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DYNAMIC VISCOSITY OF COMMERCIALLY AVAILABLE MAGNETORHEOLOGICAL FLUIDS

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Abstract: *The paper presents measurement and comparison of the dynamic viscosity of commercially available magnetorheological fluids and their temperature dependency of the dynamic viscosity. The appropriate choose of the MR fluid has positively effect to efficiency of the magnetorhelogical damper. The lower value of the dynamic viscosity (magnetic field independent) increases the dynamic force range. Eight samples of MR fluids from three manufactures were measured. MR fluids were tested on the Haake Rotovisco 1 in the temperature range -5 °C to 100 °C. The lowest dynamic viscosity with the similar solid content by weight is exhibited by MR fluids manufactured by Lord company.*

Keywords: Magnetorheological fluid, MR fluid, Dynamic viscosity of MR fluid, Magnetorheological damper, MR damper.

1. Introduction

The magnetorheological (MR) fluid is a smart material which is composed of micro-scale ferromagnetic particles, the carrier fluid and additives. This material exhibits rapid and strong change of rheological behavior under an external magnetic field. Ferromagnetic particles in the MR fluid form a chain-like structure in the direction of a magnetic field which causes change of the yield stress. The chain forms cause the yield stress of MR fluid depending on type of the MR fluid and level of a magnetic field. This effect is known as the magnetorheological effect.

The magnetorheological (MR) damper is a device that can benefit from interaction of the MR fluid and the magnetic field. The chain-like structures in the magnetic field restrict the flow of the fluid in an active zone, thereby increasing the damping force of the MR damper. The MR damper is using in the automotive industry (Nguyen, 2009), in the railway industry (Sun, 2013) or for the control of seismic vibrations in buildings (Yang, 2002). The common design of the MR damper is composed of an electromagnetic coil, a magnetic circuit and the MR fluid. One of the most important relations describing the behaviour of the MR damper is damping force- piston velocity- electric current (F-v-I) course. The efficiency of the MR damper depends on dynamic force range and response time (Strecker, 2015).

The dynamic force range $\mathrm{D}(\mathrm{v},\mathrm{H})$ of the MR damper is the damping force in on-state F(v, H) divided by uncontrollable damping force in off-state $F_{uc}(v)$ for given piston velocity v and given electric current which causes magnetic flux intensity H in MR damper (Yang, 2002).

$$D(v,H) = \frac{F(v,H)}{F_{uc}(v)} = \frac{F_\tau(H) + F_{uc}(v)}{F_{uc}(v)} = 1 + \frac{F_\tau(H)}{F_\eta(v) + F_f}$$

The damping force in on-state $F(v,H)$ is composed of the controllable force $F_\tau(H)$ and the uncontrollable force in off-state $F_{uc}(v)$. The force in off-state is consisted of the friction force F_f and the viscous force $F_\eta(v)$. The value of the viscous force $F_\eta(v)$ is depends on flow velocity in active zone, the geometry and the dynamic viscosity (field-independent) of the MR fluid in off-state (Sapiński, 2013). The higher value of the viscous force $F_\eta(v)$, the lower the dynamic force range $\mathrm{D}(\mathrm{v},\mathrm{H})$. The dynamic force range of the MR damper is also influenced by in-use-thickening of the MR fluid (Roupec, 2013). Nevertheless, the dynamic viscosity of MR fluid is the most critical off-state property of MR fluid

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(Kumbhar, 2015). The MR fluid dynamic viscosity is most influenced by three factors: the intrinsic viscosity of the carrier fluid, the particle volume fraction and additives (Kumbhar, 2015).

The main goal of this paper is comparison of the dynamic viscosity at 40 °C and the temperature dependency of the dynamic viscosity of commercially available MR fluids with similar solid content by weight.

2. Methods

MR fluids were measured by rotational rheometer Haake RotoVisco 1 (Fig. 1). The sensor system ISO 3219 Z20 DIN was used (Fig. 1-right). The experiment was controlled by software RheoWin. In every single test was used 8.2 ml of a MR fluid. MR fluids were homogenized 30 min before experiment.

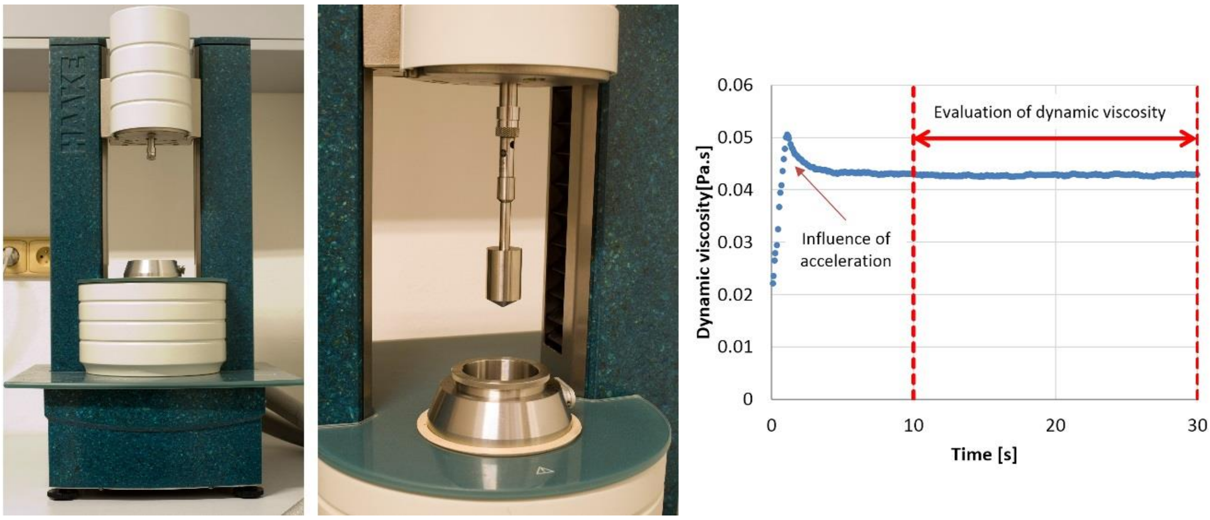

Fig. 1: Haake RotoVisco 1 and sensor Z20 DIN (left, middle); the evaluation of dynamic viscosity (right).

The dynamic viscosity of MR fluid was measured with the constant shear rate 800 s^{-1} in 30 s. The temperatures of measured MR fluids were in range from -5 °C to 100 °C. The MR fluid was mixed with shear rate 50 s^{-1} when the MR fluid was tempering. Eight samples of MR fluids with the different solid content by weight and made by different producers were tested, see Tab. 1.

Tab. 1: List of tested MR fluids.

Category	Name of the MR fluid	Solid content by weight [%]	Density [kg/m^3]	Producer
A	MRF-122EG	72	2280 - 2480	Lord
B	MRF-132DG	80.98	2950 - 3150	Lord
C	MRF-140CG	85.44	3540 - 3740	Lord
A	MRHCCS4-A	70	2490	Liquid Research
B	MRHCCS4-B	80	3080	Liquid Research
A	2.55	75.5	2550	Haohua
B	3.05	80.5	3050	Haohua
C	3.55	85.5	3550	Haohua

The presented value of dynamic viscosity of the MR fluid was evaluated from last 20 s of the experiment as arithmetic average, see Fig.1 right. The last 20 s was chosen due to acceleration of measuring rotor. The acceleration has significant effect to measured data. The viscosity index was determined by ISO 2909. The viscosity index (VI) is shown near the name of the MR fluid in each graph.

3. Results

The measured data are presented in Figs. 2 – 4 with logarithmic scale in Y axis. In Fig. 2 were compared three MR fluids with the similar solid content by weight 72 % (category A). The MR fluid MRHCCS4-A achieved the dynamic viscosity 0.17 Pa.s at 40 °C and Haohua 2.55 the dynamic viscosity 0.23 Pa.s at 40 °C. The dynamic viscosity od MR fluid Lord MRF-122EG at 40 °C has 4.4 times lower than MRHCCS4-A and 5.6 times lower than Haohua 2.55.

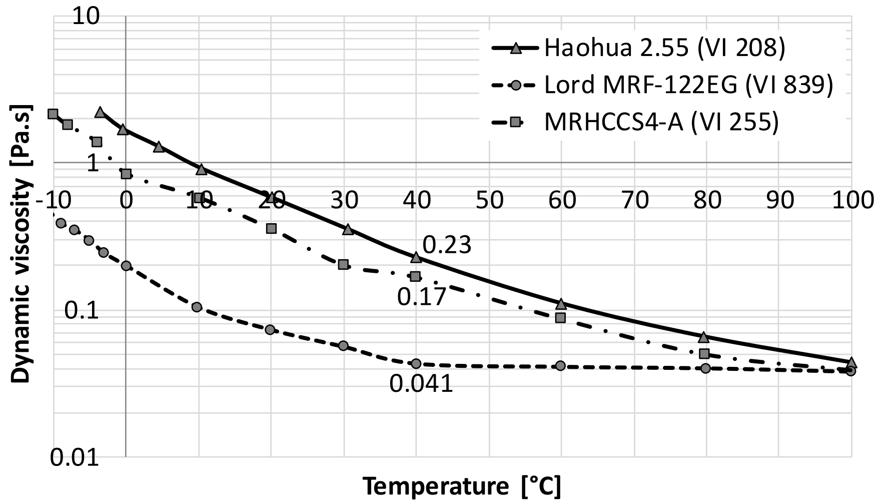

Fig. 2: Comparison of MR fluids in category A (approximately 72 % solid content by weight).

Three MR fluids with the similar solid content by weight 80 % (category B) were compared, see Fig. 3. In this category, the MR fluid Haohua 3.05 has the highest viscosity 0.35 Pa.s at 40 °C. The Lord MRF-132DG has 2.1 times lower viscosity than MRHCCS4-B and 3 times lower viscosity than Haohua 3.05 at 40 °C.

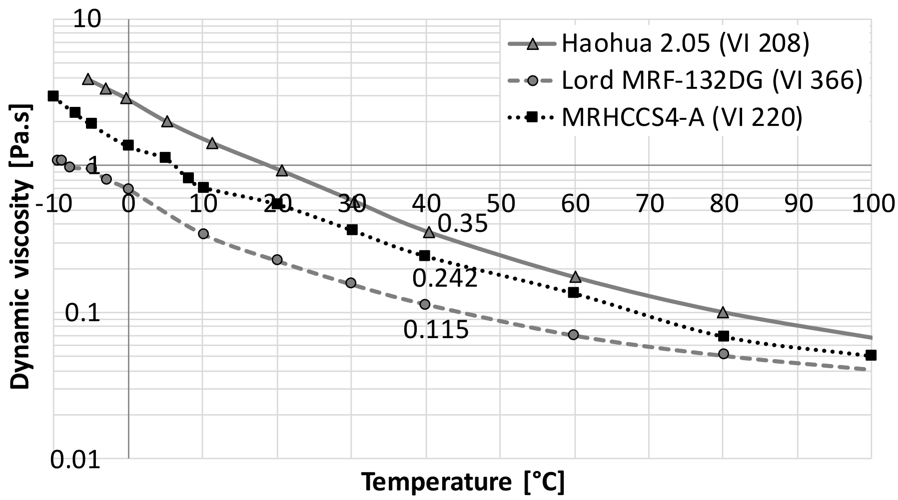

Fig. 3: Comparison of MR fluids in category B (approximately 80 % solid content by weight).

In Fig. 4 were compared MR fluids with the similar solid content by weight 85 % (category C). In this category were measured two MR fluids because the company Liquid Research hasn’t manufacture the MR fluid with 85 % solid content by weight in their product list. The Lord MRF-140CG has 1.64 times lower viscosity than Haohua 3.55 at 40 °C.

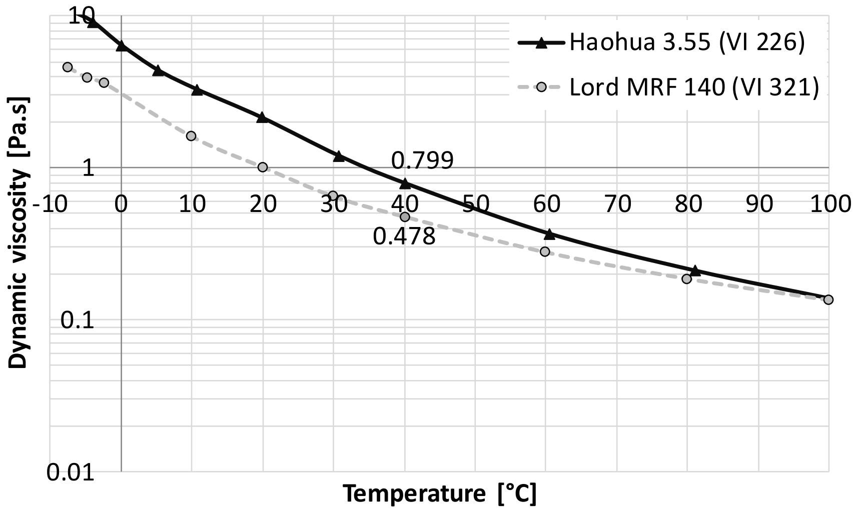

Fig. 4: Comparison of MR fluids in category C (approximately 85 % solid content by weight).

4. Conclusions

The paper presents a comparison of the dynamic viscosity and their temperature dependency of commercial available MR fluids with similar solid content by weight. The lowest viscosity in every group achieved MR fluid made by Lord. The low dynamic viscosity of MR fluid suggests the low dynamic viscosity of the carried fluid or suitably chosen additives. The highest viscosity index (VI 839) achieved MRF-122EG. MR fluids made by Liquid Research and Haohua achieved viscosity index between 200 and 300.

However, it is necessary to compare MR fluids also in others aspects: yield stress, sedimentation stability, fluid life, lubricity or wear aspects. The subsequent research will be focused on measurement and comparison of MR fluids in these aspects.

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