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CHARACTERISTICS AND APPLICATIONS OF AMORPHOUS COMPOUND FLUID

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ABSTRACT

We proposed an amorphous compound fluid (ACF) as a new intelligent or smart fluid. This fluid contains nm-size magnetite and 1μm-sized amorphous particles in a solvent. This report shows, first, experimental data regarding the viscosity of ACF in a cone-type rotating rheometer under a transverse magnetic field and its magnetization under a DC magnetic field. The experimental results are then compared with those for previous magnetic responsive fluids, magnetic compound fluid (MCF), magneto-rheological fluid (MRF), and magnetic fluid (MF). Those magnetic clusters as aggregated particles were investigated by optical observation. Finally, this report shows the experimental results of engineering applications on polishing that utilize the ACF, and compares the results with polishing that utilizes MCF.

KEY WORDS

Amorphous, Magnetic Compound Fluid (MCF), Magnetic Fluid, Magnetic Field, Magneto-rheological Fluid

NOMENCLATURE

Ra : mean surface roughness
Ry : height of surface roughness between maximum and minimum heights

INTRODUCTION

A few intelligent fluids are responsive to magnetic fields, for example, magnetic fluid (MF) and magneto-rheological fluid (MRF). Both fluids have advantages and disadvantages in engineering applications [1]. MF's magnetization and apparent viscosity under a magnetic field is smaller than those of MRF. However, the stability of the particle distribution in an MF solvent is more consistent than that in an MRF solvent. In light of this and for the purpose of producing a new intelligent or smart fluid, one of authors of the present paper, Shimada, has proposed a magnetic compound fluid (MCF) comprised of nm-size magnetite and μm-size iron particles in a solvent, which thereby compounds MF and MRF [2]. He has measured the relation of its shear stress to its shear rate using a rotating rheometer [2, 3] and has also measured its magnetic characteristics [4]. He has also proposed new engineering applications that utilize MCF, for example, in polishing [5, 6] or in a damper [7].

For the same purposes, we propose a magnetic responsive fluid containing amorphous particles: amorphous compound fluid (ACF) is comprised of 1µm order-sized amorphous particles and MF. In general, the material properties of the amorphous particles are different from those of the magnetite and iron particles regarding stiffness, large magnetization, etc. Therefore, if the amorphous particles are used in a solvent, the possibility of its having engineering applications different from the use of MCF alone can be expected.

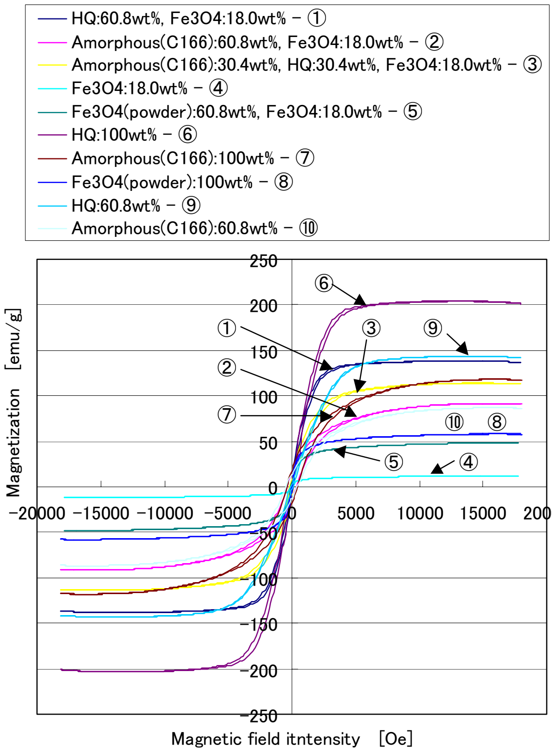
In the present paper, we first investigated the magnetic and rheological characteristics of ACF and compared them to those of MCF, MF, and MRF. Secondly, we investigated the potential engineering applications of ACF in polishing.

ACF

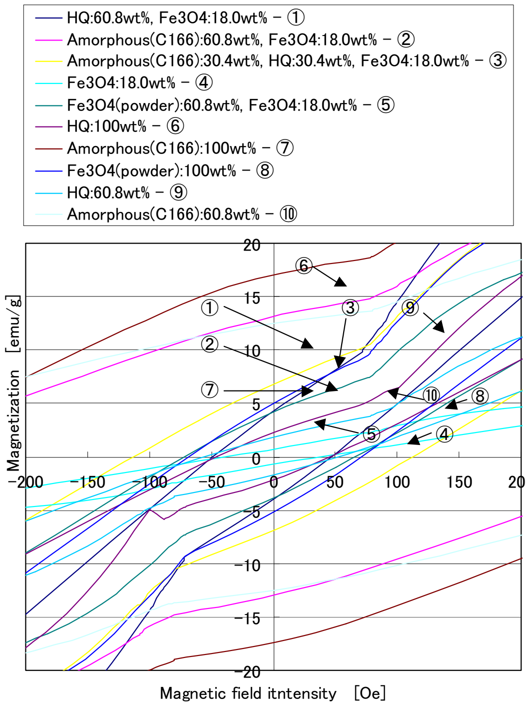
We used Co-P amorphous particles (C166) of about 1µm mean diameter that were fabricated and patented in Japan by Yuze [8], one of the present authors. We compounded the kerosene-based MF of HC50 with 1.29g of 50 wt% of 10nm mean diameter Fe_3O_4 produced by Taiho Industry Co. Ltd. in Japan and 2g of amorphous particles (C166) composed of C166 at 60.8 wt%, Fe_3O_4 at 18.0 wt% and kerosene at 21.2 wt%.

MAGNETIC CHARACTERISTICS

We investigated the magnetization of ACF under a DC magnetic field using a VSM (VSM-5S-15, Toei Ind. Co. Ltd., Japan). The experimental results are shown in



(a)



(b) detail at small magnetic field intensity of (a)

Figure 1 Magnetization of ACF and the others

Table 1 Composite and data of magnetization of ACF, MCF, MRF and MF

Mass concentration (wt%) of testing fluid	Material	Compound	Residual magnetization [emu/g]
HQ: 60.8, Fe_3O_4: 18.0, other kerosene	MCF	MRF+MF	4.851
C166: 60.8, Fe_3O_4: 18.0, other kerosene	ACF	amorphous particle +MF	13.05
C166: 30.4, HQ: 30.4, Fe_3O_4: 18.0, other kerosene	AMCF	ACF+MCF	7.003
Fe_3O_4: 18.0, other kerosene	MF		1.015
Fe_3O_4 (powder): 60.8, Fe_3O_4 (from the particles of MF): 18.0, other kerosene		powder of Fe_3O_4 +MF	4.394
HQ: 100	powder		2.493
C166: 100	powder		16.74
Fe_3O_4: 100	powder		5.669
HQ: 60.8, other kerosene	MRF		1.827
C166: 60.8, other kerosene	AF		12.48

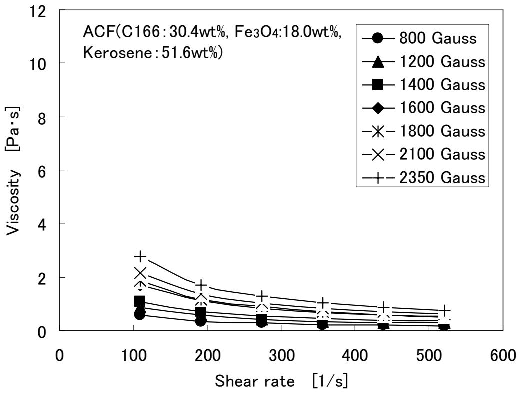
Fig. 1 and compared to those of MCF, MRF, MF, and powder. The caption in the figure is shown in Table 1 in detail. “Fe_3O_4” in the figure means the magnetite in MF, “powder” the particles only and “HQ” the carbonyl iron having 1.2 μm of mean diameter made by BASF Co. Ltd. AMCF means the compounded fluids of ACF and MCF, which we call “Amorphous Magnetic Compound Fluid”. AF means the fluid having only amorphous particles of C166, which we call “Amorphous Fluid”.

The magnetic property obtained from Fig. 1 is also shown in Table 1. The saturation magnetization is defined by that of the involved particles. That of ACF is smaller than that of MCF. Therefore, the order of the saturation magnetization is MRF>MCF>AMCF>ACF>MF.

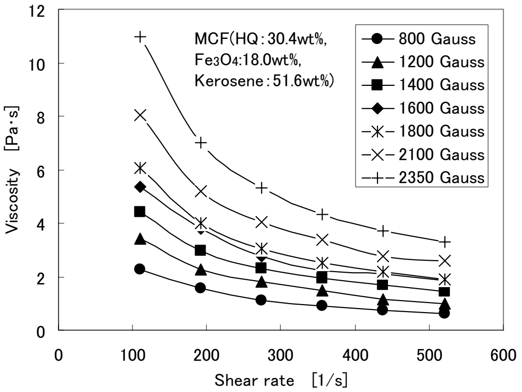
The residual magnetizations and the areas of the hysterisis loops of ACF and amorphous particles are much larger than those of MCF, MRF, Fe_3O_4, and HQ.

HYDRODYNAMIC CHARACTERISTICS

We examined the viscosity using cone-type rotating rheometers under a uniform magnetic field. The magnetic field was applied transversely to the lower plate. Details of the experimental apparatus were reported in our other investigation [2, 3]. The experimental results are shown in Fig. 2 and compared to those of MCF, MRF and AF. The viscosity of ACF is less than that of MCF. This is due to the formation of magnetic clusters. As seen in the following section, the “string magnetic cluster” of ACM is weaker than the magnetic cluster of MCF. Therefore, the string-like magnetic cluster can be distributed by a given flow rate, and the viscosity of ACF then becomes less than that of MCF.



(a)



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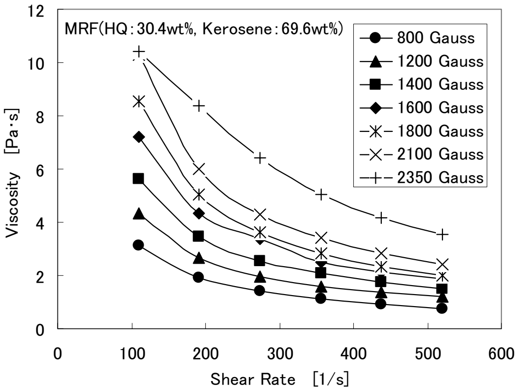

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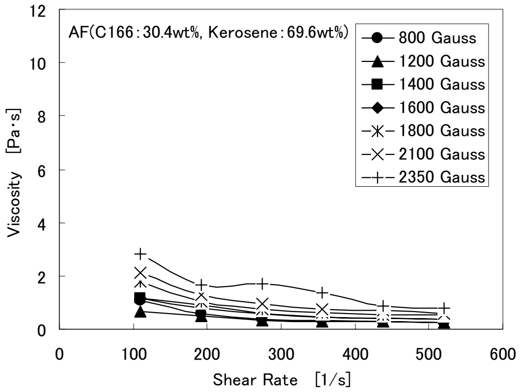
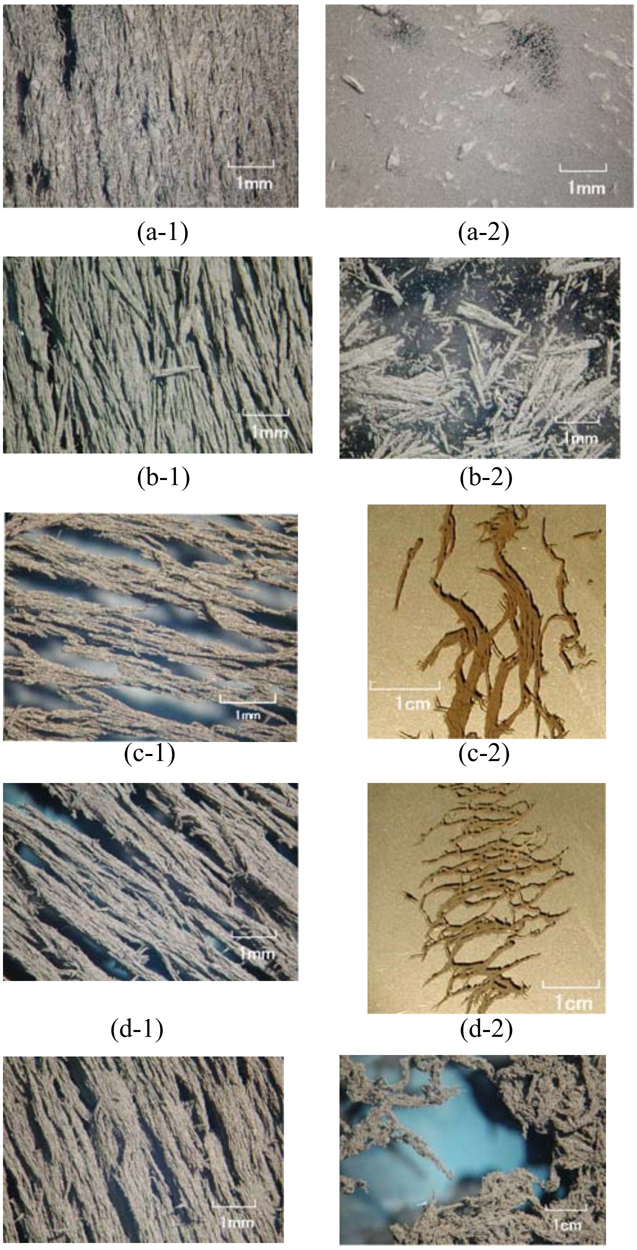


(d)

Figure 2 Viscosity to magnetic field intensity of (a) ACF, (b) MCF, (c) MRF and (d) AF

CLUSTER

The particles involved in the ACF and other fluids are aggregated as clusters. The clusters can be extracted from ACF as well as from MCF and MRF using the technique proposed by Shimada [9]. A microscope photograph is shown in Fig. 3. The magnetic cluster of ACF differs from that of MCF. The length of the former is much larger than that of the latter, as shown by Fig. 1. In addition, the attractive strength between the particles of the former is much greater than that in the latter in the case when a force is immediately applied to the magnetic clusters in order to distribute each particle uniformly. Therefore, the magnetic cluster in ACF can be called a "string magnetic cluster." However, the force holding the cluster formation in the former is much larger than that in the latter if the applied magnetic field is removed from the magnetic clusters. This is due to the remnant magnetization, as shown in the previous section. After removing the magnetic field, the particles in ACF, AMCF and AF can be held in a string-like cluster formation due to the remnant magnetization of the amorphous particles, as shown in Fig. 3(c-2), (d-2), and (e-2).



(a-1) (a-2)

(b-1) (b-2)

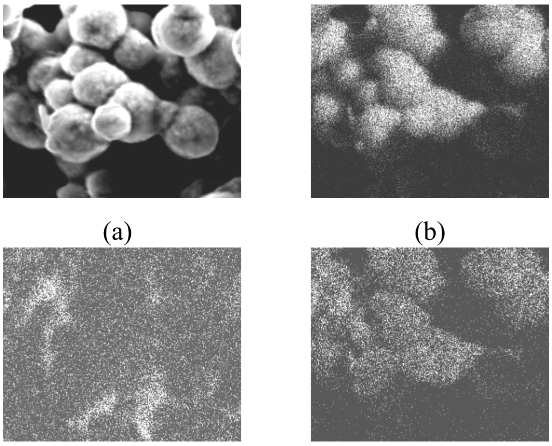
(c-1) (c-2)

(d-1) (d-2)

(e-1) (e-2)

Figure 3 Magnetic clusters of the fluids produced under a magnetic field as seen by a microscope with a multiplying ratio of 60: (a) MCF, (b) MRF, (c) ACF, (d) AMCF, (e) AF; -1 indicates just after being removed from a magnetic field without any vibration, -2 indicates after being removed from a magnetic field and given a vibration

The particles involved in the ACF were observed by TEM, as shown in Fig. 4. Co and P are in the same position while Fe is in another position. Therefore, the Fe_3O_4 particles are surrounded by the amorphous particles. On the other hand, the amorphous particles are aggregated due to the remnant magnetization.



(a) (b)

(c) (d)

Figure 4 Photographs of ACF by TEM with a multiplying ratio of 10000: (a) all particles, (b) only Co, (c) only Fe, (d) only

APPLICATIONS

We tried to apply the ACF to polishing as one of its engineering applications. We used an experimental apparatus for float polishing, as shown in Fig. 5. A polishing tool having a permanent magnet with a diameter of 8 mm and maximum strength of 4500 Gauss was rotated by a drilling machine having a constant speed of 515 rpm. A disk type testing specimen made of brass having a diameter of 30 mm and thickness of 1 mm was attached to the surface of a lower load cell capsule. A testing fluid was inserted between the test specimen and the polishing tool. The load cell capsule was moved by the vibration machine with two types of motion, rotation and knitted brows rotation, having an amplitude of 10mm and a frequency of 20rpm. The clearance between the test specimen and the polishing tool was adjusted using an attachment to the vibration machine.

Table 2 shows the testing fluids of MCF and ACF used in the present study.

Figure 6 shows the surface roughness after polishing of *Ra* as (a) and of *Ry* as (b). The initial roughness *Ra* was 0.0923 μm and the *Ry* was 0.616 μm. The polishing effect from using the ACF was a mirror-like surface, similar to the case of using the MCF. The cause of this result was the previously mentioned "string magnetic cluster": for ACF, as shown in Fig. 7(a), "string magnetic clusters" aggregated by amorphous and Fe_3O_4 particles function like a polishing cloth. ACF can polish more smoothly than MCF. On the other hand, MCF, with needle-like magnetic clusters aggregated by iron and Fe_3O_4 particles, polishes like a toothbrush, as shown in Fig. 7(b). Therefore, a mirror-like polished surface can be obtained by a polishing cloth with the ACF's clusters as well as by a polishing toothbrush with the MCF clusters.

Although the viscosity and saturation magnetization of ACF are smaller than those of MCF, the polishing effect of ACF is the same as that of MCF. The aggregated particle formation is a critical factor in the field of polishing. This result is very typical.

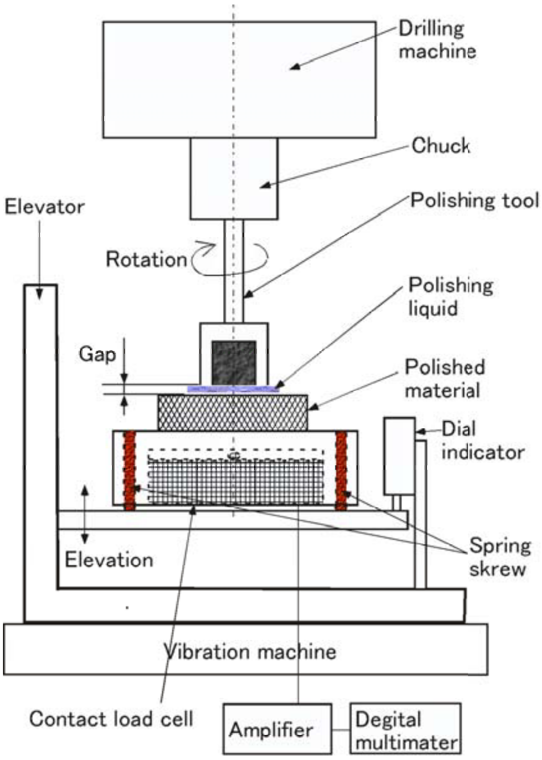
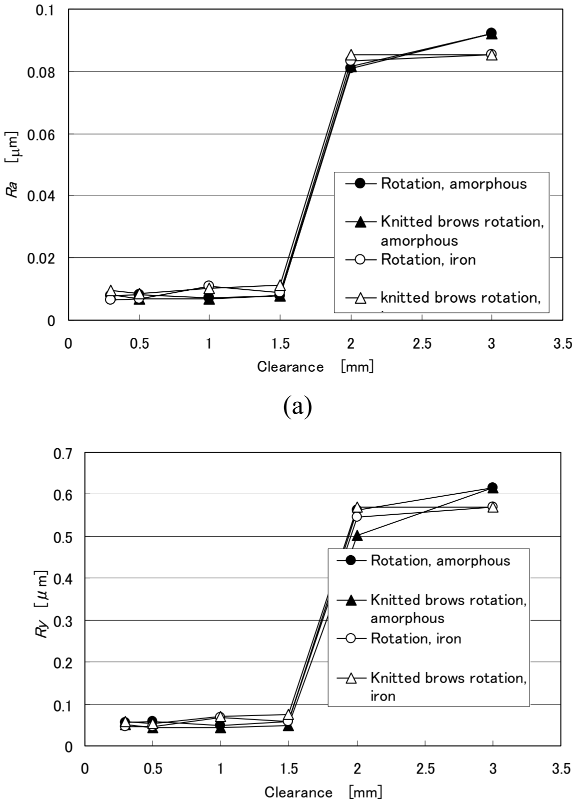


Figure 5 Schematic diagram of float polishing apparatus using the fluids

Table 2 Composite of MCF and ACF in float polishing

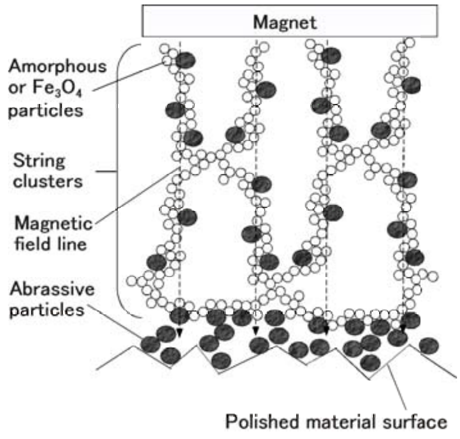
Testing fluid	Components	Mass concentration
MCF	・ HQ：30 g ・kerosene-baseed magnetic fluid（HC50 (50 wt%)）: 38.7 g ・ kerosene：29 g ・ abrasive particle (Al_2O_3 (3 μm))：19.7 g ・ α-cellurose：6.3 g	・ HQ : 24.3 wt% ・Fe_3O_4 : 15.6 wt%
ACF	・C166：30 g ・kerosene-baseed magnetic fluid（HC50 (50 wt%)）: 38.7 g ・ kerosene：29 g ・ abrasive particle (Al_2O_3 (3 μm))：19.7 g ・ α-cellurose：6.3 g	・C166：24.3 wt% ・Fe_3O_4 : 15.6 wt%



(a)

(b)

Figure 6 Surface roughness by float polishing utilizing ACF and MCF.



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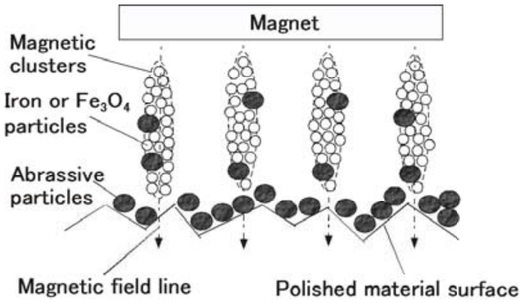

(b)

Figure 7 Schematic diagram of polishing model by string clusters in (a) ACF and (b) MCF

CONCLUSION

We proposed an amorphous compound fluid (ACF) as a new intelligent or smart fluid. We investigated the hydrodynamic characteristics of the fluid's viscosity and magnetic characteristics under a DC magnetic field. The viscosity and saturation magnetization of ACF are smaller than those of the previous magnetic responsive fluid, MCF, but its polishing effect is the same. The aggregated particle formation is a critical factor in the field of polishing.

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