Improvement in forming process using Magnetorheological Fluid Assisted Cushion in Hydraulic Press

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Abstract. The role of cushion pressure in hydraulic press plays a vital role in forming the component. In the present work, an attempt was made to analyse the influence of Magnetorheological cushion in addition to the existing cushion system, in forming small cup shaped component. The innovative Magnetorheological assisted hydraulic press of 1 ton capacity is designed and fabricated. The formability of Aluminium and Galvanised Iron sheet of different thickness was analyzed. The Magnetorheological cushion improves the formability of components with the reduced number of wrinkles in it. The forming process with the Magnetorheological fluid assisted cushion hydraulic press was more efficient than ordinary hydraulic presses.

1. Introduction
The advent research on the uses of Magnetorheological fluid (MRF) in dampers, valves and brakes made its usage commercially available in automotive industries. They are mainly meant for damping the vibration and improving the efficiency and performance of the various systems. The rheological properties of fluid can be controlled based on the requirements and hence it has wide applications in smart structures. Its basic components and different types of its operational modes along with their applications were discussed by Olabi et al [1]. The MRF emerged as tool for vibration control and mainly used as damper. Many authors attempted design of vibration damper using MRF and evaluated their performance [2-3]. Few authors did the numerical simulations [4] and finite element study [5] to evaluate the behaviour of liquid under the influence of magnetic field.

The behaviour of Magnetorheological fluid and its usage are promising in the field of manufacturing especially in fine finishing for optics, ceramics, and semiconductors. A new precision finishing process called magneto rheological abrasive flow finishing (MRAFF), which was basically a combination of abrasive flow machining and magneto rheological finishing, had been used for nano-finishing of parts even with complicated geometry for a wide range of industrial applications[6]. The rheological properties and their correlation with surface finish quality in MR fluid-based finishing process were analysed [7, 8]. Higher yield stress and viscosity of MRF improves material removal rate and the surface finish and researcher has to optimize the behaviour of MRF while changing its particle size and compositions. The vibration of cutting tools and boring bar also causes chatter while machining and several damping method while machining were analysed [9].

The usage of MRF is not only plays a significant role in machining but also in metal forming. The optimum rheological behaviour of MR fluid improves the formability of Al1060 sheet metal [10] in bulging experiment. The same fluid can be used to provide the bidirectional pressure forming to
improve the thinning rate of wall thickness with improvement in forming height [11]. The improvement in forming process is accomplished by using MRF as active medium in flexible die medium and few authors damps the vibration of hydraulic press while forming. The MRF dampers were used to control the vibration obtained in Hydraulic press which may causes break through shock while blanking [12]. This breakthrough shock was overcome either by cushioning or by MR damper.

In this present work, break through shock in hydraulic press was overcome by cushioning cylinder connected in series with the MR tank. Instead of purchasing four MR dampers of larger capacity as in Ghioiet al [12], this paper presents a new concept of developing MRF assisted cushion in hydraulic press which works on compression mode [1]. An existing single action die with draw cushion of one ton capacity hydraulic press was redesigned and fabricated to have Magnetorheological die-cushion where the MR fluid in cushion cylinder was energized to ON/OFF state and its magnetic field strength was varied by passing current of different amplitude to the electromagnets. The formability of sheet metal of different thickness of different material was analysed to understand the influence of MR cushion in the forming process.

2. Design of MRF assisted cushion

The introduction of new MRF assisted cushion in series with the cushion cylinder enhances the damping in a better way, resulting in the improvement of the forming process. The purpose of the MRF cushion was to form wrinkle free circular cups and reduce the deformation of the work-pieces to ensure a better finish. The design of MRF assisted cushion consists of MR cylinder (MR tank) and cup shaped MR piston with the clearance of 1 mm between them. The MR fluid was poured into the MR tank and the MR piston floats on it. The three electromagnets and three guide pins were fitted inside the cup shaped piston alternatively in a circular fashion as shown in Figure 1. Those guide pins passes through the frame to support the worktable. The circular ring acts as a worktable on which blank of sheet metal was placed for forming process and it had the groove to rest on the guide pins. The ram strikes the blank on worktable, which in turn pushes the piston into MR tank. This movement of MR piston was resisted by MRF when it was on the active state. In active state, the magnetic iron particles forms chain like structure and increases its yield stress resulting pilot damping before cushion cylinder does the same. The MR fluid attains its viscous nature in the presence of the magnetic field. It also offers support to the work-piece from the bottom and ensures that there is minimum defect in the formed cup

2.1 Design of electromagnet in FEMM in MR piston.

An analysis of the magnetic field between the MR cylinder and the MR piston (in the gap or across the MR fluids) was performed using the software Finite element method magnetic (FEMM)[13]. The magnetic properties of the non-magnetic materials were assumed to be linear such as low carbon steel, copper wire and air. The MR Cylinder, MR piston with the electromagnets and the clearance between them were modeled using FEMM software. The material chosen for MR Cylinder, MR Piston were

![Figure 1. View of the piston with guide pins and four electromagnets.](image)
low carbon steel, core of electromagnet as pure iron and MRF as sintered iron powder. The coil in the electromagnet was supplied with 1.25 amp and number of turns was 200. The objective of the finite element analysis was to show how the magnetic flux lines were distributed in the MR tank. When the magnetic field was ON, the carbonyl iron particles follow the path of the magnetic flux lines and forms the chain of carbonyl iron particles which was perpendicular to the moving piston to enhance the damping in compression mode as shown in Figure 2.

![FEMM analysis of MR Cylinder and MR Piston with electromagnets and the clearance between them.](image)

Figure 2. FEMM analysis of MR Cylinder and MR Piston with electromagnets and the clearance between them.

2.2 Winding of electromagnets and verification of the field.

The winding of the electromagnets were made on a soft iron core using a SWG 28 wire. The process of winding was carried out using a manual drilling machine. An insulating paper was first rolled around the soft iron core of the electromagnet for safety reasons. Next the core was fixed on the manual winding machine. As per requirement, number of turns was turned on the iron core. The electromagnets were then dipped in fast drying insulation varnish to ensure proper insulation and prevent short circuit of the electromagnet. Finally the electromagnets were dried.

The electromagnets were tested on a regulated power supply (RPS). A regulated power supply is an electronic device with which variable current and voltage can be obtained at the same time. The poles of the electromagnet were connected to the positive and negative terminal of the RPS and then tested. After testing the electromagnets taking into consideration the heat emitted, the optimum value of current was found to be 1.2 amps and voltage was 12 volts. Therefore an AC to DC convertor with rating 12volts, 1.5amps was selected. The electromagnets were connected in series which divided the current into 1.25 amps each.
2.3 Preparation of MR fluid.
Magnetorheological fluid basically has three components namely basic fluid, metal particles and stabilizing additives. MRF used in cushion was prepared by mixing carbonyl iron particles of 10 microns in size into castor oil which was used as a carrier fluid with the emulsifiers (concentrated sulphuric acid, aq. Potassium hydroxide) [14]. Carbonyl Iron particles and carrier oil were mixed using a stirrer for 1 hour at a temperature 250 °C and then the mixture is heated till 800°C followed by addition of sulphuric acid and Potassium Hydroxide. After this the fluid had been kept for 24 hours. The Standard 100g MR Fluid consist of 80% by weight Iron carbonyl particles, 10% by weight carrier oil (castor oil), 5% by weight sulphuric acid, 5% by weight Potassium Hydroxide. The fluid thus prepared were used as MRF in Cushion.

3. Experimental setup
The schematic diagram of the hydraulic press circuit is shown in Figure 3. The MRF assisted cushion resembles like another piston cylinder arrangement and it was fitted in series with single acting cushion cylinder. The specification of hydraulic press and the cushion details are given below in table 1 and 2.

| Table 1 Hydraulic press details. |
|-------------------------------|
| **Elements** | **Specification** |
| Model | : 4 pillar |
| Capacity | : 1 ton |
| Cylinder used | : Double acting |
| Cylinder type | : Rectangular flange mount-rod |
| Ram stroke | : 75mm |
| Day light | : 150mm |
| Bed size | : 200 x 275mm |
| Cylinder Bore Diameter | : 50mm |
| Dimension of pipe | : 10mm |
| Working Pressure | : 1000 psi |

| Table 2 Die cushion details. |
|-------------------------------|
| **Elements** | **Specification** |
| Motor capacity | : 1.5 H.P |
| Mode of operation | : Electric push button |
| Hydraulic elements | : YUKEN/ESCORTS |
| Oil tank capacity | : 25 litres |
| Pump used | : Gear |
| Oil | : Hydraulic oil grade 68 |
| Overall weight | : 250 Kg |
| Valve | : Solenoid controlled valve |

Cushion cylinder provides a resistive force which dampens the break through shock [12] on the workpiece when the ram strikes it. When the left side of the solenoid control valve was actuated, the hydraulic fluid moves to the blank end of the cylinder, makes the ram to move downwards and at the same time the hydraulic fluid at the bottom of the cushion cylinder offers resistance depending on the pressure setting on the counter balance valve. The hydraulic fluid in
cushion cylinder moves to tank if the pressure of the hydraulic fluid exceeds setting pressure, and thus forming of the component. When the right side of the solenoid control valve was actuated, the fluid goes to the bottom of the upper cylinder making the ram to release the formed component and also to the cushion. The one way check valve was provided in between the direction control valve and the cushion cylinder to restrict the backflow.

Figure 3 (a) Schematic diagram of Hydraulic press with MRF assisted cushion (b) Punch and Die arrangement.

A small hydraulic press of 1 ton capacity had the inverted die and punch (schematically as in Figure 3b) to form circular cups of diameter 24mm, depth 8mm and corner radius 4mm was designed and fabricated as shown in Figure 4. It has standard rectangular shaped frame to withstand full load. Hydraulic power pack which supplies the power for hydraulic press consists of electric motor, hydraulic pump, pressure relief valve, pressure gauge, solenoid direction control valve, pipe etc. The hydraulic power pack was placed to the right side of the press. The punch arrangement was attached to the frame and blank was held on the blank holding ring which was supported by three guide pins. The guide pins during the forming process pushes the cup shaped MR piston inside MRF tank.
Figure 4. MR cushion assisted Hydraulic press with Sub picture showing MR cylinder and MR piston with electromagnets and guide pins.

Figure 5a. The sample of cup shaped formed specimen. Figure 5b. The sample of Cracked GI specimen.

The blanks of 40mm diameter were placed between punch and die arrangement. When the motor coupled with pump starts to rotate, the fluid get transfer to the cylinder so that the extension of cylinder takes place which forms the work piece. It was supported by the single acting cushion cylinder to withstand the force applied to the work piece. Initial cushion pressure was set in cushion cylinder by adjusting the pressure setting valve at 20Kgf/cm². During the formation of the cup, the pressure in cushion was increased due to force exerted by the working cylinder. The final cushion pressure was noted down after the formation of the cup. The experiments were conducted for Aluminium and Galvanised Iron of different thicknesses of 0.2mm, 0.3mm and 1mm with MR cushion in active state ON and OFF state. The current supplied to the electromagnets was kept constant for every condition. The formed cups were visually tested and cushion pressure during the cup formation were noted down. The cups formed during different experimental conditions are shown in Figure 5. The experiments were repeated to confirm the readings and the aluminium and Galvanised Iron of different thickness were used by varying the current supplied to the electromagnets. The results of these experiments are shown Figure. 6-10.
4. Results and Discussion
The final cushion pressure after the formation of cup with different material of varying thickness with and without MR fluid cushion was recorded and shown in Figure 6. It was observed that the sheets of 0.2 mm thickness Aluminium and GI material cracks during the formation when the MR Cushion is in OFF state, cushion pressure attained to 48kgf/cm². The cracked sample specimens are shown in Figure 5b. The same sheets were formed without any cracks and wrinkles under the presence of MR cushion where final cushion pressure was decreased to 40kgf/cm² as in Figure 5a. The thin aluminium sheet metal could not withstand the working cylinder (ram) force and rigid cushion cylinder pressure when MR cushion was OFF. The pressure of working fluid was kept constant and the force required to form the components was comparatively less in the case of thin sheets. The resistive force offered by the cushion in formation cups was excessive and hence the specimen gets cracked. When MR Cushion was switched ON, it results in the formation of smooth components. The final cushion pressure decreases as the MR fluid got activated. This may be due to pressure transmitted via the rods that supports blank holding ring during drawing process, moves the MR Piston in MR tank against MR fluid. If MR fluid was activated by passing current in the electromagnets, the carbonyl iron particles forms the chain like structure and resist the MR piston movement in MR tank. Hence the force was partially damped by the MR Cushion in addition to hydraulic cushion cylinder. When the thickness of the sheet increases from 0.2mm to 1mm, the force required for forming the component also increases. The force exerted on the punch is utilised in forming the cups and the hence final cushion pressure decreases as shown in Figure 6. The same trend reflects for other materials also.

The initial cushion pressure was set by adjustable pressure setting knob. The initial cushion pressure was mandatory to support the blank when working cylinder exerts force on it. The experiments were conducted by setting the initial cushion pressure as 20 kgf/cm² and 25 kgf/cm² for material Aluminium and Galvanised Iron. The final cushion pressures were observed when the working cylinder completes its stroke (i.e at the time of die and punch mate completely). When I=0, MR cushion is in ‘OFF’ state and the final cushion pressure observed was higher than when the current passed through the electromagnet was 0.5 amps. The Figure 6 shows that irrespective of thickness and its material, the final cushion pressure seems to decreases with MR Fluid was in ‘ON’ state.

![Figure 6](image-url)  
**Figure 6.** Final Cushion pressure in Kgf/cm² when the MR assisted cushion is in ON/OFF state for different material for varying thickness.

Figures 7 and 8 showed the influence of the current in the electromagnet for varying thickness of Galvanised Iron at 25kgf/cm² and 20kgf/cm². When current increases from 0 to 1 amp, the damping
capacity of the MR cushion increases which in turn decreases final cushion pressure. Thus, thickness of the sheet metal was inversely proportional to final cushion pressure. Similarly, the same characteristic existed for varies initial cushion pressure settings. The final cushion pressure while forming Aluminium sheets of different thickness found to be higher than Galvanised Iron as shown in Figures. 9 and 10.

**Figure 7.** Final Cushion pressure measured for GI material when the initial Cushion is set to be 25 kgf/cm².

**Figure 8.** Final Cushion pressure measured for GI material when the initial Cushion is set to be 20kgf/cm².
Figure 9. Final Cushion pressure measured for AI material when the initial Cushion is set to be 25kgf/cm².

Figure 10. Final Cushion pressure measured for AI material when the initial Cushion is set to be 20kgf/cm².

5. Conclusion
Using the MR fluid as cushion, there was a moderate decrease in the final cushion pressure and the circular cups formed had less wrinkles. Without MR fluid, the value of cushion pressure was high and there were cracks and more wrinkles on the surface. The formability of thin aluminium sheet increases by using MR cushion without which metal was cracked and could not form into proper shape [12]. It shows that MR cushion acts as good damping medium and improves the formability of the metal in hydraulic press. It could be concluded that if the initial setting of cushion pressure was high, it increases the final cushion pressure. If the current passing through the electromagnet increases, the magnetorheological effect in MR cushion increases which in turn increases its damping capacity and decreases the cushion pressure. It could be concluded that forming process using Magnetorheological
fluid is more efficient. Thus, it has been verified by visual inspection as well as change in cushion pressure in small hydraulic press.

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6. References
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