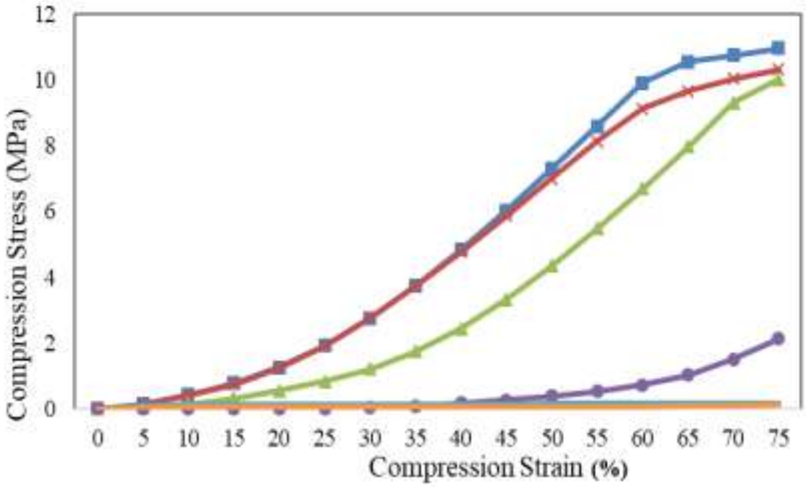

Figure 2. Compression Stress Versus Compression Strain of MR Fluid Samples

Table 2 shows the compressive strength and compression modulus, G, of all MR fluid samples under compression test. The results conclude that higher magnetic particles volume fraction will result in higher compressive strength and higher value of compression modulus, G.

Table 2. Properties of MR Fluid under Compression Test

SAMPLE	Compressive Strength, σ [MPa]	Compression Modulus, G [MPa]
1	0.72	3.45
2	10.62	26.20
3	10.95	27.24
4	2.20	11.67
5	0.59	3.03
6	0.12	0.24
7	0.16	0.30
8	0.12	0.24
9	10.32	24.58
10	2.14	9.35
11	1.56	6.32
12	0.72	0.42
13	10.62	26.20
14	0.86	3.96
15	0.07	0.22
16	0.59	3.03

The highest compressive strength (10.95MPa) and compression modulus (27.24MPa) is for SAMPLE 3 which has 40vol% of magnetic particles. The lowest is SAMPLE 15 with compressive strength of 0.07MPa and compression modulus of 0.22MPa which has 20vol% of magnetic particles.

Compression modulus, G indicated stress-resistance performance of the MR fluid. A higher modulus signified their capability to operate in a damper at high stress applications (Ismail, Mazlan, Zamzuri, & Olabi, 2012). In the present study, it can be found that compression stress, σ, and compression modulus, G, are affected by the composition of magnetic particles. Higher fraction of magnetic particles in the MR fluid will result in higher compression stress, σ, and compression modulus, G of the MR fluid as depicted in Figure3. SAMPLE 3 with 40% CIP give highest compression modulus, G (27.24MPa) compared to SAMPLE 11 with 30% CIP which give compression modulus, G of 6.32MPa. As expected, SAMPLE 6 with 20% give only 0.24MPa compression modulus, G.

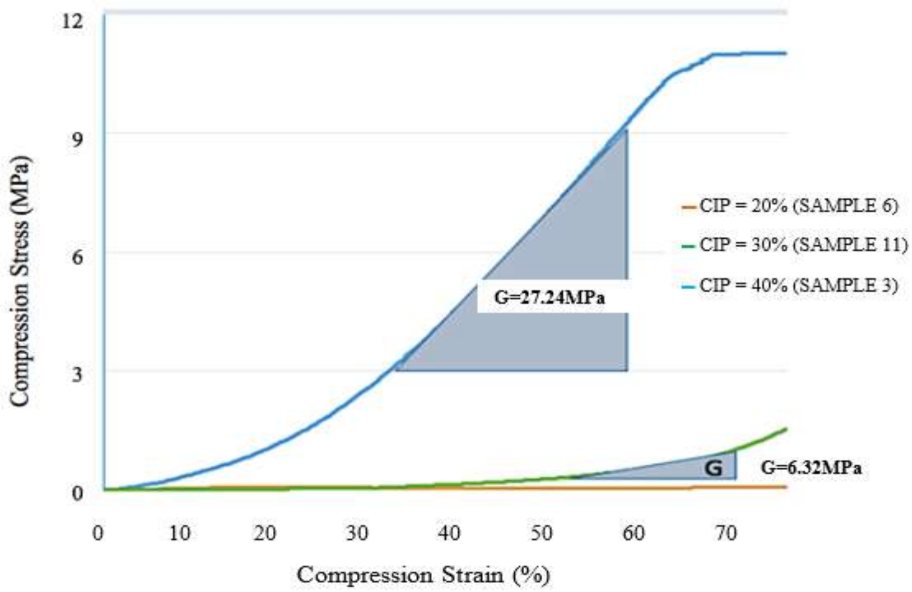

Figure 3 Compression Modulus of MR Fluid

Experimental result of maximum compression stress of all 16 MR fluid samples were analyzed by using CDMD technique to investigate the effect of each components compositions to the compression. At the same time, the best viscosity of carrier fluid also been investigated. The effect of compression stress for MR fluid samples can be seen from triangular contours plot generated by Design Expert software. This is shown in Figure 4. Fig 4(a) presents the effect of compression stress at MO viscosity is 18.50cP. Figure 4(b) presents the effect of compression stress at MO viscosity is 58.30cP. While Figure 4(c) presents the effect of compression stress at MO viscosity is 98.10cP.

Three main components which are MO, CIP and FS as additives were included in the contours plot. There are six main colours in the contours which represents the values of maximum compression stress of the MR fluid samples. Red colour represents the highest maximum compression stress followed by orange, yellow, green, cyan and blue colour.

From the triangular plots, it can be seen that blue zones dominant all three plots. Blue, green, cyan, yellow and orange zone are to be avoided. However, the highest desirability of maximum compression stress is at the highest value which is at red zone. It can be also seen that lower carrier fluid viscosity, which is mineral oil, gives an effect to the samples supported by the higher amount of CIP content. The same result was found in 2016 in the study of the effect of the volume fraction and viscosity on the compression and tension behavior of the cobalt-ferrite MR fluids(Shokrollahi, 2016).

From Figure4(a), which is at the lowest carrier fluid viscosity of 18.5cP, the best maximum compression stress is at the highest value of 76.75MPa which is at the composition of CIP 35-40vol%, MO 55-65vol% and FS 5 and 6vol%. This exhibit the best maximum compression stress for the MR fluid sample. As the MO viscosity increase to 58.3cP as depicted in Figure4(b), the value of maximum compression stress for the MR fluid samples decreases.

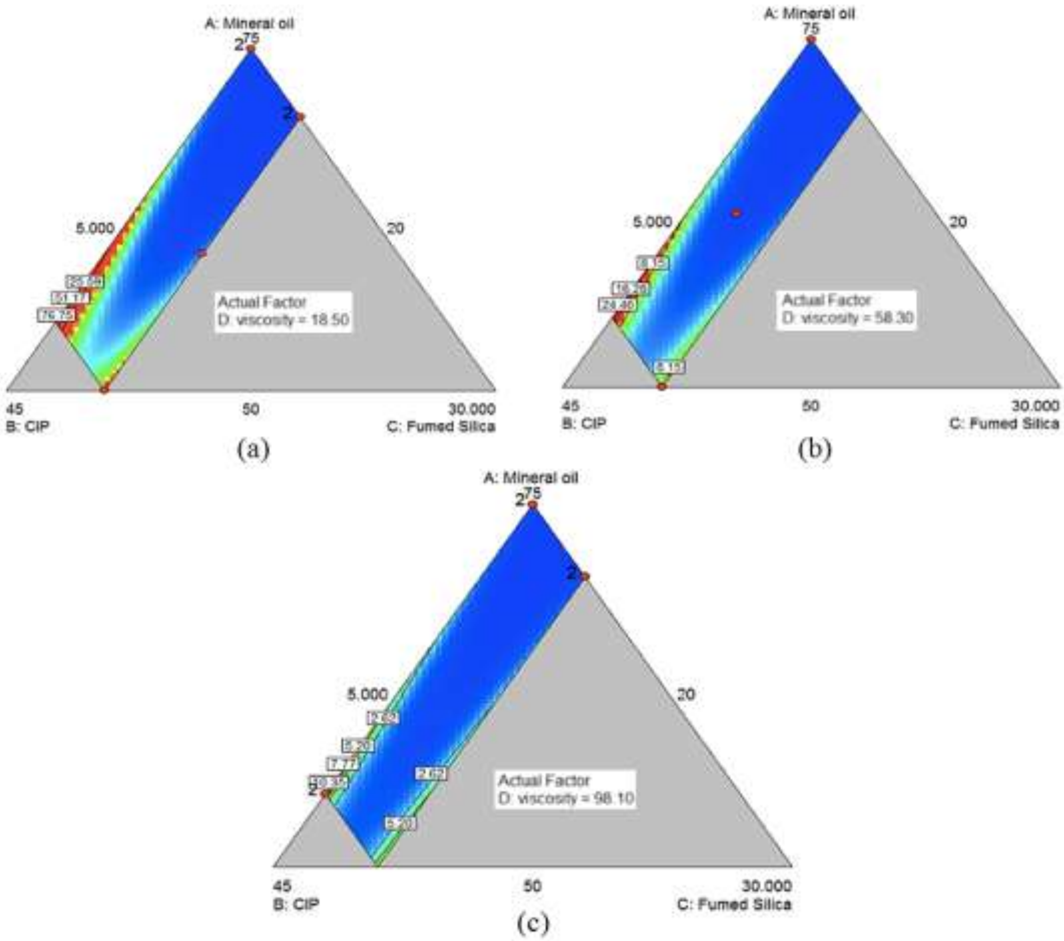

Figure 4. Effect of Compresssion Stress At Different Component Compositions and MO viscosity of (a) 18.50cP (b) 58.30cP (c) 98.10cP

The red, orange and yellow zones became smaller in the triangular contours plot. Green, cyan and blue zones become larger in the triangular contours plot. The best maximum compression stress at this medium MO viscosity is at 24.40MPa which is at the red zone with the combination of CIP 35-40vol%, MO 50-55vol% and FS 5-6vol%. The yellow, green, cyan and blue zone is to be avoided.

At highest value of MO viscosity, which is 98.1cP as depicted in Figure 4(c), the triangular contours plot produced smallest red zones. There is larger area colored with green, blue and cyan which are to be avoided. Yellow zone is self-eliminated. Therefore, it can be concluded that the best maximum compression stress at highest carrier fluid viscosity of 98.1cP is 10.35MPa at composition amount is CIP 40vol%, MO 50-55vol% and FS 5vol%. From the results obtained, the factors and responses involved with upper and lower limits are presented in Table 3. Samples with maximum compression stress were analysed by using CDMD approach.

Table 3. Optimization of Responses for MR Fluid Mixture Samples

Factors / Responses	Lower	Upper	Target
Mineral Oil (vol%)	50	75	in range
CIP (vol%)	20	40	in range
Fumed Silica (vol%)	5	10	in range
MO Viscosity (cP)	18.5	98.1	in range
Max Compression Stress (MPa)	1.00	10.95	maximize

The mixture optimization and desirability of MR fluid samples are presented in Table 4. From the data presented, solution number 1 possesses desirability value of 1 was selected as the most preferred solution for high stress resistance MR fluid sample.

Table Error! No text of specified style in document. **Mixture Optimization and Desirability of MR Fluid Samples**

No	Factors				Response	
	MO(%)	**CIP (%)**	**FS (%)**	**Viscosity(cP)**	**Max Comp Stress(MPa)**	**Desirability**
1	61	34	5	18.73	19.02	1(selected)
2	50	40	10	38.01	12.08	1
3	50	40	10	44.84	11.45	1
4	56	38	5	83.11	13.31	1
5	50	40	10	22.39	13.63	1

For solution 1, the MR fluid possessed the highest maximum compression stress with value of 19.02MPa. Therefore, the highest desirability requires combination of 61vol% MO at 18.73cP, 34vol% CIP and 5vol% FS.

Conclusions

The finding of this study shows that the composition of CIP is the most significant factor to affect the stress resistance of MR fluid for MR damper. Increment of CIP composition from 20vol% to 40vol% increased the stress resistance from 0.22MPa to 27.24MPa. Increment of carrier fluid viscosity from 18.5cP to 98.1cP reduced the compression stress resistance from 11.67MPa to 3.03MPa. Though FS composition shows least significant in the changes of stress resistance, it’s important to stabilize the suspension. Optimization of materials parameter through CDMD model analysis resulting five resultant compositions at desirability value of 1. The best resultant composition is solution 1 which produced 19.02MPa compression stress. The optimum volume fraction of MR fluid for MR damper application requires combination of 61vol% MO at 18.73cP, 34vol% CIP and 5vol% FS.

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