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Mechanical properties of smart fluids under combined electrical and magnetic fields

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1. Introduction

The “smart” media change their properties reversible under external influences. These materials include magnetic, magnetorheological and electrorheological fluids. They represent polarized or magnetized fluid-disperse materials the properties of which are defined by the state of disperse phase the particle structure of which can be changed by the influence of magnetic or electrical field. Time of properties transformation is about 10^{-3} - 10^{-4} s. Thus, it is possible to control flow, heat and mass transfer, mechanical, electrical, magnetic and other characteristics of such materials by using high-voltage low-current signal (10^{-5} A) or generating magnetic field by low potential electric signals.

This is the basic quality of “smart” media allowing consumer to develop new models of techniques and technology, e. g. vibrodamping devices [1], methods of precision polishing of nonmagnetic materials [2], seal facilities [3], manipulators [4, 5], etc.

The new disperse systems – magnetoelectrorheolo-gical fluids (MERF) – differ by a capability to change their rheological properties under the influence of both electrical and magnetic fields. During the last decade the interest to these media essentially increased [6 - 12]. The sensitivity to both fields may be attained by two means: by using composite disperse phase on the base of two fillers, or by using disperse phase on the base of one complex filler, for example, ferromagnetic particles, covered by the layer of electrosensitive actuator. Earlier the MERF on the base of disperse phase particles covered by the actuator were investigated in [13 - 16]. We present the results of experimental investigations of rheological properties of magnetoelectrorheological fluids on the base of composite disperse phase.

2. Experimental setup

The rheological experiments were performed on a special co-cylindrical viscometric bell-type cell serving as an attachment to torque meter of the viscometer RV-12 manufactured by HAAKE. The cell is similar the one described in [13]. The force lines of the magnetic and electrical fields are normal to the shear and parallel one to another.

In experiments, the measurements of shear stress τ at varying: magnetic field intensity H = (0 - 100) kA/m, electrical field strength E = (0 - 1.8) kV/mm, shear rate $\dot{\gamma}$ = (2 - 575) s^{-1} have been performed.

The fluids with disperse phase combined with two powders were investigated. The first kind of powder – carbonyl iron, the second one – iron oxide α-Fe_2O_3, or iron oxide γ-Fe_2O_3, or aerosyl activated polyethylenepolyamine. The transformer oil served as disperse media.

3. Main results

The flow curves for MERF containing carbonyl iron at volume concentration 0.05 and γ-Fe_2O_3 at volume concentration 0.05 are shown in Fig. 1. It can be seen from the figure that the essential shear stress enhancement occurs under the action of the electrical and magnetic fields. The increase caused by the influence of magnetic field is higher than the one caused by electrical field due to significant magnetic sensitivity of carbonyl iron particles. Electrorheological activity of the disperse phase of this MERF is not such significant. In difference from it, aerosyl has the greater electrical sensitivity. The flow curves for MERF containing carbonyl iron at volume concentration 0.05 and aerosyl at volume concentration 0.05 are shown in Fig. 2.

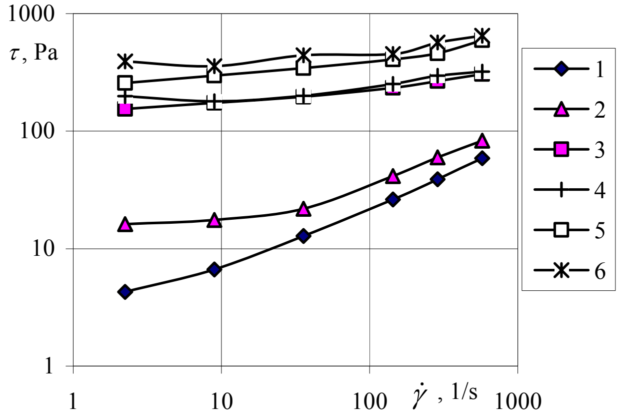

Fig. 1 Flow curves of MERF on the base of carbonyl iron and γ-Fe_2O_3: *1* – no fields; *2* – E = 1.36 kV/mm; H = 0, *3* – E = 0, H = 60 kA/m; *4* – E = 1.36 kV/mm, H = 60 kA/m; *5* – E = 0, H = 100 kA/m; *6* –E = = 1.36 kV/mm, H=100 kA/m

Further we present the rheological characteristics in relative values τ/τ_0, normalized by the values of shear stress in the absence of external fields. Fig. 3 shows the data for MERF on the base of carbonyl iron and γ-Fe_2O_3 analogous as in Fig. 1, only plotted in relative values. The corresponding curves for MERF on the base of carbonyl iron and aerosyl are presented in Fig. 4. Maximal increase occurs at low shear rates.

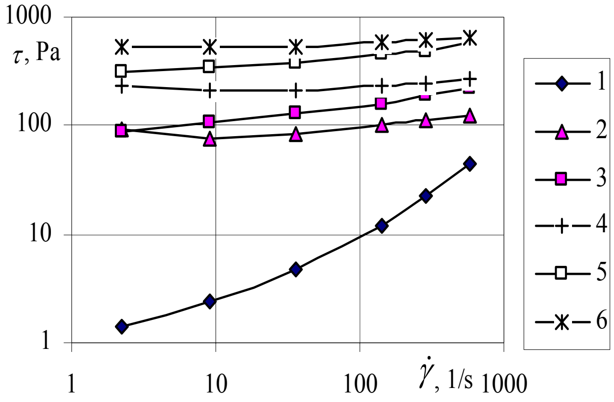

Fig. 2 Flow curves of MERF on the base of carbonyl iron and aerosyl: *1* – no fields; *2* – $E = 1.36$ kV/mm, $H = 0$; *3* – $E = 0$, $H = 60$ kA/m; *4* – $E = 1.36$ kV/mm, $H = 60$ kA/m; *5* – $E = 0$, $H = 100$ kA/m; *6* – $E = 1.36$ kV/mm, $H = 100$ kA/m

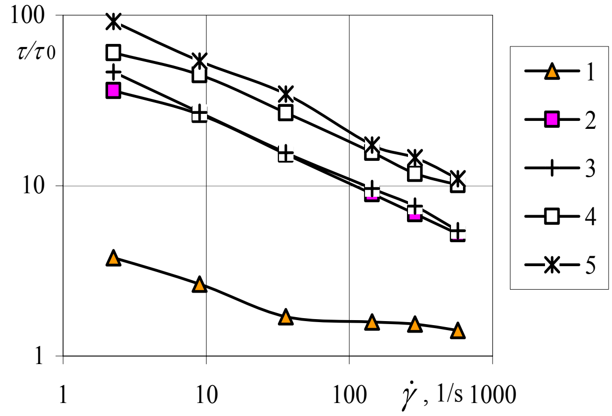

Fig. 3 Relative shear stress increment of MERF on the base of carbonyl iron and γ-Fe_2O_3 in electrical and magnetic fields: *1* – $E = 1.36$ kV/mm, $H = 0$; *2* – $E = 0$, $H = 60$ kA/m; *3* – $E = 1.36$ kV/mm, $H = 60$ kA/m; *4* – $E = 0$, $H = 100$ kA/m; *5* – E=1.36 kV/mm, $H = 100$ kA/m

Because of needle shape of γ-Fe_2O_3 particles the MERF based on them shows higher shear stresses at the absence of external fields than all other fluids. The fluids on aerosyl base give higher shear stress under the influence of electrical field. They have more significant relative shear stress increment than the fluids with γ-Fe_2O_3 under the separate or simultaneous influence of electrical and magnetic fields (Figs. 3, 4). Maximal increase is more than 100 times against 8 in the electrical field. These increments achieved under the action of magnetic field are 215 and 85 times and under the combined action of electrical and magnetic field – 380 and 180 times respectively.

The fluids with disperse phase on the base of carbonyl iron and α-Fe_2O_3 for the same disperse phase volume concentration show absolute values of shear stress lower than the ones with γ-Fe_2O_3 or aerosyl both in the absence of fields and under electrical and magnetic influence. They give the increase of shear stress in electrical field up to 15 times. These media show the more significant rheological response in magnetic field than other investigated ones (up to 290 times). The MERF with α-Fe_2O_3 display the maximal relative shear stress increment under combined influence of the electrical and magnetic fields practically equal to the increment for fluids with aerosyl – 380 times.

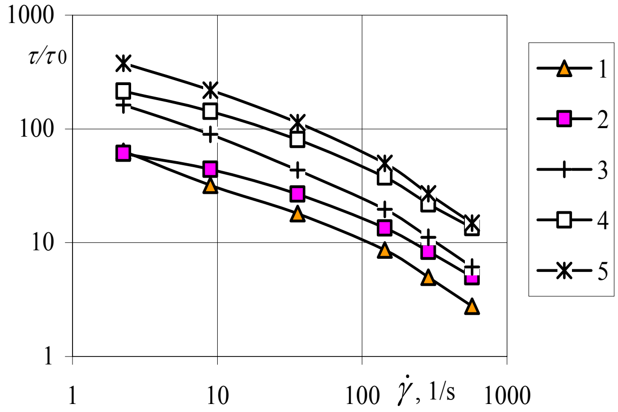

Fig. 4 Relative shear stress increment of MERF on the base of carbonyl iron and aerosyl in electrical and magnetic fields: *1* – $E = 1.36$ kV/mm, $H = 0$; 2 – $E = 0$, $H = 60$ kA/m; *3* – $E = 1.36$ kV/mm, $H = 60$ kA/m; *4* – $E = 0$, $H = 100$ kA/m; *5* – $E = 1.36$ kV/mm, $H = 100$ kA/m

The studied materials show the synergistic effect in many cases – the shear stress increase induced under combined action of electrical and magnetic fields is larger than the sum of the electrically and magnetically induced increments. However this effect occurs not always, sometimes the sum of increments in the electrical and magnetic field acting separately is larger than the increment under combined action. Especially this occurs at high shear rates. For MERF with aerosyl the synergistic effect is observed almost always.

The dependence of relation ξ (the increment under combined action to the sum of the increments in electrical and magnetic fields) on shear rate for MERF on the base of carbonyl iron and aerosyl is shown in Fig. 5. The synergistic effect is more significant for low shear rate.

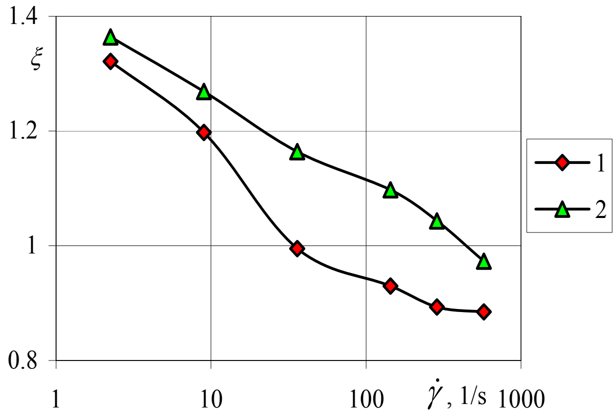

Fig. 5 The dependence of the synergistic effect on shear rate for MERF on the base of carbonyl iron and aerosyl under combined action of electrical and magnetic fields: *1* – $E = 1.36$ kV/mm, $H = 60$ kA/m; *2* – $E = 1.36$ kV/mm, $H = 100$ kA/m

The experiments were also performed for fluids containing iron oxides with different volume concentration of the disperse phase components. The total disperse phase volume concentration was 0.1 in these experiments. The concentration of carbonyl iron and iron oxide or aerosyl varied, herein their sum was constant.

The proportion between the concentrations of disperse phase components is not essential on relative shear stress increment under electrical field. The carbonyl iron concentration increase caused enlarging relative shear stress under the influence of magnetic field and under combined action of the fields. For example, the concentration influence of relative shear stress increment of MERF on the base of carbonyl iron and γ-Fe_2O_3 is shown in Fig. 6.

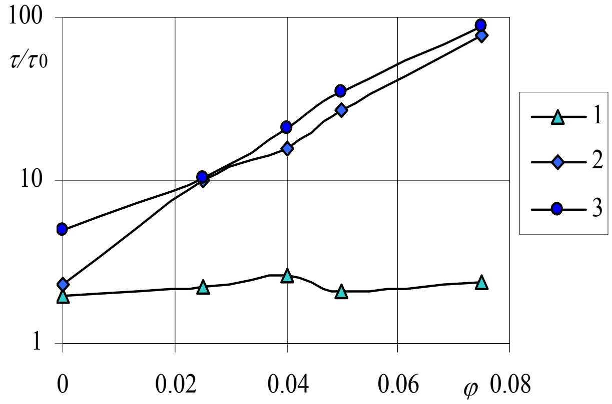

Fig. 6 The dependence of relative shear stress increment of MERF on the base of carbonyl iron and γ-Fe_2O_3 on carbonyl iron concentration in electrical and magnetic fields (shear rate 36 s^{-1}): *1* – *E* = 1.36 kV/mm, *H* = 0; 2 – *E* = 0, *H* = 100 kA/m; 3 – *E* = =1.36 kV/mm, *H* = 100 kA/m

4. Conclusions

The results of experimental investigations of rheological properties of MERF on the base of carbonyl iron, iron oxides and aerosyl are presented. The investigated fluids show shear stress increment up to 380 times under combined action of the fields. The MERF give the synergistic effect in many cases – the induced under combined action of electrical and magnetic fields shear stress increase is larger than the sum of electrically and magnetically induced increments. Especially this occurs for fluids containing aerosyl as a disperse phase component. It is defined that the enlargement of carbonyl iron concentration provides the increasing shear stress increment under the influence of magnetic field and under combined action of the fields. The possibility of the property control using two independent physical channels will allow applying magnetoeletrorheological fluids in many devices and technologies (heat exchangers, hydraulic systems, vibrodamping devices, etc.).

Acknowledgements

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INTELEKTUALIŲ SKYSČIŲ MECHANINIŲ SAVYBIŲ KITIMAS ESANT JUNGTINIAM ELEKTRINIO IR MAGNETINIO LAUKŲ POVEIKIUI

Reziumė

Darbe pateikiami magnetoelektroreologinių skysčių – terpių, jautrių ir elektrinio, ir magnetinio laukų poveikiui, mechaninių savybių eksperimentinio tyrimo rezultatai. Tirtoms įvairios sudėties medžiagoms būdingas sinergetinis efektas: kartu veikiant elektriniam ir magnetiniam laukams susidaręs šlyties įtempių padidėjimas viršija dėl atskirų elektrinio ir magnetinio laukų poveikių atsirandančių padidėjimų sumą. Galimybė valdyti minėtas savybes, naudojant du nepriklausomus fizinius kanalus, sudaro sąlygas naudoti minėtas terpes daugelyje įrenginių ir technologinių procesų (šilumokaičiuose, hidraulinėse sistemose, virpesių slopintuvuose ir kt.).

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MECHANICAL PROPERTIES OF SMART FLUIDS UNDER COMBINED ELECTRICAL AND MAGNETIC FIELDS

Summary

This paper presents the results of experimental investigation of mechanical properties of magnetoelectroheological fluids – the media which respond to both electrical and magnetic fields. The investigated materials show the synergistic effect for many compositions – the shear stress increase induced under combined action of electrical and magnetic fields is larger than the sum of the increments induced separately by the electrical and magnetic fields. The possibility of the property control using two independent physical channels will allow applying these media in many devices and technologies (heat exchangers, hydraulic systems, vibrodamping devices, etc.).

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МЕХАНИЧЕСКИЕ СВОЙСТВА ИНТЕЛЛЕКТУАЛЬНЫХ ЖИДКОСТЕЙ ПРИ СОВМЕСТНОМ ВОЗДЕЙСТВИИ ЭЛЕКТРИЧЕСКОГО И МАГНИТНОГО ПОЛЕЙ

Резюме

В настоящей работе представлены результаты экспериментальных исследований механических свойств магнитоэлектрореологических жидкостей-сред, чувствительных и к электрическому, и к магнитному полям. В изученных материалах разных составов проявляется синергетический эффект – при совместном воздействии электрического и магнитного полей индуцированное увеличение напряжений сдвига больше, чем сумма приращений, индуцированных отдельно электрическим и магнитным полями. Возможность управления свойствами с использованием двух независимых физических каналов позволит применить эти среды во многих устройствах и технологиях (теплообменники, гидравлические системы, средства виброзащиты и др.).

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