Engineering Science and Technology, an International Journal 19 (2016) 604–609

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: http://www.elsevier.com/locate/jestch

Full Length Article

The effect of the volume fraction and viscosity on the compression and tension behavior of the cobalt-ferrite magneto-rheological fluids

H. Shokrollahi *

Electroceramics Group, Department of Materials Science and Engineering, Shiraz University of Technology, Shiraz, Iran

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form
9 September 2015
Accepted 30 September 2015
Available online 3 November 2015

Keywords:
Ceramics
Magnetic materials
Chemical synthesis
Mechanical testing

ABSTRACT

The purpose of this work is to investigate the effects of the volume fraction and bimodal distribution of solid particles on the compression and tension behavior of the Co-ferrite-based magneto-rheological fluids (MRFs) containing silicon oil as a carrier. Hence, Co-ferrite particles ($CoFe_2O_4$) with two various sizes were synthesized by the chemical co-precipitation method and mixed so as to prepare the bimodal MRF. The X-Ray Diffraction (XRD) analysis, Fourier Transform Infrared Spectroscopy (FTIR), Laser Particle Size Analysis (LPSA) and Vibrating Sample Magnetometer (VSM) were conducted to examine the structural and magnetic properties, respectively. The results indicated that the increase of the volume fraction has a direct increasing influence on the values of the compression and tension strengths of fluids. In addition, the compression and tension strengths of the mixed MRF sample (1.274 and 0.647 MPa) containing 60 and 550 nm samples were higher than those of the MRF sample with the same volume fraction and uniform particle size of 550 nm.

1. Introduction

Since the magneto-rheological fluids (MRFs) were discovered in the late 1940s, numerous researchers have investigated and published the interesting results on MRFs and their applications [1]. The fundamental phenomenon in magneto-rheology is to control the structure of the two-phase fluid by magnetic fields, being responsible for a remarkable viscosity increase up to about 10^3 times. The major parameters of MRFs, directly relevant to the viscosity, are the compression and tension strengths. The increase of the compression strength, tension strength and viscosity is dependent on various variables [2–5]. Based on the behavior of MRFs being influenced by the external field, it is assumed that the higher volume fraction of solid particles leads to an increase in the resulting viscosity. Furthermore, in view of the spherical shape of the particles, should these particles be aligned on one another vertically, there will occur holes between them, resulting in a decrease in viscosity [6–9]. The use of particles with at least five times smaller in size will be so useful in achieving higher viscosity.

The sudden change in the MRFs behavior due to the magnetic application makes this material attractive for dampers and dissipative devices. The MRFs can be used to build integral, silent, quick mechanical systems enhanced by means of electronic controls. Several researchers have paid special attention to the MRFs as dampers and engine mounts (desirable in civil engineering and automotive industry) [9]. Spaggiari has studied the properties and applications of MRFs [10]. Numerous researchers have attempted to synthesize the nanoparticles with different chemical method. Molazemi et al. have investigated the compression and tension behavior of the Co-ferrite MRFs synthesized by co-precipitation as a low-cost and simple method [11]. In the area of MRFs control valve which the direction of the fluid flow is perpendicular to the external field. Imaduddin et al. have evaluated the design and performance analysis of a novel compact MRFs valve [12]. Sarkar and Hirani have improved brake performance by the use of nano silver particle-based MRFs [13]. Recently, Zhou has investigated the influence of magnetized walls on the yield stress of MRFs [14]. Rodriguez and his colleagues have focused on the strong-link and weak-link and their effects on the yielding [15]. Lee and Armijo have focused on the enhancement of MR by using uniform magnetic carbon nanoparticles and iron nitride nanoparticles, respectively [16,17]. The shape and morphology of particles are so crucial to the performance of MRFs. In line with this, Jung et al. have investigated the role of octahedral-shaped Fe_3O_4 nanoparticles in MRFs behavior [18]. In addition to particle morphology and particle size, some researchers have used some interesting modes for better performance. For example, Becnel et al. have presented the squeeze strengthening of MRFs by use of mixed mode operation [19]. An important study has been carried by Rabbani and his colleagues [20]. Due to the importance of MRF stability, they investigated the effect of two critical parameters including mag-

* Tel.: +98 71 37354520, fax: +98 71 37354520.
E-mail address: shokrollahi@sutech.ac.ir.
Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2015.09.011

netic field and temperature on the stability of MRFs. During the last years, characterization of MRFs has been widely considered. Eshaghi et al. have presented an accurate technique for pre-yield characterization of MRFs [21].

In addition to the above-mentioned parameters, the magnetic field type, temperature, particle linking type, carrier nature, particle shape, particle size and solid particle distribution, the chemical composition of particles is very effective. In this area, one of the most important magnetic particles is cobalt ferrite. This ferrite shows the relatively high Curie point, hard magnetic properties, large magneto-strictive coefficient, large magneto-crystalline anisotropy, moderate saturation magnetization, corrosion resistance and ease of synthesis [22,23]. The above-mentioned properties make Co-ferrite as one of the most promising candidates for different applications, including magnetic drug delivery, hyperthermia, magnetic resonance imaging, magnetic memories, sealing purposes, as well as MRFs sensors.

This paper has focused upon the effect of the volume fraction and particle distribution on the mechanical properties of Co-ferrite MRFs. The studies have indicated that no results have been reported on the influence of the volume fraction of Co-ferrite MRFs with the particles produced by co-precipitation regarding the structural, magnetic and mechanical properties. There are many papers in the field of Co-ferrite synthesis in the pure phase [22,23] and composite forms [24,25] and the obtained magnetic properties are comparable with the literature.

2. Experimental procedure

2.1. Materials

The whole chemical agents – sodium hydroxide NaOH, sodium dodecyl sulfate (SDS), Silicon oil, ferric chloride $FeCl_3 \bullet 6H_2O$, Cobalt (II) chloride $CoCl_2.6H_2O$ and pyridine – were purchased from E. Merck Co. in Germany and utilized without further treatment.

2.2. Manufacturing the test rig

Additionally, for the purpose of performing the compressive and tensile force tests on the samples, a specific tester was produced based upon the device shown in Fig. 1 [11]. During the tension and compression tests, the magnetic field was applied to the ferrofluid inside the core cylinder. After applying the field, the fluid viscosity varies and the mechanical properties behaved in a different manner. The test rig materials including squeeze cylinder, core cylinder, above ring, below ring, support cylinder, coil, and device base were carbon steel, carbon steel, stainless steel, carbon steel, stainless steel, copper and carbon steel, respectively.

2.3. Preparation and characterization of ferrite particles

In this research work, Co-ferrite particles with two various particle sizes were achieved following the co-precipitation. To sum up, the aqueous solutions of $CoCl_2$ and $FeCl_3$ mixtures in the alkaline medium were prepared. Then the mixed solutions of $CoCl_2.6H_2O$ (25 ml, 1 M) and $FeCl_3.6H_2O$ (25 ml, 2 M) were prepared and maintained at 60 °C. This mixture was immediately added to the solution of NaOH (150 ml, 1.32 M). Then, the solution was stirred at a velocity equal to 100 rpm. Afterward the obtained solutions were maintained at 90 °C for 1 h. This duration was sufficient for the formation of the amorphous ferrite. After synthesis, each solution was kept under equal environmental circumstances (T = 90 °C, stirring velocity = 40 rpm, pH = 11 and atmosphere of N_2) for various time ranges of 2 and 24 h (Samples A and B) to achieve different sizes of particles. To obtain spinel ferrites, the samples were heat treated at 550 °C for 1 h. A sufficient amount of fine particles was collected at this step by utilizing magnetic separation. These particles were washed several times with distilled water followed by acetone and dried at room temperature. After the collection of Co-ferrite particles, Sample C was prepared by mixing the same amounts of

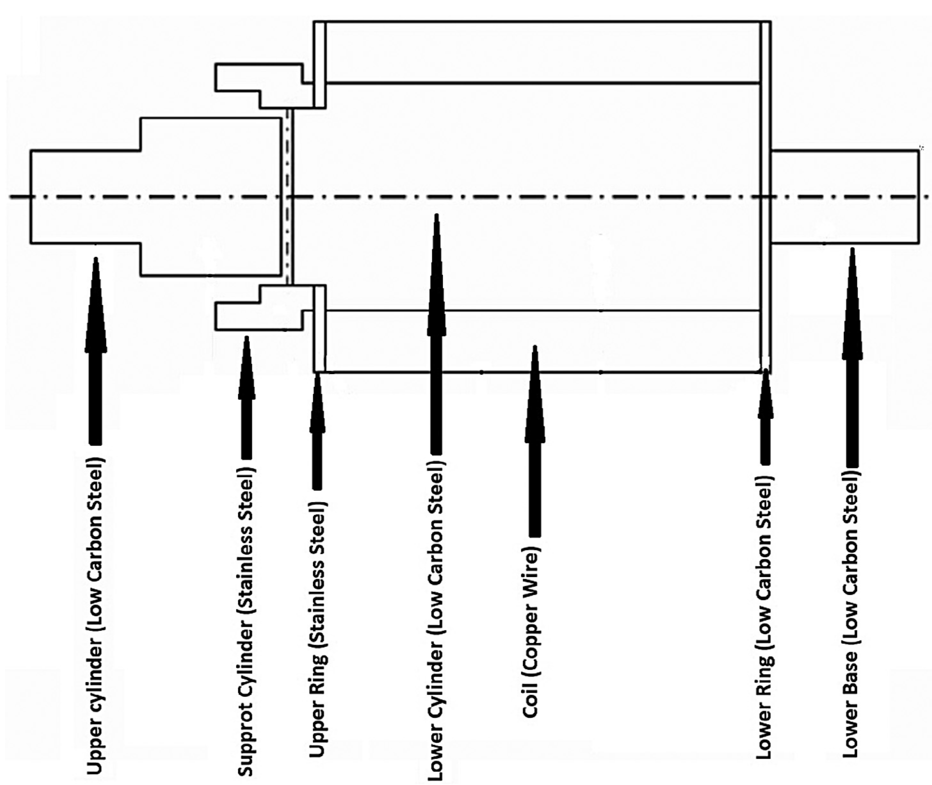

Fig. 1. Schematic of manufactured test rig.