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Preparation and study of model magnetorheological fluids

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Materials

ABSTRACT

Purpose: The aim of this work was preparation of the model magnetorheological (MR) fluids. Basic properties of prepared MR fluids, as their response to an external magnetic field and their stability, were investigated. Moreover (furthermore) few results concerning stabilizing effect of various additives are presented.

Design/methodology/approach: Model MR fluid was prepared using three type of carriers: silicone oil OKS 1050, synthetic oil OKS 352, mineral oil OKS 600 mixed with carbonyl iron powder CI HQ. Furthermore, to reduce sedimentation Aerosil 200 and 972, Arsil 1100 and Arabic gum were added as stabilizers. MR effect was measured using device working as Couette's viscosimeter equipped with coil generating magnetic field. Sedimentation was measured by simply observation of changes in boundary position between clear and turbid part of MR fluid placed into glass tube.

Findings: Influence of the additives presence on the MR effect was determined. The presence of additives did not diminish the magnetic effect but even increased the dynamic viscosity in existence of an external magnetic field. The stability of MR fluid was improved by adding additives to the formulation. Moreover, increasing stabilizer concentration further enhanced the MR fluid stability. The best result was achieved in case of Aerosil 9782 at 2 % content.

Research limitations/implications: MR fluids with excellent properties can be applied in various fields of civil and safety engineering, transportation and life science. However, due to sedimentation, MR fluid response to magnetic field is restricted and in an extreme situation could lead to the fail that is why further efforts must be still made in order to obtain even better results.

Originality/value: This article provides set of new data about improvement of MR fluid stability in the presence of selected stabilizers and contains few remarks how the formulation of MR fluid affect its properties.

Keywords: Smart materials; Magnetic properties; Magnetorheological fluids

1. Introduction

Nowadays engineers tend to use such materials which would have at least, one property that can be easily changed in a controllable fashion by the external stimuli, often called "smart materials". Change in the applied stress, temperature, moisture, pH, electric or magnetic field can altered some materials properties, e.g. viscosity, volume, shape or conductivity. Magnetorheological (MR) fluids comprise important class of controllable materials. The rheological properties of these fluids can be changed under an applied external magnetic field. The discovery of magnetorheological fluids is credited to Jacob Rabinow in 1949 [1]. In spite of their interesting properties there has been very scant information published about MR fluids and just have attracted a great deal of attention in the last 20 years, when first commercially available fluids of this type were developed and controllable devices used this materials were designed.

The benefits of such systems show wide range of applications from space technology, through civil engineering to the domestic products [2-4]. MR fluids are becoming increasingly important in applications concerning active control of vibrations or switching /control of torque/ force. Nowadays, devices such as isolators, shock absorbers, clutches, engine mounts, alternators, power steering pumps, control valves, brakes and dampers have been designed and used, e.g. in thousands of vehicles and washing machines [5-8].

In the absence of external field MR fluid behave like Newtonian fluid, but when stimulus is applied, the viscosity and plasticity of MR fluid dramatic change. These changes are repeatedly reversible and rapid (last a few milliseconds) [9]. The main advantage of MR fluids is their high dynamic yield strength due to the high magnetic energy density, allowing the small devices designing and an application in the high dynamic range. Whereas for similar electrorheological (ER) fluids their dynamic yield strength is order of magnitude lower. The MR fluids can be controlled over a wide range of viscosity values, and their operational characteristic are largely unaffected by temperature.

However, the frequent problem in some MR fluids application is the tendency of the active magnetic particles to aggregate and settle down, that disturbs the homogeneity of MR fluid and could influence its properties. It is because magnetic particles are denser than liquid carrier [10,11] and under gravity settle and form a hard ”cake”, what makes them impossible to redisperse. Due to sedimentation and incomplete chain formation, MR fluid response to magnetic field is restricted and in an extreme situation MR fluid containing device can fail.

The aims of this work were preparation of the model magnetorheological fluids and investigation of their response to applied magnetic field. Also stability of prepared MR fluids was investigated. Next, different additives were added to the MR fluid formulation in order to improve the stability. Improvement of the stability and influence of the additives presence on the magnetorheological effect were determined. There still exist a requirement for reliable methods of measurement and analysis of characteristic rheological properties of MR fluids, which can be available for design parameters of practical devices and this is one of the primary motivations of this study.

2. Experimental

Model (MR) fluids were composed of magnetically soft ferromagnetic particles and a carrier fluid. As magnetic material, carbonyl iron (CI) powder (HQ grade) kindly donated by BASF AG was used. The diameter of used carbonyl iron particles was in range 0.5–2.2 μm (D50 = 1.1 μm) and specific surface was 1.84 m2/g . These particles were dispersed with a specific weight fraction (20% or 40%) in the following medium:

- Silicone oil OKS 1050 (Spezialschmierstoffe GmbH; viscosity: 50, 150, 235 and 500 mPa·s; density 0.97 g/cm^3)
- Synthetic oil OKS 352 (Spezialschmierstoffe GmbH; viscosity 510 mPa·s; density 0.91 g/cm^3)
- Mineral oil OKS 600 (Spezialschmierstoffe GmbH; viscosity 7.3 mPa·s; density 0.84 g/cm^3)

MR fluids were agitated with mechanical stirrer for 6 hours. To reduce sedimentation of the CI particles additional components (1 or 2 % against CI amount) were added to the fluids. Depending on the carrier medium different stabilizers were used, i.e. Aerosil 200 and 972 (Degussa AG), Arsil 1100 (Rudniki S.A.) were used for silicone and mineral oil, and Arabic gum (Sigma-Aldrich GmbH) was chosen for synthetic oil suspensions. Composition of the prepared MR fluids is listed in Table 1.

Rheological properties of MR fluids were measured by a device working as *Couette's* viscosimeter (Figure 1). A drum (1) is immersed in magnetorheological fluid and rotates driven by drive. Current supplied to the coil (3) generates magnetic field that increases viscosity of the MR fluid. By increasing voltage supplied to the coil, the change in MR fluid viscosity was observed. The applied torque is transferred from an inner drum (1) to the movable outer cylindrical vessel (2). A spring stops the outer cylinder movement and shifts the needle to the appropriate position on the angular displacement scale (4). The voltage was changed gradually from 1.25 up to 6 V in 0.5 V steps. Each measurement was repeated three times and the average value was taken.

Table 1.
Composition of investigated model MR fluids

Carrier oil	CI content [wt %]	Additive	
		Type	Amount [wt % of CI]
OKS 1050 50 mPa·s	20	Aerosil 200	1
	40		1
OKS 1050 150 mPa·s	20	Aerosil 200	1
	40		1
OKS 1050 235 mPa·s	20	Aerosil 200	1
	40		1
OKS 1050 500 mPa·s	20	Aerosil 200	1
			2
	40	Aerosil 200	1
			2
OKS 352	20	Arabic gum	1
	40		1
OKS 600	20	Aerosil 200	1
	40		1
OKS 600	20	Aerosil 200	1
		Aerosil 972	1
		Arsil 1100	1

The sedimentation was measured by visual observation of the position changes of boundary between clear and turbid part of carrier oil. Prepared samples were placed into cylindrical glass test tubes (length 1 m, diameter 30 mm) for a few days. As a result sedimentation ratio (R) was calculated. Sedimentation ratio is simply defined as a proportion between length of clear and turbid part of MR fluid:

$$R = \frac{a}{a+b} \cdot 100\ \% \qquad (1)$$

where: R [%] - sedimentation ratio, a – length of the clear part, b – length of the turbid part.

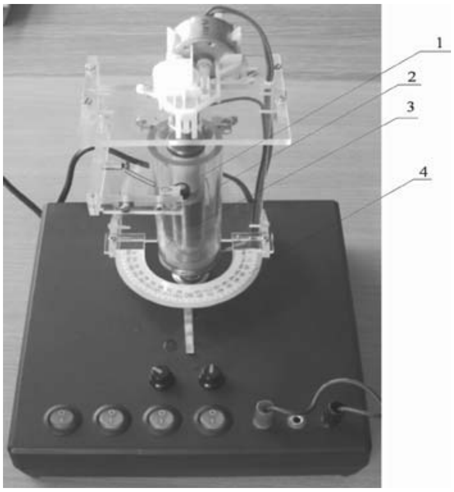

Fig. 1. Apparatus for MR effect measurement. 1 – shaft (drive) and inner cylinder, 2 – outer cylinder, 3 – coil, 4 – neddle and angular displacement scale

3. Results and discussion

An examination of magnetorheological effect was carried out to check the influence of MR fluid composition on its operational characteristic, i.e. type of liquid carrier, liquid carrier/magnetic particle ratio, presence of additional substances. The results of performed experiments show that the greater oil viscosity the bigger magnetorheological effect. Furthermore, higher content of CI has positive impact on the magnetorheological effect. The most important for the magnetorheological properties is presence of the stabilizing additives which further increase two times the MR effect. Besides that in the presence of stabilizers MR fluid are more homogeneous and faster respond to the external magnetic field at lower magnetic field intensity (see Figure 2) [12,13].

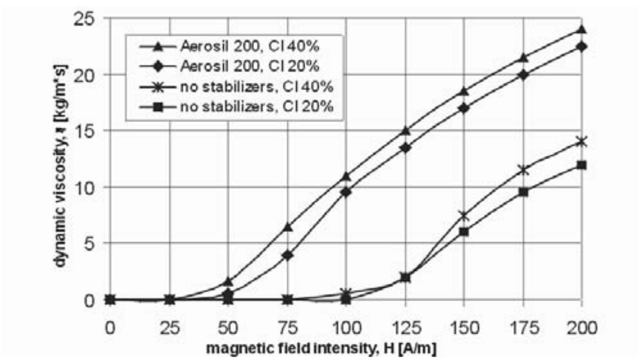

Fig. 2. Dependence of the MR fluid (OKS 1050, 150 mPa·s) dynamic viscosity on the magnetic field intensity

The effect of additives on the stability of the magnetorheological fluid has been investigated experimentally. Suspensions of carbonyl iron particles in following carrier: silicon, mineral and synthetic oils were prepared as the model MR fluids. Stability of prepared MR fluids was different in each case and it varies from few hours to even few days. It was dependent not only on the content of iron but also on type of oil, which was used. As shown on Figure 3, generally, stability of MR fluid increase with increasing of oil viscosity. For the lowest viscous OKS 1050 50 mPa·s sedimentation was very fast and in the case of 20 % load of CI at 10 hour reached almost 100 %. Furthermore, as was mentioned before, stability depends also on the amount of CI in the MR fluid. Usually, higher content of CI improve the stability, but for to viscous oils stability decreased (see Fig. 3) [14].

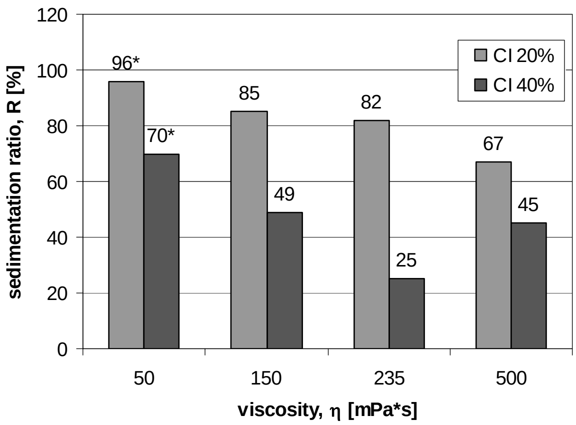

Fig. 3. Sedimentation ratio after 50 h for MR fluids based on OKS 1050 with different viscosity (* after 10 h)

Addition to the MR fluids stabilization agents should further improve their stability. The properties of such substances are very important. As one can see on Figure 4, in case of Arsil 1100 stabilization effect was not achieved and the MR fluid behave like ordinary one without any stabilizer. Such situation can be explained by the state of the silica surface and its modification [15]. The best result was obtained for Aerosil 972. Using this stabilizer sedimentation ratio decreased below 60 % after 2 days in case of low viscosity mineral oil OKS 600 (only 7.3 mPa·s) containing 20 % of CI.

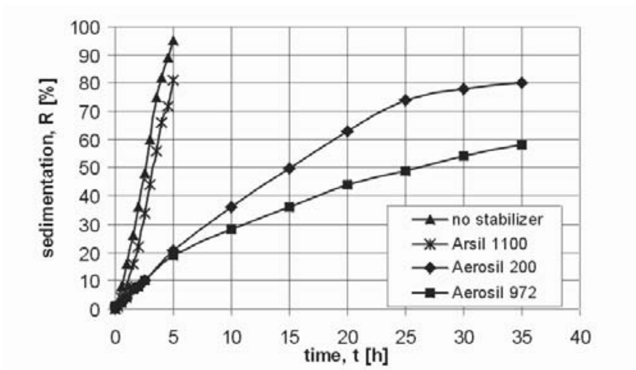

Fig. 4. Sedimentation ratio vs time for MR fluid containing different stabilizer (OKS 600, 7.3 mPa·s, CI 20%)

As was mentioned before, stability of MR fluid depends on the CI content. Usually, higher content of CI increase the stability. In contrast to the non stabilizers containing formulation, in the presence of stabilizers the lower content of CI is preferred. As can be seen on Figure 5, the stability of the 20 % loaded MR fluid in the presence of 1 % of Aerosil 972 was much better than the 40 % loaded one. Inversly, in case of MR fluids without stabilizer the higher loaded one showed better stability.

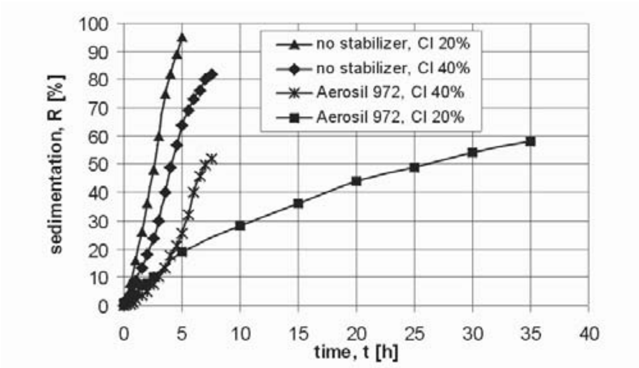

Fig. 5. Sedimentation ratio vs time for MR fluid with different CI content (OKS 600, 7.3 mPa·s)

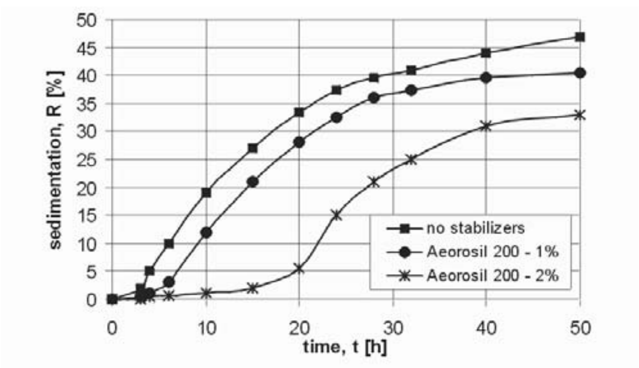

Fig. 6. Sedimentation ratio vs time for MR fluid with different stabilizer content (OKS 1050, 500 mPa·s, CI 40%)

Increasing of the amount of stabilizers also grew better stability of the MR fluid (see Figure 6). Doubling the Aerosil 200 content in OKS 1050 (500 mPa·s) decreased the sedimentation ratio from 41 % to ~32 %. Furthermore, what-ever worthy notice, at higher stabilizer content the shape of sedimentation curve was changed. One can observed kind of “inhibition” time at the firs day of sedimentation followed by acceleration after this period.

4. Conclusions

Magnetorheological suspensions composed of carbonyl iron particles and various oils as a carrier were prepared as model MR fluids.The stability of MR fluid was improved by adding additives to the formulation and increasing their concentration. The presence of additives did not diminish the magnetic effect but even increased the dynamic viscosity in existence of an external magnetic field.

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