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Research Article

EFFECT OF RECYCLED PLASTIC WASTE ON RHEOLOGICAL MODIFICATION OF CALCIUM GREASES

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ABSTRACT

There is a growing interest on the development of new materials based on recycled polymers from plastics waste, since the use of such plastics represents a low-cost source of raw material. The aim of the present work is to prepare and evaluate calcium lubricating greases based on mineral oil and recycled high density polyethylene. On this way, the influence of recycled HDPE concentration on the rheological, thermal and mechanical properties of prepared greases was explored. The flow and viscoelastic properties of the prepared calcium greases with and without recycled HDPE have been studied by programmable Rheometer HADV-III ultra system. This system operates either in a steady rotation or in an oscillatory mode. Data reveals that, the flow behavior depends on a large extent of the contents of the recycled polymer. Mathematical models based on Herschel-Bulkley, Bingham and Casson equations were applied for fitting the experimental data. It was concluded that the values of both apparent viscosity and consistency index increases with recycled HDPE concentrations. Also, recycled HDPE was found to be an effective additive to modify the rheological properties of prepared calcium grease.

Keywords: Calcium lubricating grease, Flow behavior, Rheological modifier, Recycled polyethylene

1. INTRODUCTION

Lubricating greases are generally highly structured colloidal dispersions, consisting of a thickener dispersed in mineral or synthetic oil. Fatty acid soaps of lithium, calcium, sodium, aluminium and barium are most commonly used as thickeners. These thickeners form an entanglement network, which traps the oil and confers the appropriate rheological and tribological behaviour to the grease[1,2]. Grease lubrication is dependent on the base oil being released slowly and sufficiently under load and the delivery depends strongly on temperature[3]. Grease, by its nature, cannot dissipate heat by convection like circulating oil. Consequently, without the ability totransfer heat, excessive temperatures result in accelerated oxidation or carbonization, where grease hardens or forms a crust. The presence of these oxidation products in lubricating greases may lead to an increase in viscosity which might be detrimental to the gel structure causing an adverse effect on lubrication[4,5].

In some cases, it is desirable to incorporate polymers into a grease formulation, such as polyisobutylene, styrene–butadiene copolymer, styrene– isoprene block-copolymers or ethylene–propylene copolymers. These usually play a significant role as additives in greases for modification of some performance characteristics such as dropping point, appearance, tackiness, water resistance and bleed[6], all of these related to the ability to act as rheological properties modifiers[7,8,9]. The selection of a suitable polymer as additive may offer added advantages; thus by proper matching of polymer, thickener and base oil, it should be possible to obtain an optimized formulation with maximum performance characteristics[6]. These polymeric additives can be usually added at the final stage of grease manufacturing process. The rheological modification induced by polymeric additives affects the viscoelasticity of lubricating greases, which is important for preventing loss of lubricant or reinforcing sealing properties, but also the flow properties under working conditions[10,11]**.** The use of recycled polymers is continuously increasing; the problem of post-consumer recycling of these materials has become an important issue for economic and environmental reason[12,13,14]**.**

Accordingly, the aim of the present work is to prepare and evaluate calcium lubricating greases based on heavy base mineral oil and recycled high density polyethylene. On this way, the influence of recycled HDPE concentration on the rheological, thermal and mechanical properties of prepared greases was investigated

2. MATERIALS AND METHODS

2.1. Materials:

Stearic acid, rosin (colophony) and calcium hydroxide were kindly supplied by Morgan Co. Heavy base oil was kindly supplied by Suez oil Processing Company. The recycled HDPE was obtained from local company of recycled waste polymers.

2.4. Grease Preparation:

Four grades of calcium grease designated G_0%, G_2% and G_4%, G_6% were prepared based on the ingredient concentrations of heavy base oil, lime**,** colophony as mentioned in Table (1). The prepared greases were made in batches of one liter in an open kettle with a capacity of 2 liter, fitted with a mechanical stirrer. The saponification process was performed on a mixture of heavy base oil and stearic acid with calcium hydroxide, at 100-110°C. The reaction time for each saponification process to achieve a soap structure was found to be dependent on the type of constituent. After the completion of the reaction, the different concentrations from of recycled HDPE were added, the reaction mixture was cooled gradually while heavy base oil was added to get NLGI-2. The consistency and drop point of the prepared greases were then determined. A penetration test was done using the standard ASTM D-217 method, the dropping point was assessed with ASTM D-566 Oil Separation (ASTM D-1724) and Copper Corrosion Test (ASTM D-4048).

Rheological measurements, this test was performed on a Brookfild programmable Rheometer HV DV-III UITRA used in conjunction with Brookfild software, RHEOCALC V.2, through RHEOCALC all Rheometer function (rotational speed, instrument % torque scale time interval, set temperature) are controlled by a computer. The corresponding shear stress shear rate, dynamic viscosity, mathematical model and confidence of fit consistence index were also recorded by the software.

3. RESULT AND DISSECTION

3.1. Physicochemical Properties of the Prepared Greases:

Table (2) shows that the Physicochemical and mechanical properties for prepared greases under investigation. Dropping point generally determines the thermal stability of the lubricating greases. The experimental data in this table show that the prepared greases G_0%, G_2%, G_4%, and G_6% had dropping points 95, 100, 110, and 120°C, respectively. . We noted that the better thermal performance of greases is G_4% and G_6%, which they have dropping points are 110 and 120°C respectively. On other hand, oil separation test has tendency of lubricating grease to separate during storage. In this respect, experimental data of oil separation for prepared greases in table (2) show that greases G_0%, G_2%, G_4%, and G_6% have percentages of oil separation less than 5%. Also, data of copper strip corrosion test of the prepared greases under study showed that greases G_0%, G_2%, G_4%, and G_6% didn't corrode copper parts.

The apparent viscosity of prepared greasers was clearly increased with increasing of recycled HDPE concentrations as presented in Table 2. So, this reveals that the high content of recycled HDPE acts as a rheological modifier for the prepared greases[18,19].

3.2. Mechanical Stability of Prepared Greases:

The effect of mechanical work at different double strokes from 1000 to 5000 strokes on penetration for the prepared greases (G_0%, G_2%, G_4%, G_6%) was illustrated in Figure (1). This figure shows that the role of recycled HDPE for prepared greases under investigation. . Also, the penetration values of these greases increased in the following order G_6 % < G_4 % < G_2 % < G_0 %.

3.3. Thermal Stability of Prepared Greases:

The measurement of dropping point generally determines the thermal stability of grease. In this respect, structural changes in lubricating greases due to temperature are mainly due to phase changes in the thickening agent. As the temperature lubricating greases is raised, the thickener softens stepwise due to phase transitions. At lower temperature, such softening may be great enough to permit the grease to flow[20]. Figure (2), shows that the variation of the dropping point with the mechanical work at different double strokes from 1000- 5000 as a function of binding forces between ingredients and degree of compatibility of recycled HDPE with calcium soap.

It shows that with the increase of the mechanical work the dropping points decrease in the following order: G_6 % > G_4 % > G_2 % > G_0 %. This explanation consistent with the apparent viscosity and penetration values for greases under investigation.

3.4. Rheological Characterization:

In order to predict the role of lubricating greases in the lubrication of moving parts, knowledge of their rheological properties within a wide range of temperature and stress is essential, because these properties are major factors that determine the strength of the three-dimensional network of lubricating greases. The lubricating greases are two phase colloidal suspensions consisting essentially of mineral oil in addition to a metal soap and additives. The additives are widely used in the industry as rheology modifiers at both low and high temperatures[21,22]. In this respect, the rheological behaviors of prepared greases were determined at 80 °C, 90 °C, and 100 °C and at different concentrations from recycled HDPE polymer. The viscosities of prepared grease are affected by the concentration of recycled HDPE as shown 5650, 8246, 11380, 15333 for G_0%, G_2%, G_4%, G_6%., respectively.

Figures (3-5) show that there are two distinct flow regions the first region, at low shear rate up to 5 S^{-1} reveal that the apparent viscosity decreases with shear rate increase, indicating that the rheological flow (deformation) of greases with different concentration of recycled HDPE polymer. But the flow curves at high shear rate show steady state in the second region, this reflect that the greases exhibits less dependence on shear after shear rate 5 s^{-1} [15,16].

From a rheological point of view the development of a grease formulation should consider both the linear viscoelastic and viscous responses. Thus, greases must be designed to prevent loss of lubricant but also they cannot yield a significant increase in the resistance of the motion of rubbing surfaces.

3.4.1. Rheological Models:

The rheological models have been proposed to describe the calcium greases behavior:

Bigham model $$\tau = \tau_y + \eta \dot{\gamma}^n \quad (1)$$

Herschel – Bulkley model

$$\tau = \tau_y + K \dot{\gamma}^n \quad (2)$$

Casson model

$$\tau^{1/2} = \tau_0^{1/2} + \eta_c^{1/2} \dot{\gamma}^{1/2} \quad (3)$$

Where, τ is shear stress

The results from the Rheometer calc measurement are presented in the tables (3) as results from fitting the rheological model of the measurement. Confidence % for each of the rheological models, it can to observe that the most appropriate models for prepared greases are Herschel-Bulkle. From the same point of view, the rheological models with the smallest Confidence % are the Bingham and casson models[17].

CONCLUSIONS

From the above result obtained, it can be deduced that the recycled HDPE can be potentially used as an effective rheological modifier of calcium lubricating greases. Apparent viscosity and linear viscoelasticity functions increase with increasing recycled HDPE polymer concentrations. The bulk rheology of calcium greases can be described in optimum conditions by Herschel-Bulkle model.

Table 1
Ingredients of the prepared greases

Type of Grease Ingredient, Wt%	G_0%	G_2%	G_4%	G_6%
Heavy base oil	80.0	80.2	81.4	81.5
Stearic acid	12.0	10.5	8.0	6.5
Calcium hydroxide	3.0	2.8	2.6	2.4
Colophony (Rosin)	5.0	4.5	4.0	3.6
Recycled HDPE	0.0	2.0	4.0	6.0

Table 2
Physicochemical properties of the prepared greases

Test	Prepared greases				Test method
	G_0%	**G_2%**	**G_4%**	**G_6%**	
Penetration at 25^{o}C Unworked	295	291	288	280	ASTM D-217
worked	300	296	290	290	
Dropping point, ^{o}C	95	100	110	120	ASTM D-566
TAN, mg KOH/gm, @72h	1.3	1.6	1.8	1.0	ASTM D-664
Oil separation, Wt%	2.5	2.0	1.7	1.2	ASTM D-1724
Oxidation Stability at, 99^{o}C, 96h, pressure drop, psi	3.5	6.9	8.5	3.4	ASTM D-942
Copper Corrosion 3h/100^{o}C	Ia	Ia	Ia	Ia	ASTM D-4048
Code Grease According to NLGI	2	2	2	2	
Egyptian Standard	LB	LB	LB	LB	
Apparent Viscosity, cP @ 80 ^{o}C	5650	8246	11380	15333	ASTM D-189
Yield stress, D/cm^{2}	86.9	188.7	257	319	

Table 3
Viscoelastic parameters for selected prepared greases, of Herschel Buckley at different temperatures

Test	@ 80 ^{o}C				@ 90 ^{o}C			
	G_1	**G_2**	**G_3**	**G_4**	**G_1**	**G_2**	**G_3**	**G_4**
Consistency index	1068	7186	23729	17903	2800	7067	17326	10228
Yield stress, D/cm^{2}	96.1	112.9	32	152.3	775	839	62.4	0.10
Flow Index	1.1	055	028	037	0.78	0.46	0.31	0.5
Confidence	99.8	99.3	99.4	99.6	99.5	99.8	99.3	99.5

Test	@ 100 ^{o}C			
	G_1	G_2	G_3	G_4
Consistency index	1196	1428	1149	10253
Yield stress, D/cm^{2}	77.8	15	88.9	72.8
Flow Index	0.99	0.34	0.47	0.46
Confidence	99.8	99.5	99.9	99.6

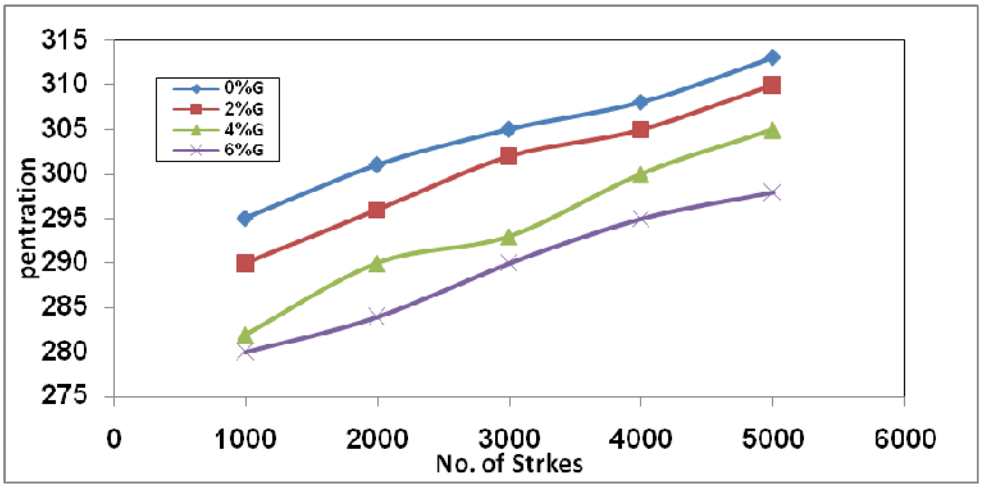

Figure1
Effect of mechanical working on the penetration for prepared greases

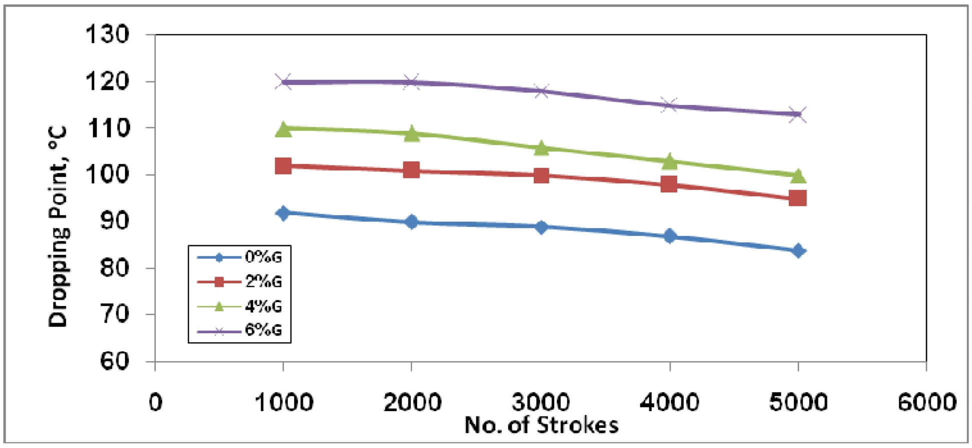

Figure 2
Effect of Mechanical working on dropping point for prepared grease

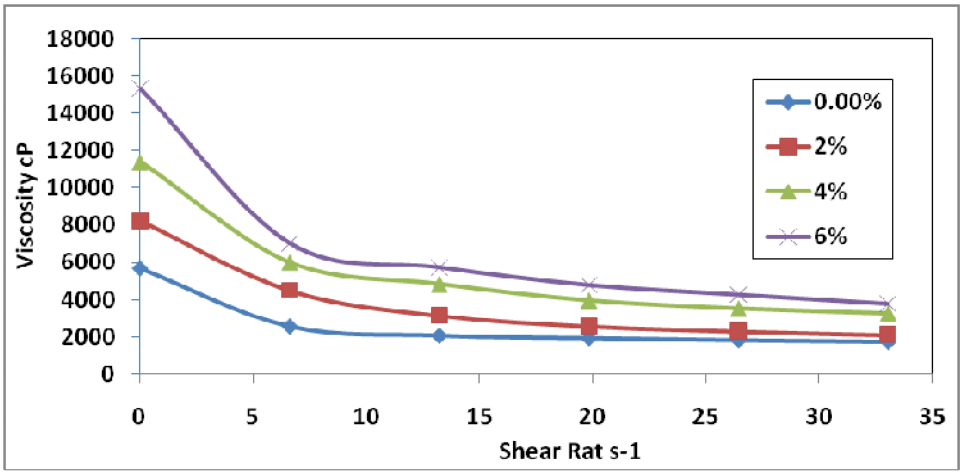

Figure 3
Variation of Viscosity with shear rate for prepared grease
at different Concenteration and temperature 80 ^{o}C

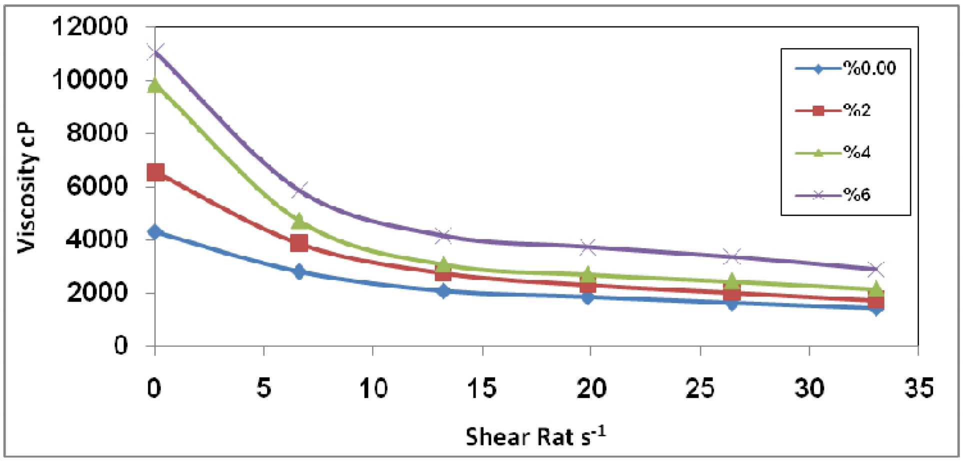

Figure 4
Variation of Viscosity with shear rate for prepared grease at different Concenteration and temperature 90 °C

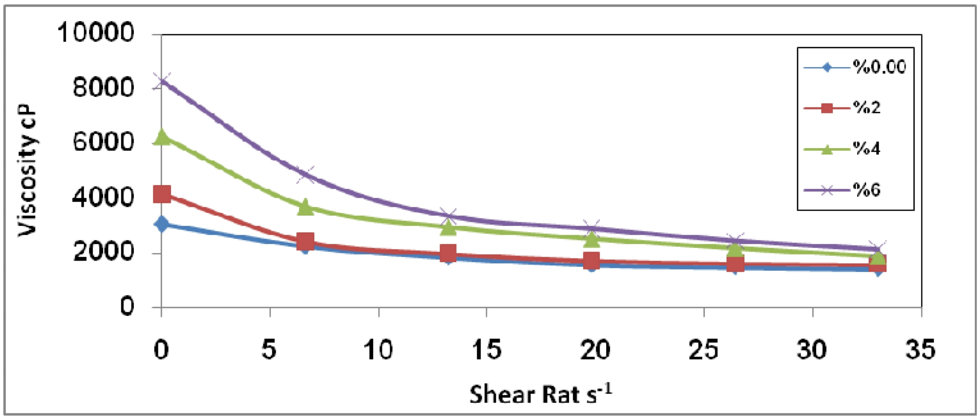

Figure5
Variation of Viscosity with shear rate for prepared grease at different Concenteration and temperature 100 °C

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