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Physical Characteristics of Grout for Low Density Roads

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Abstract: The presented study represents the results of an experimental study handled with developed grouting materials. These experimental studies cover the effects of some mineral Admixtures and chemical admixtures on the characteristics of grout such as compressive strength, bleeding, setting time and viscosity for different curing times. All grout types were prepared under same water/cement ratio. Grout mixtures that 15% of mineral admixtures replaced with cement by weight were prepared. The results showed that grouts produced with silica fume (SF) and metakaolin (MK) in all mixtures were yielded the highest compressive strength at all ages. The all strength tests of fly ash (FA) grout exhibited low values till 28 days of curing time in accordance with reference grout, but a sharp increase was observed after this period. Grouts with perlite (PRL) and blast furnace slag (BFS) showed the similar strength values according to reference grout. Mineral admixtures can be used for high-strength and low cost grout in tunneling applications. In addition, the use of waste materials can contribute to the resolution of environmental problems. Compressive strength obtained by the grout prepared by using styrene butadiene rubber was found 23.644 N/mm^2 and 34.793 N/mm^2 for 7 and 14 of curing period where compressive strength obtained by the grout prepared by using fly ash was found 20.444 N/mm^2 and 31.827 N/mm^2 for 7 and 14 days of curing period.
Keywords: Grout, Compressive strength, admixtures, cement and mix design

INTRODUCTION

Admixtures are natural or manufactured chemical added to the concrete, grout or mortar before or during mixing. Admixtures are used to give the special properties to fresh and hardened concrete. Admixtures are commonly classified depending on the function and effect on concrete [1]. Depending on the type and the amount of admixture, different advantages can be achieved through their use. Uses of chemical admixtures have greatly increased during the last three decades and are now incorporated in most mix designs. The most often used chemical admixtures are air entrainer, water reducer, accelerator, retarder, etc. The use of admixtures in the ready mixed concrete industry has increased considerably in recent years**.** The object of the admixtures is to modify the properties of the concrete to make it more suitable for certain applications and these admixtures are usually added by the ready mixed concrete manufacturers at the plant mixing stage [2]. Admixtures are ingredients other than, aggregates, hydraulic cement, and fibers that are added to the concrete immediately before or during mixing.

A proper use of admixtures offers certain beneficial effects to concrete, including improved quality, acceleration or retardation of setting time, enhanced frost and control of development strength, improved workability, and enhanced finish ability. The civil and environmental engineers have been challenged to convert the industrial wastes to useful building and construction materials. Industrial wastes concrete admixtures, generally have two main categories; organic wastes like, wood sawdust, cork granular, coconut pith, and rice husks; and inorganic wastes like broken brick aggregate, silica gel, iron splinters, SF, minced rubber and chopped worn-out tires [3].

The grout is composed of Portland cement, sand, and water and is hardened by hydration of cement [4]. Grout injection is used for sealing or strengthening the ground in order to prevent water entrance or any failure after excavation. There are many methods of grouting. Permeation grouting is one of the most common types in which the grout material is injected to the pore spaces of the ground. In cementitious grouting, the main ingredients are cement, bentonite, and water. Cement is the main ingredient of cement based grouts. The grout mixtures are prepared for both of the sealing and strengthening purposes for a structural project. In grouting operations, the grout quality is important to achieve the best results [5]. There are three main characteristics for a grout mixture including bleeding, setting time, and strength. Grout

has to be highly flowable with a maximum particle size considerably smaller than the thickness of the width of cracks [6]. It is known that the mechanical properties of certain types of concrete, mortars or grouts based on Portland cement can be improved through the use of the so-called Ultra-Fine Cements. Practice has demonstrated that the finer the cement particles size the larger the water demand and so the compressive strength of the materials prepared with ultra-fine cement is reduced.

Type of admixtures and origins were summarized in Table 1.

Table-1: Type-origins of Mineral Admixture (Teymen, 2017)

Admixture names	Codes	Admixtures Origin
Silica Fume	SF	Antalya-Etibank Ferro – Chrome Factory
Blast Furnace Slag	BFS	Iskenderun – Iron and Steel Factory
Fly Ash	FA	Adana - Sugözü Thermal Power Reactor
Colemanite	CLM	Kütahya (Emet-Espey) – CLM Quarry
Simektit	SMT	Ankara (_Imrahor) – Clay Quarry
Perlite	PRL	Izmir (Cumaovası) – Etibank PRL Quarry
Basalt Dust	BD	Osmaniye
Coal Dust	CD	Zonguldak
Metakaoline	MK	Nigˇde (Fesslegˇen) Kaolinite Quarry
Reference Grout	RF	-

Lam *et al*. studied the strength effect of SF and FA with different w/c ratios. According to their findings, a 15% SF and a 25% FA replacement increased the compressive strength of grout considerably at the end of 28 day. Tan *et al.* [7] investigated the effects of bentonite, fly ash, and silica fume on the bleeding using Taguchi approach and found the silica fume as the most efficient additive among the above additives for bleeding reduction.

Shannag outlined 26% strength increasing with 15% pozzolan and 15% SF after 28-day. Compressive strength of the concrete without SF was found to be lower than the compressive strength of the SF concrete for mixes with a w/c ratio of 0.35.

Mazloom *et al.* concluded that the workability of concrete decreases, while the proportion of SF increases. They concluded that the workability of concrete decreases, while the proportion of SF increases. Results showed that SF addition improved the short-term mechanical properties of concrete (such as secant modulus and CS) for 28 day curing time.

In 1992, both Krizek *et al*. and Liao *et al.* performed experimental research using a grout with a mixture of ultra-fine cement and sodium silicate, found that the compressive strength increased with the cured grout age.

Yoo *et al*. reported that the compressive strength of grout decreased after 7 days due to surface cracking by self-restraint of shrinkage as a result of water evaporation. According to the findings of Soliman and Nehdi reported that the maximum temperature due to cement hydration was delayed and decreased with the addition of shrinkage reducing admixtures.

According to the findings reported by D'Ambrosia et al. that early-age shrinkage of ordinary Portland concrete (OPC) increased gradually when shrinkage reducing admixture was incorporated. This was due to the fact that SRA is comprised of special organic chemicals such as surfactants, decreasing the surface tension of pore water in the hardened cement paste.

Sonebi *et al*. concluded that the percentage of MTK significantly reduced setting times. MTK replacement had a greater effect on improving the compressive strength at 3, 7 and 28 days. According to Mailvaganam and Rixom water reducing admixtures can retard the setting time of mortar or concrete. Prolonged setting time indicates that gum acasia karroo can be used as retarding admixture at 23^0 C.

Mbugua *et al*. concluded that Compressive strength generally increased with curing age Reduced water cement ratio increased the compressive strength between 0.7% and 0.9% level dosage. Increase in dosage of gum acacia karroo increased the setting time of cement grout. Bleeding of mortar decreased with increase in gum acasia karroo dosage. Al-Adili *et al*. has revealed that the flexural strengths with respect to adding 10 % of iron splinter and 5% minced rubber admixture is found to be the highest value to about 12%. Also, the compressive strength of concrete made with

admixtures is higher than the ordinary concrete. It increases to about 36% by adding 10 % of iron splinter and 5% minced rubber, while it decreased with admixture ratio of 5 % of iron splinter and 10% minced rubber.

THEORETICAL ASPECT

Characteristics of Grout Mixture

There are four main characteristics for a grout mixture including bleeding, setting time and strength. The main characteristics for cement-based grouts by which the efficiency of a grout is examined can be mentioned as follow [5]

- Bleeding: The appearance of water on the surface of grout after it has consolidated is known as bleeding. It is the form in which the layer of water migrates to the surface of grout during the initial stage of cement hydration process.
- Setting time: Setting is the stiffening of the cement paste after water is mixed. The time at which cement paste loses its plasticity is called as initial setting time or the time when the cement water paste attains a certain degree of hardness is known as initial setting time. The time taken to reach the stage when paste becomes hard mass and can sustain some minor load is known as final setting time.
- Compressive strength: It is the capacity of material or structure to withstand loads tending to reduce its size. It is the resistance of a material to breaking under compression. This test is performed to know how much compressive load a material can bear or resist.

Priority of Grout Characteristics

It is important to note that the priority of importance between the above-mentioned characteristics is first belonged to bleeding, second to setting time and finally to compressive strength. The reason for this fact is that one may build a grout mixture with noticeable strength but not with acceptable bleeding or setting time. Therefore, apart from the high strength, the grout mixture cannot be considered. Besides, there are some projects with only purpose of sealing [5].

MATERIAL AND METHODOLOGY

This section presents the material needed for the experiment and process to perform the experiment. From the research papers study, the effects of many admixtures on grout through the researcher's experimental study are discussed below.

Materials used in the researcher's experimental study

- Cement: The cement types used were CEM II /B-P 32.5 R fineness of 4503 cm^2/g. Initial setting time of cement was 128 min and final setting time was 207 min.
- Super plasticizer
- Fine Aggregate: For all mixtures, homogeneous silica sand passing through 0.5 mm sieve was used as fine aggregate.
- Mineral Admixture: SF, BFS, FA, CLM, SMT, PRL BD, CD, and MTK
- Chemical Admixture: Sodium Silicate, Sodium Carbonate

Preparation of Grouting Mixture

The grouts were prepared by using mineral admixtures at the range of 5% –25% of the cement weight. In practice, the grout must be resistant to stress. Considering this parameter, the substitution of mineral admixtures rate determined as 15%.Ten different types of grouting mixtures were prepared using 100mmx100mm cubic specimens under same mixing condition to examine the effect of mineral admixtures. One of them was prepared as a RF and no mineral admixture was used in this grout. Silica sand to binder (cement + mineral admixture) ratio was 0.10, and water to binder ratios was 0.36. The ratio of super plasticizer to binder was 0.85%. With ten different types of grouting materials and five different curing times (1, 3, 7, 28, 90 days) compressive strength of grouting mixture was determined[8].

MATERIAL

- Cement: Ordinary Portland Cement (OPC) grade -53 with fineness of 4%, soundness of 2.5 mm, std. consistency of 37.5%, initial setting time of 96 minutes and final setting time of 261 minutes.
- Mineral admixture: Fly Ash
- Chemical admixture: Styrene Butadiene Copolymer (SBR)
- Water

METHODOLOGY

The first grout was prepared by using mineral admixture i.e. Fly Ash (FA) in 34% by the weight of cement and adding water in it with W/C ratio of 0.4. Consider this grout as GROUT 1. The second grout was prepared by using

chemical admixture i.e. Styrene Butadiene Copolymer (SBR) with cement and water (20 ml in 4 kg cement). Consider this second grout as GROUT 2. Two different types of grouting mixtures GROUT 1 and GROUT 2 were prepared to examine the effect of admixtures on the compressive strength of grout. Those prepared grouting mixtures were filled in mould of 75mmX75mm and put it for 24 hours in mould for drying purpose, then was taken out from mould after 24 hours and put them for curing. With two different types of grouting mixtures and two different curing times i.e. 7 days and 14 days compressive strength of grouting mixtures were determined

Fig-1: Casted cubes after 24 hours

Fig-2: Casted Cubes after Compressive Strength Test

Testing

Compressive strength test was performed in this study. Their description of compressive strength test is as follows.

Compressive Strength Test

Fig-3: Compression Testing Machine

75mmx75mm cubic specimens were cast for each grout mixtures type and compressive strength test was conducted using these specimens. A digital compression testing machine was used for compressive strength testing. The load was constantly applied without shock until failure and the load present on the grout cube at the time of failure was noted down. That load was considered as the compressive strength of that grouting mixture cube. Compressive strength of two different grouting mixtures for 7 days and 14 days were taken.

Testing results

In this, testing results of both mineral admixture and chemical admixture on compressive strength, bleeding and setting time is mentioned as below

Testing Results of Mineral Admixtures on Grout

The test specimens of compressive strength were tested after 1, 3, 7, 28 and 90 days of curing times. The calculated mean values were given in Table 2

Table-2: Compressive Strength of Grouts Mixture [8]

Mix Code	Grout Strength (MPa)				
	1 day	3 days	7 days	28 days	90 days
	CS	CS	CS	CS	CS
M1 (SF)	6.66	19.15	26.32	51086	74.36
M2(BFS)	3.40	14.69	21.78	41.54	57.50
M3(FA)	4.33	16.33	23.76	42.46	71.87
M4(CLM)	2.20	8.60	14.61	27.95	41.79
M5(SMT)	3.83	15.87	21.93	35.71	54.88
M6(PRL)	3.69	17.36	22.66	41.57	60.00
M7(BD)	3.13	15.52	22.77	34.46	52.77
M8(CD)	3.50	14.35	19.80	31.36	44.48
M9(MK)	7.38	26.84	35.25	53.32	76.45
M10(RF)	4.69	2046	24.98	41.82	65.26

The mixture prepared with SF, MK and FA were given 74.36 MPa, 76.45 MPa and 71.87 MPa compressive strength value after 90 days of curing time. Using MK, SF and FA admixtures in grouting mortar increased the compressive strength values were compared with RF having 65.26 MPa compressive strength.

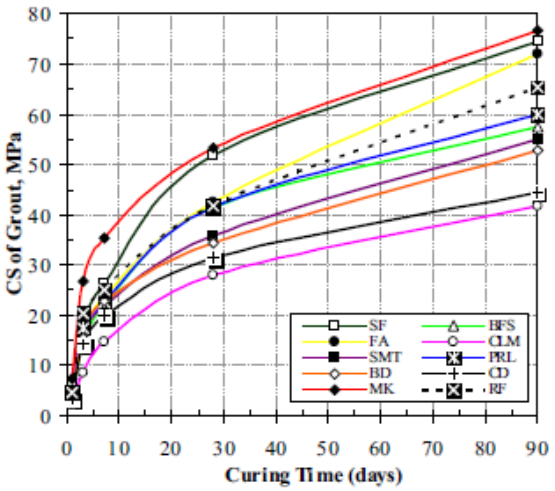

Fig 4 The Evolution of Compressive Strength according to Age [8]

The above graph was plotted between the curing time in days and compressive strength in MPa with the help of testing results.

Testing Results of Chemical Admixtures on Grout

From some research papers, there are effect of chemical admixture on grout which may enhance some grouting characteristics such as strength, bleeding, setting time and viscosity.

A] Testing Results of Chemical Admixtures on Grout Strength

(a)Testing Results of Sodium Silicate on Strength of Grout

In order to study the effect of sodium silicate on the strength of grout mixtures, some grout samples were considered with constant ratio of *W*/*C*= 1, fixed value of sodium carbonate (3%), but varying sodium silicate percentage from 2% to 5% with an interval of 1%. The results of compression test on the molded grout samples are shown in Fig. 6.2.1.

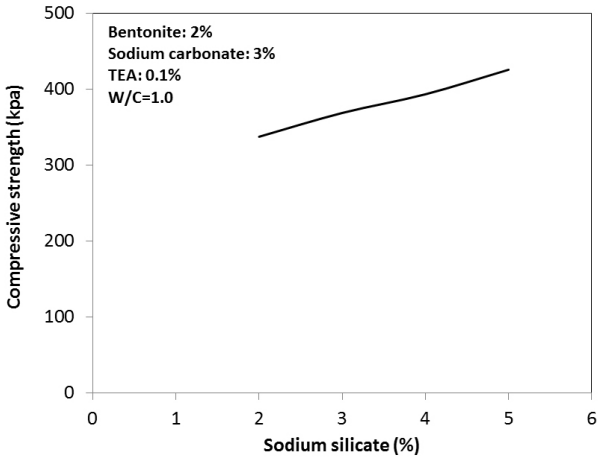

Fig-5: Effect of sodium silicate on the compressive strength of the grout [5]

In Fig. 6.2.1, the compressive strength of a grout sample increases by raising the sodium silicate amount. In this study, the value of compressive strength rises from 337.3 KPa to 425.6 KPa by raising the amount of sodium silicate from 2% to 5%. Hence, by considering the necessities of the project and the required strength for the grout, the amount of sodium silicate should be determined and suggested for use.

(b) Effect of Sodium Carbonate on The Strength of Grout

Similar to the study of the effect of sodium silicate, some grout samples were prepared with constant ratio of W/C = 1, fixed value of sodium silicate (5%), but varying sodium carbonate percentage from 3% to 7% with an interval of 1%. The results of compression tests on the molded grout samples are shown in Fig. 6.2.2.

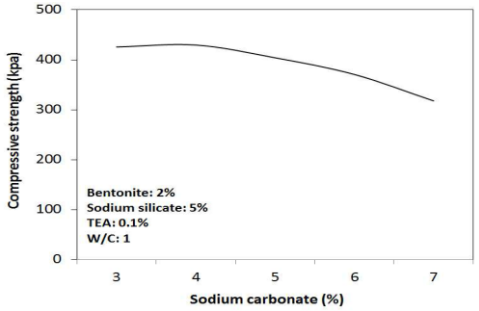

Fig-6: Effect of sodium carbonate on the compressive strength of the grout [5]

As it is evident from Fig. 6.2.2, the value of compressive strength remains unchanged by raising the sodium carbonate value from 3% to 4% but it starts to decrease from 429.5 KPa to 317.7 KPa by raising the sodium carbonate percentage from 4% to 7%. As a result, raising the amount of sodium carbonate beyond 4% may be harmful when high compressive strength is required.

[B]Testing Results of Chemical Admixtures on Grout Setting Time

(a)Testing Results of Sodium Silicate on Grout Setting Time

Setting time of a grout mixture can be highly influenced by adding only a small percentage of sodium silicate to the grout mixture. Fig. 6.2.3 shows the effect of sodium silicate on the setting time of a grout mixture. As it is evident in Fig. 6.2.2. the setting time of the grout mixtures is significantly reduced by increasing the amount of sodium silicate.

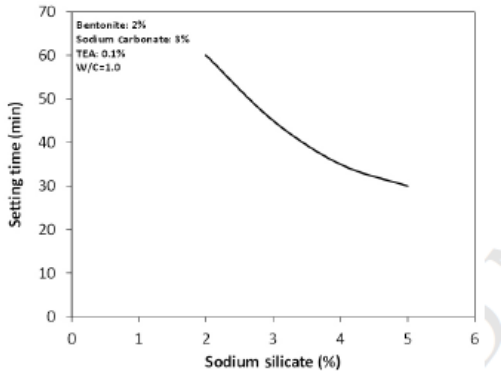

Fig-7: **Effect of sodium silicate on setting time of the grout** [5]

(b)Testing Results of Sodium Carbonate on Grout Setting Time

In this stage, sodium carbonate amount is changed in order to investigate its effect on the setting time. The results show that the setting time of the grout mixtures is gently reduced by raising the sodium carbonate.

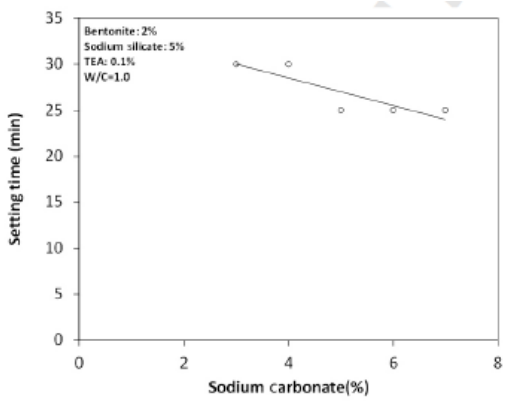

Fig-8: Effect of sodium carbonate on setting time of the grout [5]

Comparing figure 6.2.3 and figure 6.2.4, one can deduce that effect of sodium carbonate is mucgh less than the effect of sodium silicate on the setting time. Following table shows the effect of some chemical admixture on the grout characteristics such as bleeding, strength and setting time.

Table-3: Effect of chemical admixture on the Grout [5]

Material	Effect of Grout Characteristics		
	Bleeding	Strength	Setting Time
Bentonite	Decrease	Decrease	-
Sodium Silicate	Decrease	Increase	Decrease
Sodium Carbonate	Decrease	No Effect	Small Decrease
TEA	Small Decrease	Small Decrease	Small Decrease

From the experiment, compressive Strength results of both grouts i.e. GROUT1 and GROUT 2 were found with the help of Digital Compression Testing Machine. Results are in the table below.

Table-4: **Compressive Strength results of grouting admixture**

Sr. No.	Name of Grout	Cubes no.	Compressive Strength in N/mm^2			
			7 days curing	Average	14 days curing	Average
1.	GROUT 1	1st	19.2	20.444	29.667	31.827
		2nd	19.733		32.562	
		3rd	22.4		33.254	
2.	GROUT 2	1st	23.467	23.644	32.825	34.793
		2st	21.689		35.277	
		3rd	25.778		36.279	

DISCUSSION AND CONCLUSION

Conclusion Based on Researcher's study

- Compressive strengths were increased with some mineral and chemical admixture incorporation. Test results indicated that the high strengths grout produced using mineral admixture was determined to gain strengths in a shorter time than traditional grout.
- The presence of metakaolin and SF was found to increase the early strengths of grout. Such an increase in the strengths was not achieved with SMT, BD or with other admixture such as CD, CLM.
- Bentonite is known clay from montmorillonite group which has always been used for reducing the bleeding. However, it causes the strength of grout to decrease. Therefore, for cases where strength is important, an appropriate percentage of bentonite should be used in order to lessen the bleeding value.
- BFS and PRL mixtures show the similar strength properties to RF for 28 days curing time. The slow increase in the strength values of these mixtures were observed for the rest of the curing period.
- Sodium silicate is one of the main ingredients of chemical grouting which is also used for increasing the strength of cement-based grouts. It reduces the bleeding value as well. Of course, this additive may reduce the setting time up to a level in which the grout is set before being injected. Hence, high percentages of this additive cannot be recommended for a cementitious grout mixture.

Conclusion based on study

- The compressive strength obtained by the grout mixture prepared with fly ash and styrene butadiene copolymer for 7 days of its curing period were 20.444N/mm^2 and 23.644 N/mm^2 respectively. From this we can say that fly ash provide more compressive strength than styrene butadiene copolymer. The compressive strength obtained by the grout mixture prepared with fly ash and styrene butadiene copolymer for 14 days of its curing period were 31.827 N/mm^2 and 34.793 N/mm^2 respectively. From this we can say that fly ash provide more compressive strength than styrene butadiene copolymer. Hence we can conclude that styrene butadiene rubber gives more strength than fly ash

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