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POLYMER-BASED SOIL STABILIZATION FOR REDUCTION OF PARTICULATE MATTER EMISSIONS IN EGYPT: A COMPARATIVE ANALYSIS OF ACRYLATE POLYMER

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ABSTRACT

Dust emissions to air have a significant impact on airborne health, especially in regions where particulate matter (PM10 and PM2.5) levels are high. In this study, we examine the effectiveness of Acrylate polymer in soil stabilization to reduce particulate matter (PM) emissions. PM were monitored at five locations across Egypt and the results were recorded, analyzed and compared against EEAA limits. Soil samples from these locations were treated with varying percentages of the polymer and subjected to different temperatures to simulate real-world conditions. In addition to temperature variations, the study also considered the effects of humidity and soil composition on the polymer's performance. Compressive strength tests were conducted to assess the effectiveness of the polymer treatments, revealing that Acrylate polymer can improve soil compressive strength. The effectiveness increased at higher polymer concentrations and temperatures, demonstrating the polymer's effectiveness under diverse environmental conditions. Furthermore, long-term monitoring indicated that the polymer-treated soil maintained its integrity and PM reduction capabilities over time. The study provides comprehensive insights into the potential of polymer-based soil stabilization as a viable strategy for reducing PM emissions, offering a sustainable solution to air quality management in Egypt and similar arid regions.

Key Words: Acrylate Polymer; Compressive Strength; PM10; PM2.5 EEAA; Compressive strength; Soil stabilization

INTRODUCTION

Soil stabilization using effective polymers stands out as a popular technique for dust emission control and to minimize dust emissions, particularly hazardous particulate matters such as PM10, PM2.5 (Tan et al., 2020). Additionally, Polymers have emerged as promising alternatives, offering economic and eco-friendly benefits that render them suitable for geotechnical engineering applications (Almajed et al., 2022). Moreover, the compressive strength of soil stands as a fundamental indicator in the quest to minimize dust and particulate matter emissions into the air. As soil becomes more stabilized through the introduction of polymers, its compressive strength increases, thereby reducing the likelihood of soil erosion and generating dust particles. Furthermore, the application of polymer soil stabilizers extends beyond more environmental benefits; it also holds economic advantages by prolonging the lifespan of infrastructure such as unpaved roads and construction sites (Muller & Farr 2015). Polymers mitigate the need for frequent maintenance and repair by bolstering soil stability, thereby reducing operational costs and resource expenditure. They are highly effective in soil stabilization due to their ability to improve cohesion, reduce permeability, and enhance compressive strength. The stabilization mechanism involves three key processes: adsorption and electrostatic interactions, where polymer particles adhere to soil surfaces through electrostatic forces, ensuring uniform distribution (Ouf and Hussain 2019); coagulation and flocculation: where polymer particles aggregate and bridge soil particles, forming clusters that strengthen the soil matrix; and film formation: where water evaporation causes the polymer to coalesce into a continuous film, encapsulating soil particles and creating a cohesive network (Chen 2016). These mechanisms collectively reduce soil erosion, increase load-bearing capacity, and provide long-term stability, making emulsion acrylate polymers a sustainable solution for improving soil performance. Traditional soil stabilization methods like using lime and cement are widely used in Egypt for soil stabilization, especially in road construction and land reclamation projects. These materials improve soil strength and reduce permeability, making them effective for infrastructure projects. However, these methods often produce carbon emissions during material production, posing environmental challenges that requires alternative methods (Ismaiel 2013). In recent study, Firoozi et al., (2017) highlighted that, materials like quarry dust, crushed stone aggregates, and industrial by-products such as fly ash are cost-effective for soil stabilization and do improve soil density and reduce erosion, they do contribute to airborne particulate matter (PM) emissions during construction and operational phases, while Abuzaid and Jahin (2021) provided further insights that this method poses significant environmental challenges, highlighting the need for alternative methods that can mitigate

PM emissions while still providing effective soil stabilization. These traditional techniques highlight a gap in addressing the dual need for soil stabilization and particulate matter (PM10 and PM2.5) reduction. Traditional methods, though effective in enhancing soil strength, often fail to mitigate airborne dust, especially in arid environments with high PM levels. This required an investigation into acrylate polymer, a comprehensive and environmentally friendly solution for improving soil compressive strength while effectively minimizing dust emissions (Lowenthal et al., 2014). In this study we aim to thoroughly assess particulate matter emissions in the chosen locations, emphasizing the need for soil stabilization in these areas to reduce such emissions and evaluate the effectiveness of Acrylate Polymer in stabilizing soil to mitigate air pollution, particularly particulate matter.

MATERIALS AND METHODS

Study Locations

Soil samples for bearing strength testing were collected from five locations in Egypt: El Dabaa, New Alamein, Helwan, El Katameya, and Suez. At each site, twenty-four samples were collected to be tested against six different polymer concentrations (Table 1). In total, 120 samples were gathered from these five locations. Additionally, particulate matter (PM10 & PM2.5) levels have been monitored to assess air pollution in these areas. These locations were chosen to cover a broad area, ensuring they accurately represent various unpaved roads, industrial, and construction sites. This selection facilitates a comprehensive study of the effects of polymers on different soil types, helping to evaluate their effectiveness in soil stabilization and dust emission reduction in these regions.

Table 1: PM Monitoring and Soil Sampling Locations

NO	LOCATION	COORDINATES	TYPE
1	El Dabaa Nuclear Power Plant, Matruh	31° 2'56.52"N 28°29'12.92"E	Coastal & Desert
2	New Alamein, Red Sea	30°50'55.76" N 28°55'49.95" E	Coastal & Desert
3	Helwan Cement – Helwan, Cairo	29°49'23.75" N 31°18'39.09" E	Residential & agricultural
4	The Arab Contractors Asphalt Mixer Stations - El Katameya, Cairo	29°57'53.18" N 31°21'19.46" E	Residential
5	Lafarge Cement, Suez	29°48'16.60"N 32° 4'57.37"E	Desert

Fig.1 Particulate Matter Monitoring and Soil Sampling Locations

Chemicals

Emulsion Acrylate polymer, also known as acrylic or polyacrylate, is a group of polymers synthesized from acrylate monomers, which are derived from acrylic acid or its derivatives. These polymers are typically produced through free radical polymerization of acrylate monomers. The polymer has been used in various percentages of the soil sample (1%, 3%, 5%, 10%, 20%, and 30%) to investigate the effectiveness of the polymeric effect in soil stabilization.

Characteristics of Emulsion Acrylate Polymer

The used type of Acrylate polymers is Acronal® S 728 supplied by a BASF which is well-regarded for its flexibility and ability to bind soil particles effectively, making it ideal for dust suppression and soil stabilization. Its durable film formation and stability under UV exposure make it especially suited for applications in challenging environments. The specific characteristics of Acronal® S 728 are outlined in Table 2 as follows:

Table 2: Characteristics of Acrylate Polymer

CHARACTERISTIC	PRODUCT NAME: ACRONAL® S 728
Type	Anionic
Molecular Weight	Approximately 450,000 g/mol
Solubility	Water-dispersible
Viscosity	500 – 1,500 cP at 25°C
pH Range	6.0 - 8.0
Glass Transition Temperature (Tg)	-5°C
Film-Forming Ability	Flexible and durable

The anionic nature of acrylate polymer (Acronal® S 728) facilitates strong electrostatic interactions with positively charged soil particles. These interactions promote the adhesion of the polymer to soil surfaces, forming a stable matrix. This process reduces soil particle mobility, thereby limiting the suspension of fine particles (PM10 and PM2.5) into the air. Upon application, the acrylate polymer particles coagulate and bridge soil grains, creating a cohesive structure (Fungaroli and Prager 1969). This action strengthens the soil matrix and fills pores, reducing soil porosity and susceptibility to erosion under wind or mechanical disturbance (Afrin 2017). By binding loose particles, acrylate polymer effectively curtails the generation of airborne particulates (Song et al., 2019). As the water in acrylate polymer evaporates, it coalesces into a durable, flexible film with a low glass transition temperature (Tg = -5°C).

Soil Sampling Methodology

Soil samples were secured from five different locations across Egypt prone to dust emissions, such as arid or semi-arid regions, construction sites, and unpaved roads. The exact source varied depending on the study's focus and the intended use of the soil stabilizer Katra (2019). Soil samples comprised sand, silt, clay, organic matter, and various minerals. Soil samples were thoroughly combined with the polymer solution using a mechanical mixer to ensure uniform distribution of the polymer throughout the soil. This method helped achieve a consistent blend, ensuring that the polymer was evenly spread across the soil particles. Additionally, the moisture content of the soil was carefully controlled during the mixing process to maintain the desired consistency and prevent over-saturation or drying out, which could affect the soil stabilization process. The use of the mechanical mixer ensured effective mixing and uniformity in the soil-polymer mixture.

Physical Characteristics of Soil Samples

The physical characteristics of the soil samples are outlined in Table 3 as follows:

Table 3: Physical Characteristics of Soil Samples

NO.	LOCATION	PARTICLE SIZE DISTRIBUTION	BULK DENSITY (G/CM³)	MOISTURE CONTENT (%)	POROSITY (%)	SOIL TEXTURE	MAXIMUM DRY DENSITY (G/CM³)
1	El Dabaa Nuclear Power Plant	Typically, sandy with silt	~1.55	~7-10	~35-45	Sandy loam	~1.80
2	New Alamein City	Sandy with calcareous content	~1.60	~5-8	~40-45	Loamy sand	~1.85
3	Helwan Cement - Helwan	Silty clay with sand layers	~1.65	~15-20	~30-35	Clayey silt	~1.70
4	The Arab Contractors Asphalt Mixer Stations - El Katameya	Sandy with gravelly layers	~1.58	~8-12	~35-40	Sandy clay loam	~1.78
5	Lafarge Cement	Sandy-silty composition	~1.60	~10-15	~30-40	Silty sand	~1.75

Compressive Strength Testing Methodology

To evaluate the soil treatment effect on soil samples collected from different locations, we conducted compressive strength tests for soil stabilization using a 250 KN motorized compression machine with Autotec control unit. Soil samples were compacted into 4 x 4 x 4 cm cubes, dried for 3 days, and then placed in an air oven at 50, 70, and 90 °C. Additional samples were dried for 7 to 14 days at room temperature to determine the compressive strength at the normal day temperature (Khan al., 2019). At the beginning of the work, Acrylate polymer was tested on soil samples from various locations to assess its effectiveness for further development. The methodological standard for the compressive strength testing adhered to in this study is ASTM C39/C39M, which outlines the procedures for determining the compressive strength of cylindrical concrete specimens.

Particulate Matter Monitoring Methodology

Particulate monitoring was performed at five soil sampling locations to assess the impact of ongoing activities on air quality. The selected indicators included PM2.5 (particulate matter less than 2.5 µm) and PM10 (particulate matter less than 10 µm), measured using Aeroqual S500 portable monitors. Data collection was conducted at various sampling points within each location, with each session lasting 30 minutes (Badawy et al., 2021). The Aeroqual S500 monitor features a base with a range of functionalities that enhance its versatility across different applications. The monitoring standards applied were in accordance with the USEPA Federal Reference Method (FRM) 201A or equivalent, utilizing a gravimetric measurement principle based on a size-selective inlet and filter. Throughout the study, the operational manual instructions were followed to ensure the accuracy of the monitoring data. According to EEAA guidelines, particulate matter classification was based on PM2.5 and PM10 levels (Esworthy, 2015; Lin et al., 2017).

RESULTS

PM10 and PM2.5 Monitoring Results

The collected particulate matter (PM10 & PM 2.5) monitoring data from the chosen locations are presented in Tables (4 – 5). The particulate matter (PM) monitoring data at El Dabaa reveals concerning levels, with PM10 concentrations ranging from 611 µg/m³ to 841 µg/m³, averaging 726 µg/m³. PM2.5 levels recorded between 417 µg/m³ and 687 µg/m³, with an average of 608 µg/m³, surpassing the EEAA standard of 150 and 50 µg/m³.

New Alamein shows notably elevated particulate matter levels, with PM10 concentrations ranging from 554 µg/m³ to 749 µg/m³, averaging 631 µg/m³, and PM2.5 levels between 369 µg/m³ and 494 µg/m³, with an average of 424 µg/m³. Both PM10 and PM2.5 findings exceed the EEAA thresholds of 150 µg/m³ for PM10 and 50 µg/m³ for PM2.5.

In Helwan, PM10 concentrations vary from 1011 µg/m³ to 1382 µg/m³, with an average of 1157 µg/m³, far exceeding the regulatory limits. Similarly, PM2.5 levels range from 603 µg/m³ to 895 µg/m³, averaging 753 µg/m³, surpassing the allowable limits.

PM10 levels in El Katameya ranged from 402 µg/m³ to 597 µg/m³, with an average of 480 µg/m³, while PM2.5 levels vary between 207 µg/m³ and 475 µg/m³, with an average of 302 µg/m³, both exceeding the allowable limits.

In Suez, PM10 levels range from 475 µg/m³ to 499 µg/m³, with an average of 482 µg/m³, significantly exceeding the EEAA limit of 150 µg/m³. PM2.5 concentrations are between 311 µg/m³ and 364 µg/m³, averaging 311 µg/m³, surpassing the allowable limit of 50 µg/m³.

Table 4: PM10 Monitoring Results (µg/m³)

TIME (MIN)	EL DABAA	NEW ALAMEIN	HELWAN	EL KATAMEYA	SUEZ
1	725	580	1113	495	475
2	730	572	1197	430	482
3	682	554	1098	474	447
4	710	749	1011	423	496
5	780	647	1124	410	417
6	715	714	1135	465	498
7	702	706	1156	423	473
8	698	622	1199	479	473
9	754	630	1023	402	499
10	756	671	1098	413	517
11	725	612	1128	418	502
12	671	627	1157	438	571
13	746	632	1152	475	632
14	657	675	1046	491	675
15	680	618	1157	472	537
16	750	623	1122	513	623
17	761	614	1098	507	614
18	712	609	1217	522	609
19	743	611	1214	511	631
20	611	681	1286	413	608
21	710	616	1314	491	616
22	614	609	1304	523	609
23	657	672	1311	511	572
24	841	617	1382	538	517
25	812	638	1068	576	503
26	807	604	1039	575	627
27	667	607	1030	512	607
28	796	622	1109	597	610
29	790	597	1197	437	519
30	785	584	1170	432	511
Max.	841	749	1382	597	675
Min.	611	554	1011	402	417
Average	726	630	1155	479	549

Table 5: PM2.5 Monitoring Results (µg/m³)

TIME (MIN)	EL DABAA	NEW ALAMEIN	HELWAN	EL KATAMEYA	SUEZ
1	613	420	731	252	311
2	642	427	767	217	450
3	617	411	759	211	432
4	687	488	750	288	400
5	605	490	758	209	311
6	595	393	714	393	364
7	611	486	712	300	415
8	565	414	685	357	404
9	590	435	674	319	434
10	619	425	784	315	478
11	684	419	603	317	444
12	611	467	800	367	471
13	675	483	804	457	500
14	612	399	855	328	516
15	573	387	847	327	416
16	612	413	815	317	425
17	617	388	822	386	438
18	621	396	813	359	441
19	417	481	851	373	517
20	574	379	895	279	487
21	560	422	692	237	491
22	607	416	689	274	395
23	659	423	680	261	388
24	675	389	693	286	400
25	678	369	613	207	369
26	621	383	725	312	519
27	622	387	792	314	513
28	684	494	764	327	520
29	538	412	754	217	379
30	569	421	769	208	480
Max.	687	494	895	457	520
Min.	417	369	603	207	311
Average	608	4246	7536	3026	4356

Figures (2 -3) provide a visual representation of PM10 and PM2.5 monitoring results against EEAA limits as follows

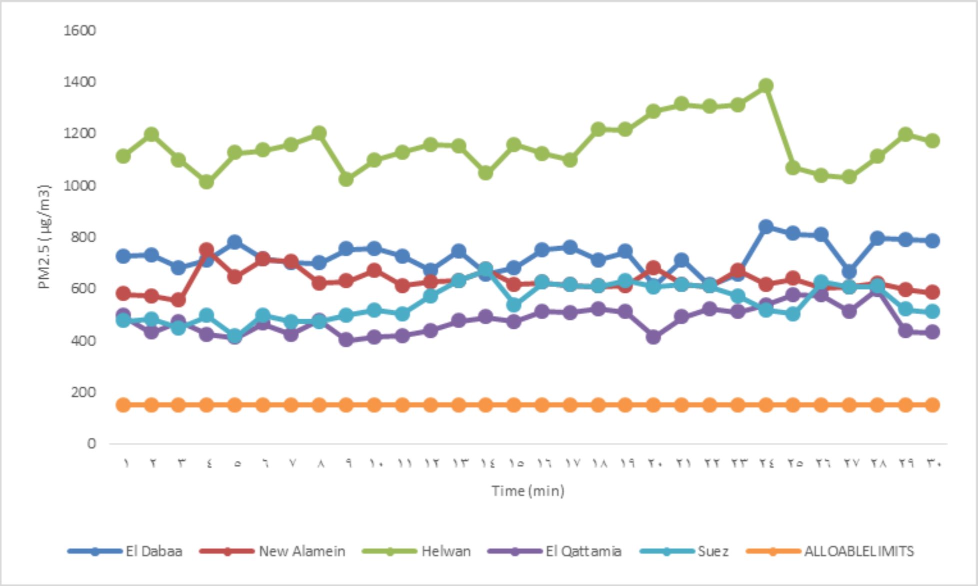

Fig. 2: PM10 Monitoring Results Against EEAA Limits

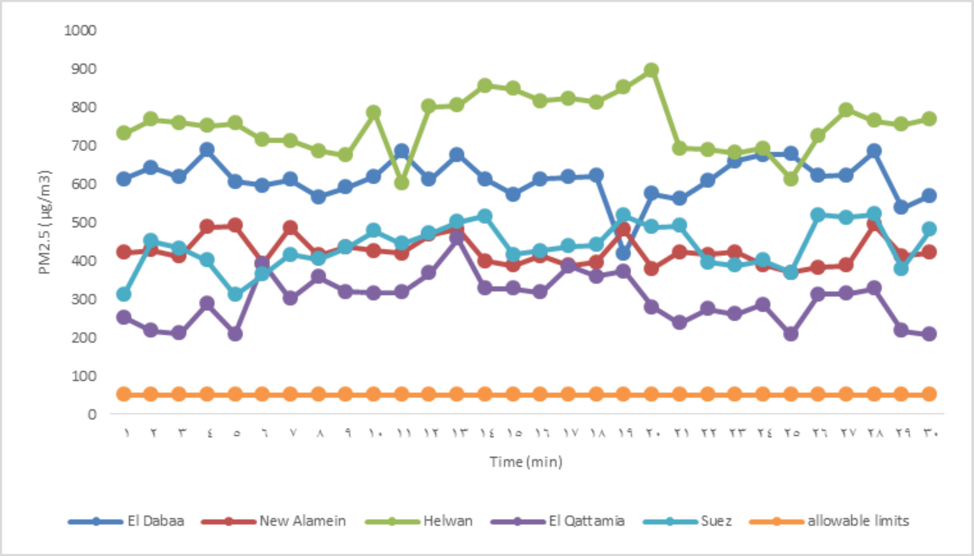

Fig. 3: PM2.5 Monitoring Results Against EEAA Limits.

2- Compressive Strength Testing Results

The compressive strength testing results revealed a consistent trend across all locations where increasing the concentration of acrylate polymer enhances the compressive strength of soil samples at different temperatures.

The compressive strength values in El Dabaa increase with both polymer concentration and temperature up to 70°C. The highest strength recorded is 14.17 kN at 30% polymer and 70°C, while a slight reduction is noted at 90°C (9.99 kN), likely due to thermal effects. The average compressive strength for 30% polymer across all temperatures is 12.47 kN. Lower polymer concentrations (1%-5%) show consistent increases from 4.88 kN at room temperature (RT) to 10.44 kN at 90°C.

The maximum value is 14.29 kN at 30% polymer and 90°C, and for 20% polymer, the strength peaks at 13.32 kN at 90°C. The average strength for 30% polymer across all temperatures is 12.78 kN, slightly higher than El Dabaa. At lower concentrations (1%-5%), strengths range from 5.02 kN at RT to 10.57 kN at 90°C.

In Helwan, the maximum peak strength is 14.07 kN at 30% polymer and 90°C. The average strength for 30% polymer is 12.39 kN, while the value at 20% polymer reaches 13.1 kN at 90°C. Lower polymer levels (1%-5%) show improvements from 4.75 kN at RT to 10.34 kN at 90°C.

The highest compressive strength in El Katameya is 13.93 kN at 30% polymer and 90°C and the average for 30% polymer is 12.5 kN, similar to other locations. Lower concentrations yield values ranging from 4.62 kN at RT to 10.2 kN at 90°C.

Suez records the highest compressive strength among all locations, with a maximum of 14.53 kN at 30% polymer and 90°C. The average strength for 30% polymer is 12.99 kN, the best overall. At 20% polymer, strength reaches 13.56 kN at 90°C. Lower concentrations (1%-5%) see improvements from 5.2 kN at RT to 10.7 kN at 90°C.

The compressive strength measurements of the soil samples using Acrylate polymer are presented in Table 6 as follows:

Table 6: Compressive Strength Measurements (kN)

LOCATION	% ACRYLATE POLYMER	ROOM TEMPERATURE	50°C	70°C	90°C
El Dabaa	1	4.88	7.52	7.84	10.12
	3	5.26	8.03	8.96	10.28
	5	5.63	8.53	9.5	10.44
	10	6.75	10.15	10.64	10.29
	20	9.63	10.14	11.92	13.2
	30	12.52	13.2	14.17	9.99
New Alamein	1	5.02	8.58	7.68	10.25
	3	5.39	9.12	8.17	10.41
	5	5.76	9.66	8.67	10.57
	10	6.88	10.8	10.32	10.33
	20	9.76	10.18	12.04	13.32
	30	10.03	12.65	13.32	14.29
Helwan	1	4.75	7.42	8.32	10.02
	3	5.12	7.92	8.86	10.18
	5	5.49	8.42	9.4	10.34
	10	6.61	10.07	10.54	10.29
	20	9.49	11.82	10.14	13.1
	30	9.99	12.38	13.1	14.07
El Katameya	1	4.62	7.28	8.18	9.88
	3	4.99	7.78	8.72	10.04
	5	5.36	8.28	9.26	10.2
	10	6.48	9.93	10.4	10.15
	20	9.36	10	11.68	12.96
	30	9.85	12.25	12.96	13.93
Suez	1	5.2	7.88	8.78	10.38
	3	5.57	8.38	9.32	10.54
	5	5.94	8.88	9.86	10.7
	10	7.06	10.65	11	10.49
	20	9.94	10.34	12.28	13.56
	30	10.19	12.83	13.56	14.53

Figures (4–9) provide a visual representation of the compressive strength trends, illustrating the combined effects of polymer concentration and curing temperature on compressive strength.

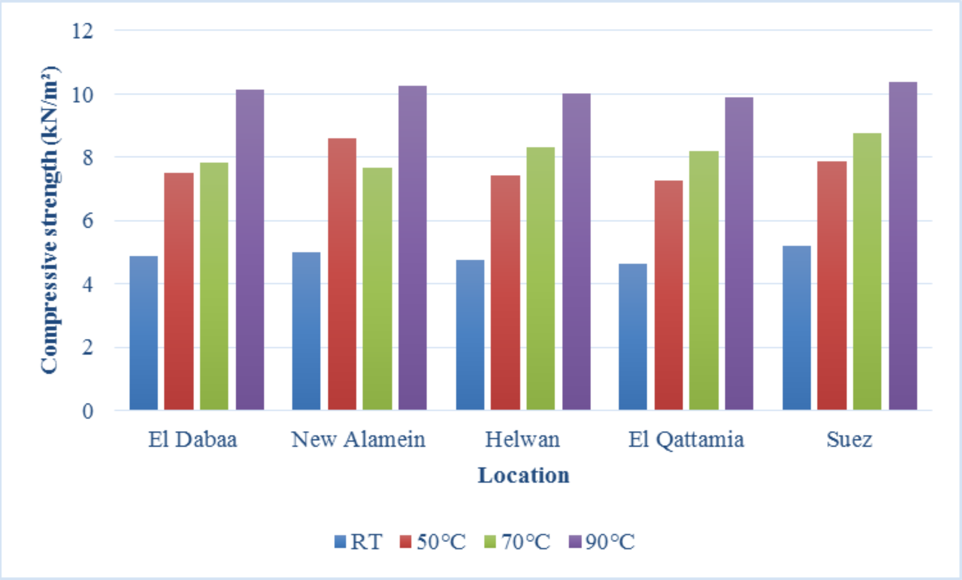

Fig. 4: Compressive Strength (kN) Measurements at 1% Acrylate Polymer

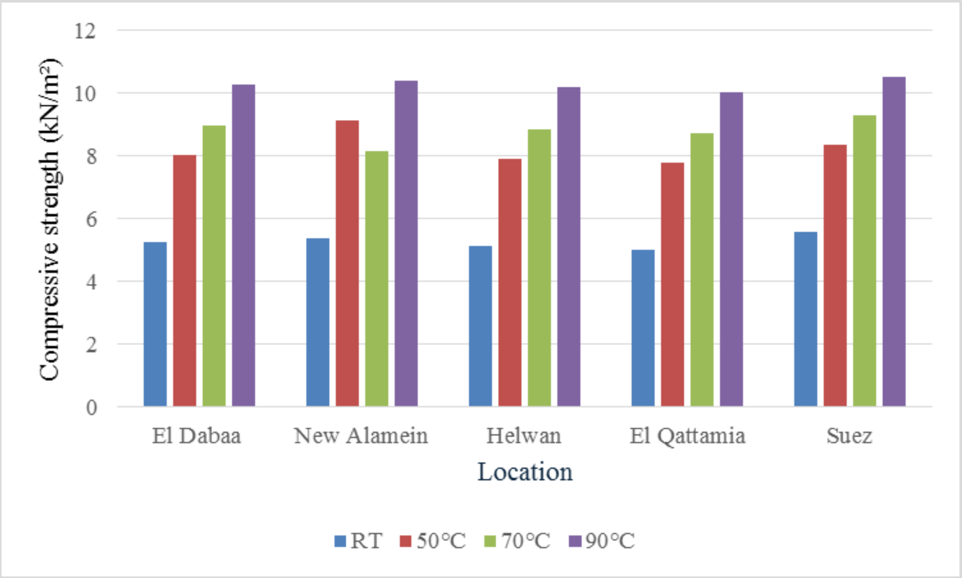

Fig. 5: Compressive Strength (kN) Measurements at 3% Acrylate Polymer

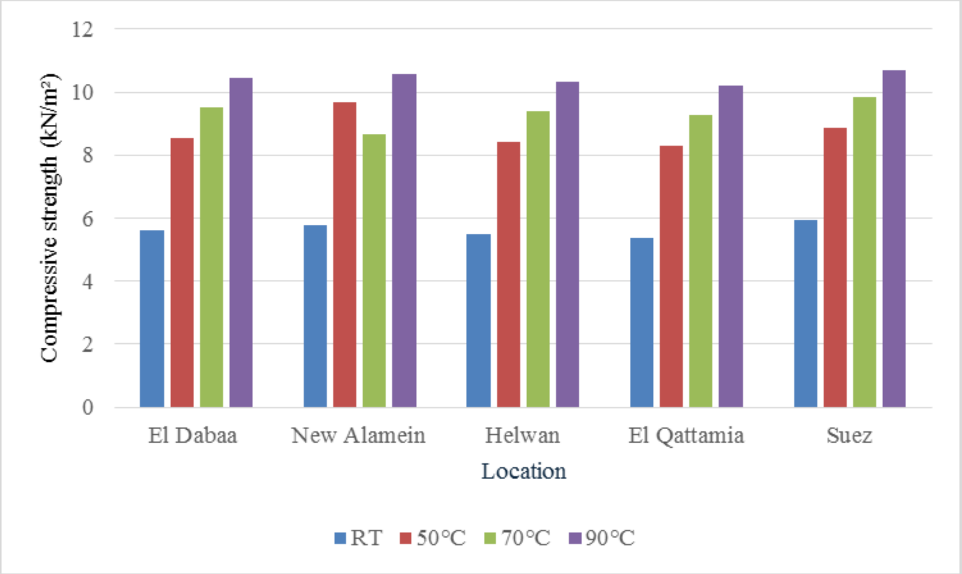

Fig. 6: Compressive Strength (kN) Measurements at 5% Acrylate Polymer

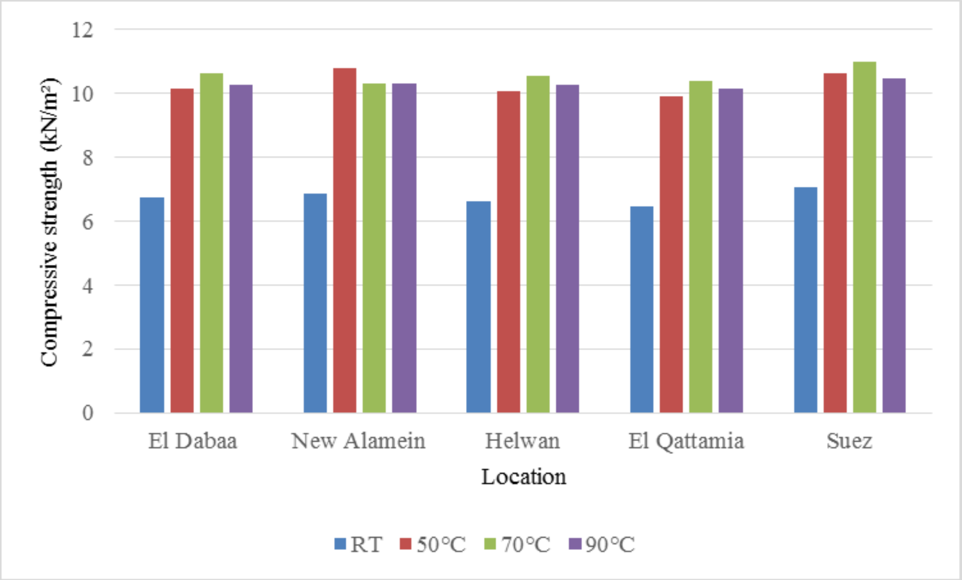

Fig. 7: Compressive Strength (kN) Measurements at 10% Acrylate Polymer

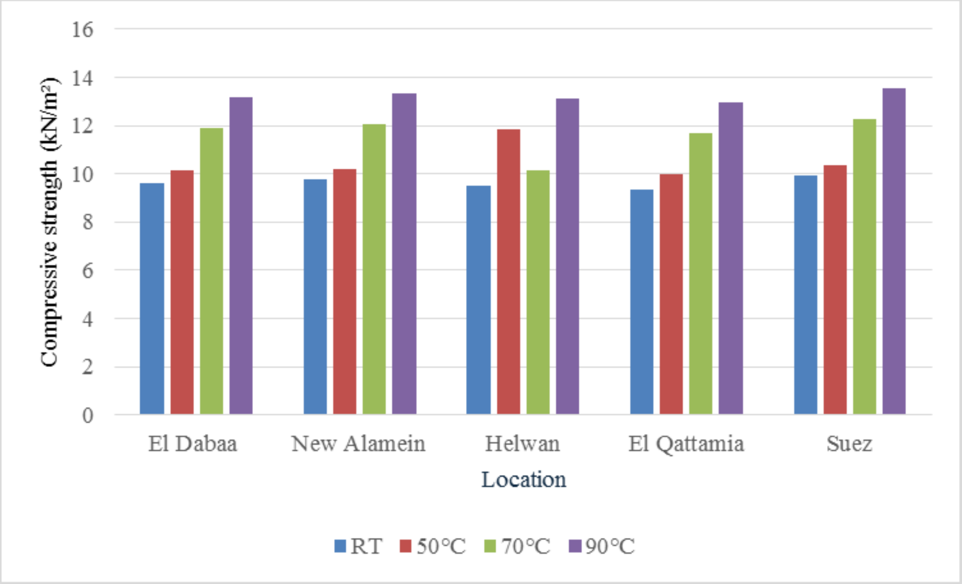

Fig. 8: Compressive Strength (kN) Measurements at 20% Acrylate Polymer

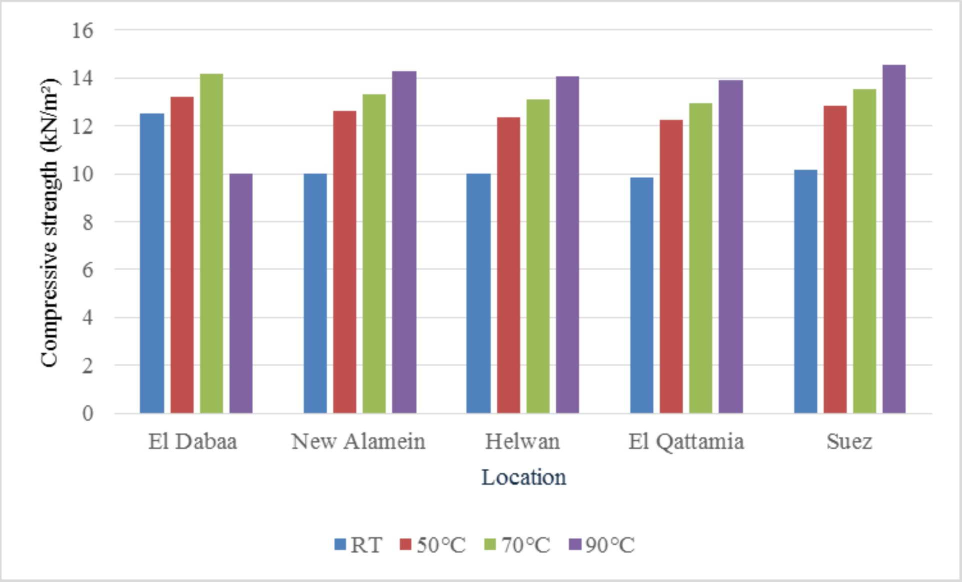

Fig. 9: Compressive Strength (kN) Measurements at 30% Acrylate Polymer

DISCUSSION

Particulate Matters Monitoring Results

The PM monitoring results at El Dabaa revealed concerning levels, surpassing the EEAA limits. This is due to the large-scale infrastructure and development projects, such as nuclear power plant construction, involve significant land disturbance, dust generation, and emissions from heavy machinery. Furthermore, natural soil composition characterized by loose sandy soils, can increase dust generation.

Helwan showed extremely high PM10 and PM2.5 concentrations, surpassing the EEA limits, likely due to industrial emissions. Helwan has substantial manufacturing activities (cement, steel), which contribute heavily to airborne particulate matter. Thes findings aligned with Elawa et al., (2022) study, who conducted the air quality monitoring across 21 cement industry sites in Egypt.

In coastal areas like New Alamein also showed PM10 and PM2.5 values well above the allowable limits. These findings supported with the Zahran et al., (2018) study findings, identified major pollution sources, such as transportation and industrial activities, which significantly contribute to elevated particulate levels.

Urban industrial areas like Suez and El Katameya, high levels of PM10 and PM2.5 are likely the result of a combination of traffic emissions, construction activities, and limited green spaces. These findings aligned with Hereher et al., (2022) study, which investigated the cumulative effects of these factors and highlighted the urgent need for effective urban planning and pollution control measures to mitigate the impact of air pollution on public health

Compressive Strength Testing

In El Dabaa, the compressive strength showed an increase as polymer concentration rises, starting from a lower value at 1% polymer and peaking at 30% concentration at room temperature (RT). However, at elevated temperatures, strength decreases slightly, which may be attributed to thermal degradation of the polymer. This trend is consistent with findings of Ouf and Hussain (2019), who highlighted the effectiveness of polymer additives in improving soil strength at higher concentrations, due to the polymers' ability to effectively bind soil particles.

In New Alamein, the testing results exhibited a clear improvement, reflecting the effectiveness of polymer-enhanced stabilization methods. At room temperature (RT), the strength progressively increases with higher polymer concentrations. These results were consistent with (Elnahas 2016) study findings, demonstrated that heat can improve polymer-soil bonding and mechanical performance.

When comparing the compressive strength results from Helwan and El Katameya, both locations demonstrated slightly lower strength values than those observed in El Dabaa and New Alamein. At a 30% polymer concentration, compressive strength at room temperature (RT) was marginally reduced, reflecting the influence of regional soil composition and moisture content.

In Suez, the compressive strength of the soil showed a noticeable increase with both higher polymer concentration and temperature. At room temperature, the strength improved as the polymer concentration increases, with further enhancement observed as the temperature rises. This pattern aligns with (Ouf and Hussain 2019) study findings, found that increasing polymer concentration and curing temperature significantly improved the compressive strength and other mechanical properties of sandy soil.

Soils treated with 30% acrylate polymer at 90°C achieved satisfactory compressive strengths values, which align with Ding et al., (2019). Soil samples subjected to higher temperatures (e.g., 90°C) displayed greater compressive strengths compared to those cured at room temperature (RT) or lower temperatures (50°C and 70°C). These findings aligned with (Abdel-Wahed and Mahmoud 2022) study, highlighted that compressive strength is a fundamental indicator of soil quality, and stronger soils lead to reduced erosion and dust generation. Furthermore, it offers long-term economic advantages by extending the lifespan of infrastructure and reducing the need for frequent maintenance (Zhang et al., 2018).

Influence of Temperature on Compressive Strength

At 1% polymer concentration, compressive strength increases consistently with temperature across all locations. New Alamein and Suez exhibit the highest compressive strength at 90°C (10.25 kN and 10.38 kN, respectively). El Katameya consistently has the lowest compressive strength across temperatures. However, Suez and New Alamein demonstrate significant increases in compressive strength from RT to 90°C.

At 3% polymer concentration, a noticeable increase in compressive strength is observed, particularly at 50°C and 90°C. New Alamein achieves the highest strength at 90°C (10.41 kN). Suez and El Dabaa exhibit strong performance at 70°C and 90°C. El Katameya continue to record lower values compared to other locations but shows improvement with rising temperatures.

At 5% polymer concentration, compressive strength steadily increases with temperature, particularly noticeable at 50°C and 70°C. Suez and New Alamein reach the highest strengths at 90°C, achieving 10.7 kN and 10.57 kN, respectively. El Katameya, while on the lower end, shows consistent improvement with temperature.

At 10% polymer concentration, compressive strength peaks around 50°C and 70°C, with a slight decrease at 90°C for some locations. Suez and New Alamein exhibit the highest strengths at 70°C, reaching up to 11 kN and 10.8 kN, respectively. This trend suggests that 10% concentration may yield optimal compressive strength between 50°C and 70°C, rather than at the highest temperature of 90°C.

At 20% polymer concentration compressive strength increases significantly with temperature, with peak values at 90°C for most locations. Suez and New Alamein achieve the highest compressive strengths at 90°C (13.56 kN and 13.32 kN, respectively). Helwan also shows high values, with a peak of 13.1 kN at 90°C.

At 30% polymer concentration, compressive strength typically peaks between 70°C and 90°C for most locations. Suez and New Alamein record the highest compressive strengths at 90°C (14.53 kN and 14.29 kN, respectively). El Dabaa, however, shows a decrease in strength at 90°C (9.99 kN), indicating that the maximum effectiveness of a 30% concentration for this location may occur around 70°C.

Generally, higher concentrations and higher temperatures improve compressive strength, with notable variations by site. Peak performance is often observed at 70°C or 90°C, though specific trends depend on the location and concentration.

Limitations and challenges Associated with the Use of Acrylate Polymer in Soil Stabilization

Acrylate polymers, like many other synthetic polymers, may degrade under certain environmental conditions. Exposure to UV light, extreme temperatures, or prolonged contact with moisture can cause the polymer to break down over time, reducing its long-term effectiveness in stabilizing soil. This can be especially problematic in areas with high temperature fluctuations or heavy rainfall (Gaytán et al., 2021).

Furthermore, improper application can lead to uneven distribution within the soil, reducing the polymer's effectiveness. Additionally, the performance of acrylate polymers can vary depending on the soil type. They tend to work better with certain soils, like sandy or silty soils, while their effectiveness may be reduced in highly clayey or highly organic soils such as Helwan (Green et al., 2001).

Although acrylate polymers provide immediate stabilization benefits, their long-term performance can be limited and may release volatile organic compounds (VOCs) or other harmful substances during application or breakdown. This can pose health risks to workers and affect the surrounding environment.

In areas with heavy traffic like Helwan and El Katameya, constant moisture, or significant soil erosion, the polymer may lose its effectiveness faster than more traditional stabilization methods like cement or lime**.** In certain high-load or highly compacted areas such as Suez, it may not provide the same level of stabilization as more rigid stabilizers such as cement or lime. (Almajed et al., 2022).

CONCLUSION AND RECOMMENDATIONS

The study concludes that polymer concentration and temperature significantly influence the compressive strength of acrylate polymer composites. Higher concentrations enhance strength, with optimal results observed at 70°C to 90°C. While location-specific variations exist, the general trends confirm the reliability of acrylate polymers for high-strength applications. This suggests their potential in soil stabilization to reduce PM10 and PM2.5 emissions, particularly in highly polluted areas. However, further research is required to assess the long-term environmental impacts, cost-effectiveness, and durability of treated soils under diverse conditions. Optimizing polymer formulations for specific soil types and conducting life cycle assessments are essential for large-scale application. Acrylate polymers' strong adhesive properties improve soil compaction and reduce permeability, though incorporating additives like cross-linking agents may enhance their resistance to environmental stresses. The findings underscore the need for tailored strategies based on soil composition and environmental conditions to ensure sustainable implementation and maximize performance.

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تثبيت التربة باستخدام البوليمرات لتقليل انبعاثات الجسيمات الدقيقة في مصر: تحليل مقارن لبوليمر الأكريليت

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الملخص

تؤثر انبعاثات الغبار في الهواء بشكل كبير على الصحة التنفسية، خاصة في المناطق التي تكون فيها مستويات الجسيمات العالقة ذات قطر اقل من 10 ميكرون و2.5 ميكرون مرتفعة. تدرس هذه الدراسة فعالية البوليمر الأكريلي في تثبيت التربة لتقليل انبعاثات الجسيمات العالقة في بعض المناطق في مصر. تم قياس ورصد مستويات الجسيمات في خمسة مواقع مختلفة، حيث كانت المستويات تتجاوز بشكل متكرر الحدود المقررة من جهاز شئون البيئة المصري. تم معالجة عينات التربة من هذه المواقع بنسب مختلفة من البوليمر وكذلك درجات حرارة مختلفة وتعريضها لظروف مشابهة للواقع. بالإضافة إلى التغيرات في درجات الحرارة، أخذت الدراسة أيضًا في الاعتبار تأثيرات الرطوبة وتركيب التربة على أداء البوليمر. أظهرت اختبارات مقاومة الانضغاط أن البوليمر الأكريلي يعزز من قوة التربة. وازدياد الفعالية مع ارتفاع تركيزات البوليمر ودرجات الحرارة، مما يظهر قوة تأثير البوليمر في ظل الظروف البيئية المختلفة. علاوة على ذلك، أظهرت المراقبة طويلة المدى أن التربة المعالجة بالبوليمر حافظت على تكاملها وقدرتها على تقليل الجسيمات العالقة مع مرور الوقت. تقدم الدراسة رؤى شاملة حول إمكانية استخدام تثبيت التربة باستخدام البوليمرات كاستراتيجية فعالة لتقليل انبعاثات الجسيمات العالقة، مما يقدم حلاً مستدامًا لإدارة جودة الهواء في مصر والمناطق الجافة المشابه.

الكلمات المفتاحية: بوليمر الأكريليت؛ قوة الضغط؛ الجسيمات الدقيقة اقل من 10 ميكرون؛ الجسيمات الدقيقة ذات قطر اقل من 2.5 ميكرون؛ جهاز شئون البيئة المصري؛ تثبيت التربة.