Viscosity Behavior of Magnetic Nanoparticle Filled Fluids and Impact Resistance of Their Fabric Composites

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ABSTRACT

In this study, viscosity behaviors of the FMF and MRF were investigated with a magneto-rheometer and the fabric composites treated with the FMF and MRF were tested and evaluated in the viewpoint of impact resistance. Polyethylene glycol(PEG) and silicone oil were used as the liquid medium of the FMF and MRF. Nanoparticle content in the FMF and MRF was controlled in the range of 50 to 300wt%. Under magnetic field, the FMF and MRF showed a crown shaped arrangement of the fluid in the direction of magnetic. The results of viscosity measurement with the magneto-rheometer showed the highest solution viscosity. A drop weight impact test was conducted to evaluate the impact resistance of their fabric composites.

Keywords: Ferromagnetic fluid, Magnetorheological fluid, Impact test, Nano particle, Novel nanocomposite

1 INTRODUCTION

The FMF(Ferromagnetic fluid) and the MRF (Magnetorheological fluid) are liquids having nanometer-sized particles of iron dispersed in the PEG or silicon oil medium. These fluids are flexible dispersion state as a liquid. But when the magnetic field applied, iron nano particles are oriented in the direction of the magnetic field. Then, the FMF and MRF show solid-like properties of a solid. Ferromagnetic fluid has been prepared from nano-particles with PEG medium. These nanometer-sized particles have an important role in the rheological behaviour of the fluid. Using these characteristics, we can get a bulletproof effect by applying them to the conventional fabric armor materials. We can expect impact resistance from the magnetic properties of the FMF and MRF as well as the shear thickening fluid (STF) effect.

In this study, we measured the viscosity of MRF and FMF with the content of magnetic nanoparticles. We observed the change of viscosity according to the magnetic field at certain shear rate. Bulletproof composites have been prepared from FMF and MRF with the para-aramid fabric well known in textile composite field. A drop weight impact test was performed to evaluate their feasibility of the protective materials according to the magnetic field.

2 EXPERIMENTALS

2.1 Sample preparation

2.1.1 Magnetic fluids

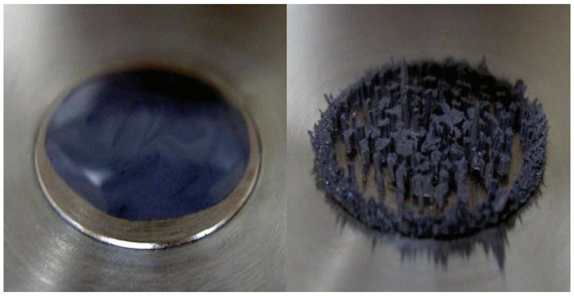
The FMF was prepared by a common chemical dispersion method. Particle size of the FMF is about 15nm. On the other hand, nanoparticles of the MRF were obtained by mechanical milling of the iron-silicon alloy and dispersing it in the medium. Two type of liquid, PEG and silicon oil, were used as a medium of the FMF and MRF.

2.1.2 Fabric composites

In this study, a bulletproof fabric for the impact test is the Kevlar®(para-aramid) from DuPont Co. At first, Kevlar fabric was cut into 150mm × 150mm size suitable for the impact test jig. Fabric was dried for an hour in the 110℃ oven to remove the effect of the moisture before loading of the FMF or MRF. The FMF and MRF were coated well on the dried Kevlar fabric with the predetermined amount .

2.2 Viscosity measurement

Viscosity measurement of FMF and MRF was performed using a magneto-rheological viscometer (Physica MCR301, anton paar, Austria). Viscosity and shear stress using a magneto-rheological viscometer according to various shear rate and magnetic field. Viscosity and yield stress are indicated with the effect of the particle size, when the external magnetic field is applied. In this study, magnetic field is ranged from 0 T to 0.2 T. A certain effect from the magneto-rheological properties was shown in Figure 1; a crown-shaped chain structure in the direction of magnetic field was observed when the magnetic field applied. Viscosity of the FMF and MRF was recorded according to the applied magnetic field.



(a)Non-magnetic field (b) Magnetic field

Figure 1. Behavior of magnetorheorogical fluid according to magnetic field

2.3 Impact test

Impact test for the fabric composites was performed with an Instron Dynatup model 8250. With the drop weight impact procedure, the impact energy of the composite specimen was obtained. For this experiment, a self-made electromagnet having a disc shape was used. Magnetic force is calculated from the magnetic field intensity and material properties. The fabric composite having MRF or FMF was fixed at the bottom part of the drop weight impact tester using an air compressor. Then the electromagnet was equipped on the top of the fabric composite. Magnetic force of electromagnet was ranged from 100 to 150 Gauss (G). In this test, impact energy is fixed at 10 J by adjusting the drop height.

3 RESULTS AND DISCUSSION

3.1 Analysis of viscosity

The results of the viscosity measurement are shown in Table 1. Viscosities of three samples are largely influenced by the applied magnetic field. Viscosity of FMF (in PEG) has more than doubled during applying magnetic field. Viscosity of MRF (in PEG) showed a fivefold increase under the magnetic field than non-magnetic field. This is due to the stiffening structure of the FMF and MRF which have nanoparticles oriented in the direction of the magnetic field. Thus, their viscosities under magnetic field are much higher than under non-magnetic field. Their stiffening is influenced by various factors such as the permeability, susceptibility and dispersion state of the iron particles.

Viscosity of MRF (in silicon oil) is considerably higher than that of the other samples. The difference stems from the different basic properties of the silicone oil medium from PEG. Silicone oil has approximately two times higher viscosity than the PEG medium.

Table 1. Viscosity of fluid according to magnetic field

Samples \ Magnetic field	0	0.2T
Ferromagnetic Fluid(in PEG)	50 cP	100 cP
Magnetorheological Fluid(in PEG)	60 cP	300 cP
Magnetorheological Fluid(in Sillicon oil)	1050 cP	3360 cP

3.2 Impact resistance of the composites

Impact strength of the FMF and MRF fabric composite is almost not changed by the magnetic field shown in Figure 2 and 3. But impact resistance of the FMF fabric composite increased than untreated one. This is because nanoparticles of the FMF penetrated deeply into the fabric which increased the stiffness of the composite.

Impact strength is similar in both MRF (in PEG) composite and untreated fabric as shown in Figure 3. In the MRF composite, max load of the impact test is lower than that of the FMF composite. This is due to relatively large iron particles of the MRF didn't block the space between the fabric.

Impact resistance of MRF (in silicon oil) was a significantly lower than that of the untreated fabric as shown in Figure 4. In this case, fabrics become more relaxed because the oil medium penetrated into the space between the fabrics and weakened fabric friction enormously. The MRF composite has a highest impact resistance in relation to the content of fluid with applying magnetic field.

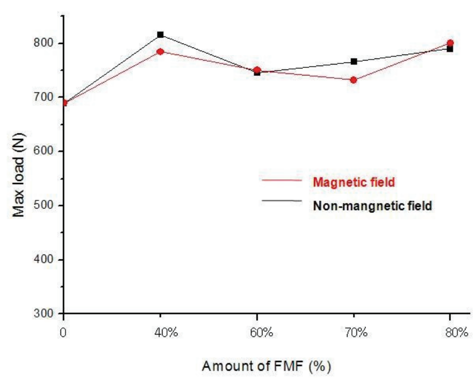


Figure 2. Impact strength of the FMF(in PEG) composite

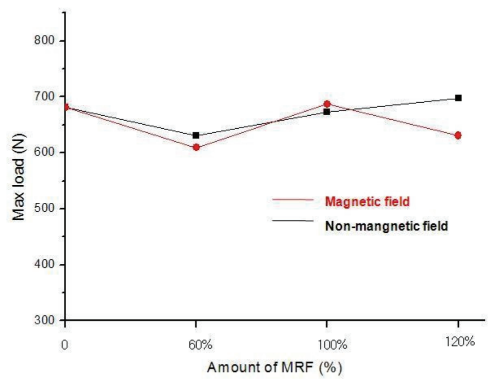


Figure 3. Impact strength of the MRF(in PEG) composite

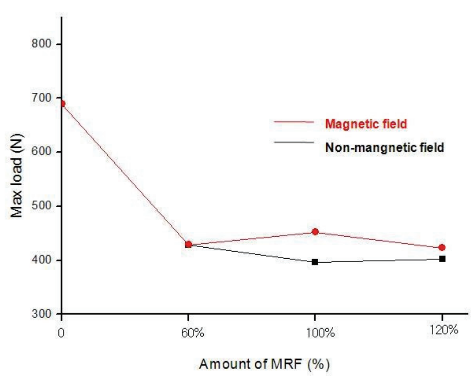


Figure 4. Impact strength of the MRF(in Silicon oil) composite

4 CONCLUSIONS

In this study, the viscosity of the FMF and MRF was investigated with the magnetic field effects. The results of the viscosity measurement of the FMF and MRF showed an increase of viscosity about five times high under the magnetic field. Also, FMF treated fabric has higher impact resistance than untreated fabric in the impact test. It is considered that the nanoparticles in FMF increase the stiffness of the fabric composite. However, magnetic field gave almost no effect the impact strength of the FMF and MRF fabric composites. The impact resistance of PEG medium MRF treated fabric was similar to the untreated fabric and is not significantly different between under the magnetic field and non-magnetic field. In the case of MRF with silicon oil medium treated fabric, however, had lower impact resistance than untreated fabric. It is caused that oil penetrate the inner space between the fabric and its friction was weakened. The results show that the magnetic field gave a little higher impact resistance than non-magnetic field.

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