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ABRASION OF MAGNETORHEOLOGICAL FLUIDS

F. Jeniš*, J. Roupec, J. Žáček, M. Kubík, O. Macháček, J. Smilka, M. Smilková, I. Mazůrek

Abstract: *This paper deals with the study of the abrasive effect of commercial magnetorheological (MR) fluids on steel material. The tests were performed on a tribometer with a pin-on-plate configuration; the sample was flooded with the examined fluid. The rate of abrasion, caused by MR fluids and hydraulic oil, was compared. The difference among the tested MR fluids has been shown to be minimal and the abrasion is approximately twice as large as when using hydraulic oil. The results are beneficial for the development of MR dampers, a material with a higher resistance against abrasion wear must be used for a hydraulic tube. Furthermore, the testing procedure and test conditions were established and thus this test can be repeated with new materials until the abrasion is not as extensive as that with hydraulic oil.*

Keywords: abrasion, magnetorheological fluid, pin on plate, wear, MR damper

1. Introduction

With increasing demands on damping systems, adaptive or semi-active dampers are being used in a variety of technical applications. These dampers can change the damping characteristics, according the control system requirements. One such type of dampers are magnetorheological (MR) dampers. Instead of hydraulic oil, they use MR fluid – the suspension of micron-sized ferromagnetic particles in the carrier fluid. When the MR fluid is exposed to an external magnetic field, the ferromagnetic particles are concatenated in the direction of the magnetic field and thus the apparent viscosity increases rapidly. This increase in the apparent viscosity causes an increase in the hydraulic resistance of the piston in the MR damper, and hence an increase in damping forces.

The applicability of these dampers in progressive damping systems has several limitations. The first is the MR damper response time. The long response time significantly degrades the performance of the control strategy (Strecker, 2018). The particle sedimentation (Roupec 2017), In-Use-Thickening (Roupec 2013) and abrasive wear of the MR damper parts by MR fluid are other limiting factors.

Iron particles in MR fluid cause abrasive wear inside the contact pairs – pairs such as: piston and hydraulic cylinder, piston rod and its sealing, sliding bearing and piston rod, floating piston and hydraulic cylinder. In addition, MR fluid can cause the wear of a flow channel by mere flow. Wear of these parts significantly reduces the MR damper's life and may make it less competitive compared to other technologies.

The Miller test (ASTM G75) is the method often used, which measures the loss of reference material (steel Cr27) caused by the suspension abrasivity. However, this method is not commonly used in MR fluid wear measurement because it determines only the suspension abrasivity. It can be useful if a different suspension can be selected as a fill of the designed device. In reality, the range of possible MR fluids is limited, because there are only three commercially available fluids, and thus the appropriate resistance material for damper parts fabrication must be chosen. Therefore, the wear of specific materials in contact with the MR fluid is more often study, but not unified by any standard. Iyengar (2004) tested the abrasion of MR fluids – he measured the wear of polyurethane, often used as a material in seals. Sohn (2009) tested the wear rate and friction coefficient of MRF-132DG on various plate materials; Lee (2001) studied the influence of additives on abrasion rate, whereas Zhang (2016) tested the influence of different magnetic fields on wear.

* All authors: Institute of Machine and Industrial Design, Brno University of Technology, Technická 2898/2, 616 69 Brno; CZ, Ing. Filip Jeniš: Filip.Jenis@vutbr.cz

The main aim of this paper is to provide a valuable insight of the abrasive behavior of commercially available MR fluids on the material from which the MR damper is manufactured, and to compare it with common hydraulic oil.

2. Materials and Methods

Tests were performed on tribometer Bruker UMT TriboLab (Fig. 1 a) with a pin-on-plate configuration (Fig. 2). A hardened ball bearing with a diameter of 6.35 mm was used as a pin. The material for a common damper hydraulic cylinder (ST52.3 BK+S = E355SR or ČSN 11 523) is available only as a tube, not in plane form. Therefore, the plate was made of S355J2C+C (1.0579) with the identical chemical compound and identical strength properties. The pin is in contact with the plate and performs linear reciprocating motion. The contact is flooded with the examined fluid (Fig. 2b).

a) b)

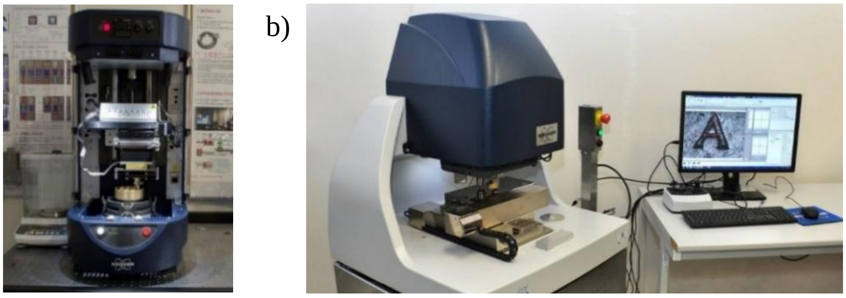

Fig. 1: (a) tribometer Bruker UMT TriboLab; (b) 3D optical profilometer Bruker Contour GT-X8.

The test setting of the experiment was the following: compressive (normal) force of 80 N; motion amplitude of 5 mm; frequency of 4 Hz (Fig. 2b); plate roughness of Ra 0.2. The depth of the track was measured in checkpoints after 2.000, 4.000, 7.000 and 10.000 load cycles. For each checkpoint, a new track was created. The test was repeated three times. Thus, in total there were 12 tracks for one fluid. Three MR fluids from Lord Corporation (122ED, 132DG, 140CG) and HM32 hydraulic oil from Paramo were tested. The effect of the electromagnetic field on the abrasive behavior of tested MR fluids was not considered.

a) b)

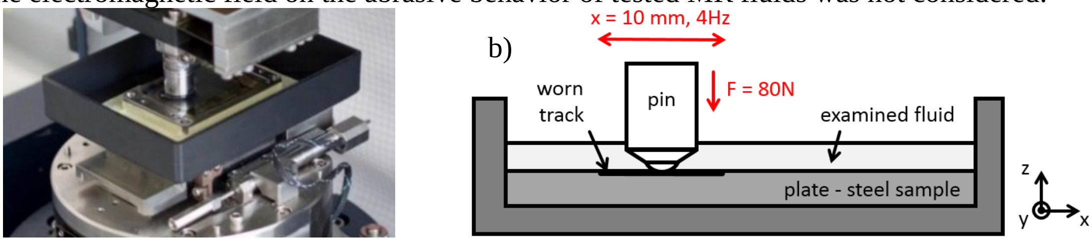

Fig. 2: (a) Reciprocating test module; (b) test scheme.

The 3D optical profilometer Bruker Contour GT-X8 (Figure 1b) was used for track scanning. Each track was scanned at five different places, and in each scan image the depth of the track was measured on two profiles in 1/3 and 2/3 scan lengths (Fig. 3) – these 10 measurements were averaged into one value.

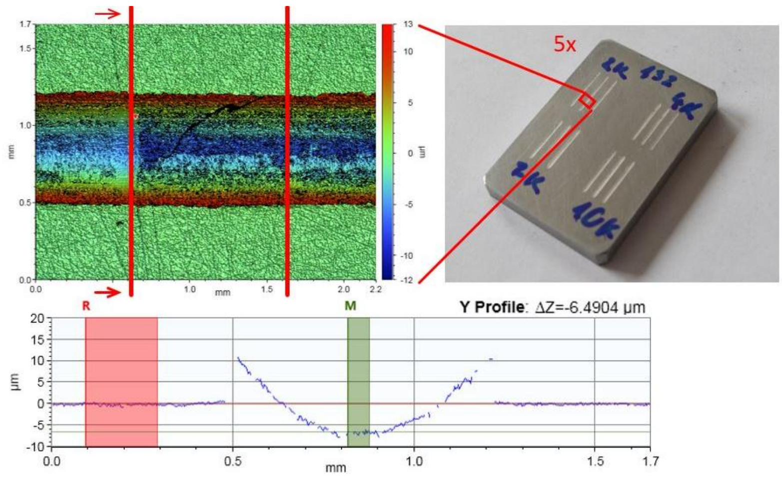

Fig. 3: Method of evaluation.

The testing plate was prepared with a roughness of Ra 1.0, but the wear process with this surface was unstable (Fig. 4). Excessive wear of some tracks was probably due to the slip-stick phenomenon. The wear rate decreased rapidly and was stabilized when the plate surface roughness was ground on Ra 0.2.

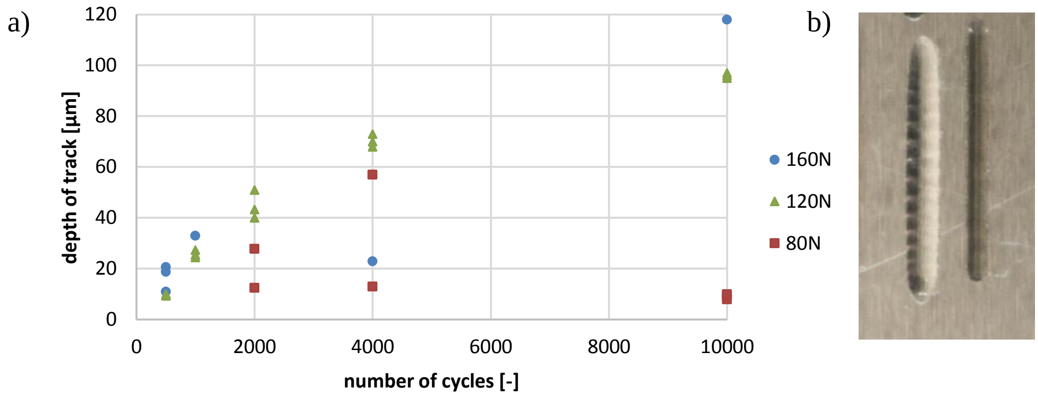

Fig. 4: (a) First experiment (HM32); (b) Two tracks for the same conditions (80 N, 4000 cycles, Ra 1.0).

The hypothesis that the pin (ball) during loading presses out MR particles from the contact was considered during the preparation of the test. The holder with the ball was lifted every 50 cycles for the particles to run back. This process should lead to an increase in the wear from MR fluid, but not with hydraulic oil. However, it has been shown that the wear increases also with hydraulic oil (Fig 5). Therefore, the increase in wear cannot be caused due to the running back of MR particles into the contact.

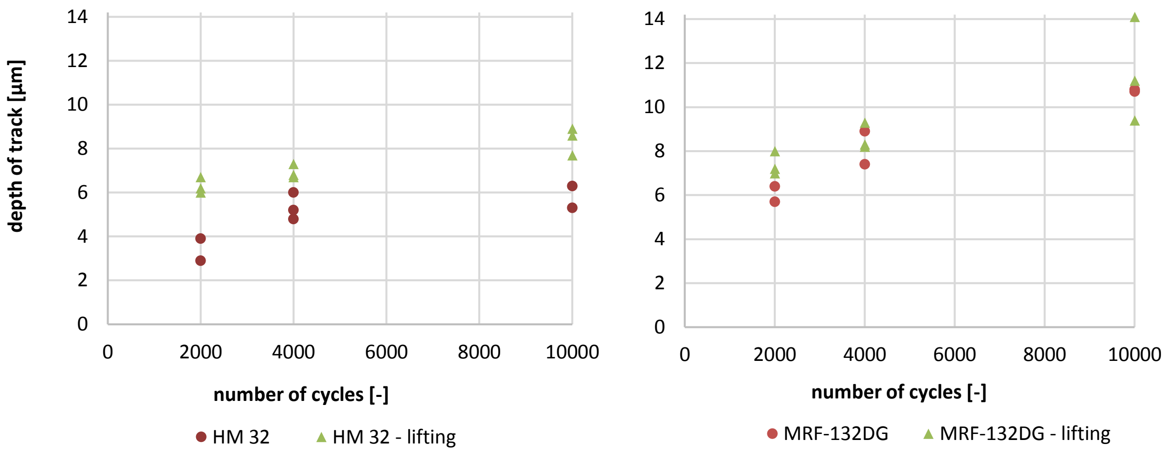

Fig. 5: Comparison of lifting and non-lifting modes for HM 32 and MRF-132DG.

It has been considered that this phenomenon causes another friction mode that occurs before and after the unloaded cycle (each 50 cycle). This consideration was confirmed by the higher wear occurring at the ends of the track in the 4 Hz mode without unloading (Fig. 6). This area corresponds to the run-up of the pin, which is the place where the pin moves slower. It was observed that the pin moves much slower also 2 cycles before and after pin unloading, which caused probably higher wear due to a more aggressive friction mode.

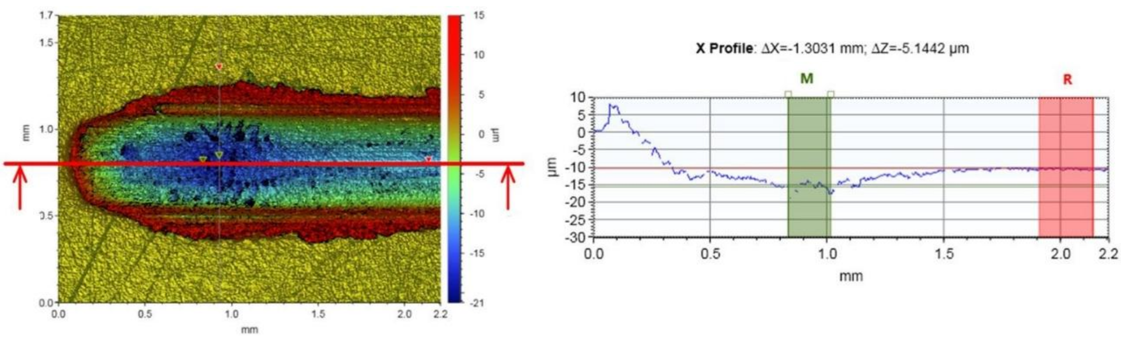

Fig. 6:Higher rate of wear at the ends of the track.

3. Results and conclusion

The depth of tracks for various MR fluids is shown in Fig.7. Each point is the average of 10 measurements of one track.

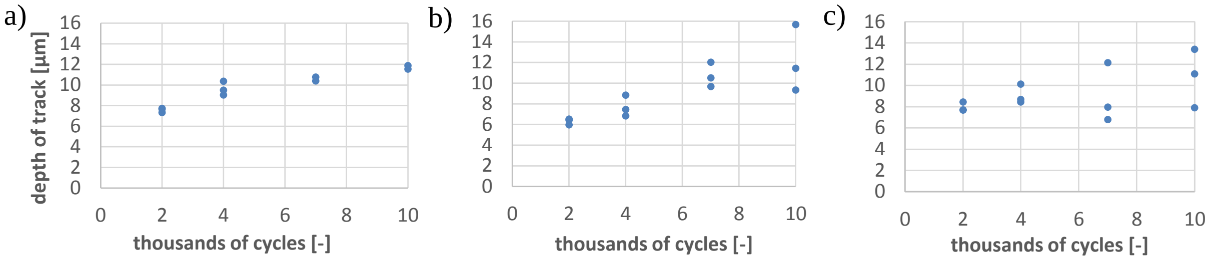

Fig. 7: Results for individual MR fluids a) 122ED, b) 132DG, c) 140CG.

The average depth of tracks from particular checkpoints is shown in Fig. 8. The concentration of iron particles has no influence on the rate of abrasion wear in the concentration range from 22 to 40 vol. %. Fluids with higher concentrations than 40 vol. % have a very low fluidity, so they are not used. However, the fundamental hypothesis that MR fluid causes greater wear than hydraulic oil has been confirmed. MR fluid causes two times higher wear than hydraulic oil. This fact will be considered during MR damper designing. It is recommended to choose abrasion-resistant materials for tribological pairs.

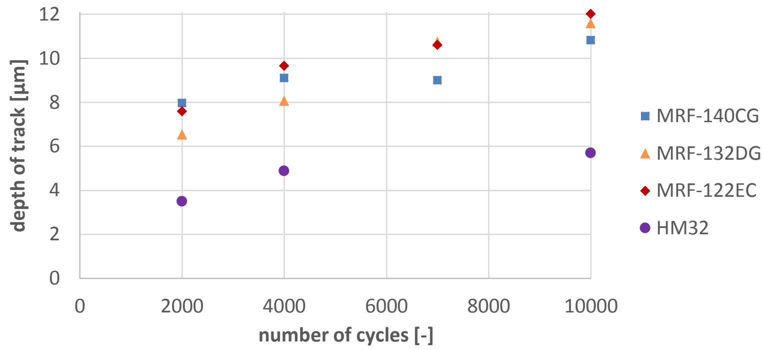

Fig. 8: Comparison of all studied fluids.

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