Eco-friendly Hydrophobic Epoxy - Fly Ash Coating to Prevent Fat, Oil and Grease Deposition in Sewers

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Abstract

The deposition of fat, oil, and grease (FOG) from food service and residential sources in sewer pipes causes frequent blockages, sanitary sewer overflows (SSOs), and high maintenance costs, mainly due to saponification reactions that create calcium-based, insoluble materials (fatbergs). The aim of this study is to create an eco-friendly and low-cost hydrophobic coating by mixing locally available biomass fly ash with epoxy resin to reduce FOG adhesion in concrete sewer pipes. The specific objectives are: (1) to develop and characterize a novel fly ash - epoxy coating focusing on reduction in FOG deposition, and (2) to evaluate the coatings' performance by comparing FOG deposit formation in concrete sewer pipes before and after coating application. This study presents an innovative, environmentally friendly coating material made with locally-sourced biomass-based fly ash to mitigate deposition of FOG in sewer pipes. This fly ash contains high silica (SiO_2) content that can contribute to increased hydrophobicity, reducing the odds of deposition of FOG. The coating is made by mixing fly ash particles less than 63 µm with clear epoxy sealer and ethanol. Coatings were prepared by varying fly ash content from 1 to 30 % (w/w%). Prepared solutions were applied to concrete/mortar paste substrates to evaluate the performance of each coating. Selected coatings after preliminary inspection were characterized using contact angle, sliding angle, scanning electron microscopy (SEM) imaging and energy-dispersed X-ray (EDX) spectroscopy. The coatings were subjected to 21 days of synthetic FOG wastewater treatment to simulate sewer conditions. The 5% of fly ash coating showed the highest contact angle, at $101.1^{0,}$ and FOG deposition was decreased by 48.5% compared to the uncoated sample. The results indicated that mixing epoxy with a lower amount (1% - 5%) of fly ash enhanced the coating's hydrophobicity and demonstrated lower adhesion to FOG. By repurposing high-SiO_2 biomass fly ash waste, this method provides a sustainable and economically viable alternative to traditional FOG disposal practices, which can be used to address environmental waste disposal issues as well as the challenges associated with sewer infrastructure.

Keywords: *Coating, FOG, Fly ash, Hydrophobicity, Sewer*

1. Introduction

Fat, oil and grease (FOG) in sewers are mainly discharged from food service establishments (FSEs) and multifamily residential buildings. FOG can react with other wastewater components to form insoluble solids or precipitates that cause sewer pipe clogging. These solids will likely lead to

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sewer overflows (SOs). Adhesion of FOG inside sewer pipes is a major cause of the development of "fatbergs" [1]. Not only do these enormous solid formations obstruct the flow of wastewater in sewer pipes, but they also trap other solid waste material, further complicating their removal [2]. The impact of SOs is negative, with the emission of harmful substances to the environment due to untreated waste dumping and public exposure to disease pathogens and hazardous chemicals. FOG waste is largely responsible for most sewer blockages in the world [2]. In sewer systems, 50% of blockages in the United States and 75% of blockages in the United Kingdom occur due to FOG deposition [3]. The deposits are mainly composed of fatty acids, palmitic acid, along with oleic and linoleic acids [4]. FOG deposit texture is described as sandy and grainy and white to light brown in colour. One of the most outstanding aspects of these deposits is that they are low in gas-filled porosity, with very variable yield strength, moisture content, and lipid content [4,5]. The most prominent feature of FOG deposits is that they contain very high percentages of calcium, much greater than water hardness. This calcium is likely from corrosion of concrete because sewer pipes typically corrode in anaerobic environments [6].

Fatberg formation is mainly a result of saponification, where FFAs from the hydrolysis of FOG interact with calcium ions (Ca^{2+}), which are leached from corroding concrete pipes in an anaerobic environment, to produce calcium soaps that are insoluble. The resultant precipitates, which are mainly palmitic, oleic, and linoleic acids, produce a viscous and granular paste that holds debris and clogs pipes [4,5]. Anaerobic sulfate reduction reactions also enhance pipe corrosion, thereby increasing the concentration of Ca^{2+} ions. The anaerobic conditions of sewer networks also lead to the production of odorous gases and corrosion of sewer pipes [7].

Traditional technologies such as grease interceptors [5], upgrade of sewer infrastructure using gradient, diameter and roughness alteration of pipes [7], and concrete corrosion control [8] have traditionally been applied in the management of FOG. Traditional technologies are ineffective since they are accompanied by such limitations as the high cost of maintenance and operational drawbacks. These limitations have led to the development of coating material to keep sewer lines from FOG deposition as an effective, efficient, and environmentally friendly method [9]. Recently, researchers have investigated coatings for sewer like "hybrid coating material with triple distinct healing bond coating" and "hydrogen bonded organic frameworks based coating" [10,11].

To decrease FOG deposition using coatings, coatings should have properties like hydrophobicity or super hydrophobicity, self-healing and self cleaning. Super hydrophobic and hydrophobic surfaces are characterized by low adhesion force and low surface energy, leading to less amount of dust particles accumulated. Apart from repelling property, super hydrophobicity gives antimicrobial as well as anti-corrosive protection. A surface is said to be hydrophobic when it has a static water contact angle of more than 90°, and to achieve super hydrophobicity, the contact angle should be greater than 150^0 [12]. In order to achieve self-cleaning properties, a sliding angle of less than 10° is also required, generally referred to as the "lotus effect" since it replicates lotus leaf self-cleaning behavior [13]. Hydrophobicity and super-hydrophobicity can be achieved by creating a rough surface on low-surface-energy substrates. Various micro particles have been used to create rough surfaces, including TiO_2, SiO_2 nanoparticles and polytetrafluoroethylene (PTFE) [14]. Self-healing capability can be achieved by incorporating micro/nanocapsules within coatings, where they release the core material upon cracking. The released healing agents, like dicyclopentadiene (DCPD), linseed oil, either cross-link in the presence of a catalyst or encapsulate the damage in situ, restoring protective function and preventing corrosion [15].

Silicon dioxide (SiO_2) has been generally accepted as one of the important components for achieving hydrophobicity and self-cleaning properties on the surface, as it has the potential to reduce surface energy and produce nano-scale roughness on the surface. It has been confirmed in the existing literature that the hydrophobicity of the surface can be enhanced significantly with the use of SiO_2 with a nanometer-scale particle size [16]. Surface modification of SiO_2, either through silane chemistry or incorporation into polymer matrices, has been shown to further intensify hydrophobic behavior and improve durability of coatings [17]. Hybrid coatings based on SiO_2, such as $SiO_2 – TiO_2$ and SiO_2 – polymer composites, have demonstrated strong self-cleaning ability, highlighting the effectiveness of SiO_2 [18]. The existence of biomass fly ash with high SiO_2 content has been identified as an environmentally friendly and economical substitute for synthetic sources of silica [19]. Based on the chemical composition and the environmentally friendly nature of biomass fly ash, it has high potential as an additive in hydrophobic coating applications. As such, the use of SiO_2-rich fly ash as an additive in an epoxy coating has high potential in the development of environmentally friendly coatings that are hydrophobic and self-cleaning. The aim of this study is to develop and evaluate an environmentally friendly epoxy-fly ash composite coating for reducing FOG deposition in sewer systems. Specific objectives of this study are to develop and characterize a novel fly ash - epoxy coating focusing on reduction in FOG deposition, and to evaluate the coatings' performance by comparing FOG deposit formation in concrete sewer pipes before and after coating application.

2. Materials and Methods

This study entails the sourcing and characterizing of biomass fly ash, the preparation of concrete and mortar paste substrates and the formulation of epoxy-based coatings with 1 - 30 % (w/w %) fly ash. The procedure entails the characterization of the coating, preparation of the trial coating, and a series of tests to evaluate the hydrophobicity, self-cleaning properties, and durability of the formulated coating. Synthetic wastewater was also used to simulate sewer conditions to compare the resistance of the coatings to FOG deposition.

2.1. Analysis of fly ash

The fly ash used in this research was obtained from a biomass combustion plant in Sri Lanka, where it is generated as a result of the combustion of a combination of Gliricidia sepium, Leucaena leucocephala (Ipil-Ipil), and paddy husk. These are some of the common biomass materials that are readily available in Sri Lanka and are normally used in small to medium-scale boilers for energy production. The fly ash was tested using sieve analysis and X-ray fluorescence test (XRF). XRF was selected for chemical characterization as it provides rapid, non-destructive quantitative analysis of major oxide composition, which is critical for assessing SiO_2 content relevant to hydrophobicity enhancement [19]. A sieve analysis test was conducted to identify the particle size distribution. In the subsequent formulations, fine particles less than 63 μm were utilized since they enhanced the effectiveness of the coating to prevent FOG deposition by providing extra surface area, which enhances the hydrophobicity and adhesion of the coating material [20].

2.2. Preparation of substrates

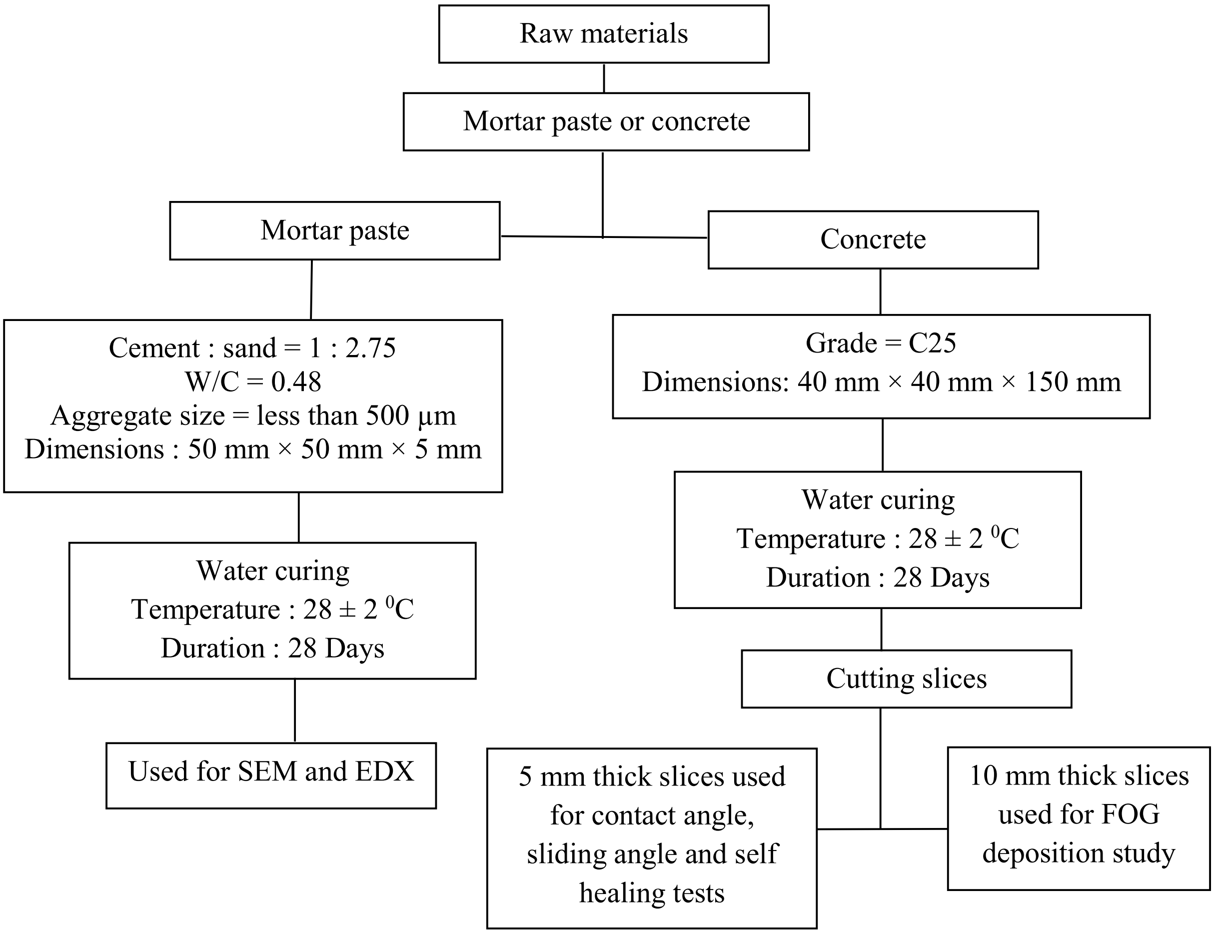

Figure 1. Flow chart of substrate preparation process.

Figure 1 shows the flow chart of the substrate preparation process. Test substrates for the study were prepared through concrete blocks with dimensions of 40 mm × 40 mm × 150 mm and mortar paste blocks, which had dimensions of 50 mm × 50 mm × 5 mm. The mortar paste was prepared by mixing cement with sand at a ratio of 1:2.75 and using 0.48 water content and 500 µm aggregate size [27]. Concrete grade used to cast 40 mm × 40 mm × 150 mm was C25. 40 mm × 40 mm × 150 mm concrete cubes were cut into 5 mm and 10 mm slices. The 5 mm concrete slices were used for coating characterization tests, and 10 mm concrete slices were used for the FOG deposition study. The 50 mm×50 mm×5 mm mortar paste slices were used only for SEM imaging and EDX. The substrates were cured in water at 28 ± 2°C for 28 days to ensure complete hydration of the cement, thereby achieving the design strength and minimizing unhydrated phases that could influence the adhesion of the coating.

2.3. Coating preparation

The main components for preparing the coating consisted of fly ash, epoxy and ethanol. Ethanol was used as a solvent to reduce the viscosity, enhance the dispersion of fly ash in the epoxy resin matrix, and ensure a uniform application by preparing a homogeneous slurry prior to adding the hardener [21]. The amount of ethanol was varied depending on the fly ash content to ensure a workable viscosity and avoid thinning. The study used BP Epoxy Sealer – Art from Petrokem (Petrokem Lanka (Pvt) Ltd., Moratuwa, Sri Lanka) as its epoxy resin product. The density of epoxy resin and hardener was 1.12 g/ml and 0.9 g/ml, respectively. The epoxy hardener and epoxy resin were mixed in a 1:2 ratio. Fly ash, epoxy resin and ethanol were mixed manually using a glass rod for 30 minutes to achieve a homogeneous solution [21]. After 30 minutes of mixing time, the epoxy hardener was added and mixed for another 10 minutes. The coating mixture was applied to concrete surfaces using a glass rod, which allowed the production of a uniform layer. The coated substrates were cured for 24 hours at room temperature between 30 ± 2 °C. Different trial coatings were prepared by varying fly ash content from 1% to 30% with the total weight of epoxy resin, hardener and fly ash. The composition of all the coatings is listed in Table 1.

Table 1. Composition of coatings

Trial no	**01 (Epoxy only)**	**02 (1%)**	**03 (5%)**	**04 (10%)**	**05 (15%)**	**06 (20%)**	**07 (25%)**	**08 (30%)**
Epoxy resin (ml)	3	3	3	3	3	3	3	3
Epoxy hardener (ml)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Fly ash (g)	-	0.0476	0.2479	0.5233	0.8312	1.1775	1.570	2.0186
Ethanol (ml)	-	0.5	0.5	0.5	0.5	1.0	1.0	1.5

2.4. Characterization of coatings

Coatings were characterized through a series of characterization techniques. Initially, the water droplet method was conducted to identify the best trial coatings for characterization. 5% of fly ash coating was selected for contact angle measurement, SEM and EDX using the water droplet method and 5%, 10%, 20%, 30% samples were chosen for sliding angle measurement and FOG deposition study. The epoxy-only sample was also subjected to all characterizations for the purpose of comparison. Contact angles of trial coatings were determined using a tensiometer to quantify the hydrophobicity of surfaces. Microstructural characteristics were investigated through scanning electron microscopy (SEM, Carl Zeiss EVO 18 Research, Germany), while elemental composition was established through energy-dispersed X-ray (EDX) spectroscopy and the incorporation of fly ash into the epoxy matrix [22]. The self-cleaning property of the coatings was investigated in sliding angle tests using a custom-made setup by placing water droplets onto coated surfaces (5%, 10%, 20%, 30%, and epoxy-only) and determining the inclination angle required for droplet motion and averaging over three trials. Finally, the protective layer's self-repair potential was explored using self-healing experiments, where scratched samples were immersed in water under ambient conditions for 14 days to observe surface recovery [10].

2.5. Synthetic FOG wastewater preparation

Synthetic FOG wastewater (1 L total volume) was prepared to simulate typical sewer conditions with FOG saponification potential. This was achieved by adding 175 ml of used cooking oil to 625 ml of distilled water in a laboratory beaker. The mixture was then heated to 70°C with constant stirring to facilitate the emulsification of the immiscible oil and water phases. After reaching a temperature of 70°C, 200 ml of coconut oil and 5 g of calcium chloride ($CaCl_2$) were added to the mixture while still at 70°C with continuous stirring for 30 minutes to promote partial saponification and homogeneous distribution of components [5]. The synthetic FOG wastewater was characterized through COD measurement to determine organic pollutant levels. In addition, electrical conductivity assessment and pH testing were carried out. The prepared wastewater served as the test medium to assess coating performance against FOG deposition in the experiments. Table 2 shows properties of the prepared wastewater.

Table 2. Characterization of synthetic waste water

Characterization method	**Value**
COD (mg/l)	1071.00
Electric conductivity (ms/cm)	8.673
pH	5.74
Temperature (^{0}C)	29

2.6. FOG deposition study and comparison

The evaluation of coatings' performance against FOG deposition involved submerging uncoated and epoxy-only samples, along with selected coatings (5%, 10%, 20%, 30%), into synthetic FOG wastewater for a 21-day period at room temperature. The 21-day immersion period was chosen based on literature that showed visible FOG deposition and saponification in simulated sewer tests in 2-4 weeks. No measurements were made in between, since the aim was to compare the total deposition after the period. After the 21-day exposure period, the samples were taken out of the solution [11]. The surface deposits of FOG were carefully removed by scratching after the samples had dried. The measurement of FOG deposition on each sample occurred through weighing the removed deposits. The testing method enabled the evaluation of different coating performances for their FOG resistance capabilities.

3. Results and Discussion

This section presents the characterization of the fly ash, the hydrophobicity of the coating, microstructure, and anti-FOG properties. The results are explained in the context of the fly ash content and its effect on the surface properties and adhesion of FOG.

3.1. Analysis of fly ash

Sieve analysis of fly ash was performed to quantify particle size distribution because this measurement determines coating performance. The particle size distribution of the fly ash indicates that most of the fine particles are below 600 μm. Finer fly ash particles (< 63 μm) were selected for coating preparation, as they provide improved dispersion in the epoxy matrix, higher packing density, and enhanced hydrophobicity due to increased surface area [23]. Results of the particle size analysis using sieve analysis are shown in Table 3. The composition of fly ash was determined through X-ray fluorescence (XRF) analysis, which serves to identify chemical properties in order to develop coating formulations. XRF test results are shown in Table 4. XRF test results show a noticeable compositional difference between the two fly ash samples. Sample 2 shows a higher SiO_2 content compared to other chemicals. However, sample 1 shows relatively lower SiO_2 content compared to sample 2. These variations may have resulted due to difference sampling locations or combustion conditions. However, both samples contain considerable amounts of SiO_2, which is beneficial for enhancing the hydrophobicity of the coating [16].

Table 3. Particle size analysis of fly ash

Aperture (µm)	**Container + Aggregate(g)**	**Container (g)**	**Aggregate retained**	**Total passing(g)**	**Percentage passing**
2000	470.27	470.27	0	0	100%
1180	421.34	421.34	0	0	100%
850	493.72	486.73	6.99	92.8	93.00%
600	365.05	345.02	20.03	72.77	72.92%
425	478.01	465.97	12.04	60.73	60.86%
300	401.44	389.47	11.97	48.76	48.86%
150	316.69	306.62	10.07	38.69	38.77%
75	318.52	296.15	22.37	16.32	16.35%
63	418.43	415.02	3.41	12.91	12.94%

Table 4. Composition of fly ash samples

Chemicals	**Sample 1**	**Sample 2**
SiO_2 (%)	10.61	58.09
CaO (%)	27.07	11.87
K_2O (%)	31.73	13.52
MgO (%)	2.76	1.62
P_2O_5 (%)	3.07	2.50
Al_2O_3 (%)	0.61	1.76
Fe_2O_3 (%)	1.35	1.32
Na_2O (%)	1.25	0.87
SO_3 (%)	11.04	3.79
TiO_2 (%)	0.11	0.33

3.2. Contact angle

The 5% fly ash coating was selected for detailed characterization (contact angle, SEM, EDX) based on preliminary water droplet tests showing superior repellency compared to other coatings. Water-repellent properties of 5% fly ash-coated surfaces against epoxy-only surfaces were evaluated through water contact angle measurements. Contact angle measurement was done by the sessile drop (396) method at 20^0C water using a tensiometer. Three measurements taken from different surface locations were used to compute the average contact angle value for each trial coating. The average contact angle measurement of 101.10° demonstrated excellent water-repellent capabilities of the 5% of fly ash coating. The hydrophobicity of the coated surfaces was assessed and categorized based on the static water contact angles. Surfaces with contact angles below 90° are considered hydrophilic, those between 90° and 150° are hydrophobic, and angles exceeding 150° indicate super hydrophobicity [14]. The hydrophobic properties of the 5% of fly ash sample were confirmed by its contact angle measurement, which exceeded 90°, while the epoxy-only coating had a contact angle measurement of 65.42°, which did not show hydrophobic properties. The results are summarized in Table 5. These results highlight the improved hydrophobicity of the coating by adding fly ash to epoxy, which is crucial for reducing FOG accumulation in the sewer.

Table 5. Summary of contact angles.

Coating	**Average contact angle**	**Classification**
Epoxy only coating	65.45°	Hydrophilic
5% of fly ash coating	101.10°	Hydrophobic

3.3. Sliding angle test

Selected coatings (5%, 10%, 20%, 30%) and an epoxy-only coating were tested using the sliding angle to compare the self-cleaning capabilities of coatings. Figure 2 represents the variation of sliding angles. The epoxy-only coating showed a sliding angle of 19.5° while the 5% fly ash coating showed a slightly higher sliding angle of 20.5°. The 10% fly ash coating exhibited the lowest sliding angle of 17.5°, which demonstrated better water droplet sliding capability than the other coatings because it has the lowest sliding angle. The 20% and 30% fly ash coatings produced water sliding angles of 20.1° that are almost identical to the 5% fly ash coating results. The increase of fly ash content above 10% did not enhance the water repellency of the coating since the sliding angles remained equal to the lower concentration values. However, any coating did not show self cleaning ability. The sliding angle of all coatings was higher than 10^0. To achieve self-cleaning ability, the sliding angle should be less than 10^0 [22]. The differences in sliding angles for these coatings may be explained by considering differences in surface roughness, coatings' thickness, dispersion of particles, and coating application method. Highly dispersed SiO_2 particles produce microscale surface roughness that increases the entrapment of air under water droplets, thus decreasing the sliding angles of water droplets on these surfaces by reducing contact between the liquid and solid phases [24]. Additionally, low surface energy chemical modifications such as alkyl silanes, fluoroalkyl silanes, organosilanes for silica [25] and polydimethylsiloxane [18] may be required to improove self cleaning ability.

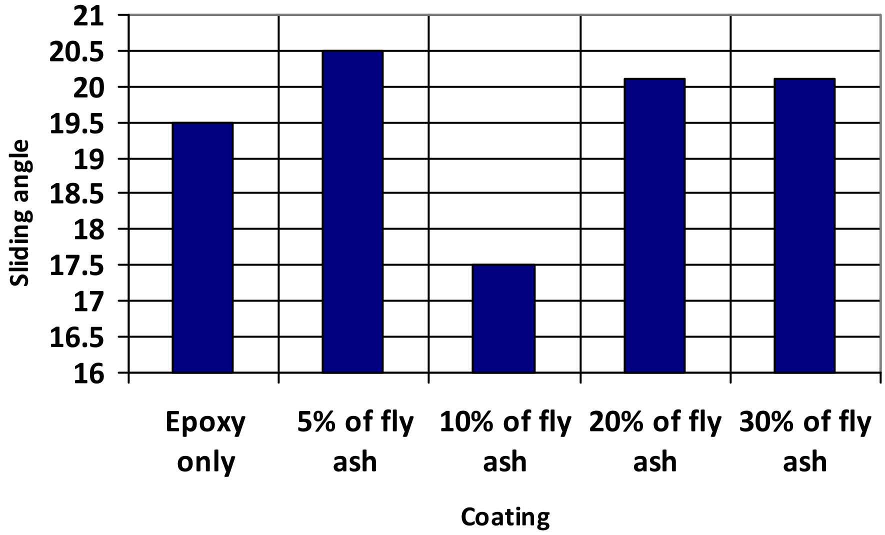

Figure 2. The variation of sliding angles

3.4. Microstructure examination

The surface morphology and texture, along with structural features of epoxy-only and 5% of fly ash coatings, were examined using Scanning Electron Microscopy (SEM). The evaluation took place at 100x to 25,000x magnifications, which enabled observation of both broad surface characteristics and complicated details at elevated magnifications. The broad magnification spectrum enabled detailed inspection of coating characteristics from surface texture to fly ash particle distribution patterns at the microstructural level. Figure 3 (a) - (f) and Figure 4 (a) - (f) represent SEM images of epoxy-only coating and 5% fly ash coating, respectively.

The epoxy-only coating shows a different pattern of surface morphology from the 5% of fly ash coating. The epoxy-only coating presents a smooth surface which lacks roughness features typical of single-phase epoxy material coatings. The 5% fly ash coating shows an uneven surface texture, which becomes more prominent due to fly ash particle inclusion.

The particle distribution distinguishes the two coatings by their particle arrangement. The epoxy-only coating displays a consistent structure with no visible particles or additives. The 5% of fly ash coating displays fly ash particles spread throughout the epoxy matrix. The fly ash particles need to be distributed evenly across the surface since their clustering would negatively impact the coating's performance. The result obtained from the SEM test proves that the inclusion of fly ash particles has provided the required roughness for the epoxy matrix. This roughness is critical for achieving hydrophobicity and reducing FOG adhesion [26].

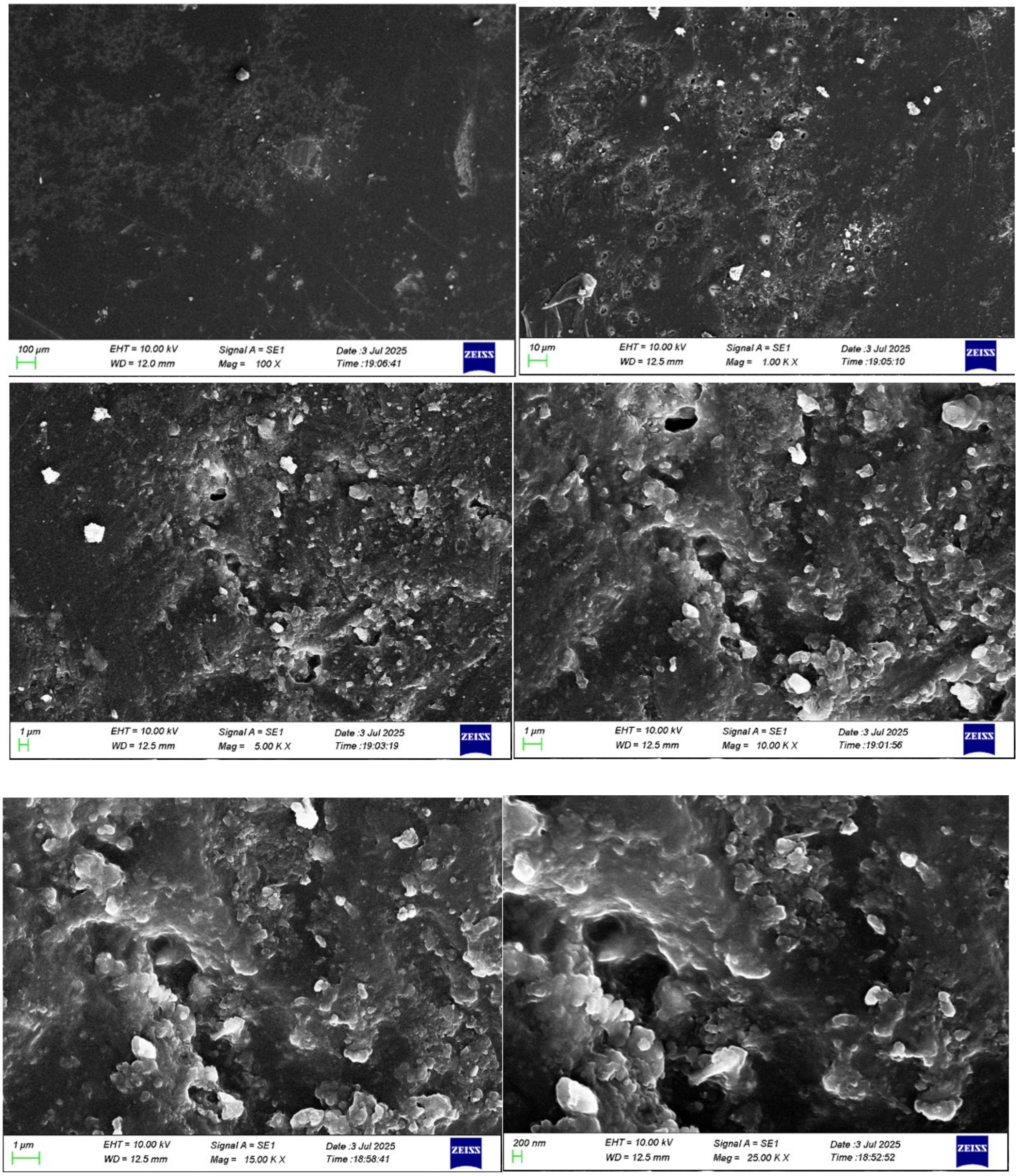

Figure 3. SEM images of epoxy only coating. a) 100x, b) 1000x , c) 5000x , d) 10000x, e) 15000x, f) 25000x.

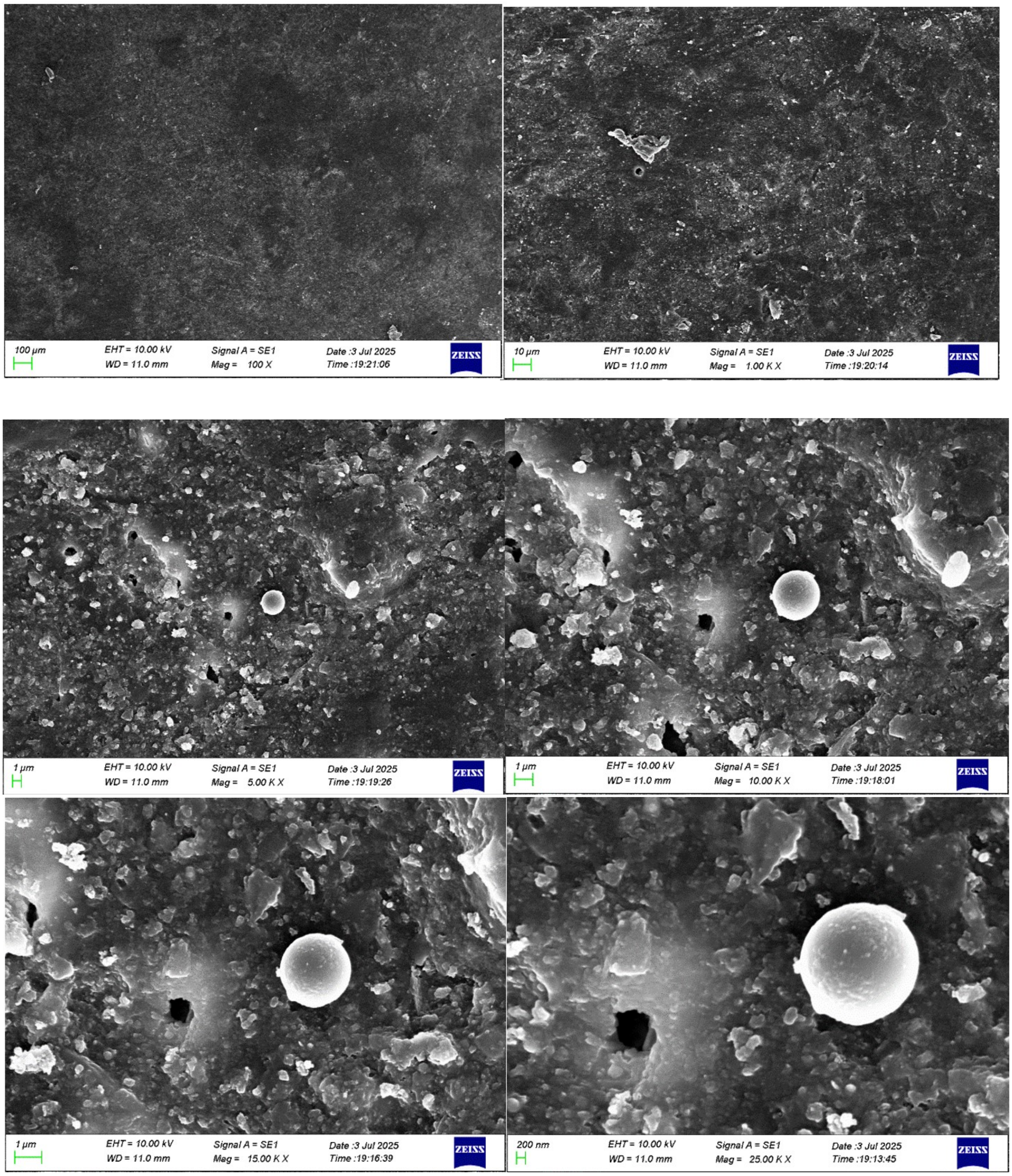

Figure 4. SEM images of 5% of fly ash coating. a) 100x, b) 1000x , c) 5000x , d) 10000x, e) 15000x, f) 25000x.

3.5. Energy Dispersive X-ray (EDX) spectroscopy

Energy Dispersive X-ray (EDX) spectroscopy was utilized for chemical composition analysis of coated samples to measure elemental concentrations in epoxy-only and 5% of fly ash coatings. The EDX results provide important composition data which reveals how fly ash affects coating performance by enhancing both hydrophobic and FOG-resistant characteristics. Elemental compositions are listed in Tables 6 and 7. According to EDX test analysis, the epoxy only coating consisted mainly of carbon and oxygen, with a lower amount of silicon, nitrogen, chlorine, calcium and iron. The 5% of fly ash coating also consisted of carbon, nitrogen, oxygen as major elements and elevated composition of silicon, calcium and chlorine with additional inorganic elements such as potassium and aluminium. These compositional differences revealed the incorporation of fly ash into the epoxy matrix and its contribution to the overall elemental composition of the coating. These increased compositions of silicon and other inorganic compounds may contribute to the enhanced performance of 5% of fly ash coating compared to the epoxy-only coating [16].

Table 6. EDX analysis of epoxy-only coating

Element	Weight %	Atomic %	Net Int.	Error %	K ratio	Z	A	F
C	78.70	84.13	1216.03	5.38	0.5153	1.01	0.6465	1.0000
N	2.13	1.95	4.29	99.99	0.0015	0.98	0.0716	1.0000
O	16.01	12.85	83.26	20.96	0.0196	0.96	0.1265	1.0000
Si	0.39	0.18	16.72	23.52	0.0031	0.87	0.8995	1.0082
Cl	1.29	0.47	41.64	13.41	0.0110	0.81	1.0188	1.0219
Ca	0.93	0.30	21.27	23.08	0.0083	0.82	1.0329	1.0439
Fe	0.55	0.13	7.31	62.54	0.0049	0.73	1.0231	1.1904

Table 7. EDX analysis of 5% fly ash coating

Element	Weight %	Atomic %	Net Int.	Error %	K ratio	Z	A	F
C	65.30	73.10	636.67	99.99	0.3677	1.0208	0.5514	1.0000
N	2.80	2.69	4.70	99.99	0.0022	0.9966	0.0802	1.0000
O	26.45	22.22	111.96	14.25	0.0355	0.9755	0.1377	1.0000
Al	0.05	0.03	1.36	81.77	0.0003	0.8660	0.7587	1.0059
Si	0.55	0.26	17.11	21.77	0.0042	0.8847	0.8677	1.0089
Cl	1.64	0.62	39.75	11.18	0.0139	0.8237	1.0072	1.0252
K	0.32	0.11	6.54	66.02	0.0028	0.8194	1.0223	1.0516
Ca	2.90	0.97	49.54	15.11	0.0255	0.8342	1.0265	1.0269

3.6. Self-healing test

After immersing the scratched samples in the water for 14 days, there were no visible changes to the scratch marks on the surfaces of the coating. Any noticeable reduction in the width of the scratches or any observable repair of the surface structure of the coating over time was not observed. The scratched regions of the coatings were visibly damaged, and it was apparent that they were incapable of self-healing. Self-healing materials such as dicyclopentadiene (DCPD), linseed oil, dimethylglyoxime (DMG) and dynamic bond agents such as isophorone diisocyanate (IPDI), dibutyltin dilaurate (DBTDL), and zinc(II) chloride networks should be incorporated, which would allow the coating to self-heal small damages. This would be able to improve the longevity of the coating and would support the ability for self-healing performance with less frequent maintenance [10,15].

3.7. FOG deposition test

The findings from the FOG deposition study present a comprehensive evaluation of how well the different coating formulations reduced the accumulation of fat, oil and grease (FOG) in sewers. The FOG deposition test was designed to simulate ambient operating conditions in a sewer pipe over a 21-day period, with different coated and uncoated concrete samples exposed to a synthetic FOG wastewater. Table 8 represents the weighted FOG in each sample. Figure 5 shows samples after the FOG deposition test. The FOG deposition study results reveal a relative effectiveness of the coatings in reducing FOG deposition, but the major factor was the fly ash content for each of the coatings and their ability to prevent FOG accumulation. The results provide information about the potential application of developed coatings for the management of FOG in sewer systems, as well as relative comparisons of effectiveness based upon composition and performance based on these controlled conditions.

All the fly ash coatings and epoxy-only coatings showed a significant reduction of FOG deposition compared to the uncoated surface. The epoxy layer reduces the physical adhesion of FOG by reducing the surface porosity and creating a smoother, less absorbent surface. Incorporation of fly ash further enhanced the epoxy coating's performance by introducing silica-rich particles that contribute to enhancing surface hydrophobicity and lowering surface energy. Coatings exhibit a balanced microstructure with better dispersion of particles in moderate fly ash contents. However, higher concentrations of fly ash lead to particle agglomeration, which may locally increase roughness and partially reduce the hydrophobic properties. Dense packing of fly ash particles in higher concentrations minimize available binding sites and stabilizes the surface against fat, oil and grease adhesion [23]. That may be the reason that 30% of the fly ash sample shows the highest reduction in deposited FOG. However, further increasing the fly ash content was not effective because an excessive amount of fly ash led to poor dispersion and incomplete mixing with epoxy.

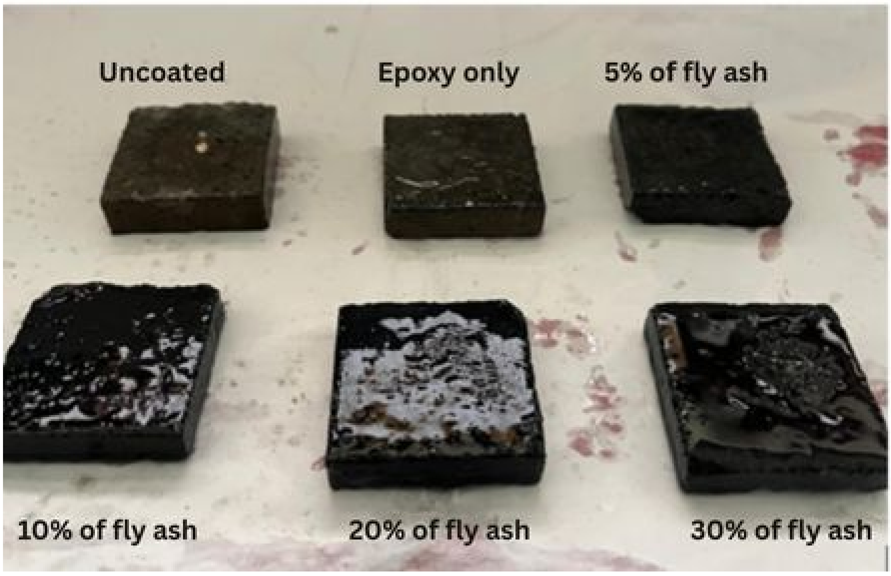

Figure 5. Samples after FOG deposition test

Table 8. FOG deposition test results

Sample	Deposited FOG (g)
Uncoated	0.4317
Epoxy only coating	0.3004
5% of fly ash coating	0.2225
10% of fly ash coating	0.3173
20% of fly ash coating	0.1850
30% of fly ash coating	0.1701

4. Conclusions

In this study, an eco-friendly hydrophobic coating was formulated using locally available biomass fly ash generated from the burning of Gliricidia sepium, Leucaena leucocephala, and paddy husk into epoxy resin with the main objective of inhibiting the deposition of fat, oil, and grease in sewers. The two specific objectives of the research were met successfully: first, to develop and characterize a novel fly ash-epoxy coating with the main focus of inhibiting FOG deposition, and second, to analyze the performance of the coatings by determining the formation of FOG deposits in concrete sewer pipes before and after coating application. This was done by varying the concentration of fly ash from 1% to 30% by weight, analyzing the surface properties of the coatings using contact angle, sliding angle, SEM, and EDX, and conducting a 21-day FOG immersion test. The 5% fly ash coating confirmed hydrophobicity with a static water contact angle of 101.1°, while the epoxy-only coating showed a static contact angle of 65.42°, which remained hydrophilic. The 30% fly ash coating showed the highest reduction in FOG deposition at 60.6% lower than the uncoated concrete surface, showing effective mitigation through enhanced surface roughness, silica-induced low surface energy, and reduced adhesion sites at higher filler contents. Although self-cleaning ability was not reached, as the sliding angles were above 10°, the coatings significantly outperformed both uncoated surfaces and pure epoxy in preventing FOG accumulation. This method of utilizing waste materials is a cost-effective and sustainable method of protecting sewer infrastructure, especially in developing areas, and illustrates the enormous possibilities of biomass fly ash as a secondary material in hydrophobic coatings for wastewater applications.

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Conflict of Interest

We declare no conflict regarding the publication of the study.

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