

Development of Lubricant Grease from Plastic Wastes for Possible Industrial Application

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ABSTRACT

The increasing accumulation of polyethylene plastic waste poses a significant threat to the environment due to its non-biodegradable nature and widespread use in packaging and consumer products. With global concerns over plastic pollution and the urgent need for sustainable waste management solutions, this research proposes the formulation of lubricant grease from polyethylene waste. This made a low-value polyethylene plastic waste into high-value industrial product (lubricant). This involves subjecting shredded polyethylene waste via pyrolysis, producing low molecular weight hydrocarbon product pyro-wax by thermal decomposition, which was used as thickeners replacing metal soap in a conventional grease where 30% weight pyro-wax give a grease NLGI 4 standard value on consistency test 180mm penetration length. Other parameters analyze includes dropping point 118 °C, Oil separation 0.041%, Oil bleeding 0.013%, percentage sample wash-off 0.26%, Oxidation stability 1kPa after 1000hrs and corrosion free all performed using American Society for Testing and Materials (ASTM) standard and the result were within accepted limit of the ASTM standard Grease for bearings lubrication. The significance of this work demonstrates that polyethylene waste can be recycled into a functional lubricant product; these outcomes not only contribute to waste valorisation efforts but also encourage innovation in the recycling and up-cycling sector, fostering greener production. It also contributes to circular economy efforts by transforming nuisance into useful engineering materials and also promoting a more sustainable industrial future.

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INTRODUCTION

The development of lubrication technology has been closely associated with human ingenuity and technological advancement throughout history. Even today, lubrication remains an active and increasingly important area of research, particularly with the growing complexity of modern machinery. One of the earliest documented examples of lubricant use is found in ancient Egyptian hieroglyphics from approximately 1880 BCE. These records depict animal fat being applied to the path of a wooden sled to facilitate the movement of a large statue. Similarly, evidence of early friction-related mechanical technology can be found in wheels dating to around 3500 BCE (Bhushan, 2013). Practical problem-solving efforts of early civilizations to the systematic investigations conducted by scientists such as Leonardo da Vinci and Amontons, the understanding of friction, lubrication, and wear evolved considerably (Bhushan, 2013).

Although liquid oils account for the largest proportion of lubricants used globally, semi-solid lubricants known as greases are essential in applications where service intervals, exposed operating conditions, extended or high mechanical loads are encountered (Blau, 2008). Unlike oils, greases possess a complex and highly structured internal network, which makes many conventional characterization methods developed for liquid lubricants unsuitable for their analysis. As a result, the scientific understanding of grease has historically progressed more slowly than that of lubricating oils (Blau, 2008). To overcome these limitations, researchers

have incorporated principles from rheology; the study of the deformation and flow behavior of complex materials alongside conventional tribological approaches, which focus on friction, lubrication, and wear (Gorbacheva *et al.*, 2020; Morrison, 2001). The combined application of rheological and tribological techniques has consequently provided an effective means of evaluating grease behavior and its lubricating performance in mechanical systems.

Environmental management services must bring resource supply and demand in agreement to a waste reduction for sustenance (Idisi and Ogumeyo 2024). Despite increasing global awareness of environmental protection and sustainability, only a limited number of commercial grease manufacturers have actively pursued the development of alternative materials aimed at minimizing environmental impacts (Diphare *et al.*, 2013, Jameel, *et al.*, 2011). In contrast, the academic research community has shown growing interest in the development of more sustainable grease formulations, partly in response to increasingly stringent environmental regulations, particularly those established by the European Union. Recent studies have explored a range of renewable and environmentally friendly materials, including vegetable oils, clay, Kraft lignin, cellulose, polymers, and waxes, as potential components of lubricating greases (Gorbacheva *et al.*, 2020, Yadykova and Ilyin, 2021, Soltannia, *et al.*, 2023, Nowak *et al.*, 2019, Rubio-Valle *et al.*, 2023, Fernández-Silva *et al.*, 2021, Gallego *et al.*, 2015, Martín-Alfonso *et al.*, 2018, Kozdrach, 2020). Against this background, this article seeks to

contribute to the development of environmentally sustainable lubricating grease through the valorization of waste plastics. Specifically, pyro-wax obtained from the pyrolysis of waste plastics is investigated as a potential thickening agent for grease formulation where properties evaluation through physicochemical characterization confirms the pyro-wax as thickener suitability for sustainable lubricant materials.

MATERIALS AND METHODS

Materials

Pyrolysis reactor, oxidation stability tester LOST-D20, LABTRON, UK, Hot air Oven DHG9023A UK, Analytical weighing balance AR2140 Ohaus Carp Pine Brook NJ, USA, cone penetrometer, pressure control tank, Engine oil, Additive (treatment oil), Beakers, Buckner funnel, stirrer, sample bottles, measuring cylinder, waste polyethylene (WPE), petridish.

Pyrolysis of Polyethylene

A batch-operated, locally fabricated pyrolysis reactor equipped with a large heating chamber was employed for the experimental process in accordance with the method reported by Osemeahon *et al.*, 2025. For each experimental run, approximately 20 kg of waste PE was charged into the reactor vessel, which was then tightly sealed. An outlet pipe was connected to the reactor and directed through a condenser to a collection container for the recovery of liquid products. The reactor was heated externally using a gas burner, with the heating intensity controlled to maintain an operating temperature of approximately 500 °C. At the completion of each pyrolysis cycle, the resulting pyro-wax was discharged into silicone molds and allowed to cool for approximately 30 minutes. The solidified pyro-wax was subsequently collected and utilized as a thickening agent in the formulation of the lubricating grease.

Grease Formulation

The grease preparation process commenced with the pre-treatment of the base oil and pyro-wax to eliminate coarse particles and other impurities. The pyro-wax was first melted, while the base oil was passed through a sieve to remove suspended particles. The grease was then prepared following the procedure reported by Abdulbari *et al.*, (2008), with some modifications to suit the present study. Initially, the base oil was heated at a constant temperature of 120 °C for approximately one hour to remove any residual moisture. A predetermined quantity of pyro-wax was subsequently weighed into a beaker and combined with the required amount of preheated base oil. The mixture was placed in an oven maintained at 120 °C to facilitate melting of the wax and promote its incorporation into the oil. After sufficient melting had occurred, the mixture was removed from the oven and thoroughly stirred to achieve uniform dispersion and complete homogenization. Continued mixing resulted in the formation of homogeneous, gel-like grease. The formulated grease was finally allowed to cool naturally to room temperature stored in a sealed container for further characterization.

Grease Characterization

Consistency Test

Grease consistency was evaluated in accordance with the standard procedure established by the American Society for Testing and Materials (ASTM D-217). The consistency of the formulated grease was assessed using a Seta Universal Cone Penetrometer, Model 17000-2 (Stanhope-Seta, UK). During the test, a prepared grease sample was placed beneath the

penetrometer cone, which was allowed to penetrate the sample under its own weight for a period of five seconds. Following the specified penetration time, the depth reached by the cone was recorded and expressed in tenths of a millimeter. The penetration value obtained from the instrument was used as an indication of the consistency of the grease (Nadkarni 2007).

Oil Separation Test

Oil separation from the formulated grease was evaluated according to the standard procedure specified by the American Society for Testing and Materials (ASTM D-1742). The test was conducted to determine the tendency of the grease to release oil during storage. A clean pressure-bleeding apparatus was first prepared, and the sieve was weighed to the nearest 0.05 g before being filled completely with the grease sample. Care was taken during filling to prevent the entrapment of air within the sample. The surface of the grease was leveled, and its initial mass was recorded. The assembled test setup was maintained at approximately 37 °C for 30 hours. During the test, the grease sample was supported on a 40 µm (924-mesh) sieve and subjected to an air pressure of 1.72 kPa. Any oil released from the grease passed through the sieve and was collected in a clean, pre-weighed beaker positioned beneath the apparatus. At the end of the test period, the separated oil was recovered and weighed. The percentage of oil separation by mass was then calculated and used to assess the storage stability of the formulated grease with respect to oil bleeding (Mohd Najib Razali *et al.*, 2017).

Dropping Point Test

The dropping point of the formulated grease was determined in accordance with the standard method specified by the American Society for Testing and Materials (ASTM D-2265). A small quantity of grease was carefully introduced into the test cup and placed in a heating apparatus under controlled temperature conditions. A thermometer was positioned within the test assembly such that it measured the temperature of the grease sample without making direct contact with the grease. The temperature was gradually increased while the sample was continuously monitored. The dropping point was identified as the temperature at which the first portion of the grease flowed through the opening at the bottom of the test cup and fell into the lower section of the test-tube jacket. At this stage, the temperature indicated by the sample thermometer was recorded to the nearest degree Celsius. Simultaneously, the temperature of the surrounding heating block was also measured and recorded.

A correction factor, corresponding to one-third of the temperature difference between the heating block and sample thermometer readings, was applied to the observed temperature. The corrected value was reported as the dropping point of the grease. This measurement is particularly important because the type and characteristics of the thickening agent can have a significant influence on the dropping point of the formulated grease (Mohd Najib Razali *et al.*, 2017).

Oil Bleeding

Oil bleeding was evaluated in accordance with the standard procedure established by the American Society for Testing and Materials (ASTM 522). In addition, the SKF Grease Test Kit TGKT 1 was employed as an alternative approach because it requires only a small quantity of grease for the analysis (Lugt, 2013). The test was conducted following the procedure outlined in the SKF manual. A portion of freshly prepared grease was placed on blotting paper and maintained

on a hot plate at 60 °C for two hours. During heating, oil released from the grease migrated into the blotting paper, producing a visible stain. The extent of oil bleeding was determined from the dimensions of the resulting oil stain or by weight. Equations (1) and (2) were used to quantify the bleeding behavior and compare the performance of fresh and aged grease samples:

$$S_i = 0.785 \times (D_{\text{AVi}}^2 - 100) \quad (1)$$

$$\% \text{ Difference} = 100((S_{\text{used}} - S_{\text{fresh}}) / S_{\text{fresh}}) \quad (2)$$

Where:

- i. S_i represents the variation in bleeding area between fresh and used grease samples.
- ii. D_{AVi} represents the average diameter of the oil bleeding area.
- iii. % Difference indicates the percentage change in bleeding area between the two grease samples.
- iv. S_{used} refers to the bleeding area obtained from aged grease samples, where the grease was conditioned for 10 days under controlled conditions at room temperature and 70°C.
- v. S_{fresh} represents the bleeding area measured from the untreated fresh grease sample.

Corrosion Testing

The corrosive tendency of the formulated grease toward copper was assessed using the copper strip corrosion test in accordance with the standard procedure established by the American Society for Testing and Materials (ASTM D-4048). The test was conducted to evaluate the extent to which the grease could cause tarnishing or corrosion of a copper surface. A prepared copper strip was immersed in the grease sample and maintained at a controlled temperature of 52 °C for 24 hours in an oven. After the specified exposure period, the copper strip was carefully removed from the grease, cleaned to eliminate residual lubricant, and examined for evidence of discoloration or tarnishing. The appearance of the treated strip was subsequently compared with ASTM Copper Strip Corrosion Standards to determine the corresponding corrosion rating (ASTM D-4048, 2018).

Water Resistance

The water washout resistance of the formulated grease was evaluated according to the standard method specified by the American Society for Testing and Materials (ASTM D-4049). In the test, approximately 30 mL of the grease sample was applied uniformly onto a designated metal surface. The coated panel was positioned horizontally and exposed to a continuous water spray at a temperature of 38 °C and a flow rate of 5cm³/s for five minutes. After the water exposure

period, the test assembly was removed and allowed to dry under controlled conditions. The mass of the coated surface was then measured and compared with its initial mass. The loss in mass was used to determine the percentage reduction in grease content, which served as an indication of the grease's resistance to water washout.

Oxidation Stability

The oxidation stability was evaluated in accordance with the standard procedure prescribed by the American Society for Testing and Materials (ASTM D-942). The analysis was performed using an oxidation stability tester (LOST-D20, LABTRON, UK). Five small Petri dishes were each coated uniformly with 25 g of the grease sample and placed inside a sealed oxidation bomb. The vessel was then charged with high-purity oxygen to an initial pressure of 760 kPa. The assembled apparatus was maintained at a controlled temperature of 99 °C, and the grease samples were subjected to oxidation for periods of 100, 500, and 1000 hours. Throughout the test, changes in the internal pressure of the oxidation vessel were monitored. The pressure reduction recorded during the exposure period was used as an indication of the grease's resistance to oxidative degradation.

RESULTS AND DISCUSSION

Polyethylene (PE) Pyrolysis

Waste polyethylene (PE) was thermally converted through pyrolysis, producing a wax-like solid residue referred to in this study as pyro-wax. The principal products obtained from the process were pyrolysis oil (condensed liquid fraction) and pyro-wax (solid residue). Many research already proved the establishment of the feasibility of pyrolysis for particular plastics as ways of recycling waste (Aforolagba-Balogun and Towaju, 2025). Table 1 presents the results obtained from three replicate pyrolysis runs. The findings indicate that more than 70% of the processed PE was recovered as solid residue following thermal cracking. This relatively high proportion of pyro-wax is significant because discarding the dominant product would undermine the environmental benefits intended through recycling and up cycling. Considerable attention has been given in previous studies to the liquid fraction generated during plastic pyrolysis, whereas the solid residue has comparatively received less attention. Failure to utilize this residue could potentially create an additional waste-management and environmental pollution problem. The substantial yield of pyro-wax obtained in the present study therefore demonstrates its potential for further value-added applications rather than disposal.



Figure 1: (1) Polyethylene (PE) waste;



(2) Pyro-wax

Previous research has similarly reported substantial wax formation during the pyrolysis of both high-density polyethylene (HDPE) and low-density polyethylene (LDPE), with wax yields reaching approximately 90% under certain operating conditions. Temperature and residence time have

been identified as important factors influencing the quantity of wax produced (Yousef et al., 2021). The findings of the present study are therefore relevant because the pyro-wax generated as a major residue can be converted into a useful material for grease formulation. Such utilization provides an

additional pathway for recovering value from waste plastics while reducing the quantity of pyrolysis residue requiring

disposal, thereby supporting the broader objectives of recycling, upcycling, and environmental pollution mitigation.

Table 1: Pyro-Wax Yield from Pyrolysis of Polyethylene

S/N	Mass of PE used (g)	Mass of wax obtained (g)	Percentage (%)
1	20	14.5	72.5
2	21	15	71.5
3	20.5	15	73.5

Development of Grease

Two grease formulations, designated as Samples A and B were prepared using pyro-wax derived from the pyrolysis of polyethylene (PE) as the thickening agent and engine oil as the base fluid. Sample B was formulated solely from the pyro-

wax and engine oil, whereas Sample A contained an additional 0.1 g of treatment oil to investigate the influence of the additive on the resulting grease properties. The incorporation of the additive produced noticeable changes in the physical characteristics of the grease.

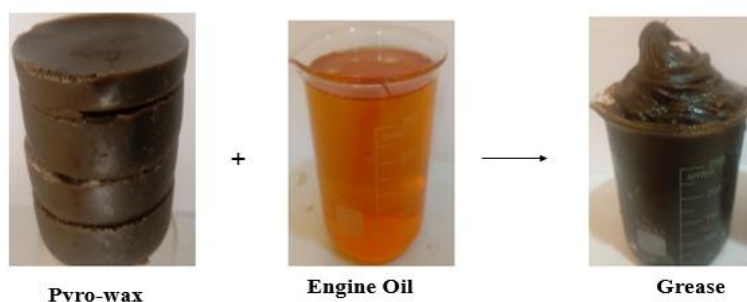


Figure 2: Grease Formulation using engine oil and pyro-wax

In particular, Sample A exhibited a softer and glossier appearance, suggesting that the additive enhanced certain properties of the formulation and may improve its suitability for specific applications. Nevertheless, the formulation

without the additive also produced visually uniform and satisfactory grease. The absence of the additive may further be advantageous where minimizing potentially undesirable or toxic additive components is a priority.



Figure 3: Formulated Grease sample

As presented in the table below, the formulated greases exhibited a dark-brown coloration and a semi-solid, thick, sticky consistency, with an oily-waxy texture. The products demonstrated good adhesion to metallic surfaces, indicating potential for use in applications requiring friction reduction

and lubrication, including bearing surfaces. Following preparation, the grease samples were transferred into plastic containers and stored prior to physicochemical characterization.

Table 2: Formulation of grease using pyro-wax thickener

S/N	Sample	Pyro-wax (g)	Engine Oil (g)	Additive (g)	Type
1	A	30	70	0.1	Soft and Shiny
2	B	30	70	Nil	Hard

Characterization of Grease

Grease Consistency Test

Consistency was assessed using the cone penetration test, with penetration depths of 330 mm and 180 mm obtained for Samples A and B, respectively. These values fall within the specified ranges for soft and hard greases, which are approximately 310–340 mm and 175–205 mm, respectively. Grease consistency is a critical performance parameter

because it reflects the resistance of the lubricant to deformation and is strongly influenced by the concentration, molecular structure, and characteristics of the thickening agent (Razali et al., 2018). Based on the measured penetration values, Samples A and B correspond to NLGI grades 4 and 1, respectively. NLGI classification provides an indication of grease firmness and consistency and is closely associated with both the quantity and type of thickener used in the

formulation. In general, grease consistency describes the ability of lubricating grease to resist deformation when subjected to an applied force (Mohd Najib Razali et al., 2017). This behavior arises from the internal structure of the grease, which is maintained by various intermolecular forces,

including weak electrostatic interactions such as van der Waals forces, hydrogen bonding, and capillary forces. These interactions contribute to the formation of a three-dimensional thickener network that restricts the movement of the base oil and gives the grease its semi-solid character.

Table 3: Grease Consistency

S/N	Sample	NLGI Number	ASTM worked penetration 0.1mm at 25 °C (3.28 x 10 ⁻⁴ ft)		Type
			Measured	Standard	
1	A	4	330	310-340	Soft
2	B	1	180	175-205	Hard

As shown in Table 3, the consistency values obtained for Samples A and B can be attributed primarily to the concentration and structure of the pyro-wax thickener, together with the properties of the base oil. At 25 °C, both the viscosity of the base oil and the molecular arrangement of the thickener network influence the elastohydrodynamic behavior and resistance to deformation of the formulated grease. The difference in penetration between the two samples can largely be associated with the treatment oil incorporated into Sample A. The additive resulted in a softer formulation, allowing the cone to penetrate further than in Sample B. The influence of additives on grease structure can also depend on their interaction with the thickener network and base oil. Such interactions may alter the physical structure of the grease (Kaperick, 2013), and can consequently affect properties such as consistency, odor, corrosion behavior, low-temperature performance, and permeability (Bhat and Charoo, 2019; Canter, 2012). Thus,

although the additive improved the softness of Sample A, its incorporation also altered several characteristics of the grease compared with the additive-free formulation.

Grease Dropping Point

Table 4 presents the dropping-point values obtained for grease Samples A and B. This property is an important parameter for identifying grease characteristics and establishing appropriate quality-control criteria. The measured dropping points were 98 °C for Sample A and 118 °C for Sample B. The dropping point represents the temperature at which the grease loses its semi-solid structure and begins to flow under the specified test conditions, similar in principle to the melting transition observed in solid materials. It provides an indication of the temperature limit at which the grease can maintain its structural integrity and functional properties during service (Mohd Najib Razali et al., 2017).

Table 4: Grease Dropping Point

S/N	Sample	Observed sample dropping point temperature (°C)	Block oven temperature set maximum at 200°C	Dropping point of Grease (°C)
1	A	97	100	98 ± 0.6
2	B	115	106	118 ± 1.4

The dropping point can therefore be used as an indicator of the upper temperature range within which grease is capable of retaining its consistency and structure (Mohd Najib Razali et al., 2017). According to Mohd Najib Razali et al., 2017, commercially available NLGI grade 2 greases commonly exhibit dropping points above 180 °C, and the recommended operating temperature is generally at least 50 °C below the grease's dropping point. The comparatively lower values obtained for the present formulations indicate that their high-temperature performance is more limited than that of conventional NLGI-2 greases. The thermal behavior of pyro-wax-based lubricants, as with other thickener systems, is strongly dependent on the chemical composition and structural characteristics of the thickening agent employed (Ranskiy et al., 2024).

Grease Oil Separation

The mass of oil released from the grease samples during the pressure-controlled separation test was measured, and the corresponding percentage oil separation was calculated. The

results are presented in Table 5. Both grease formulations exhibited relatively low levels of oil separation, indicating that the amount of oil released was insufficient to cause any substantial change in the consistency or structural stability of the products. Samples A and B recorded oil separation values of 0.390% and 0.041%, respectively. These results suggest that both formulations possess good resistance to oil bleeding and are likely to maintain their consistency during extended storage under suitable conditions. The low oil separation observed may be attributed to the strong interaction between the base oil and the pyro-wax thickener network. A more rigid and well-developed grease structure generally provides greater resistance to oil migration and consequently improves consistency and storage stability. Oil retention in grease is largely governed by mechanisms such as capillary forces and mechanical immobilization within the thickener network. These mechanisms can account for at least 75% of oil retention in thickener–oil systems, highlighting the important role of the thickener in determining the final performance and stability of a grease formulation (Uhryn, 2024).

Table 5: Grease Oil Separation

Sample	Weight of the Sample (g)	Weight of Strainer (g)	Weight of Strainer and Sample before separation (g)	Weight of Strainer and Sample after separation (g)	Weight of The oil separated (g)	Percentage oil separated (%)
A	81.94	118.67	200.61	200.29	0.32	0.390 ± 0.03
B	98.44	106.80	205.24	205.20	0.04	0.041 ± 0.01

Grease Oil Bleeding

Oil bleeding, also referred to as dynamic oil release describes the controlled migration of base oil and additives from the grease structure when the lubricant is subjected to mechanical or thermal conditions. In this study, the extent of oil bleeding was determined through mass measurement, with the results presented in Table 6. Samples A and B exhibited oil bleeding values of 0.106% and 0.013%, respectively. The relatively low bleeding rates observed in both formulations indicate satisfactory oil retention characteristics. The extent of oil release is influenced by factors such as the concentration and structure of the thickener, as well as the presence of additives,

which can modify the response of the grease to mechanical and thermal stresses and consequently influence its lubricating and friction-reducing performance (Uhryn, 2024). Oil bleeding is an important characteristic of lubricating grease because a controlled release of base oil is necessary to maintain lubrication at the contact zone under operating conditions. However, excessive oil release can result in lubricant leakage, depletion of the base oil, and eventual loss of lubrication. The low bleeding values obtained for Samples A and B therefore suggest that the formulated greases possess suitable oil-retention properties while still having the potential to supply oil to the lubricated contact.

Table 6: Grease Oil Bleeding

S/N	Sample	Weight of the Oil Bled (g)	$S=0.785 (D_{AV}^2 - 100)$	% Diff = $100(S_{use} - S_{fresh})/S_{fresh}$	Oil Bleeding (%)
1	A	0.12	-78.40	0.106	0.106 ± 0.02
2	B	0.03	-78.48	0.013	0.013 ± 0
3	C	0.03	-78.48	0.013	0.013 ± 0
4	A _{use}	0.03	-78.48	NA	NA
5	B _{use}	0.01	-78.49	NA	NA
6	C _{use}	0.01	-78.49	NA	NA

KEY; A_{use}Bleed of use sample A, B_{use} is the Bleed of the used sample B and C_{use}Bleed of use sample C, S_i is the difference between the bled areas from the fresh and used samples, D_{AV} is the bleeding area's average diameter, %Diff is the bled area's difference between the two samples and NA-Not Applicable.

Note; Weight of the blotting paper used throughout = 0.21g

Within a grease structure, the base oil is retained within the microstructure of the solid thickener, which can be considered a porous network. This structure functions in a manner similar to a sponge, retaining the oil and releasing it gradually when required. The relationship between oil bleeding and lubrication performance is particularly important because the controlled migration of oil from the grease can replenish the lubricating film at the tribological contact (Saatchi, 2019). Thus, grease bleeding is not necessarily an undesirable phenomenon; rather, an appropriate level of oil release is essential for maintaining effective lubrication. The results obtained for both formulations indicate a favorable balance between oil retention and release, supporting their potential application as lubricating greases (Saatchi, 2019).

Grease Water Resistance

The water washout test showed that Sample B experienced only 0.26% grease loss, indicating a high degree of resistance to water. This property suggests that the formulation could be

suitable for applications where the lubricant is exposed to water or operates under wet conditions. The pyro-wax thickener demonstrated considerable potential for producing water-resistant grease, possibly because of its polymeric origin and the structural characteristics retained during processing. The absence of the additive in Sample B may also have contributed to its superior water resistance. In comparison, Sample A recorded a higher grease loss of 4.58%, indicating comparatively lower resistance to water washout. The results presented in Table 7 demonstrate that the formulated greases possess appreciable resistance to water exposure. This behavior may be associated with the water-repellent characteristics and structural integrity of the pyro-wax thickener, which can help the grease adhere to metallic surfaces and remain in the lubricated region. Maintaining structural consistency at the contact surface also enables the grease to release base oil gradually and in a controlled manner, thereby supporting continued lubrication while limiting water penetration (Uhryn 2024).

Table 7: Grease Water Resistance

Sample	Weight of sample (g)	Sample and metal before wash-off (g)	Weight of sample and metal after wash-off (g)	sample wash-off (g)	Percentage sample wash-off (%)
A	21.28	113.28	112.33	0.94	4.58 ± 0.7
B	25.50	117.50	117.43	0.07	0.26 ± 0.7

Water resistance is particularly important for both lubricant performance and storage stability. Exposure to moisture during storage can promote chemical deterioration, while water contamination during service may contribute to corrosion of metallic components. Greases with high water resistance are therefore advantageous in equipment operating in wet or submerged environments. Such applications include heavy-duty machinery, submarine equipment, and submersible pumps, where the lubricant must maintain its structural integrity and protective function despite prolonged contact with water.

Grease Corrosion Resistance

The grease corrosion test is an important assessment used to determine the tendency of a lubricant to chemically interact with and deteriorate metallic surfaces. Such corrosive behavior may be influenced by factors including the chemical composition of the grease, pH, and moisture content. In this study, corrosion performance was evaluated using the copper strip tarnish test in accordance with the standard procedure of the American Society for Testing and Materials (ASTM D130 lip154). The results are illustrated in Plate 4. Both grease formulations, Samples A and B, produced only slight discoloration on the copper strips. The untreated reference strips, designated A₀ and B₀, exhibited a very light orange

coloration, whereas the strips exposed to Samples A and B showed a somewhat deeper coloration. The visual distinction between corrosion ratings 1b and 2a was relatively subtle under the test lighting conditions. Rating 1b was characterized by a darker orange appearance, while 2a showed a slight reddish coloration, as indicated by the applicable color chart.

The water-resistant characteristics of the pyro-wax thickener may have contributed to the relatively low degree of copper tarnishing observed. By forming a protective and adherent layer over the metallic surface, the grease can limit the penetration of moisture and other corrosive contaminants. In addition, the increased viscosity and structural strength provided by the thickener can enhance the sealing capability of the grease, helping to isolate the contact surface from the surrounding environment (Mortier et al., 2010). Corrosion

and associated wear can also be controlled through lubricant components capable of forming protective films on metallic surfaces. Polymer-based additives and thickeners, for example, may contribute to the formation of such protective films (Mortier et al., 2010). The ability of grease to maintain a stable protective layer is particularly important in components exposed to moisture and contaminants, such as vehicle steering knuckles. By remaining adhered to the metal surface and gradually releasing oil into the contact region, the grease can provide both lubrication and environmental protection (Uhryn 2024). When assessing copper-strip discoloration, however, careful consideration of lighting and color perception is necessary because minor differences in hue can influence visual classification. Consistent observation conditions and appropriate reference standards are therefore essential for obtaining reliable corrosion ratings.

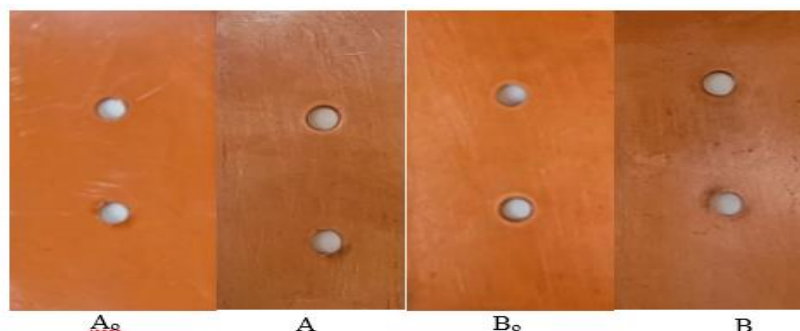


Figure 4: Copper Strip before and after Grease Corrosion resistance

Comparison of the exposed copper strips with the reference colour chart placed the observed results within corrosion classifications 1a and 1b, corresponding to slight tarnishing. This level of discoloration indicates that both formulated greases exhibited minimal corrosive activity and did not produce significant chemical attack on the copper surface. Such behavior is particularly noteworthy because conventional greases containing chemically derived additives or metal-soap thickeners may interact with copper and other metallic surfaces, resulting in more pronounced discoloration. These interactions can often be identified through characteristic and progressive changes in the colour of the copper strip (Mortier et al., 2010).

The satisfactory performance of Samples A and B in the copper corrosion test demonstrates their compatibility with metallic surfaces and indicates the absence of substantial corrosive components in the formulations. Consequently, the developed greases have potential for use in applications involving copper, metal alloys, bearings, and other components where effective lubrication is required. The corrosion results are also consistent with the water-resistance findings, since limiting water and moisture penetration can reduce the conditions that promote corrosion. This characteristic is particularly beneficial in applications where the lubricant may be exposed to water or submerged operating

environments, where moisture-related degradation and hydrolysis can adversely affect lubricant performance.

Grease Oxidation Stability

Oxidation stability is an important property for assessing both the storage life and expected service performance of lubricating grease. In this study, oxidation resistance was evaluated by monitoring pressure changes inside a sealed, oxygen-filled vessel containing the grease samples at elevated temperature. A reduction in pressure over time is associated with oxygen consumption during oxidation and therefore provides an indication of the susceptibility of the grease to oxidative degradation. The results demonstrated that the formulated greases maintained considerable oxidation stability throughout the test period. After 100 hours, no measurable pressure reduction was observed in any of the samples. At 500 hours, the pressure change was only approximately 1.0 kPa for the tested formulations. Following extension of the test to 1000 hours, Sample B showed no further pressure variation, whereas Sample A exhibited an addition of approximately 0.5 kPa. The slightly greater pressure change observed for Sample A may be associated with the presence of the additive, which could have influenced the structural stability and oxidation behavior of the grease.

Table 8: Grease Oxidation Stability

Measurement parameter	Instrument name/model	Time (hrs)	Pressure drops (kPa)		Oxidation
			Sample A	Sample B	
Pressure drop	Digital Pressure drop meter	100	0	0	Stable
		500	1.0	1.0	Stable
		1000	1.5	1.0	Stable

The observed stability may also be related to the viscosity characteristics of the formulations, since lubricants with favorable viscosity properties can demonstrate improved

resistance to oxidative degradation (Nur Amir et al., 2024). In general, oxidation stability refers to the ability of a lubricant to withstand chemical deterioration when exposed to oxygen,

elevated temperatures, and pressure. Oxidation involves reactions between oxygen and hydrocarbon components of the base oil, initially producing peroxides and subsequently generating compounds such as alcohols, ketones, aldehydes, and carboxylic acids. Progressive breakdown of the hydrocarbon structure can ultimately reduce the lubricating effectiveness of the grease (Silverstien and Rudnick 2017). The relatively small pressure changes recorded throughout the 1000-hour test indicate that both grease formulations possessed good resistance to oxidation.

CONCLUSION

Improper waste management continues to pose a significant environmental challenge worldwide, particularly because of the large volume of plastic waste generated. Addressing this problem requires innovative approaches that extend beyond conventional waste disposal methods. Although pyrolysis provides an effective pathway for converting waste plastics into useful products, the process remains incomplete from a waste-management perspective when the substantial solid residue, with approximately 80–90% of the output under certain conditions, is discarded without further utilization. The conversion of this pyrolysis-derived residue, referred to as pyro-wax, into a thickening agent for lubricating grease therefore provides an additional route for waste valorization. In the study, the pyro-wax was successfully incorporated into grease formulations, demonstrating that the residue of the plastic pyrolysis can be transformed into a functional lubricant component rather than becoming another source of environmental waste. A further important outcome of the study was the successful formulation of grease without the addition of conventional chemical additives. Despite the absence of an additive, the resulting lubricant exhibited physicochemical characteristics that satisfied the minimum requirements for effective lubrication under the conditions investigated.

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