반능동형 뎀퍼 적용을 위한 여러가지 전동유체 개발

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Development of Electrorheological Fluids for Semi Active Damper

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Introduction

Electroactive electrorheological (ER) fluids belong to a class of colloidal suspensions, which exhibit large reversible changes in their rheological behavior when subjected to external electric fields. In general, ER fluids can solidify in the order of milliseconds, and they can fluidize under applied deformation that destroys the chain structure formed by the particles. Furthermore, it has a very fast response characteristic to the electric field and hence wide control bandwitch [1]. This inherent feature has triggered tremendous research activities in the development of various engineering applications, such as shock absorbers [2,3], engine mount [4], squeeze film damper [5], clutch/brakes [6] and smart structures [7,8]. Nonetheless, this attractive and powerful material has not yet been used for commercial products because of several unsolved problems including colloidal stability, yield stress, high current density, application device and so forth.

Among the promising materials for ER fluids, semiconducting polymers including poly(acene quinone) radicals [9] polyaniline [10,11] and copolyaniline [12,13] have been adopted as anhydrous ER fluids because of their ease of handling and their superior physical properties. In particular, polyaniline (PANI) and its many derivatives based upon modification of oxidation state, dopant and polymerization conditions [14] are of technological interest. This is because they have better thermal stability and smaller density than the other polymers. Furthermore, polyaniline is easy to polymerize by oxidation polymerization at relatively low temperature and it can be doped from a conducting emeraldine hydrochloride form to an insulating state using simple protonic acids. Therefore we can change the dielectric constant and the conductivity of the particle while keeping all other particle properties the same for studying the ER characteristics.

In this work, we adapt both PANI and phosphated cellulose based ER fluids for semi-active ER damper, using polymer particles and silicone oil. There are three types of ER damper depending on the working mode of the ER fluid: flow-mode type, shear mode type and squeeze-mode type [15]. A cylindrical flow-mode type ER damper is chosen in this study because it has similar geometrical configuration to the conventional damper.

Experimental

1. Preparation of ER fluids

Polyaniline in silicone oil was adopted for preparing the ER fluids. Polyaniline was synthesized through chemical oxidation polymerization. An amount of 0.6 mol of aniline was added to 400 ml of 1M HCl, and was chilled and stirred. A pre-chilled solution of ammonium peroxysulfate (0.36 mol in 200ml of 1M HCl) was then added dropwise to the reaction system, with a continuous stirring, for 1 hour. The reaction proceeds very quickly; the solution color becomes dark-green within a few minutes of addition. After adding drops for 2 hours, the

reaction conditions were maintained for 2 hours in order for completion. A polymerization temperature was fixed at 0 °C using a constant temperature bath. To obtain semiconducting polyaniline, we dedoped the polyaniline particles by reducing the pH of the aqueous medium which contained the particles to be pH 9.0 using an aqueous NaOH solution. The pH-controlled particles were filtered and washed using distilled water, ethanol, and cyclohexane. Finally, products were dried in a vacuum oven at room temperature.

On the other hand, phosphate cellulose particles were synthesized by phosphate-ester reaction using the method suggested by Arslanov et al. [16]. At first, phosphoric acid (orthophosphoric acid, 85% assay, Junsei Chemical co.) aqueous solutions containing 4M of urea with several different phosphoric acid concentrations were prepared, with stirring for an hour at a room temperature to make the solution homogeneous. Ammonium phosphate was thereby generated by reaction of phosphoric acid and urea. 40 g of cellulose particles with average particle size of 20 μm (Sigmacell, Type 20, Sigma Chemical Co.) were introduced into the 400 ml ammonium phosphate solution and maintained at a room temperature for 48 hrs for the phosphoric ester reaction of cellulose [17]. A complex stabilized by hydrogen bond between H_3PO_4, $(NH_2)_2CO$ and cellulose is assumed to be a transition state in this cellulose phosphorylation [18].

The ER fluid was prepared by dispersing either synthesized polyaniline or phosphated cellulose in silicone oil, respectively. The density and kinematic viscosity of the silicone oil are 0.95g/ml and 30cS at 25°C, respectively. Rheological properties were determined by a rotational rheometer (Physica MC120) with Couette type geometry, a high-voltage generator, and an oil bath for temperature control. In addition, current density is an important property for the safety during operation on the ER application, and it is limited to be about $300\mu A/mm^2$ at 5kV/mm and 25 °C.

2. Damper test

A cylindrical flow-mode type ER damper was proposed in this work. The schematic configuration of the ER damper is shown in Fig. 1.
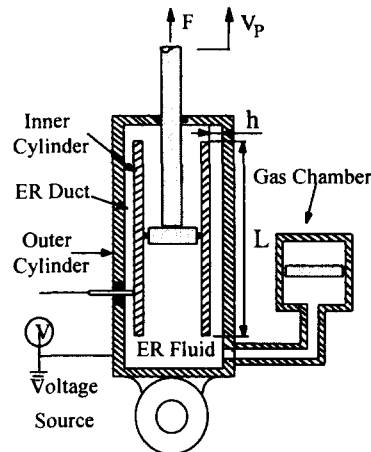

Figure 1. Schematic configuration of cylindrical ER damper.

The ER damper is divided into the upper and lower chambers by the piston, and it is fully filled with the ER fluid flows through the duct between inner and outer cylinders from one chamber to the other. Then positive voltage is produced by a high voltage generator connected to the inner cylinder and the negative voltage connected to the outer cylinder. On the other

hand, gas chamber positioned at the lower parts acts as an accumulator of the ER fluid induced by the motion of the piston. The gas of the chamber is a nitrogen and the gas pressure is 10 bar. The electrode gap (h) of the damper is 0.75 mm. The electric field is applied to the ER damper using a high voltage amplifier which has a gain of 1000 and output voltage range of ±10kV. The excitation magnitude and frequency on the ER damper are chosen by ±20 mm and 1.89 Hz, respectively.

Results and discussion
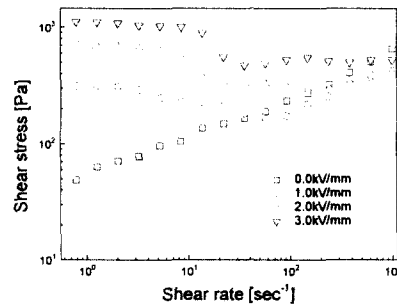
Figure 2. Shear rate vs. shear stress curves of PANI based ER fluids at different electric field strength (20vol%, pH=9.0)

Figure 2 shows the shear rate vs. shear stress at different electric field strength. From this plot, we could deduce the dynamic yield stress, which is obtained by an extrapolation from constant stress region. In the low shear rate region, the shear stress was sustained because the electrostatic force from polarization is larger than the hydrodynamic interaction. In the high shear rate region, the behavior of curve becomes a Newtonian flow motion. This process was explained by relaxation process from dielectric spectrum [12]. From Fig.2, we can obtain the dynamic yield stress at 3kV/mm to be about 1.3kPa. Therefore, we adopted PANI ER fluid to damper system and then observed the damping effect of PANI ER fluid for semi-active ER damper.
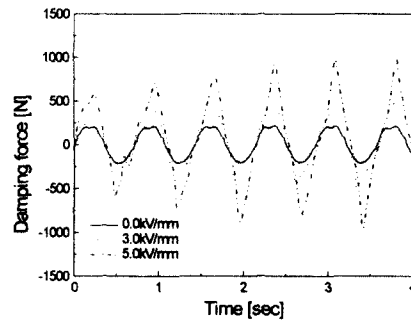
Figure 3. Damping force vs. time curves at 25°C (PANI)

Fig.3 presents the damping forces with time at the operating temperature of 25 °C. It is evident that as the electric field increases, the damping forces of the ER damper filled with PANI based ER fluid increases, and thus the force required to move the piston increase. This is mainly attributed to the increment of the yield stress of the ER fluid. From this result, we obtained the damping force to be 210 N at 0kV/mm electric field. On the other hand, damping

force at 5kV/mm is 970 N and thus the increment of damping force is 760 N. This result implies that a large range of the damping force of the ER damper can be continuously controlled by tuning the electric field.
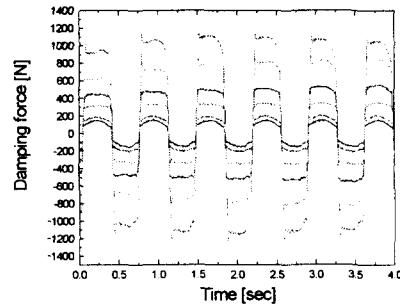

Figure 4. Damping force vs. time curves at 25°C (phosphated cellulose)

Fig. 4 shows the damping force with time at 25°C. This result looks much different from Fig. 3. The shape of curve is fully developed, indicating that the rising and falling are well followed with the imposed electric field. It means that the phosphated cellulose based ER fluid shows better ER performance than PANI based one.

Conclusion

In this study, we synthesized both PANI and phosphated cellulose based ER fluid and adapted to semi-active damper system. From these results, it is found that the damping force of the ER damper can be controlled by tuning an applied electric field.

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