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A Study on the Viscosity of Viscoelastic Magnetic Abrasive Gel under Different Volumetric Proportions

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ABSTRACT

In the present study, the Viscosity of the Viscoelastic Gel used in Magnetic Abrasive finishing is analysed based on the test conducted on the Compact Rheometer. Silicon-based Transformer oil is used as the base oil and Aluminium Stearate is used for increasing the abrasive holding capacity under very high magnetic field strength. The media prepared is commonly used for performing Nano-finishing of various metals' internal and external surfaces. The Viscosity of AP3 Grease, transformer oil and silicon oil is computed and compared using Rheometer, and the sample of viscoelastic Magnetic Abrasive media is prepared using these base oil. Six samples have been tested and the results have been analysed. The Media selected for the Viscoelastic magnetic abrasive finishing is tested after 30 days of preparation and compared its viscosity with the freshly prepared medium. The result highlighted the successful application of transformer oil and Silicon oil to prepare gel for the viscoelastic Magnetic Abrasive Finishing process.

1. Introduction

The importance of computational fluid flow has shaped the dynamics of the modern flow system and improved products and manufacturing quality. A recent example is the MAF and AFM process in which the machining operations occur due to the flow of Media inside the constrictive passage. The Media used in the Magnetic Abrasive flow Finishing is non-newtonian. The Media is a mixture of Abrasive, Gel and polymer, due to which viscosity plays a significant role in the machining operations. Many scholars have worked on the non-Newtonian fluid and contributed to the development and analysis of the non-Newtonian fluid in various aspects. Various research has been carried out for the flow governing peristaltic movement in porous walls, which acts as a reference for the non-newtonian fluid flow [1-6].

The viscoelastic Magnetic Abrasive finishing process is one of the leading solutions in the field of the nano finishing process. It consists of carbonyl particles along with abrasive and viscoelastic putty, allowing the viscoelastic putty to act along the line of the magnet. The carbonyl particles present in

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the viscoelastic putty get attracted toward the magnet. As a result, a magnetic brush is formed. The machining process occurs when this brush is rotated over the surface of the workpiece for effective machining.

A similar process may be applied when machining the internal surface of the hollow workpiece. Here the viscoelastic magnetic abrasive Media is allowed to reciprocate within the boundary of the workpiece, where the workpiece is placed co-axially along the cylindrical workpiece and the magnet is placed around it. The carbonyl particle in the media would be attracted towards the wall of the workpiece due to the magnetic field. Thus, effective machining occurs due to magnetic forces and the finishing process.

Many researchers modelled the viscoelastic Magnetic Abrasive Finishing process and studied the media's flow parameters. The researchers study the effect of Extrusion pressure, no of cycles, Abrasive mesh size, Media viscosity, abrasive, Type of Abrasive particles, Size of carbonyl particles, and Base oil for viscoelastic media and gel [7-11]. The concept of preparation of viscoelastic fluid is confined to the viscoelastic magnetic abrasive finishing and abrasive flow machining. The primary difference between the media of Abrasive Flow Machining and viscoelastic Magnetic abrasive finishing is that the media of AFM does not contain carbonyl particles, but the synthesis process remains the same [12-15].

2. Methodology

In this article, a brief discussion will be made about the linear Viscoelastic Models. Subsequently, a Viscoelastic Magnetic abrasive Medium preparation will be discussed. In total, 7 Viscoelastic Magnetic Abrasive Media have been prepared and their Viscosity has been tested using Modular Compact Rheometer (MCR 102). The graphical Results have shown the shear stress vs shear strain and shear stress vs viscosity and are also validated [16]. Based on this, a suitable Viscoelastic Magnetic Abrasive Medium has been proposed for the internal finishing of the Complex surface and the external surfaces. In the present research, the abrasive medium prepared is known as Viscoelastic Magnetic Abrasive Medium, specially prepared for performing both internal and external finishing of metallic specimens. The main problem found during the literature review is that the medium used for Magnetic abrasive finishing experiences sedimentation of the heavier particles [17,18].

In Magnetic Assisted finishing process, the Carbonyl Iron particle's density is higher than the Abrasives used. As the CIP particle settles down before and after exposure to the magnetic field, it becomes difficult to form the CIP chain under the Magnetic field. So, a Viscoelastic medium that addresses the sedimentation is prepared and experiments have been performed to find the viscosity before choosing a suitable medium. Materials with Viscoelastic properties exhibit both Viscous behaviour and Elastic behaviour. Most of the materials exhibit Viscoelasticity, both Natural and artificial. However, the dominance of Viscosity or Elasticity depends upon the individual material prepared and the operating conditions. All the Rheological materials will exhibit Viscoelastic properties. When a material is under Static loading, the Elastic behaviour dominates, whereas the Viscous behaviour dominates with Dynamic loading.

2.1 Viscosity Measurement

The Viscosity and Rheology measurement could be done using three different equipment pieces. Each piece of equipment has a specific purpose and would be used depending upon the type of loading. The types of equipment used for measuring Viscosity/Rheology are:

a) Rotational Viscometer: Used for Steady loading conditions. The probes used for this purpose are Cylindrical, Flat plates having Circular cross-sections and Conic sections. For measuring fluids with Very high viscosity, the flat plate Viscometer is usually preferred.
b) Oscillatory Rheometer (Viscometer): Used for finding the viscosity when the force Associated with it is Oscillatory or bending force.
c) Transient Condition Rheology tester: This equipment is the advanced version of the SteadyState Viscometer, in which the variation in the deformation of the specimen with time under impulsive loading would be measured.

In the present research work, Modular Compact Rheometer (MCR 102), a RotationalViscometer, is used to find the Viscosity of the Viscoelastic Magnetic Abrasive Finishing Medium, especially prepared.

The critical part associated with the Rheometer is as follows:

a) Measuring Head: Holds the rotating probe known as PP 50 measuring system.
b) MICR coupling: A part used for holding the rotating probe.
c) Flange ring: Holds the Temperature device holder.
d) Colour Display: Displays the temperature, position in mm, Normal force and status.
e) Soft keys: Used for initiating different operations of the instrument.
f) Adjustable feet: For making the platform plane.

Figure 1 shows the schematic diagram of the modular compact Rheometer and Figure 2 shows the experimental setup. Figure 2(i) shows the actual experimental setup, while Figures 2 (ii), Figure (iii) and Figure (iv) show the different types of measuring probes used for the measurement of viscosity. Plate-Plate filling and plate cone filling are used for the present work.

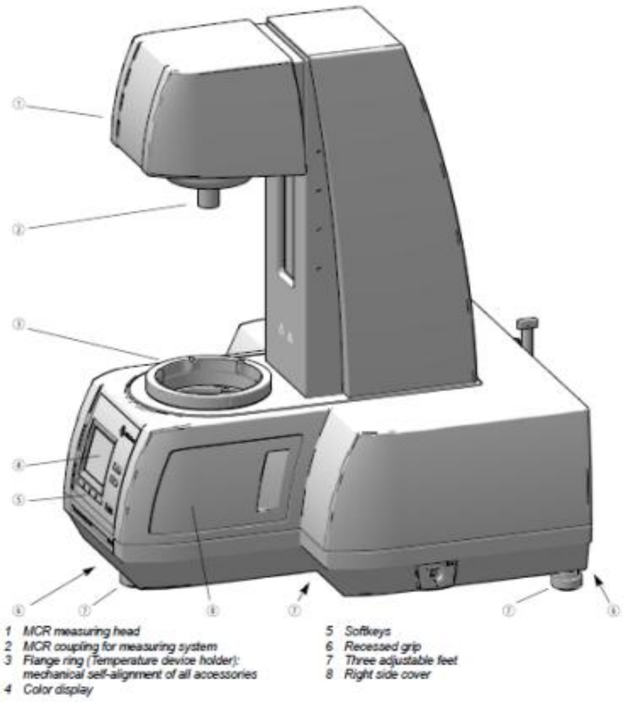

Fig. 1. Modular compact rheometer with important parts

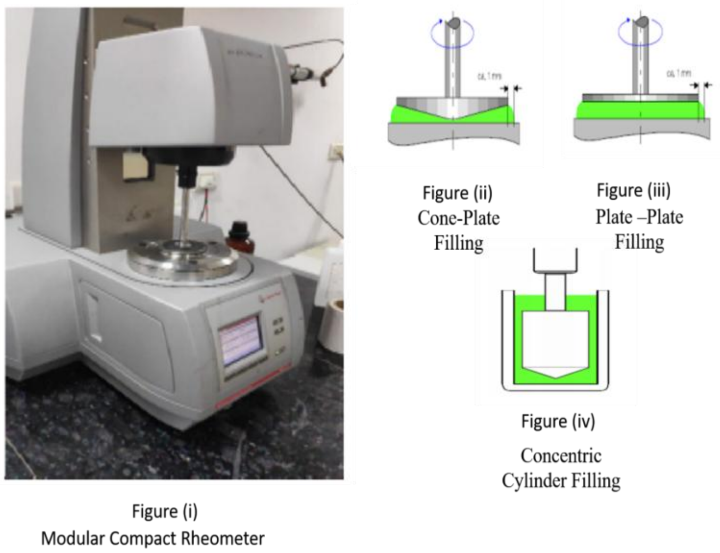

Fig. 2. Experimental setup (i) modular compact rheometer (ii) Cone Plate Filling (iii) Plate-Plate filling (iv) Concentric Cylinder Filling

2.2 Viscoelastic Magnetic Abrasive Medium Preparation

In the present work, Sevensamples have been prepared, and their viscosity has been measured using MCR 102. Initially, the viscosity of the Rheological fluids used in preparing the samples was measured and based on the experimental results, the base fluid for preparing the ViscoelasticMagnetic abrasive finishing (VEMAF) Medium has been decided. Subsequently, adding the required ingredients has taken place, producing the required Viscoelasticmedium [19-21]. By adding the mixture of Carbonyl Iron Particle (CIP) of CS grade and the Silicon Carbide abrasive in predefined proportion with the Viscoelastic Medium, the requiredViscoelastic Magnetic abrasive Medium has been prepared.

Three types of Viscousfluids and AP3 grease have been considered for preparing the samples, and they are as follows:

a) Transformer Oil (white)
b) Transformer Oil (Red)
c) Silicone Oil
d) AP3 Grease

While performing the viscosity measurement experiment for the base fluids mentioned at 1 to 3 above, a Plate-Plate filling type probe was used and for the AP3 Grease Cone-Plate A filling-type probe has been used. The sample has been placed below the probe, which is initially compressed and then the probe starts rotating, which in turn induces shear stress and shear strain on the sample. The sample quantity depends upon the gap between the probe and the platform. The experimental results are shown below.

From the Graphs for Viscosity Vs Shear strain and Shear Stress vs ShearStrain for White Transformer oil, it may be noted that after initial disturbance, viscosity is almost constant and obtained an average value of 12.183 mPa-s and the Shear stress vs Shearstrain is maintaining a constant slope from point 11 in the table.

From the tabulated data and the Graphs for Viscosity Vs Shear strain and Shear Stress vs ShearStrain for Red Transformer oil, it may be noted that viscosity drops to a lower value for a strain rate of 1.2 after that, viscosity is almost constant and obtained an average value of 20.466mPa-s and the Shear stress vs Shear strain is maintaining a constant slope from the point 11 in the graph.

From the tabulated data for Silicone oil, it may be noted that the viscosity of the Silicone oil is almost constant within the experimental range and has a magnitude of 236.2 mPa-s. Also, the Shear Stress-Shear Strain curve is almost linear. Based on the results obtained above, Silicone oil and Red transformer oil have been chosen as the base Rheological fluids for making the Viscoelastic Magnetic Abrasive Medium.

Figure 3 shows the viscosity measurement results for the transformer oil red, Transformer oil White and silicone oil. The graphs were made based on tabulated data obtained from the modular compact Rheometer.

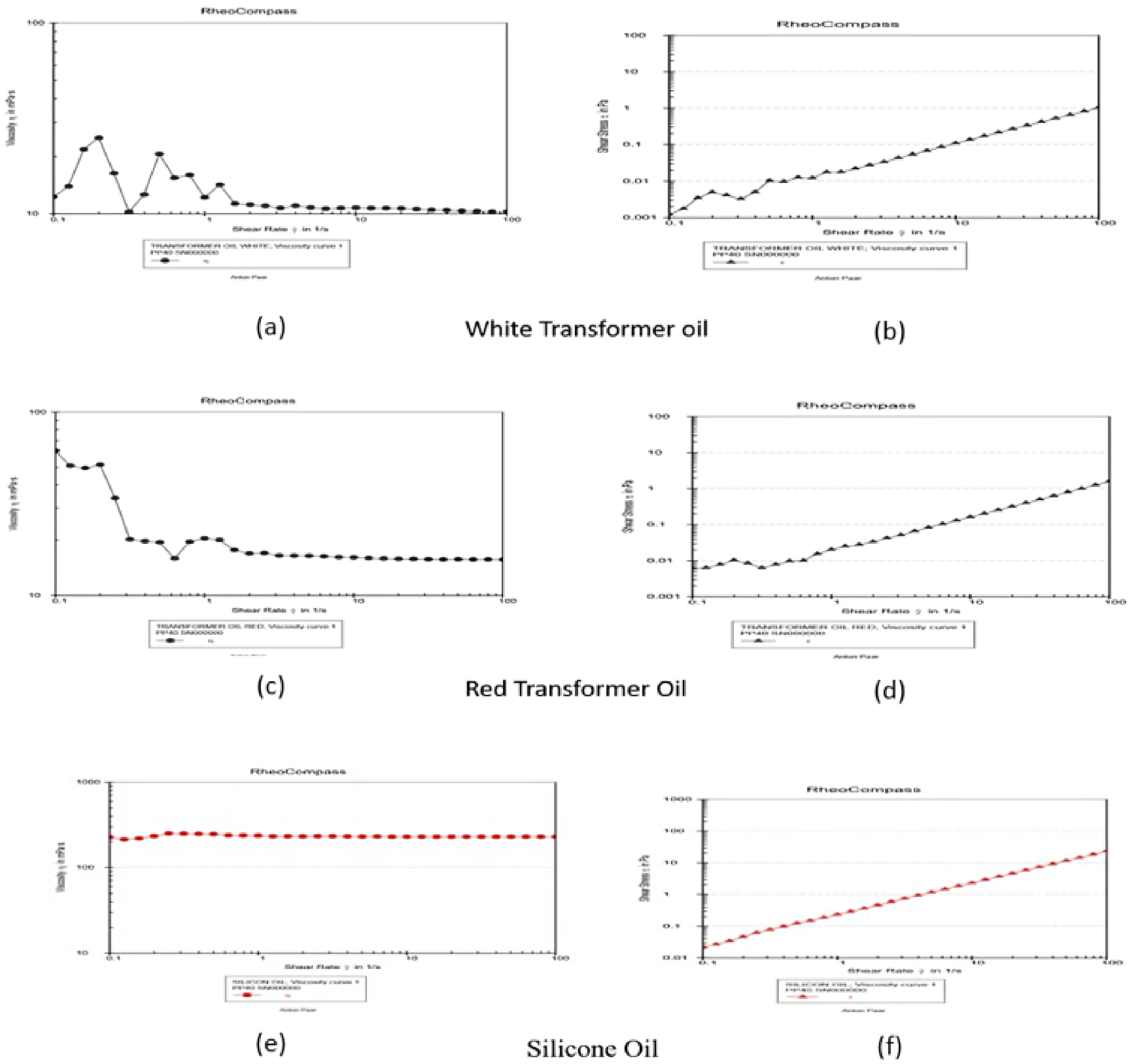

Fig. 3. Viscosity measurement for Transformer oil and the silicon oil (a) viscosity vs shear strain for white transformer oil (b) shear stress vs shear strain for white transformer oil (c) Viscosity VS shear strain for red transformer oil (d) Shear stress vs shear strain for red transformer oil (e) viscosity vs shear strain for silicon oil (f) Shear stress vs Shear strain for the silicone oil

2.3 Preparation of Silicone Oil-Based Vemaf Medium

The preparation has got the following steps.

2.3.1 Preparation of polymer

Mixing 1000 ml Silicone oil with 50 grams of Boric acid thoroughly and heating from room temperature up to 60° C makes the required polymer which would be white. Here, the cross-linking of Silicone oil's chained structure with Boric acid occurs. Figure 4(i) below shows a schematic representation of Cross-linking. Subsequently, 10 Lewis acid grams were added at 40° C of temperature, followed by adding ammonium Carbonate and heating up to boiling temperature along with Continuous stirring, bringing the final stage to the polymer, which is having pale yellow colour shown in Figure 4(ii) below. Cooling takes place in the open atmosphere. The prepared polymer will behave as a Viscous medium in the Viscoelastic Magnetic Abrasive Finishing Medium and has a marginal reduction in viscosity compared to the Silicon oil Figure 4(iv).

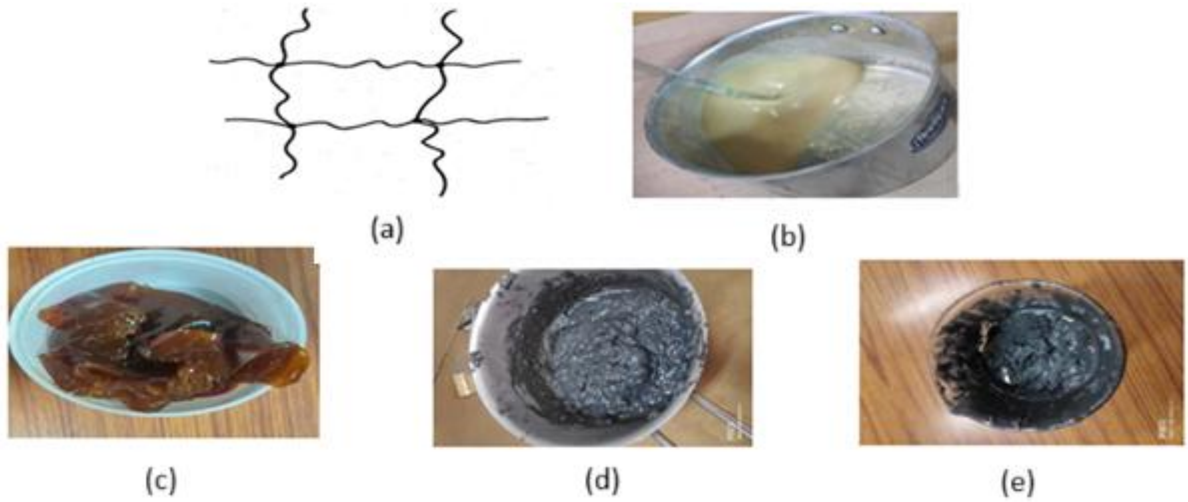

Fig. 4. (a) Cross-linking polymers (b) Prepared Polymer (c) gel (d) Silicone oil-based Magnetic Abrasive Media (e) Transformer oil-based viscoelastic magnetic abrasive based Media

2.3.2 Preparation of gel

The gel is prepared with the chemical reaction of the hydrocarbon oil and the aluminium stearate. 500 ml of the Hydrocarbon oil and 25 grams of Aluminium Stearate are mixed thoroughly and heated up to 120 degrees Celsius. The Product obtained is called the gel, having red colour and very high Viscosity [21-23].

2.3.3 Mixing of carbonyl iron particle and silicon carbide

Carbonyls Iron Particles (CIP) of CS grade and Silicon Carbide(SiC) of Abrasive Mesh Numbers 320, 400, 600 and 800 have prepared the mixture. The density of CIP is approximately 7.2 grams per cm3 and the Sic powder from the manufacturers' catalogue has a density of 2.6 grams per cm3. Carbonyl particles and Silicon Carbide have been taken in a ratio of 3:1 by weight. Separately, the mixture has been prepared for each abrasive Size. A ball mill has been used to mix CIP and the abrasive powder thoroughly.

2.3.4 Final mixing

Here, the polymer and the gel have been mixed in a ratio of 8:1 by weight Thoroughly by Gel mixing machine. Now the Polymer-Gel medium hence prepared, is mixed with CIP- Abrasive mixture in a ratio of 2:1 by weight and finally, the viscosity of the Viscoelastic Magnetic Abrasive medium has been found. This medium is used for the Internal finishing of the Spline shafts.

2.4 Preparation of Transformer Oil (Red)-Based Viscoelastic Magnetic Abrasive Medium

The following steps are followed in sequence for making the Viscoelastic Magnetic abrasive Medium.

a) 1000 ml Red transformer oil is heated till the moisture is removed. 500 ml Transformer oil is heated up to 50° C, and 50 grams of Sodium Stearate is added and thoroughly stirred until a thorough mixing occurs. This will make the medium thick compared to its initial condition.
b) Further heating up to around 150° C will saponify the mixture and it becomes further thick. The water content left is removed.
c) The remaining 500 ml transformer oil is heated up to 40O C, and Simultaneously 50 ml boric acid solution and 50 ml Sodium hydroxide solution are added and thoroughly stirred. This converts the transformer oil to highly viscous.
d) Viscous oil, both the saponified semisolid and the viscous transformer oil, were mixed thoroughly at 50° C and stirred for 60 minutes. An antioxidant solution of 1% concentration is added. This gives Viscoelastic medium.
e) Now the Carbonyl Iron Particle and SiC mixture in a 3:1 ratio by weight have been mixed Thoroughly in the ball mill.
f) Now the Viscoelastic medium and the CIP and SiC powder in 1:3 ratios by weight have been mixed and thorough stirring takes place by the Chemical stirrer. This makes the Viscoelastic Magnetic Abrasive Medium.

The Viscoelastic Magnetic Abrasive Medium prepared based on Transformer oil (Red colour) has a Viscosity of 2926.2 mPa-s (Milli Pascal-Second). This lies in the viscosity of semisolids. Also, Shear-thinning is observed as a decrease in Viscosity with Shear strain.

2.5 Preparation of Viscoelastic Magnetic Abrasive Medium Based On AP3 Grease

The Carbonyl Iron Particle and Silicone Carbide abrasive mixture have been added to the AP3 grease, and a semisolid is prepared. The viscosity of each sample is found.

2.5.1 AP3 grease-based viscoelastic magnetic abrasive medium lab sample 5

In this sample, 30 grams of AP3 Grease and 10 grams of CIP and SiC mixture is thoroughly Stirred, and the sample has been tested for viscosity using MCR 102. The viscosity obtained is 1640mPa-s. The results are given below. Graph.3.17 and Graph.3.18 show the relation between Viscosity Versus Shear strain and Shear stress versus Shear Strain.

2.5.2 AP3 grease-based viscoelastic magnetic abrasive medium lab sample 6

In this sample, 30 grams of AP3 grease and 15 grams of CIP- SiC mixture is thoroughly mixed and the sample has been tested for viscosity. The graphs show a relation between Viscosity Versus Shear strain and Shear stress versus Shear Strain.

2.5.3 AP3 grease-based viscoelastic magnetic abrasive medium lab sample 7

In this sample, 30 grams of AP3 grease and 20 grams of CIP- SiC mixture is thoroughly mixed, and the sample has been tested for viscosity.

2.5.4 AP3 grease-based viscoelastic magnetic abrasive medium lab Sample 8

In this sample, 30 grams of AP3 grease and 30 grams of CIP- SiC mixture is thoroughly mixed and the sample has been tested for viscosity.

3. Results and Discussion

All the prepared samples were tested under the Compact Rheometer and their Viscosity vs strain rate curves were obtained. Also, Graphs were plotted for the shear stress vs strain rate. Figure 5 shows the obtained graph for various samples. The Viscoelastic Magnetic Abrasive medium is 30 days old viscoelastic magnetic abrasive media, and the graph of viscosity vs strain rate for polymer and gel is also plotted in the following Figure (Figure 6). The results are shown in the graph.

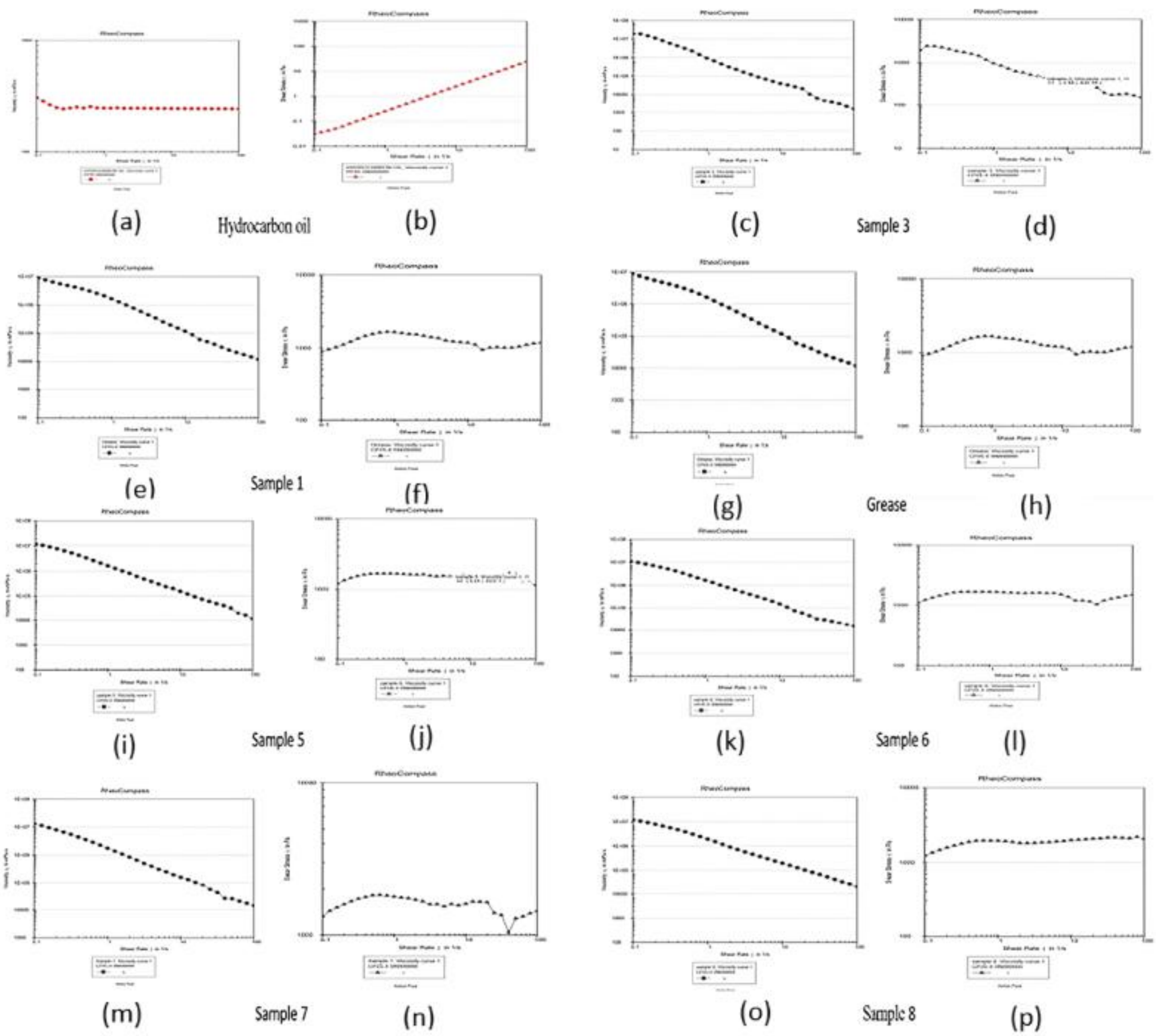

Fig. 5 Viscosity vs shear strain and shear stress vs shear strain graph for hydrocarbon oil, Sample 3, Sample 1, Grease, sample 5, Sample 6, sample 7 and sample 8. Fig 5 (a) Viscocity vs Strain rate hydrocarbon oil (b) shear stress vs strain rate (c) viscosity vs strain rate sample 3 (d) shear stress vs strain rate for sample 3 (e) viscosity vs strain rate sample 1(f) shear stress vs strain rate sample 1 (g) Viscocity vs Strain rate grease (h) shear stress vs strain rate for grease (i) viscosity vs strain rate sample 5 (j) shear stress vs strain rate sample 5 (k) viscosity vs strain rates sample 6 (l) shear stress vs strain rate sample 6 (m) viscosity vs strain rate sample 7 (n) Shear stress vs strain rate Sample 7 (o) viscosity vs strain rate Sample 8 (p)shear stress vs strain rate sample 8

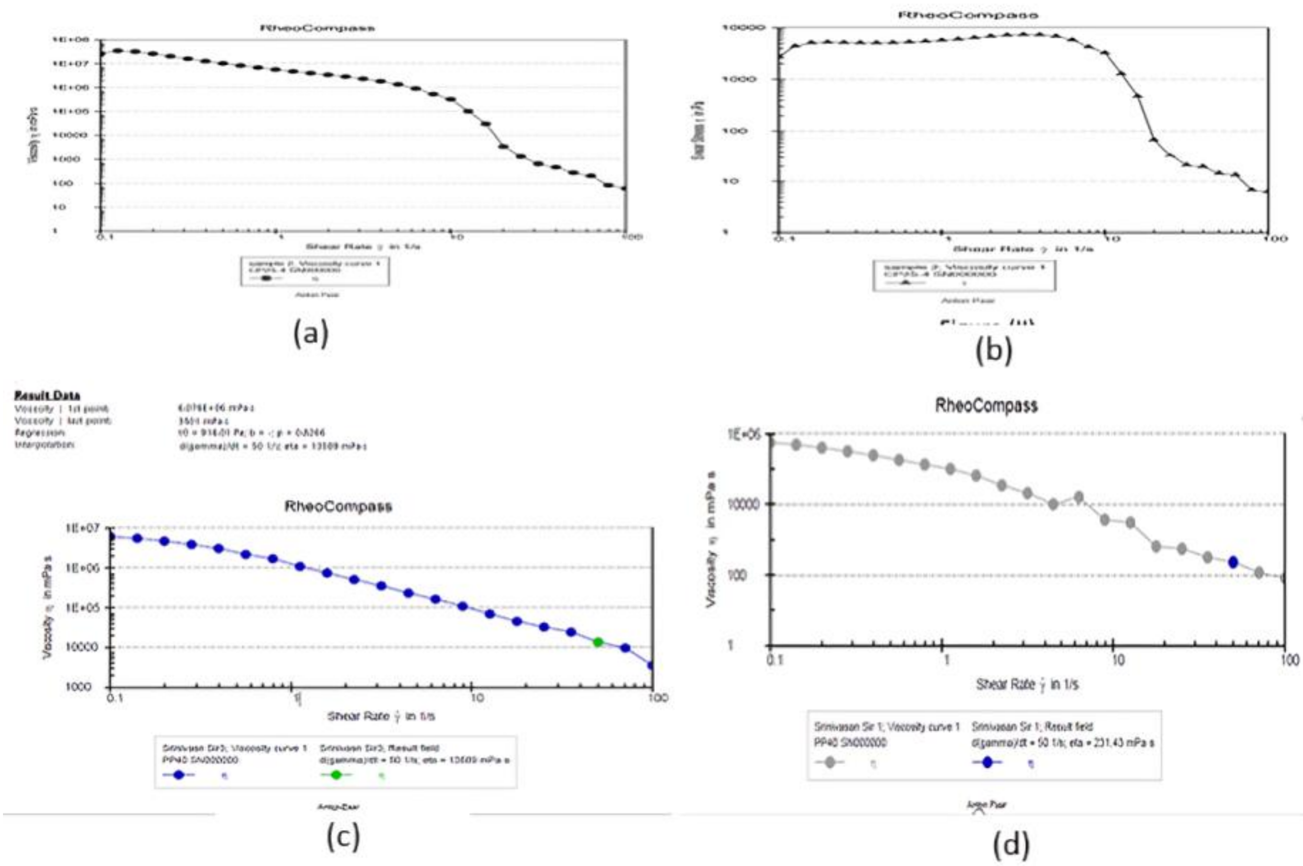

Fig. 6 Viscocity vs strain rate for 30 days old sample for VMAF Media, Gel and polymer 6 (i) Viscocity vs strain rate for 30days old VMAF sample (ii) Shear stress vs strain rate for a 30-day old sample of VMAF (iii) Viscocity vs Strain rate for gel (iv) Viscocity vs strain rate for polymers

4. Conclusions

In the present research, an attempt was made to prepare a gel for the VMAF process using different types of hydrocarbon oil as the base material. The researcher also computed the viscosity of transformer oil (Red and White), Grease, Hydrocarbon oil and silicon oil wittth the help of a Rheometer and predicted their application for the Viscoelastic Magnetic Abrasive Finishing Process. The researchers concluded the following points:

a) A total of six Viscoelastic Magnetic abrasive media have been prepared and their viscosity tested.
b) The Viscosity of the AP3 Grease-based Viscoelastic Magnetic Abrasive Media has shown an increase in the viscosity with the increase in the proportion of CIP-Abrasive Powder. However, with the increased temperatures during the finishing operations, there is a higher chance of reduction in the viscosity.
c) White transformer oil could not be used due to its instability during the initial loading period.
d) Silicone oil-based Viscoelastic Magnetic Abrasive Medium is preferred for internal Finishing. The sample also showed flow ability.
e) The viscosity of the Silicone oil has drastically increased from 954.06 mPa-s to 5688 mPas in 30 days from the date of preparation, and at this higher viscosity, this medium can't be used for finishing operation.

The viscosity of the Media is the major parameter for machining the workpiece, as the viscosity holds the abrasive particles and the polymer provides the flow to the media. The gel provides viscosity. Thus, selecting the proper base oil for the preparation of gel results in effective machining for the AFM and MAF process.

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