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Characterizing polymer modified cementations grout for semi-flexible pavement mixtures

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ABSTRACT

In general, injecting grouts into small fractures, cavities, porous soil media, areas of water leakage, fixing cracks or defects in concrete, and filling spaces beneath metal bases or digging anchors are widely applied because of the great strength and workability of the cement in these materials. Furthermore, grout is employed effectively in the manufacturing of semi-flexible pavement mixes. The goal of this research is to develop a polymer-modified grout that can be used as a flowable grout for semi-flexible pavement mixes. The grout combination was made up of Ordinary Portland Cement (OPC), Acrylic emulsion (ACR), superplasticizer (SP), and water. ACR doses were 0.25, 0.5, 0.75, and 1.0 as a percent of OPC content. Flowability, compressive strength, and flexural strength tests were conducted to characterize the produced grout, with different amounts of the specified components being employed for each test. The results revealed that the flow time rises slightly as the ACR increases. It is also shown that there is an ideal ACR dose based on compression strength. Where in most cases, the upgrading of the produced grouts was validated by a flexural strength test. As conclusion, polymer-modified grout worthily adds acceptable features to grout mechanical characteristics if the constituents of the grout are optimized.

1. Introduction

Initially, geotechnical engineers employed cement-based grouts to address foundation performance issues such as strengthening weak soils or rock masses, infilling gaps, and enhancing the water tightness of subterranean soil masses. In the field of geotechnical engineering (Grouting is a method of improving soil strength by injecting a solution in the underlying layers or soil containing cavities or voids (Mozumder, Laskar and Hussain, 2018), and (Rosquoët et al., 2003). It is difficult to create a cementation grout that is strong, durable, and readily penetrates such composites. A high-performance cementations grout for usage should have good fluidity, strength, impermeability, corrosion protection, sulfate resistance, and sometimes frost resistance. Grouts are composed of many ingredients that are blended in a variety of ways depending on the in-situ circumstances and the grouting goal. PPolymer-modified mortars (PMM) and apolymermer-modified grouts (PMG) have become more popular

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(Zhang et al., 2020). Polymer dispersions are biphasic systems made up of polymer particles that are solid suspended in water. When polymer particles are mixed with cement, they become equally spread throughout the new cement paste, enhancing the stiffness and endurance of the binder system as it hardens (Larbi and Bijen, 1990). Today's studies are mostly focused on developing grout mixtures that are affordable in cost, possess outstanding fresh-state characteristics, and have high mechanical performance (Bonicelli et al., 2019). Besides boosting fire resistance and security, grout may also be used to improve acoustic Termite resistance, blast resistance, performance, thermal storage capacity, and anchoring capabilities (Jawad, 2021). Grouts come in a variety of varieties, depending on the application, including auger cast pile grout, masonry grout, and pre-placed aggregate (Hlail, 2021). Several chemical admixtures, such as plasticizers, superplasticizers, viscosity-modifying agents, accelerators, anti-freeze agents, air-entertainers, and volume stabilizers, have been widely employed to tailor the characteristics of grouts to the job site circumstances and project objectives. Recently, several polymers that are soluble in water and polymeric particles that are distributed in water (latexes) have been introduced in mortars and to concretes increase their fluidity (Anagnostopoulos and Dimitriadi, 2021). One of the best performances was achieved by “C6”(an acrylic-modified cementations coating compound), which was sprayed toon a corroded highway wayside barrier in Xinjiang as part of a project to safeguard it, and three years of monitoring revealed that the coating functioned well in the field without visible delamination or cracking (Guo et al., 2017). In another study, the polymer has been successfully employed to improve the properties of concrete mixtures (Aggarwa et al., 2007). Other research studies stated that within three days, the temperature, and degree of hydration of cement with AR polymer distribution are lower than those of control cement (Wang and Shi, 2014). Additionally, the acrylic addition (ACR) polymer to the mortar of cement boosts compressive and flexural strengths and decreases water absorption. This study’s objective is to develop a more quality grout by integrating two distinct materials: namely, acrylic (ACR), and superplasticizer (SP), which were facilitated by d a grouting material that flows for the construction of semi-flexible pavement mixes the goal of this research is to develop a polymer modified grout that can be used as a flowable grout for semi-flexible pavement mixes. in recent years (Anagnostopoulos, 2007). The grouting method is widely utilized in practice because it improves the mechanical qualities of loose deposits. Increase the formation's strength while reducing its deformability as well as hydrostatic characteristics (reduce the permeability). Grouting studies suggest that one of the most important aspects in obtaining successful grouting is the grouting material.

2. Experimental work

2.1. Materials

The used Ordinary Portland Cement, OPC was (CEM I 42.5R) type I, which is in accordance with Iraqi standard No: 5/1984. The chemical and physical properties of this material are shown in Table 1.

The provided superplasticizer (SP) Nano Flow 5500 is the trade name for this product. Polycarboxylate is Nano Flow 5500 derivative that can be changed or purified.

Table 1. Physical and chemical properties of OPC

Physical properties		
Property	Results	Requirement
Fineness (m^2/Kg)	438	250
Density (gm./cm^3)	2.00	Not specified
Initial Setting Time (min)	125	≥ 45
Final Setting Time (hr.)	3.3	≤ 10
Expansion (mm)	1	≤ 10
Chemical properties		
SiO2	20.03	Not specified
Al2O3	3.86	Not specified
Fe2O3	4.32	Not specified
CaO	60.15	Not specified
MgO	3.61	≤ 5%
SO3	1.79	C_3A ≤ 5 % C_3A more than 5 %
Insoluble materials (%)	1.09	Not specified
C3S	55.4	Not specified
C2S	15.7	Not specified
L.O.I (%)	2.81	≤ 4.0 %
S. P. O	-	1.5 %≤
C2A %	2.91	>% 3.5
L.S.F %	.92	
F2O3- Al2O3%	.89	% For low

With the same volume of water, it provides a significant increase in slump and has a slump retention effect. Additionally, it strengthens both the initial and end stages of hydration product development. This product line is intended for use with concretes classified as C30/37 or higher. Usage Domains in workplaces where leveling issues may arise and where performance and economic solutions are required without the risk of segregation of slab and foundation concretes, curtain walls, girders and columns, bridges, architectural constructions, and RCC concretes all use this material. The characteristics of Nano Flow 5500 are listed in Table 2.

Table 2. Summarizes the properties of Nano Flow 5500 S.P

Property	specification
Density (kg/lt)	1.06 – 1.10
PH	5.9 - 7.9
Total Chloride	Maximum % 0.1
Color	Brown
Alkali	Max 5%

Figure 1. Acrylic emulsion

Acrylic (ACR) polymer is used as a modifier for cement in this investigation. The material was obtained from the neighborhood market and is manufactured by Forson Nitobond ACR Company. It was hand blended with the Water, S.P., and cement for approximately 5 minutes at laboratory temperature to create the consistency of the polymer-modified emulsion as shown in Fig. 1 . The mixture was made with purified water, while the curing water was made with tap water.

2.2. Methods

These Grouts were created in a variety of ways. ACR dosages as a percentage of OPC, which allows for the completion of the investigation goal in a single phase, namely the 1st phase which involves defining the optimal blend through the use of four mixtures in several ACR proportions, with a fixed value of W/C ratio of 0.4 percent and an SP dosage of 1 percent of the weight of the OPC. It is worth mentioning that the controlled mix is produced with a W/C ratio of 0.45. However, 2nd and 3rd phases were achieved with 1.5 and 2 % SP for demonstrating it reliability. Table 3 shows the Acrylic proportions calculated from OPC using four different proportions 0.25, 0.50, 0.75, and 1.00%.

Table 3. Matrix of cementations grouting material used in 1st and 2nd and 3rd phases

Mix	Phase	OPC (%)	AC (%)	W/B (%)	SP (%)
M1		100	0	0.45	0
M2		100	0	0.4	1
M3		100	0.25	0.4	1
M4	One	100	0.5	0.4	1
M5		100	0.75	0.4	1
M6		100	1	0.4	1
M7		100	0.0	0.4	1.5
M8		100	0.25	0.4	1.5
M9	Two	100	0.5	0.4	1.5
M10		100	0.75	0.4	1.5
M11		100	1	0.4	1.5
M12		100	0.0	0.4	2
M13		100	0.25	0.4	2
M14		100	0.5	0.4	2
M15	Three	100	0.75	0.4	2
M16		100	1	0.4	2

2.3. Preparation of Cementations Grout Materials

The following were the processes that must be completed in order to prepare the cementations grout materials. Adding the SP and ACR to the water and thoroughly mixing them together to get a homogeneous liquid from them or ensuring that the SP and Acrylic vanish completely. Once the dry cementation materials have been progressively incorporated into the prepared liquid, the mixing device is run continuously for a further 3 to 5 minutes to ensure that all mixed elements are homogeneous.

To determine the flow time of the prepared mix, the cone test according to the ASTM C939 (ASTM, 2010a)) was conducted. The test was performed immediately after GROUT preparation. The grout was next poured into the cubic molds with dimensions of 50 x 50 x 50 mm and beam molds with dimensions of 200 x 50 x 50 mm. The specimens were demanded after one or two days, depending on how well welly have hardened (mold curing). The temperature of mold curing is maintained at 20 degrees Celsius. The specimens were then allowed to mature until the day of testing, which is done under a controlled temperature level.

2.4. Experiment with Cementations Grout Materials

There were two kinds of tests have been done on grouts:

1. Test for fluidity: This test measures the fluidity of the grout over time by utilizing a flow cone test mold with specified dimensions that comply with the ASTM C939 (ASTM, 2010a). This test reflects the ability of the grout to penetrate the porous media of the asphalt mix.

2. Mechanical properties tests: Two methods were proposed to determine the mechanical properties of the hard grout. These are compressive strength tests at 3, 7, and 28 days (performed in accordance with ASTM C942 (ASTM,2010)) and flexure strength tests at 28 days (performed in accordance with ASTM C348 (ASTM, 2008)).

3. Cementation grouting results

The findings derived from all mixtures' flow test, compression, and flexure strength at various ages are addressed in the following subsection

3.1. Fluidity of cementations grout

The fluidity results for all mixtures are shown in Table 4 and Figs 2, 3, and 4. The results indicate that the fluidity of mixes M2 to M16, which contains constant percentages of W/C, increases as the flow time increases; the greatest value of flow is 18.3 s, manufactured by 0.4% of W/C, and the minimum is the flow rate 12.3 s by 0.4%. Obviously, mixes M7 to M16 fall within this range, however, mixtures M12 to M16 have a high degree of fluidity, compressive strength, and flexure strength, and are best from M7 and M11 as will see hereinafter. As demonstrated in the study, increasing the S.P ratio causes the grout mixes to become more liquid and flow more easily. This component enables more grout to escape the output tube of more on the flow cone tester rapidly, which conforms to (Koting et al., 2014). This indicates that the superplasticizer is displacing the cement particles. When developing new superplasticizers, it is necessary to foresee an interaction issue; cement and superplasticizer will be able to induce abrupt changes in fluidity and stiffness, depending on the mix of cement and superplasticizer (Hallal et al., 2010). As a result, incorporating SP in the grout is necessary to satisfy the required cement slurries' workability and reduce the high W/C ratio, as previously indicated by Albusaisi (2021). The SP facilitates the dispersion of cement particles, resulting in a more fluid paste. The amount of water in the mixture affects workability since just adding water enhances the antiparticle lubricant. This is because the flow rate is inversely proportional to the amount of water present, the higher the W/C means the lower the viscosity. The findings of mixes from (M8, M9, M10, M11, M12, M13, M14, M15, and M16) indicated that the flow time rose as the emulsion concentration increased, but that the fluidity decreased as the emulsion concentration increased. This finding implies that lower emulsion ratios may be utilized to attain this.

Table 4. Fluidity of cementations grout used in 1st and 2nd and 3rd phases

Mix	Phase	OPC (%)	AC (%)	W/B (%)	SP (%)	Flow Time, sec
M1		100	0	0.45	0	15.4
M2		100	0.25	0.4	1	16.1
M3	One	100	0	0.4	1	16.5
M4		100	0.5	0.4	1	17

M5		100	0.75	0.4	1	17.6
M6		100	1	0.4	1	18.3
M7		100	0.0	0.4	1.5	14.7
M8	Two	100	0.25	0.4	1.5	14.4
M9		100	0.5	0.4	1.5	15
M10		100	0.75	0.4	1.5	15.2
M11		100	1	0.4	1.5	15.7
M12		100	0.0	0.4	2	12.3
M13	Three	100	0.25	0.4	2	12.8
M14		100	0.5	0.4	2	13.5
M15		100	0.75	0.4	2	14.4
M16		100	1	0.4	2	14.9

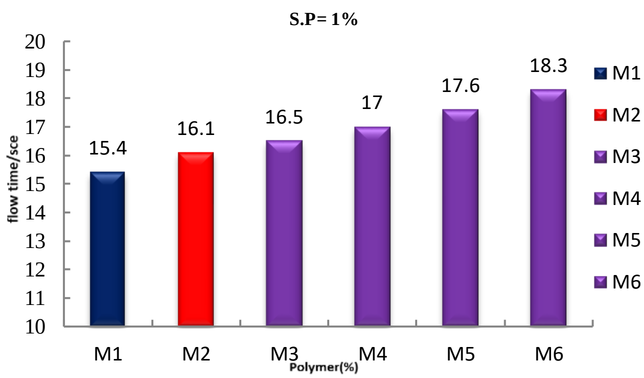

Figure 2. Fluidity of cementations grout by use S.P 1%

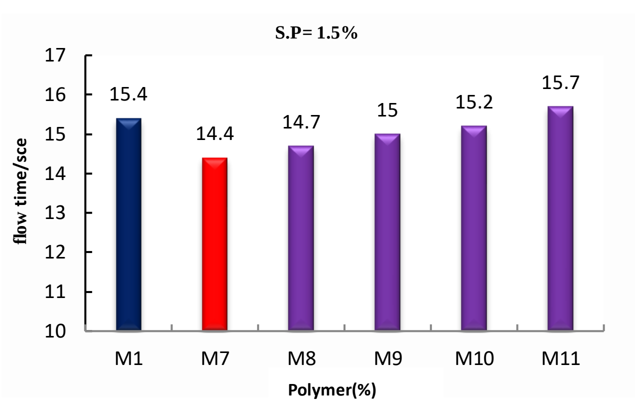

Figure 3. Fluidity of cementations grout by use S.P 1.5%

3.2. Strength of Compression Cementations Grout Materials

The development of compressive strength of grouts at 3, 7, and 28 days at constant W/C ratios is presented in Table 6. The compressive strength of all grouts at 3, 7, and 28 days is shown in Figs 5-7. Compressive strength rose with age for all mixtures because the cement hydration process took time to finish and reach a state of maturity strength (Hlail et al., 2020). This is noteworthy since it is well established that S.P. and ACR increase the compressive strength of concrete mixes.

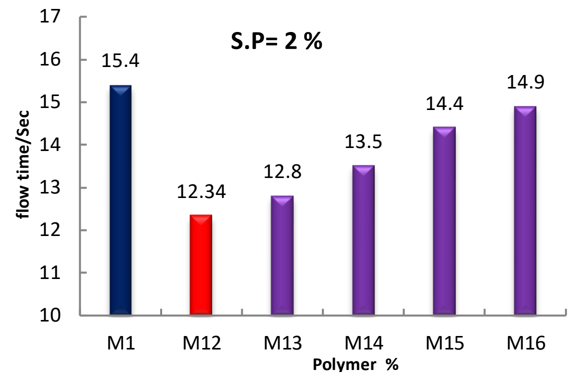

Figure 4. Fluidity of cementations grout by use S.P 2 %

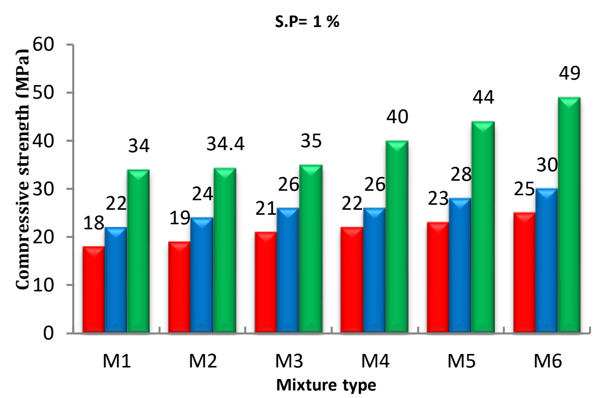

Figure 5. Compressive strength for all ages of 3,7, 28 days S.P 1%

All mixtures developed the bulk of their compressive power during their early development (7 days). After 28 days, noticeable strength improvements occur. The most compressive strength may be reached when employing 2% S.P., which is regarded optimal afterward, compressive strength diminishes as an additional more than 2% S.P. is added from the W/C weight. It can be observed that increasing the SP dosage does not result in significant improvement as long as the water content remains constant, early-age strength will be maintained in addition to the cement sufficient water to finish the hydration process.

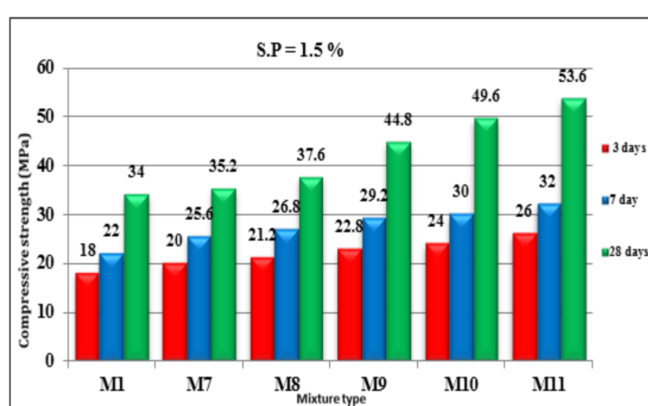

Figure 6. Compressive strength for all age of 3, 7, 28 days S.P 1.5%

To a certain degree, an increase in water produces a loss in compressive strength since water will take up space if it does not evaporate, as well as these voids will act as weak spots. As the W/C ratio grows as well as a reduction in flow time. the ratio of additional water to resistance must be adjusted. The compressive strength of M12, M13, M14, M15, and M16 increase more than M7 to M11 due to the use of 2% SP. The compressive strength of grouting pastes increases as the S.P. and ACR percentages rise, as previously shown.

Table 5. Compressive strength for different ages is used in 1st and 2nd and 3rd phases

		Control/developed mix (%)		
Mix	stage	3 days	7 days	28 days
M1	One	100.00	100.00	100.00
M2		94.74	91.67	98.84
M3		85.71	84.62	97.14
M4		81.82	84.62	85.00
M5		78.26	78.57	77.27
M6		72.00	73.33	69.39
M7	Two	90.00	85.94	96.59
M8		84.91	82.09	90.43
M9		78.95	75.34	75.89
M10		75.00	73.33	68.55
M11		69.23	68.75	63.43
M12	Three	81.82	81.48	91.89
M13		78.26	75.86	87.18
M14		75.00	73.33	72.34
M15		72.00	73.33	64.15
M16		69.23	66.67	57.63

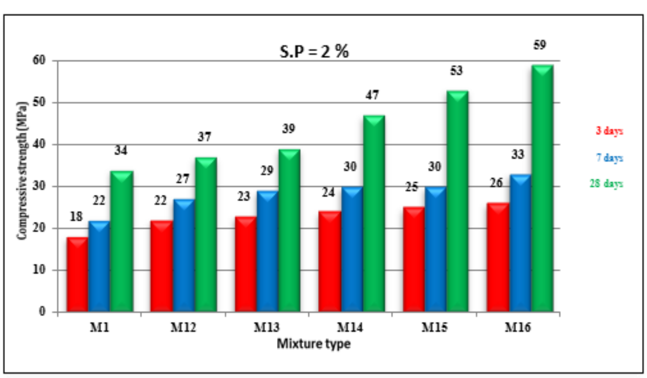

Figure 7. Compressive strength for all ages of 3, 7, 28 days S.P 2%

3.3. Flexural Strength of Cementations Grout Materials

The development of flexural strength of cementations grout is shown in Table 7 and Fig. 8. The flexural strength of the mixtures M1 to M16 improves with age, with the mixture containing 40 percent W/C having the maximum flexural strength, as compared to Koting et al (2014b), who found that employing 30 percent W/C provided the best flexural strength. However, the mixture containing 2 % S.P from W/C weight and different ACR (0.25,0.5,0.75, and 1%) have the highest flexural strength compared to the mixture containing 1.5% S.P. as well capacity to pierce unfilled compacted skeletons when subjected to gravity. However, it can be observed that the increase in SP of more than 2% dosage does not give significant enhancement to the early-age strength, and also improves cement dispersion therefore decreasing compressive strength. So best not to use S.P. more than 2% percent when mechanical qualities are dictated by the necessary values, however, 2 % SP and 0.25, 0.5, 0.75, and 1.00 %) substitution of OPC in grout manufacturing is the optimal value.

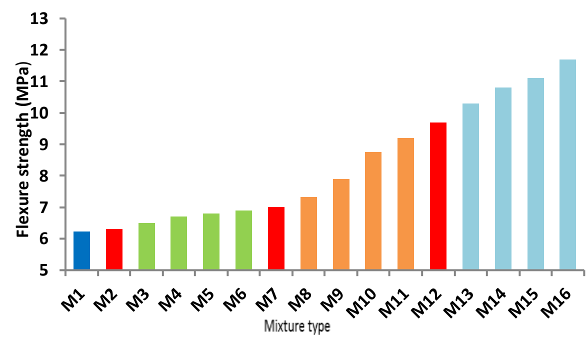

Figure 8. Flexural strength of cementations grout at 28 days

Table 6. Value of Flexural Strength of Cementations Grout Materials

MIX	OPC%	W/C%	S.P%	ACR%	28 days	Control
M1	100	45	0	0	6.23	100.00
M2	100	4	1	0	6.3	98.89
M3	100	4	1	0.25	6.5	95.85
M4	100	4	1	0.5	6.7	92.99
M5	100	4	1	0.75	6.8	91.62
M6	100	4	1	1	6.9	90.29
M7	100	4	1.5	0	7	89.00
M8	100	4	1.5	0.25	7.33	84.99
M9	100	4	1.5	0.5	7.89	78.96
M10	100	4	1.5	0.75	8.76	71.12
M11	100	4	1.5	1	9.2	67.72
M12	100	4	2	0	9.7	64.23
M13	100	4	2	0.25	10.3	60.49
M14	100	4	2	0.5	10.8	57.69
M15	100	4	2	0.75	11.1	56.13
M16	100	4	2	1	11.7	53.25

4. Conclusion

The following conclusions may be drawn after comprehensive testing and analysis of the results:

1. Increasing SP ratios necessarily make a batter more fluid Moderate is ideal. However, increasing ACR ratios is usually a flow time slow value. Therefore, by using percent from (0.25,0.5,0.75,1%) ACR in the grout mixture, it is preferable to use a high dose of up to 2% from S.P.
2. When mechanical qualities are dictated by the necessary properties, 1% of AR incorporation of OPC in grout manufacturing is the best value.
3. When mechanical features determine the characteristics of grout, the ideal value is 2 % S.P of OPC value.
4. In terms of mechanical qualities, combining ACR and S.P. with optimal OPC in the production of grout provides substantial advantages over using OPC alone.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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