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Comparison of Electrorheological Measurements Based on Different Methods of Electric Field Generation

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Abstract:
Electrorheological measurements represent a key approach in characterizing the efficiency of electrorheological fluids. The rotational rheometers, the Physica MCR 501 (Anton Paar) equipped with an electrorheological cell and the Bohlin Gemini CVOR 150 (Malvern Instruments) modified for electrorheological experiments generate an electric field in two completely different ways. Each of the two generations has a specific influence on electrorheological measurements. The experimental data were obtained and compared for a suspension of polyaniline powders mixed (10 wt%) in silicone oil. For a concentric-cylinders arrangement, it was shown that the data are fully comparable for both rheometers. However, for a parallel-plate arrangement, the data using the Physica MCR 501 provide higher values in comparison with both the corresponding plate-plate data obtained with the Bohlin Gemini CVOR 150 and with the mutually comparable concentric cylinders data.

Key words:
rheology, electrorheology, rheometry, PANI powder, silicone oil

1 INTRODUCTION

Electrorheological (ER) fluids are suspensions of fine particles in an electrically insulating fluid, usually mineral or silicone oil. When exposed to an electric field their apparent viscosity can increase by several orders, thus shifting their substance from a liquid to almost a solid-like behavior. Hence, their structural and rheological properties can be controlled by electric field strengths. Numerous studies on this topic have been summarized [1–10]. The common factors influencing the measurements of rheological characteristics are, in the case of ER experiments, amplified by the mode of generation of an electric field. Naturally, any mode has, owing to its mechanical effect, an adverse impact on the quality of the measurements. This evokes the question as to whether these negative contributions are comparable for the individual modes. Moreover, this situation is further complicated by the geometrical arrangement used – either a parallel-plate (PP) system or a concentric cylinders (CC) system. As far as the authors are aware, no attention has been paid hitherto to this problem.

The aim of this contribution is to compare the ER characteristics obtained by two rotational rheometers (a Physica MCR 501 (Anton Paar) and a Bohlin Gemini CVOR 150 (Malvern Instruments)) equipped with electrocells generating an electric field in two different ways. Both rheometers are equipped with both geometrical arrangements. Each system is covered with a hood ensuring safety regulations and temperature stability is controlled by either Peltier elements (Physica) or a fluid circulator (Bohlin). The bottom plate for the parallel-plate device and the cup in the CC setup are grounded. In the case of the Physica MCR 501, opening the hood automatically switches off the power supply. The rheometers themselves are fully isolated from the electric current. The substantial difference between the two electrorheologically adapted rheometers consists of the completion of an electric circuit through an upper shaft (described in more detail in the following section).

2 EXPERIMENTAL

2.1 MATERIAL

The ER suspension was prepared by mixing polyaniline (PANI) powder (Sigma Aldrich, USA, base, 50000 g/mol) with silicone oil (Lukosiol M200, Chemical Works Kolin, Czech Republic) in a 10 wt% concentration. The PANI

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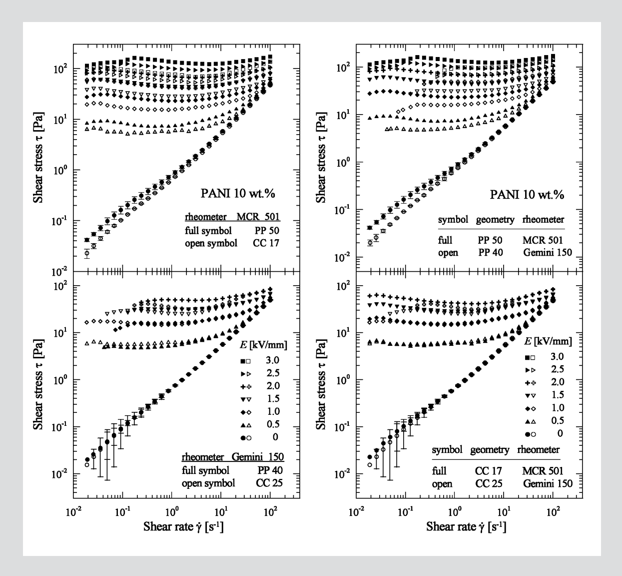

Figure 3: Shear stress dependent on shear rate: (left) different geometrical arrangements (PP and CC, same rheometer) and (right) same geometrical arrangement (PP or CC, different rheometers).

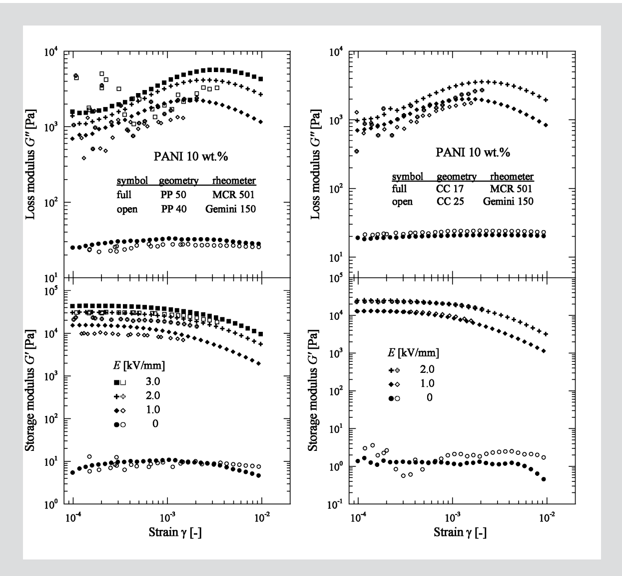

Figure 4: Storage and loss moduli dependent on strain, same geometrical arrangements (PP or CC, different rheometers).

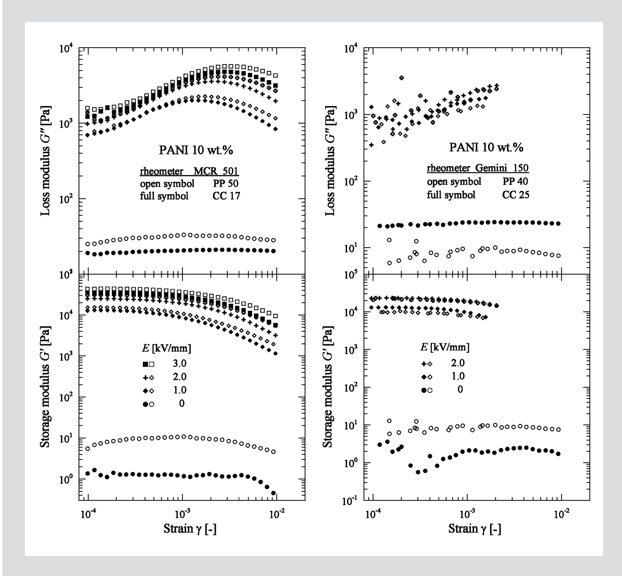

Figure 5: Storage and loss moduli dependent on strain (different geometrical arrangements, same rheometer).

ation is negligible for shear rate exceeding 50 1/s. Analogous analysis is valid for the processing of the data obtained with the help of the Gemini 150, for which a circuit loop is completed through an electrolyte housed in the circumferential gutter and resistance is formed between a contact ring and the electrolyte. This adverse phenomenon is reflected by adjusting the parameters used in the data processing by the Gemini software.

2.4 INDIVIDUAL MEASUREMENTS

All the measurements were always carried out for all four electrocells: PP and CC arrangements in either rotational rheometer. Each measurement started with a carrier fluid (silicone oil) only, followed by an application of the prepared ER suspensions. As expected, the flow curves of shear rate in the range 1 – 100 1/s corresponding to a pure silicone oil (without PANI powder) are identical (Figure 2). It implies that the differences obtained under the application of an electric field are not influenced by the a priori differences appearing in the classical measurements (absence of electric field).

Three types of measurements were carried out (steady shear, amplitude and frequency sweeps) with the prepared suspensions (10 wt% concentration of PANI powder in silicone oil). The entry parameters of the measurements (time intervals, electric field strength (xxx V stands for the individual values of voltage as indicated in the Figures), ranges of measured points) are summarized in Table 1. Figures 3 – 7 depict the behavior of the flow curves for the same geometry (PP or CC) of both rheometers, and for both geometries of either rheometer. In the case of the MCR 501, the experimental data in these Figures are always reduced by the values obtained for the corresponding measurements with air only.

3 DISCUSSION AND CONCLUSIONS

Non-negligible discrepancies in the measured data are exhibited for different geometrical arrangements of the electrocells and different rheometers. This does not seem to be surprising, since e.g. Rides et al. [12] who compared the shear viscosity results obtained at high shear rates using extrusion rheometers (the same manufacturer) including an instrumented injection moulding machine.

These deviations can be the result for a variety of reasons: differences in construction of both rheometers (in both cases all the parts in contact with the materials are made of stainless steel (1.4571 – MCR 501, 316 – CVOR

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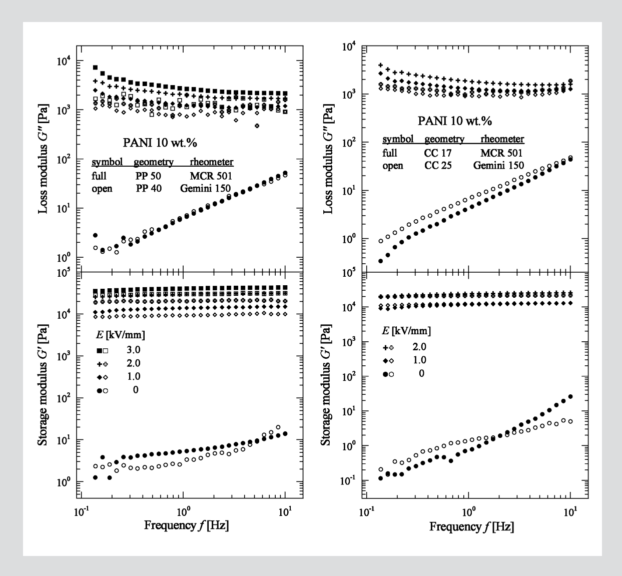

Figure 6: Storage and loss moduli dependent on frequency (same geometrical arrangement (PP or CC), different rheometers).

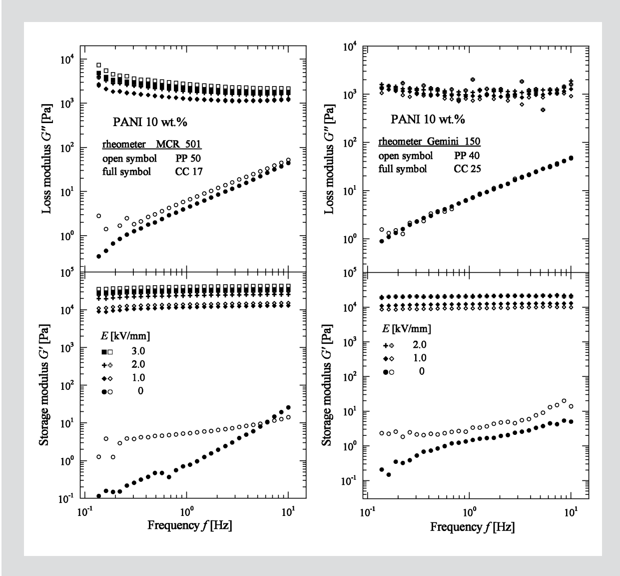

Figure 7: Storage and loss moduli dependent on frequency (different geometrical arrangements, same rheometer).

150)), anti-shock balance precautions in the laboratories, the method of generation of the electric field, the diameters of the corresponding geometrical arrangements (e.g. for a PP arrangement 40 versus 50 mm). Based on Figures 3 – 7 it is possible to come to the conclusions that:

- The effect of completion of an electric circuit is different, but, loosely speaking, in both cases the values, if mere air only is measured, are comparable to those corresponding, for example, to those obtained for water with no additional mechanical contact. However, these values are negligible in comparison with those for ER fluids.
- The data from the Physica MCR 501 are smoother and the behavior of the corresponding curves is more continuous (at this point the age difference of the individual devices is probably also a factor).
- In the case of the Gemini 150, the experimental data are closer for both geometries used.
- In the Physica MCR 501, usage of parallel-plate geometry provides – on average – higher values in comparison with the CC geometry.
- When using parallel-plate geometry, the data obtained by the Physica MCR 501 provides higher values (shear viscosity, storage and loss moduli versus strain or frequency) than those obtained by the Gemini 150.
- When using CC geometry, the data obtained by the Physica MCR 501 and the Gemini 150 are comparable in spite of the difference in corresponding gaps.

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