Manufacturing and testing of an optimized Magneto-Rheological fluid and modelling of a Twin tube Magneto-Rheological damper using a modified non-Newtonian model using analytical quasi-static, analytical unsteady, numerical and experimental methods

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ABSTRACT

Magneto-Rheological Fluids are one of the intelligent fluids which have been extensively used in engineering application including Magneto-Rheological Dampers. Having yield stress in a magnetic field and ability to control and increase their viscosity are their most important characteristics. After three different carbonyl iron powders were subjected to analysis, five different Magneto-Rheological Fluids were synthesized and were tested for stability and the optimized fluid obtained. The results obtained from the optimized Magneto-Rheological Fluid with 85% (weight %) iron powder was similar to that of LORD oil. Also, a modified non-Newtonian rheological model was developed to predict the behavior of the optimized Magneto-Rheological Fluid which is more accurate than Bingham and Herschel-Bulkley models and could be implemented in computational fluid dynamic modelling. The modelling of the damper was conducted by implementing modified non-Newtonian and Bingham models using analytical quasi-static, unsteady and computational fluid dynamic methods and the results were validated with experimental data. The results show that neglecting factors including fluid shear thinning, wall shear stress and inertia term effects and effect of magnetic field on plastic viscosity in conventional modelling methods results in considerable error that will increase as magnetic field, Reynolds number and gap are increasing.

KEYWORDS

MR fluid, MR damper, new modified non-Newtonian model, Magnetic field, Damping force

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1. Introduction

Magnetorheological fluid (MRF) and electrorheological fluid (ERF) are smart fluids that display a reversible and rapid transition behavior from a free flowing state to a semi-solid state in the presence of external magnetic and rapid transition behavior from a free flowing state to a semi-solid state in the presence of external magnetic and electric field. In the past decades, many studies have been conducted for MRF and MR damper modeling. Experimental, computational fluid dynamics (CFD), and analytical modeling of MR dampers have been presented by several researcher [1-8].

2. Methodology

In this study and after three different carbonyl iron powders were subjected to SEM and EDX analysis, five different MRFs were synthesized and were tested for stability. Effect of iron powder weight percentage in the fluid and preservative on level of sedimentation in the MRFs were investigated and the optimized fluid in terms of stability and concentration was selected for rheological characterization in various magnetic fields.

Using obtained rheumatic test results, a modified non-Newtonian rheological model was developed to predict the behavior of the optimized MR fluid which is more accurate than Bingham and Herschel-Bulkley models and could be implemented in CFD modelling. This model is shown in equations (1and2)

$$\tau=\left(\frac{\tau_y(H)\operatorname{sign}(\dot\gamma)}{\sqrt{\dot\gamma^2+\varepsilon^2}}+\tanh(m(H)\dot\gamma)K(H)\dot\gamma^{n(H)-1}\right)\dot\gamma \qquad |\tau|>\tau_y \tag{1}$$

$$\dot\gamma=0 \qquad |\tau|\le\tau_y \tag{2}$$

Also, An unsteady analytical model is developed for magnetorheological fluid flow through the annular gap which is opened on the piston head of twin tube magnetorheological damper, and The system of three nonlinear equations (3-5) with three unknowns is solved numerically and K, ypi, and ypo are obtained

$$\delta=y_{po}-y_{pi}=2\tau_y L_f\,\operatorname{sign}(U_p)\Delta P_{MR}^{-1} \tag{3}$$

$$\Delta P_{on}=\frac{12\mu L_f\left(A\omega\left(A_p-A_r+2\pi R_{ave}h\right)\cos(\omega t)\right)}{\pi R_{ave}h^3\left(2+(\bar\delta)^3-3(\bar\delta)\right)} \tag{4}$$

The modelling of the MR damper was conducted by implementing modified non-Newtonian and Bingham models using analytical quasi-static,

$$Q_h=2\pi R_{ave}\left(\begin{array}{l}\int_0^{y_{pi}}U_{abs1}(y,t)dy\\ +\int_{y_{pi}}^{y_{po}}U_{abs2}(y,t)dy\\ +\int_{y_{po}}^{h}U_{abs3}(y,t)dy\end{array}\right) \tag{5}$$

Unsteady and CFD methods and the results were validated with experimental data. In CFD modeling, continuity and Navier stocks equations (6and7) are solved numerically, using FEM method.

$$\frac{\partial\rho}{\partial t}+\nabla.(\rho U)=0 \tag{6}$$

$$\rho\frac{\partial U}{\partial t}+\rho(U.\nabla)U=\nabla(-PI+\mu(\nabla U+(\nabla U)^T)-\frac{2}{3}\mu(\nabla.U)\mathrm{I}) \tag{7}$$

Results and Discussion

Fig. 1 shows the graphs of the stress-strain rate relationship of the MRF 140-CG and optimized MRF. As is shown in this figure, the results obtained from the optimized MRF with 85% (weight %) iron powder was similar to that of LORD MRF-140CG oil.

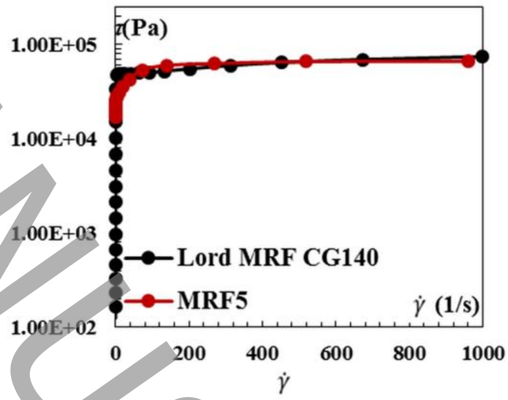

Fig. 1. A Comparison of Magnetic Rheumatic tests results of MRF 5 and Lord MRF CG 140 Oil

Experimental results is shown in Fig2. It is observed that the modified model is in good agreement with the measured values and is more accurate than Bingham and Herschel-Bulkley models.

Force–displacement hysteresis loops of MR damper from analytical and CFD models and experimental results are compared in Fig3.

It is observed that the CFD model is in good agreement with the measured values and is more accurate than present and conventional investigated analytical methods. Because, new modified Non-Newtonian model is used in CFD model. Also, present analytical models is more accurate than conventional investigated quasi-static method. It is due to, neglecting factors including fluid shear thinning, wall shear stress, inertia term effects and effect of magnetic field on plastic viscosity in conventional modelling methods

3. Conclusions

In this study, five different MRFs were synthesized and were tested for stability. Effect of iron powder weight

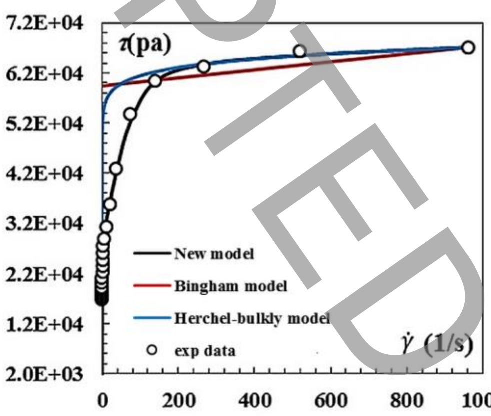

Fig. 2 Fitted data of Magnetic Rheumatic tests of MRF5 with new modified model, Bingham-plastic and herchel-bulkly model

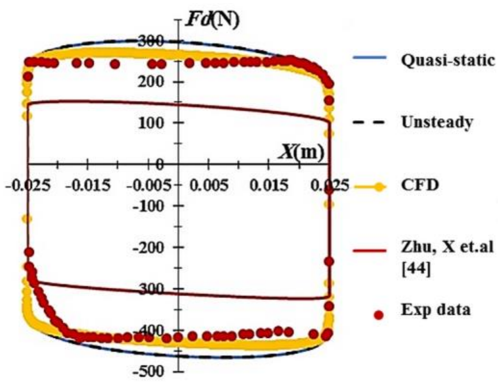

Fig. 3 A Comparison between quasi-static, unsteady, conventional model, CFD and experimental data

percentage (85%, 75% and 65%) in the fluid and preservative (1%2% and 3%) on level of sedimentation in the MRFs were investigated and the optimized fluid in terms of stability and concentration was selected for rheological characterization in various magnetic fields. The results obtained from the optimized MRF with 85% (weight %) iron powder and 1% preservative was similar to that of LORD MRF-140CG oil. Also, a modified non-Newtonian rheological model was developed to predict the behavior of the optimized MR fluid which is more accurate than Bingham and Herschel-Bulkley models and could be implemented in CFD modelling. The modelling of the MR damper was conducted by implementing modified non-Newtonian and Bingham models using analytical quasi-static, unsteady and CFD methods and the results were validated with experimental data. The results show that neglecting factors including fluid shear thinning, wall shear stress and inertia term effects and effect of magnetic field on plastic viscosity in conventional modelling methods results in considerable error that will increase as magnetic field, Reynolds number and gap are increasing. Consequently presented model and methods, could be used for improved MR damper.

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