

Variable Stiffness of a Shoe Sole Using Electro Rheological Fluids

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ABSTRACT: The study was conducted to analyse the characteristics like variable stiffness acting on a shoe sole. Constant stiffness in shoe sole is sometimes the reason for fall in case of sudden change in physical activity. This project mainly involves the study of viscosity of various Electro-Rheological (ER) fluid and its behaviour when a force is applied. Paper clearly involves the study of behaviour of various fluids with different concentration of copper particles under certain amount of force. Viscosity, sedimentation of the fluids and its behaviour when copper particles are suspended in the presence/absence of small amount of electricity is studied.

KEYWORDS: Variable stiffness, Electro-Rheological, force, copper particles, suspended, electricity.

I. INTRODUCTION

Rheology is the study about flowing of matters. Electro-rheological (ER) fluids contain suspensions that exhibit a rapid, reversible and tuneable transition from a free-flowing state to a semi-solid state upon the application of an external magnetic field which is generated by the help of electric field. These materials demonstrate dramatic changes in their rheological behaviour in response to a magnetic field generated in the presence of electricity supplied by the battery.

ER Fluid is prepared by mixing small particles of copper or iron with a liquid. These particles include copper powder, obtained by grinding a bigger unit of iron. The liquid which is to be used as carrier fluid is tested for viscosity and sedimentation of particles at room temperatures. The liquid to be used should be thicker or more viscous than water. Vegetable oil, castor oil, toothpaste, honey and shampoo are taken for testing. The viscous carrier liquid helps the copper particles to stay suspended which allows the particles to move with minimal clumping when the force is applied. When the fluid filled with copper particles is exposed to magnetic field, the copper particles align with the magnetic field (which is generated due to electric field) and form a bond that holds the carrier fluid.

The fluid under the application of magnetic field shows a transition from a liquid behaviour to a solid one. The force applied and the displacement values are noted down using Universal Testing Machines (UTM) by varying the concentration of percentage of copper particles in various liquids. This type of behaviour is used in the shoe sole so as to vary the hardness as per the requirement of the user. It is mainly helpful for various age groups like 15-20, 20-40 and 60 and above. The novelty of this paper is mainly to study and analyse the behaviour of the different fluids, their sedimentation and viscous properties of the fluids. The behaviour of the particles in the presence and absence of the electric field is as shown in figure [1]



Figure [1]:- Alignment of particles in the presence of electric field and in the absence of electric field.

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The above figure [1] shows the alignment of the copper particles in fluid mixture with the presence and absence of electric field. The particles align themselves in a straight line as and this helps in varying the stiffness.

II.MATERIALS AND METHOD

Various types of tests were carried out in order to analyse the behaviour of copper particles in fluid under the presence/absence of electricity.

- Sedimentation test
- Viscosity test
- Compression test

And based on these, stress-strain curves were obtained. The results were obtained based on the above tests. Various materials like shampoo, castor oil, tooth paste, vegetable oil and honey were the fluids used.

A.VISCOSITY TEST

Viscosity is defined as the force of friction which one part of the liquid offers to another part of the liquid. The viscosity of given fluid is measured with respect to water whose viscosity is known very accurately at different temperatures. The experiment was carried out for different fluids at room temperature. Viscometer, rubber tube with cock, bottle, stand, beaker, various fluids, and distilled water were used to carry out the experiment.

The laboratory temperature was noted down; the bottle was washed with distilled water and dried to remove the moisture. Weight of empty bottle was measured first, it was then filled with water and weighed again. Later, the bottle was filled with different fluids and weighed. Using these data the densities were calculated. The viscometer was cleaned and rinsed properly with distilled water fixed vertically on the stand and filled with specific amount of mixture. Times of flows for different fluid were recorded. The same procedure was carried out for the mixture of fluid and copper particles. The viscosity of each fluid was calculated and hence tabulated as shown in table [1].

Laboratory temperature: 28°C

| SL NO. | FLUID | VISCOSITY IN CENTIPOISE |
|--------|---------------|-------------------------|
| 1. | VEGETABLE OIL | 72.35 |
| 2. | SHAMPOO | 2.45 |
| 3. | TOOTH PASTE | 65.83 |
| 5. | CASTOR OIL | 1.34 |
| 6. | HONEY | 1.73 |

Table [1]:-Viscosity table for different fluids

B.SEDIMENTATION TEST

Sedimentation is defined as the tendency for small particles suspended to settle out of the fluid in which they are mixed and come to rest. It mainly occurs due to the motion of the particles through the fluid in response to the forces acting on it. These forces may be of many types, like gravitational force, electromagnetic force. The motion of the suspended particles is blocked by a hard boundary which results in an accumulation of particles at the boundary which is called sediment. The concentration of these particles at the boundary is opposed by the diffusion of the particles. It uses gravitational forces to separate particulate material from fluid streams. In sedimentation, particles are falling from rest under the force of gravity

In this experimental analysis various fluids were taken, they were weighed and copper particles were added to it at different proportions.

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40 grams of each solution was weighed in a cup. To these fluids 25%, 50%, 75% by weight, copper particles were added. For every 40 grams of fluid 10 grams, 20 grams and 30 grams of copper particles were added gradually and checked for sedimentation. The fluid was taken in a test tube, copper particles were added and the test tube was placed to observe in a holder for an hour. Then the test tube is observed in presence of sunlight for the presence of sediments. The following materials were tested for sedimentation test: Castor oil, vegetable oil, tooth paste, honey, and shampoo. After obtaining the sedimentation test results, some fluids were found to have sediments formed after two hours. Hence these fluids were not considered for the stress strain tests. Very less sediment were formed in shampoo, tooth paste, castor oil and honey. Now these fluids were considered for further stress strain tests in laboratories. The experiment was carried out under room temperature conditions. The sedimentation results are tabulated as shown below in table [2]:

Laboratory temperature: 28°C

| Sl.NO. | FLUID | 25% | 50% | 75% | Remarks |
|--------|---------------|-----|-----|-----|-------------------------|
| 1. | VEGETABLE OIL | YES | YES | YES | Sedimentation occurred. |
| 2. | SHAMPOO | NO | NO | YES | Low sedimentation. |
| 3. | TOOTH PASTE | NO | NO | YES | Low sedimentation. |
| 4. | CASTOR OIL | NO | NO | YES | Low sedimentation. |
| 5. | HONEY | NO | NO | YES | Low sedimentation. |

Table [2]:-Sedimentation test for various percentage of copper powder in fluids

The above table [2] gives us the results of sedimentation test conducted. Yes, indicates that sediment is formed and No indicates that there was no sediment formed.

III.SHOE SOLE CONFIGURATION

After the sedimentation test the fluids were shortlisted for further experiments. The shoe sole was designed in such a way that it was capable of responding to various physical activities and provide the at most comfort for the individual. Moreover, feet of different individual vary in size, walking styles are different, and pressure points vary a lot from one individual to another. This is mainly designed such that it is adjustable for different individuals as per their requirement. The shoe is designed such that the stiffness of the sole varies based on the force applied. The sole is divided into three sections namely; lags, outer sole and mid sole. Lags are usually made up of E-SBR (Emulsion Styrene Butadiene Rubber); they are highly elastic, less wearable rubber. Outer sole, these are mainly made up of rubber or PVC, they are usually less elastic and play an important role on stiffness of the shoe sole. The thickness of this part of sole decides the type of shoe. It also differentiating different shoes like Sports shoe, formal shoe. Mid sole is a thin portion of rubber in the middle of the sole and does not involve much surface contact with the ground compared to other parts of the sole. The shoe sole considered was of 312mm in length a 52mm thick sole on which a cross section of 26mmX31mm was cut out as shown in the figure [3].



Figure [2]:-Side view of the shoe sole used for carrying out the experiment.

The sole dimensions used for experiment is as shown in figure [2]. The dimensions of the cross section cut out is as shown in figure[3].

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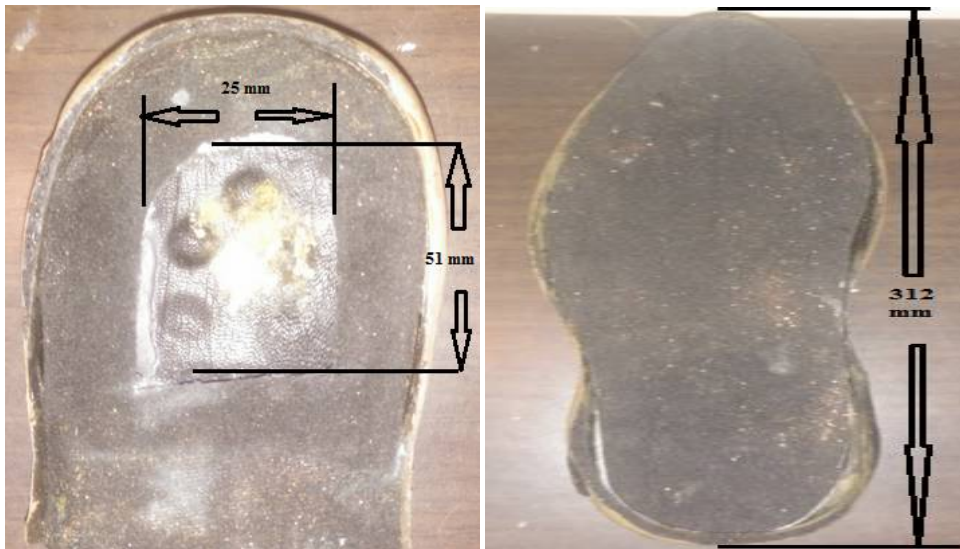


Figure [3]:-Dimensions of the cut out in shoe sole that is used for the analysis.

Electroreological shoe mainly works on the outer sole. The outer sole was considered for carrying out the analysis. A cross section of 51mmX26mmX31mm (length X width X thickness) is cut out from the shoe sole as shown in the figure [3]. A cavity is formed in which the fluid with certain amount of copper powder sandwiched between two copper plates is placed. The sole is first tested for plain sole without the presence of fluid, later the force is applied with the fluid in presence. The stress strain curve for different fluids with different percentage of copper powder is obtained by the help of Universal testing Machine. The same experiment is repeated with presence and absence of electricity (which is generated by piezo crystals ,which is in built on the outer casing walls ,here it is supplied by a battery through copper plates).The stiffness of the sole depends on the electric field supplied to the copper plate. The electric field by plates and piezos is directly proportional to the impact force or vibration generated by the person. In this case the force was applied by the UTM. The electric field was applied using a battery of 9V and 100mAh.The copper powder used is of less than 45 μ m and is made up of 98% copper. Various graphs of load versus displacement were obtained as shown in figure [5], [6], [7], [8], and [9].

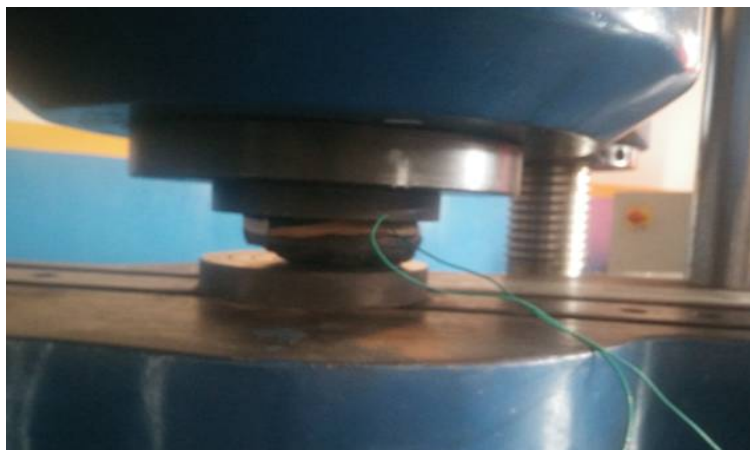


Figure [4]:- Shoe sole under compression in UTM

The sole to be tested is placed with the fluid mixture and copper plate under the Universal Testing Machine which is shown in figure [4].

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IV. RESULTS

The experiment was carried out on the fluid-copper powder mixture in the presence of electric field and also in the absence of the same. The stress strain curves for different fluids were obtained as shown. From the graphs obtained it is evident that the mixture of copper powder and electro rheological fluids vary in stiffness under different electric field. We can clearly see that the stress strain curve increases rapidly in the presence of electric field as in most of the cases except for shampoo, this shows that the material becomes more stiffer. More the electric field more will be the stiffness. The magnitude of electric field generated is in turn varied by the force applied on the sole. This clearly tells us that the stiffness can be varied by varying the force, which in turn changes the electric field, thereby, changing the alignment of particles present in the fluid. At first, viscosity test was conducted and the values were tabulated as shown in table [1]. The sedimentation test was conducted and was found that toothpaste, shampoo, castor oil and honey did not give rise to sedimentation as shown in table [2]. Further, these fluids were mixed with copper particles and compression test was carried out. The stress strain curve was obtained for 25%, 50% of castor oil, tooth paste, honey and shampoo. With 75% of mixture it was found that the mixture was very stiff and hard in the presence of electric field, which did not serve the purpose. We can say that by controlling the force applied on the sole, the electric field is also controlled which varies the stiffness. Thus it helps different age group of people who apply different forces on sole, the electric field can be generated by the help of piezo crystals (the ac current generated can be converted to DC by an IC).

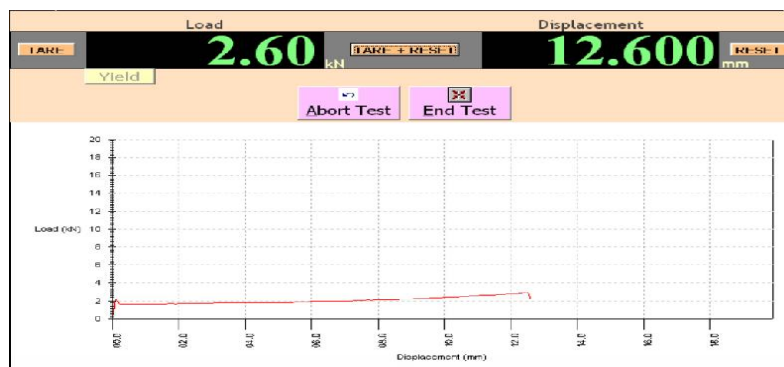


Figure [5]: It represents the Stress-Strain curve for normal shoe sole without fluid

The stress strain curve for normal shoe sole is obtained and it is shown in figure [5]. The test was carried out only on the shoe sole in the absence of fluid mixture and electric field.

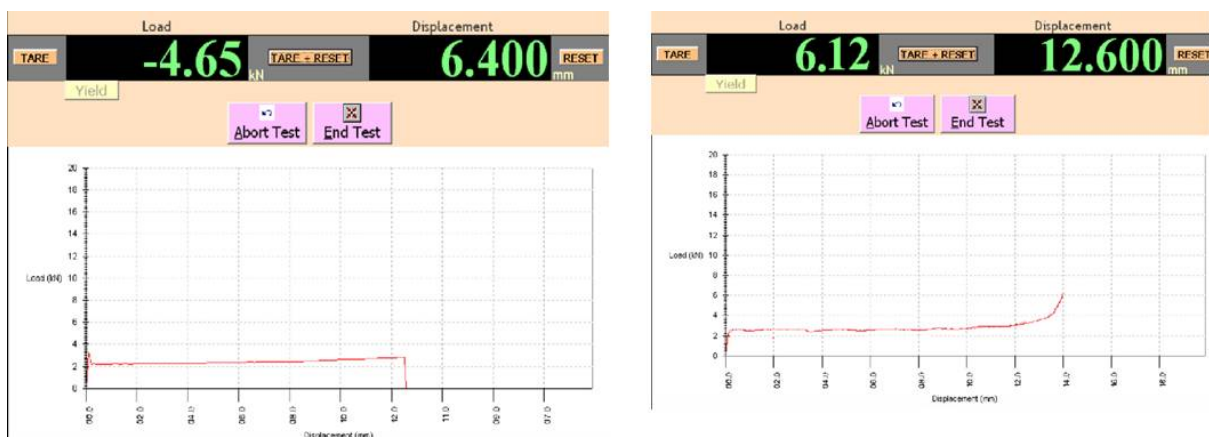


Figure [6]:- Stress strain curve for TOOTH PASTE and powder without the presence of electric field and with the presence of electric field.

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The stress strain curve for toothpaste and copper powder mixture is represented by figure [6] in the absence of electric field and presence of electric field. The force exerted is directly proportional to stiffness in the presence of electric field.

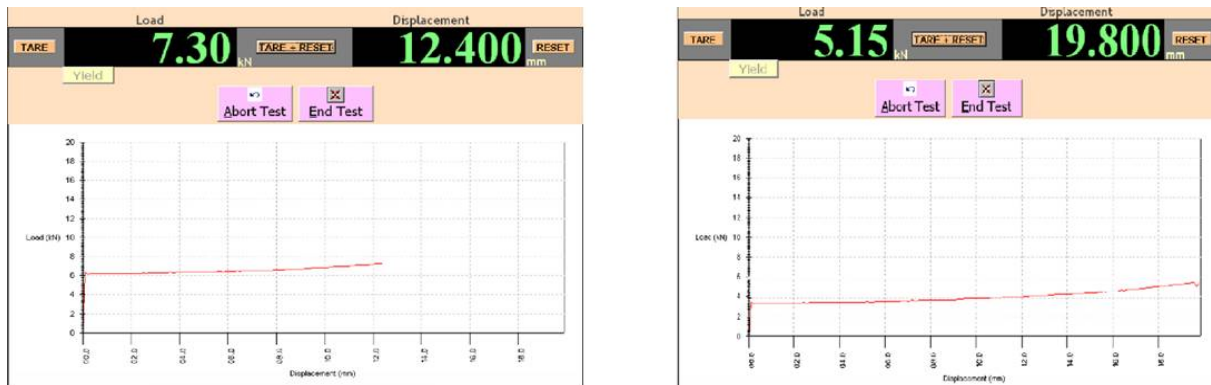


Figure [7]:- Stress strain curve for CASTOR OIL and powder with the presence of electric field and without the presence of electric field.

The stress strain curve for castor oil and copper powder mixture is represented by figure [6] in the presence of electric field and absence of electric field. The force exerted is directly proportional to stiffness in the presence of electric field.

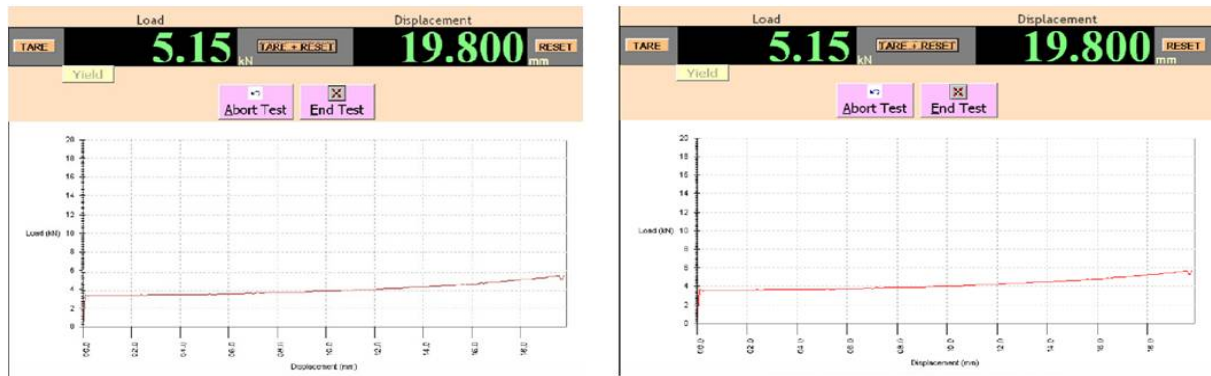


Figure [8]:- Stress strain curve for HONEY and powder with the presence of electric field and without the presence of electric field

The stress strain curve for Honey and copper powder mixture is represented by figure [6] in the absence of electric field and presence of electric field. The force exerted is directly proportional to stiffness in the presence of electric field.

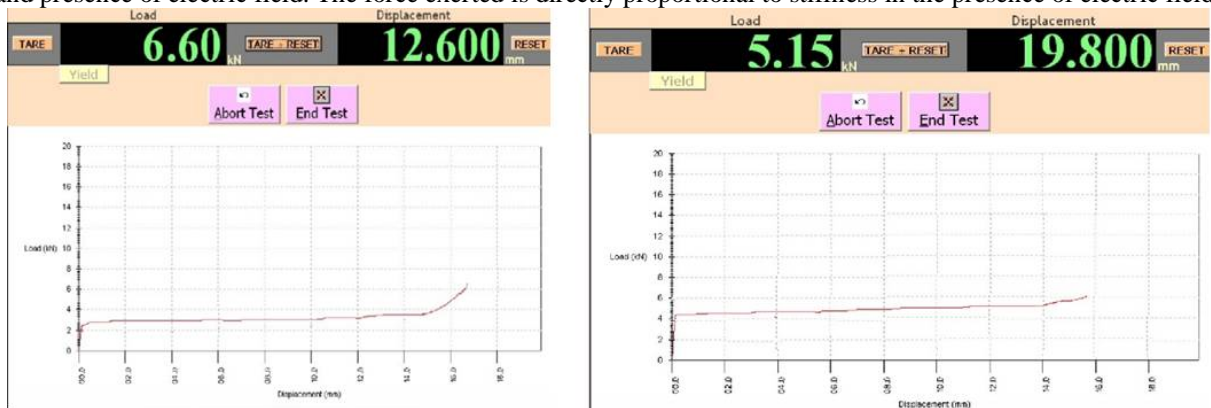


Figure [9]:- Stress strain curve for SHAMPOO and powder with the presence of electric field and without the presence of electric field.

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The stress strain curve for shampoo and copper powder mixture is represented by figure [6] in the absence of electric field and presence of electric field. The force exerted is directly proportional to stiffness in the presence of electric field.

It is clear from the graphs obtained above that there is a drastic increase in the curve whenever the electric field is applied for different proportion of mixture. The force exerted varies the stiffness accordingly.

V.CONCLUSION

There are various age groups, 15-20, 20-40 and 60and above who exert different amount of force on the shoe sole while doing various activities. The fluid mixture can exhibit different stiffness at different electric field, which in turn varies with the force applied on the crystals(AC generated can be converted to DC using an IC). There are various methods available for utilising the piezoelectric energy. In particular, Piezocrystals are economical as it has low cost, flexibility and easy integration into shoe soles. In this paper battery of 9Vand its electric field along with various rheological fluids are used to design a variable stiffness sole of a shoe. This also makes use of the energy generated and helps in varying the stiffness according to the requirement of each human being. It can be used by a variety of people who apply different amount of force on their feet and need different stiffness. In order to optimize the maximum energy transfer, number of the piezoelectric crystals to be integrated into the shoe sole must be increased, which allows to vary the stiffness a lot more. From the graph it is clear that material gets stiffer with the increase in electric field as it follows the equation,

$$F = K * X$$

Where F is the yield load, X is deflection and K is stiffness. In the above equation the displacement remains constant, hence the stiffness varies with the force applied.

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