Ultrasonic Propagation Velocity in Magneto Rheological Fluid under a Uniform Magnetic Fields

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The formation of clusters in a magneto rheological fluid under a magnetic field has a strong influence on the rheological properties of the magneto rheological fluid. However, it is difficult to analyze the inner structure of MR fluids because they are opaque. In this study, we measured ultrasonic propagation velocity in an MR fluid precisely to study the cluster formation. Based on these results, the clustering structures of these fluids are analyzed experimentally in terms of time dependence, time interval, of-removal the magnetic field, and the angle of the magnetic field applied. The ultrasonic propagation velocity in an MR fluid change according to the magnetic field intensity, interval time and angle ϕ. The ultrasonic propagation velocity increases when a higher magnetic field is applied. The result also shows that the intensity of the external magnetic field has an influence on the ultrasonic propagation velocity even after the magnetic filed is removed. The ultrasonic velocity propagation also decreases when the interval time between application of the magnetic field and measurements increases.

Key Words: magneto rheological fluid, ultrasonic propagation, sound velocity, and magnetic field

1. Introduction

Magneto-rheological (MR) fluids are made of fine iron powders dispersed in silicon oil. These fluids are used in many smart structures and devices because their significant rheological properties can be changed by applying a magnetic field [1]. Magnetic functional fluids are typically divided into two groups: magnetic fluids and MR fluids. The difference between these two fluid groups is the iron particle size. The particles in a magnetic fluid are about 10 nm in diameter, while those in an MR fluid are in a range of 100 nm to 10 μm. When an external magnetic field is applied to MR fluid some of the colloidal particles coagulate and form a cluster. The formation of clusters has a strong influence on the rheological properties of MR fluids.

Li et al. [2] investigated the dynamic properties of MR fluids in terms of storage modulus, loss modulus, and loss factor at various frequency ranges (below 100Hz). The storage modulus as well as loss modulus increases with the frequency. However, the loss factor does not change in the same way as the storage modulus and loss modulus. Sawada et al. [3] visualized the inner structure of magnetic fluids, with and without external magnetic fields, using a Rayleigh light scattering technique. Motozawa and Sawada [4] experimentally examined the velocity and attenuation of ultrasonic propagation in magnetic fluids subjected to a magnetic field. They showed that the ultrasonic propagation velocity and attenuation are dependent on the intensity and the elapsed time of the magnetic field. Jozefczak [5] reported the ultrasonic experimental study of a ferrofluid subjected to a magnetic field that was applied in two ways: stepped up and swept continuously. Nevertheless, it is difficult to analyze the inner of magnetic and MR fluids because of its their characteristics.

Ultrasonic propagation velocity in MR fluids changes with the application of an external magnetic field [6]. It seems that the formation of a clustering structure influences the ultrasonic propagation. Therefore, we propose a qualitative analysis of these clustering structures by measuring properties of ultrasonic propagation. Because this ultrasonic technique can be applied to an opaque fluid, it could be useful for analysing the inner structures of MR fluids. In this study, we measured ultrasonic propagation velocity in an MR fluid precisely

2. Experiment Apparatus

Fig. 1 is a schematic diagram of the experimental apparatus. The ultrasonic measurement is based on the pulse method. Ultrasonic propagation velocity in the test fluid can be calculated based on this apparatus.

The ultrasonic frequency is 2 MHz, and 0 – 550 mT of magnetic field is applied. The angle ϕ between the direction of the magnetic field and the ultrasonic wave propagation is adjustable from 0° to

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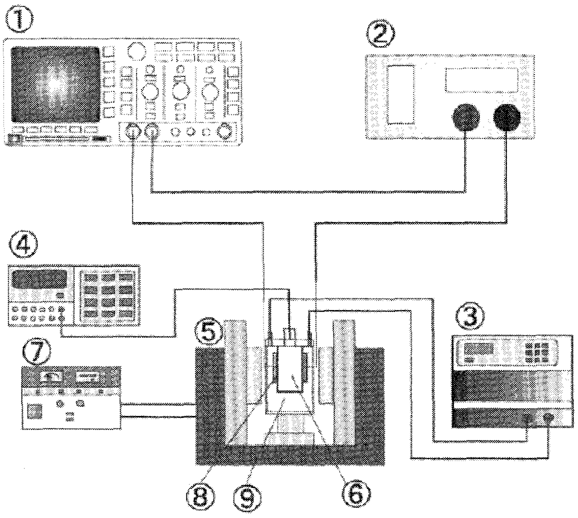
Table 1 Properties of MR fluids at 40°C.

	MR Fluids
Manufacturer	LORD Co.
Serial name	MRF 132-DG
Particle material	Iron
Carrier liquid	Hydrocarbon oil
Viscosity (mPa.s)	92 ± 15
Density (kg/m^3)	2.98 ~ 3.18 × 10^3



1. Digital oscilloscope
2. Burst wave generator
3. Coolnics circulator
4. Thermister
5. Electromagnet
6. MR fluid
7. Power amplifier
8. Ceramic oscillator
9. Test cell

Fig. 1 Experimental Apparatus.

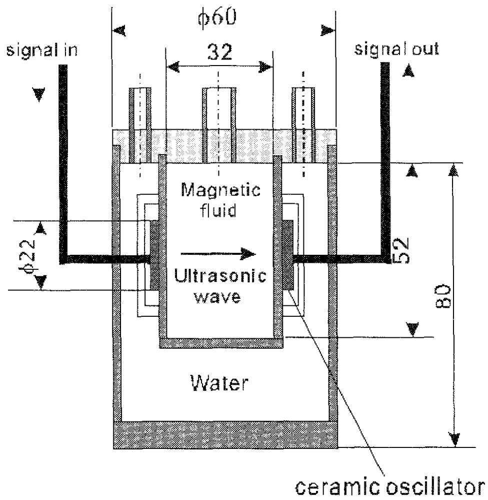


Fig. 2 Test cell.

180°. The temperature of the test fluid is kept constant at 25°C by a temperature control unit. Fig. 2 shows the test cell as used in this experiment. The properties of the MR fluids are shown in Table 1.

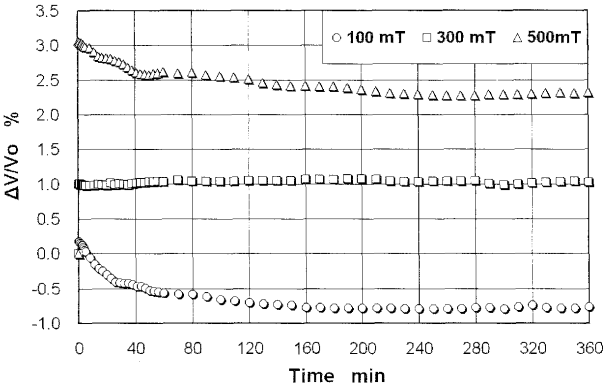


Fig. 3 Elapsed time dependence of ultrasonic propagation in MR fluid.

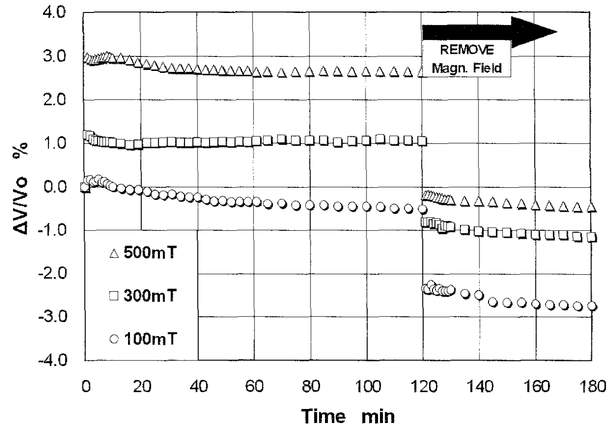


Fig. 4 The ultrasonic propagation velocity before and after removing the magnetic field in MR fluid.

3. Results and Discussion

Ultrasonic propagation velocity changes with applied magnetic field. The change of ultrasonic propagation velocity can be expressed by $\Delta V/V_0$. ΔV is defined by $\Delta V = V - V_0$ where V and V_0 are ultrasonic propagation velocity with and without an external magnetic field, respectively.

Fig. 3 shows the change of ultrasonic propagation velocity in MR fluid versus elapsed time of applying an external magnetic field. In this experiment, the angle ϕ is 0° and each of three levels of magnetic field intensity (100 mT, 300 mT and 500 mT) are applied for 6 hours. The ultrasonic propagation velocity increases when a higher magnetic field is applied. This change seems to be caused by cluster formation. Because the inner magnetic particles form clusters along the direction of the magnetic field, the particle concentration is thicker when a higher magnetic field is applied. Therefore, the ultrasonic propagation velocity increases. Fig. 3 also shows an interesting curve; within the first 2 hours the curve is slightly

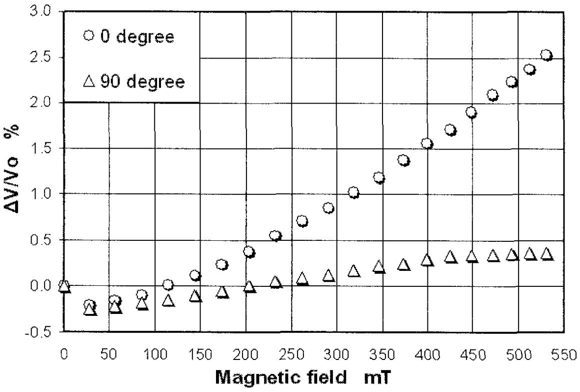


Fig. 5 Effect of angle on ultrasonic velocity propagation in MR fluid.

decreasing. Its seems that in this area the MR fluid is not yet stable, either the cluster formation is still developing or sedimentation of micro magnetic particles is in progress because of natural gravitation. The curve becomes straight and stable after 2 hours. In these regions the velocity of ultrasonic propagation does not change and the cluster formation in the MR fluid appears almost constant.

The effect of removal of the external magnetic field is shown is Fig. 4. In these experiments, the angle ϕ is 0° and each of three levels of magnetic field intensity (100 mT, 300 mT and 500 mT) are applied for 2 hours, after which we remove the magnetic field for 1 hour. The measurement was conducted precisely during the first 10 minutes to investigate the cluster formation. The results are nearly the same as the previous data in Fig. 3.

After removal of the magnetic field, the velocity of ultrasonic propagation suddenly decreases. This appears to mean that the cluster formation was broken suddenly, but it is supposed that some cluster formations still remain because the ultrasonic propagation velocity is not constant.

This result also shows that the intensity of the external magnetic field has an influence on the ultrasonic propagation velocity, even after the magnetic field was removed. The $\Delta V/V_0$ curves are different when the higher magnetic field was applied before removing. The 100 mT curve is lower than the 300 mT curve, and the 300 mT curve is lower than the 500 mT, curve respectively. It seems that the remaining cluster formations depend on the intensity of the magnetic field.

The effect of angle between the direction of the magnetic field and the direction of ultrasonic wave propagation when an external magnetic field applied is shown in the Fig. 5. In this experiment, the magnetic field is increased 24 mT every 2 minutes. During the increasing process, the change $\Delta V/V_0$ also

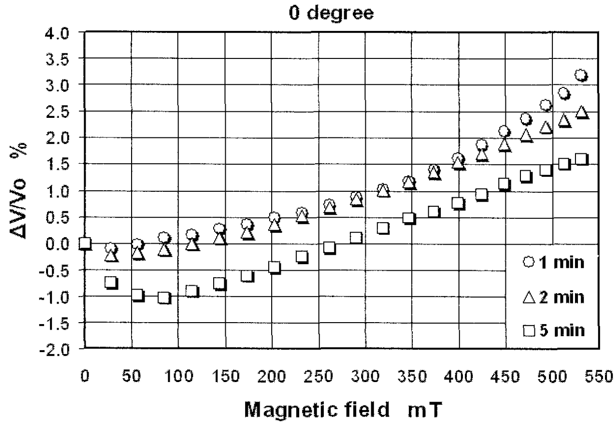


Fig. 6 The effect of interval time on the ultrasonic velocity propagation in MR fluid in 0° angle.

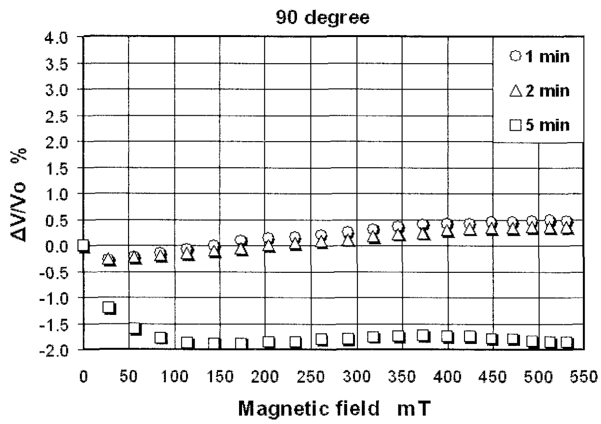


Fig. 7 The effect of interval time on the ultrasonic velocity propagation in MR fluid in 90° angles.

increases with increasing magnetic field intensity. These results are caused by the cluster formation in the MR fluid as the magnetic field intensity increases.

The clusters form in proportion to magnetic field intensity. This phenomenon becomes more interesting if the angle ϕ is changed. When the angle ϕ = 0°, the $\Delta V/V_0$ is higher than the angle ϕ = 90°. This means that the velocity of ultrasonic wave propagation at angle ϕ = 0° is faster than that at angle ϕ = 90°. This velocity difference is caused by the shape and direction of cluster formation in MR fluids.

Fig. 6 shows the effect of interval time on the ultrasonic propagation velocity in MR fluid at 0° angle ϕ. The interval time is the time between two measurements. In this experiment, the interval times are 1 minute, 2 minutes and 5 minutes. A one minute time interval means that the external magnetic field is increased 24 mT every 1 minute from 0 mT – 528 mT. The result shows that ultrasonic propagation velocity is smaller when the interval time is longer. The 1 minute curve is close to the 2 minutes curve while the 5 minute curve is quite a bit lower.

The ultrasonic propagation velocity is decreasing in the first part of the curve, and then increases gradually after a certain value of magnetic field intensity. The decreases of the ultrasonic velocity propagation are caused by the formation of the cluster particles in MR fluid. After the cluster formation seems stable, the curve increases gradually.

Fig. 7 shows the effect of interval time on the ultrasonic velocity propagation in MR fluid at 90° angle ϕ. The results are different when compared with those for 0° angle ϕ. In the 90° angle ϕ, the slope of the curve is lower than the 0° angle ϕ. This means that the ultrasonic propagation velocity at 90° angle is slower than 0° angle. This analysis is also in agreement with the previous data measurement shown in Fig. 5.

4. Concluding Remarks

An experimental investigation of the ultrasonic propagation velocity in MR fluid under a uniform external magnetic field is described. Measurements were carried out by varying the magnetic field intensity, elapsed time, interval time and the angle between the ultrasonic propagation direction and the direction of the external magnetic field. A change of the ultrasonic propagation velocity in the MR fluid was observed. The ultrasonic propagation velocities in the MR fluid change according to the magnetic field intensity, interval time and angle ϕ. These results seem to be related to Brownian motion and the particle clustering and degradation in the MR fluid. There is a strong relation between the ultrasonic propagation velocity and cluster formation in MR fluid under an external magnetic field. In order to understand these clustering phenomena, it is necessary to investigate the Brownian motion of magnetic particles as well as the timing and the size of cluster formation. Because the sizes of magnetic particle are relatively large in MR fluids, it is also necessary to consider the influence of sedimentation of the magnetic particles.

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