EFFECT OF FINE PARTICLES IN THE FRESH PROPERTIES OF GROUT

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Abstract - *Grouting is one of the most widely used reinforcement techniques to improve the integrity of structures. A detailed review of existing research related to fresh properties of grout is hereby presented including different types of fine particles, their properties, test methods, and the influence of various types of particles on fresh properties. From this analysis, many relevant fine particle characteristics were discovered to have a positive influence on the fresh property of grout. From this study, we have to obtain a cement grout with improved performance. Properties like flowability, bleeding, compressive strength, and shrinkage of cement grouts have been studied. Rheological parameters were also studied to explain the grout workability.*

Key Words: Grout, Fresh Property, Rheology, Fine Particles, Additives

1.INTRODUCTION

In the masonry research field, grouting is defined as the introduction of a liquid form of binder into a masonry building, to fill the cracks and voids in the structure and compensate mechanical strength of the structure. Grouting is one of the most widely used reinforcement techniques to improve the integrity of these structures. The main factors affecting the grouts reinforcement effect is, injectability (fluidity) is an important characteristic to ensure that the grouts can well fill the cracks and voids. Stability (bleeding, shrinkage), mechanical properties, and compatibility between grouts and consolidated matrix are also essential. The poor performance of these properties may cause the failure of the grouting. The performance of fresh grouts is as important as that of the grouts in a hardened state. At present, many kinds of grouting materials, including cement-based grouts and lime-based grouts have been applied in the grouting reinforcement project of building structures. Cement-based grouts are the most widely used reinforcing material in modern architectural structures, such as road, bridge, pipe, house, and another municipal engineering.

Cement grouts contain cement and water with or without sand and admixtures. Admixtures are added to improve the properties of grout like flowability, permeability, strength, etc. Superplasticizers (SP) is the most common admixture used in grout mixes. Sand if used will require more water and superplasticizer to provide the requisite workability. Cement grouts have many areas of application in construction. It is utilized as a ground improvement technique attained by injecting into the ground. Grouting has a lot of applications in repairing masonry structures. Grouting using cement slurry to fill up the voids and cracks in the poor-quality porous concrete is the most simple and economical remedial measure. The grouting technique is widely used in filling post-tensioning ducts of prestressed concrete structures. It is important that the grout mix used must be flowable to ensure proper filling of the ducts and should have low bleeding to limit the free water nearby the tendons. In short, a grout should satisfy the ACI definition as “a mixture of cementitious material and water, with or without aggregate, proportioned to produce a pourable consistency without segregation of the constituents.”

This paper represents presents various types of fine particles, experimental test methods, and obtained results of each method at which some are evaluated.

1.1 Research Objective

This study aims to review existing literature on experimental testing of cementitious grout and the influence of fine particle additions on fresh properties of the grout. The literature presents various types of fine particles, experimental test methods, and obtained results of each method at which some are evaluated in the present study. The materials used, replacement percentage, and the water-cement ratio of previous studies are included in a database.

2. MATERIALS

Table -1: Material Used in Several Studies

No.	Journal	Materials Used	Replacement %
1	(Baltazar et al. 2014) w/b 0.5	Natural Hydraulic Lime	
		Silica Fume	2%
		Polycarboxylate-Type Superplasticizer	0.8%
2	(He et al. 2018)	Portland Cement	0.5 w/c
		Ultra-Fine Blast	80%, 90%,

	0.5	Furnace Slag	95%
		Polycarboxylate Superplasticizer	0.2%
3	(Huang 2001)	Portland Cement	w/c+fly ash
		Fly Ash	0.5, 0.7, 0.9, 1.1
		Polypropylene (PP) Fiber	1%
		Superplasticizer	1%
4	(Huang 1997)	Portland Cement	w/c+fly ash
		Flyash	0.4, 0.5, 0.6, 0.7, 0.8
		Polypropylene (PP) Fiber	1%
		Condensed Silica Fume	5%
		Bentonite	1%
5	(Khayat and Yahia 1997)	Cement	0.4 w/c
		Naphthalene-Based HRWR	0, 0.075, 0.12, 0.25
		Rheology-Modifying Admixtures (Welan Gum)	0, 0.03, 0.05, 0.075
6	(Li et al. 2019)	Cement	1 w/c
		Nano Silica	0-3%
		Naphthalene Superplasticizer	0, 0.5%, 0.75%, 1%
7	(Sonebi et al. 2020)	Portland Cement	w/b 0.34, 0.39, 0.44
		GGBS	60%, 70%, 80%
		Anhydrite	0%, 10%, 20%
8	(Sowmini and B 2018)	OPC	w/c 0.3, 0.35, 0.4
		Ultra-Fine Slag	0% 5% 10% 15%
		Sulphonated Naphthalene Formaldehyde	0.4%, 0.6%, 0.8%, 1%, 1.2%
		Poly Carboxylate Ether	0.6%, 0.85%, 1.1%, 1.35%, 1.6%
9	(Xiang et al. 2018)	GGBS	Equal amount & replaced by Limestone powder
		Fly Ash	
		Limestone Powder	0%, 5%, 10%, 20%
10	(Xu et al. 2018)	Natural Hydraulic Lime	NHL 100 NHL80%-SF20% NHL80%-SAL20% NHL60%-SF20%-SAL20%
		Silica Fume	
		Silicon-Acrylic Latex	

3. TEST FOR FRESH PROPERTIES OF GROUT

Flowability is an important property indicating the workability of grout to ensure efficient pumping and injection.

Grout workability can be characterized by the Flow cone test, according to ASTM C939. Based on this standard the measurement of the time of efflux of a specified volume of grout from a standardized flow cone is measured. The efflux time was determined by measuring the time taken for 1 L out of 1.7 L grout to flow through the flow cone. Flow time is connected to the grout fluidity, meaning that the longer the flow time, the lower is the grout fluidity.

A similar test which is widely adopted as a workability test for the specification and quality control of cement-based grout is the marsh cone test. As per EN 445, the fluidity of grout, expressed in seconds, is measured by the time necessary for a stated quantity of grout (1 ltr) to pass through the orifice of the cone. Marsh's time informs about the fluidity of the grout but it does not provide the parameters of the rheological behaviour.

As per EN 445, a spread test was conducted by placing a cylinder on a glass plate. The spread diameter was measured after grout spread became constant value after lifting the cylinder.

Mini slump test was carried out using a mini-slump cone of top diameter 19 mm, bottom dia 38 mm and height 57 mm. The grout mix was poured into the cone until it gets filled. The mix is allowed to spread by lifting the slump cone. The spread diameters in orthogonal directions were measured and the average spread diameter calculated.

The bleeding test was based on ASTM C940. After mixing, a 1,000 mL glass graduated cylinder was filled with 800 mL of grout and covered to prevent water evaporation. For each grout, the thickness of the bleeding water was measured after, complete sedimentation. The final bleeding was calculated using the equation

$$\text{Final bleeding\%} = V_w/V_i \times 100$$

V_i = volume of sample at beginning of the test, mL,
V_w = volume of decanted bleed water, mL

These are the main tests that can conduct to study the effect of fine particles in the fresh properties of the grout.

4. TEST METHODS AND RESULTS

Table -2: Test Results from Journals

NO	JOURNAL	TESTS	RESULTS
1	(Baltazar et al. 2014)	Wettability Measurement	Significantly decrease of the contact angle between grouts with and without replacement of Lime by silica fume. No noticeable change was observed in contact angles with increasing silica fume replacement dosage.
		Marsh Cone Test	An increase of silica fume dosage leads to an increase in grout flow time
		Mechanical Strength	For silica fume dosages higher than 2% there is a slight increase in mechanical strength and the maximum strength value reached 10%.
2	(He et al. 2018)	Setting Time	Both initial setting time and final setting time gradually decrease as GS(acquired by cyclone dust collector) dosage increases while the WS (vertical stirred mill)system presents the opposite tendency.
		Electrical Resistivity	The electrical resistivity of WS specimens develop at a faster rate than GS
		Compressive Strength	Adverse impact on compressive strength gain when the slag dosage increases. But GS replaced by 90% presents a positive effect.
		Porosity	GSPC mixtures have a greater porosity than that of WSPC
3	(Huang 2001)	Viscosity	The apparent viscosity at any shear rate was decreased as the amount of SP increases
		Flow Cone Test	SP is found to be effective in improving the flow property of grouts
		Setting Time	1% SP delays the initial and final setting times by 2–4 h, depending on the water/solid ratio. The addition of PP fiber shows an accelerating effect on the setting times of grout mixes.
		Bleed	Water/solid ratio up to 0.5, the addition of PP fiber to the grout slightly increases the final bleed. The incorporation of SP Increases the compressive strength of the grouts, especially for mixes with a high water/solid ratio. Slight reductions in compressive strength can be observed with the use of PP fiber.
		Compressive Strength	No significant difference in the total porosity exists between grouts containing PP fiber.
		Water	The addition of PP fiber

		Permeability	shows an increasing effect on the permeability of grouts. Grouts containing SP have a low coefficient of permeability.
		Porosity	Significant reductions in total porosity and pore size were observed in mixes containing SP.
4	(Huang 1997)	Flowability	The addition of PP fiber and bentonite shows a greater effect on reduction in flow, at low water/solid ratios.
		Setting Time	The 3 additives had a negligible effect on the initial and final setting times.
		Bleeding	The addition of PP fiber increases the final amount of bleeding. Silica fume and bentonite are both very effective in reducing bleeding.
		Porosity	The pore structure of grouts with silica fume is found to be finer than that of non-silica fume grouts.
		Resistance To Wetting–Drying Cycles	Grouts containing silica fume are more sensitive to shrinkage and subjected to expanding-shrinking damage as the water/solid ratio decreases. It is recommended that the amount of silica fume be reduced for grouts with water/solid ratios below 0.7 which are to be used in areas undergoing wet-dry cycles.
		Resistance To Sulfate Attack	As the water/solid ratio increases, the control and bentonite-added grouts show obvious deterioration after exposure to sulfate solution. Grouts containing PP fiber and silica fume perform well under sulfate attack within the range of water/solid ratio investigated.
5	(Khayat and Yahia 1997)	Mini Slump	For a given concentration of RMA, the addition of HRWR enhances fluidity which is reflected in a reduction in flow time and an increase in minislump spread.
		Flow Time	
		Washout Mass Loss	The washout resistance is enhanced by the increase in RMA dosage and reduction in HRWR content.
		Viscosity	The increase in the dosage of RMA is more effective in increasing viscosity at a low shear rate than that at a high shear rate.
		Forced Bleeding	Combinations of RMA and HRWR can secure high resistance to forced bleeding.
		Initial Setting	The combined effect of RMA-HRWR delays the initial setting of cement grout.
6	(Li et al. 2019)	Shear Strength	The addition of 3.0% nano-SiO_2 improved the shear strength parameters.
		Microstructure Characteristic	The addition of 3.0% nano-SiO_2 led to a better filling of microvoids, forming a denser structure than the referenced grouted specimens.
		Rheological Properties	Grouts containing nano-SiO_2 always exhibited higher viscosity. The optimal SP dose levels, 1.5%, and 0.75% were recommended for superfine cement grouts with and without nano-SiO2 addition
		Flow Spread and Flow Rate	With the addition of SP, the flow spread and

			flow rate were increased significantly.
		Bleeding	Grout containing nano-SiO_2, the bleeding was relatively lower (0.5–3%) These grouts possessed higher viscosity and poor fluidity.
		Setting Time	The addition of nano-SiO_2 can promote the gelling process of C-S-H gels, thus reduced the setting time of the sediments.
		Shrinkage	Shrinkage of grout with nano-SiO_2 was higher than that without nano-SiO_2 with the addition of SP, the shrinkage decreased, as the grout had more water to finish the hydration.
		Grouting Effectiveness	Increased grouting effectiveness of superfine cement grout with nano-SiO_2 and SP addition
7	(Sonebi et al. 2020)	Mini Slump Test	Mini-slump increased significantly when the dosage of W/B and ANH increased.
		Marsh Cone	An increase in W/B and ANH, or a reduction in GGBS, led to decreasing the Marsh cone flowtime
		Cohesion Plate	Increased W/B led to a decreased cohesion plate value. An increase in GGBS increased the cohesion plate value. Increased ANH caused a reduction in the cohesion plate.
		Plastic Viscosity	Increased W/B had approximately a 4.4 times greater influence on reducing plastic viscosity than increased ANH or decreased GGBS
		Induced Bleeding	It can be seen that when an anhydrite value is selected and the W/B ratio is increased the bleeding will also increase. Similarly, if a W/B ratio is selected and the anhydrite content is increased the bleeding will again increase.
		Permeability	Increased W/B and AHN had the greatest primary effect on permeability at 1 min. It seems there is an optimum reached at W/B = 40 and AHN at 17%.
8	(Sowmini and B 2018)	Mini Slump Test	It enhances the flowability characteristics of SNF based grouts at 0.35 w/c. It enhances the flowability characteristics of PCF based grouts at 0.30 w/c.
		Marsh Cone	0.3 w/c ratio, 5% replacement of OPC with ultra-fine slag (UFS)showed an increasing trend in flow time
		Bleeding	There is a considerable reduction in bleeding with UFS addition.
		Compressive Strength	PCE mixes showed slightly higher strengths than SNF mixes.
		Shrinkage	For SNF based grouts, shrinkage rate has reduced by 59% at 10% cement replacement with UFS, whereas for PCE based mixes a reduction of 42% at 15% replacement was attained.
9	(Xiang et al. 2018)	Rheology (Rheometer)	The addition of limestone powder did not change rheological parameters But GGBS & FA provides enhanced rheology. Plastic viscosity

			decreased when fine limestone powder was added to the pastes.
		SEM Analysis	Limestone powders provided a physical filling effect.
		Compressive Strength	A 10% replacement enhances strength.
10	(Xu et al. 2018)	Fluidity	SF &SAL mix reduces the fluidity of NHL
		Contact Angle	Low for SF & SAL
		Wettability	Low contact angle means high wettability i.e, the interfacial bond is improved
		Density	All mix shows a nearly same density
		Bleeding	SF shows low bleeding rate than SAL Addition of SF & SAL enhanced stability of grout
		Mechanical Strength	Enhanced by SAL & SF addition

5. FRESH PROPERTIES OF GROUT

5.1 Initial and Final Setting Time

The time required for grout to achieve the initial and final set is of great importance in the field. The initial setting time represents the time at which fresh grout can no longer be properly handled or injected; and the final setting time approximates the time at which hardening and development of strength begin. In the field, the setting times provide a guide of available time for an injection of a given batch before it must be discarded. Also, a very short and controllable set time may be required for injection into a formation with a water flow to avoid washing the grout out before it hardens. The influence factors of initial and final setting time mainly include particle size of cementitious material and dissolution and sedimentation rate of ions from particles.

5.2 Bleeding

Bleeding is the appearance of water on the surface of the grout during the early stage of cement hydration. It is a form of segregation resulting from the inability of the solid particles to hold all mixing water in a dispersed state as the solids settle. Injection of grout mixes exhibiting excessive bleed may leave numerous uncontrolled open channels within the grouted mass, which leads to weakness, porosity, and a lack of durability. Grout has good behavior if the bleeding rate is less than 5% (Xu et al. 2018). The water/solid ratio has a great effect on the bleeding of the grout. Stable cement grout must be used in practice because unstable grout may lead to a partial filling of fracture due to its high bleeding. Excessive bleeding can weaken the grout by increasing porosity, thus affecting durability.

5.3 Flowability

It is an important property indicating the workability of grout to ensure efficient pumping and injection. The time needed for a grout sample to flow through the Marsh cone is proportional to the viscosity of the cement grout; the flow time becomes an index of fluidity, so the longer the flow time, the lower the fluidity. The flowability is an important parameter relative to grout-mix design. Good flowability or low viscosity grouts are preferred for injection into fine fissures, or to increase the distance of penetration into fractures.

5.4 Rheology

Grouts with low viscosity are preferred for penetrating fine fissures or long distances. High-viscosity grouts find applications in injection into wider fractures or limited depths. Due to the high specific surface area of superfine particles, the hydration reaction will be fast, which causes high viscosity. Higher viscosity grouts might be preferred to limit penetration or fill wider fractures. The hydration was improved by superfine particles and the superfine particles can be easily infilled.

5.5 Compressive Strength

Compressive strength is an indication of grout quality to its bond and shear strength. It is important to ensure the quality of grout used. The compressive strength of the grout is a property that relates directly to the structure of the cement paste and provides a good indicator of its quality of the hardened grout. The flexural strength is an important property because underground containment barriers are frequently subjected to high lateral earth pressure.

5.6 Pore Structure

The pores in cement grout form a continuum and the pore structure have been used in predicting permeability and durability of cement pastes. The pore structure is a major component of the microstructure that affects water permeability and durability of cement grouts. Particles finer than 3 micrometers led to the reducing of pores in hardened cement pastes

5.7 Water Permeability

The major function of subsurface grout barriers is to prohibit the migration of groundwater flow in or out of the waste. Most deleterious reactions, including sulphate attack, corrosion, alkali-aggregate reactions, and freezing and thawing, involve the ingress of water or aggressive solutions. Impermeable grouts not only provide hydraulic isolation but also enhance durability. Therefore, permeability is the most important property of watertight and durable grout barriers in aggressive underground environments.

6. CONCLUSIONS

A review covering existing research on grout properties in cement-based materials and lime-based materials was carried out to analyse the influence of the addition of different types of fine particles. The review indicates the desirable properties that grouts should possess as good flowability, reduced bleeding, not too short initial setting time, adequate strength, and durability.

Fineness is an important element in achieving the highest strength performance. Cement grouts used for crack injection, anchorage sealing, and post-tensioning applications are proportioned to exhibit high flowability to facilitate casting and adequate cohesion to prevent phase separation and bleeding.

Based on the review, conclusions that can be made are: by adding superplasticizers and fine particles in the grout can reduce the water-cement ratio and produce a higher strength than conventional grout. It reduced the final bleeding of grout or incorporating additives can effectively eliminating bleeding. The higher fluidity made the grout easier to inject into the fracture. The use of the water-retentive grouting admixture seems to resolve the problem of water separation from cement grout.

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