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Performance of high workability plaster mortar for water tanks

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Abstract

Cement sand mortar is frequently used as water proofing plaster layer for water retaining structures. However, the current practice of using standard mortar for plastering has shown to be infective due to observed leakages and low durability of some water retaining structures. In the effort of solving these problems, materials engineers have used artificial chemicals like Zypex to control leakages and improve durability with some success. This paper reports on a study done to address the use of high workability plaster mortar as a solution to meet serviceability requirements for water retaining structures. The study involved the development of mix ratios 1:2, 1:3 and 1:4 for standard mortar mixes and using the same mix ratios with different doses of super-plasticizer from 0.00% to 0.50%, testing all mortar mixes for physical properties then determining their performances. The performance of mortar mixes was investigated in terms of workability, unit weight, strength development, tensile strength and water absorption. The test results have indicated high performance and suitability of high workability mortar mixes for plastering water retaining structures.

Keywords: Mortar, superplasticizer, workability, water absorption, strength, mix rations, durability

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1. Introduction

1.1 General background

Mortar is a traditional construction material that is widely used for plastering walls, flooring, masonry works and concrete repairing works. Depending on the type of the binder used, it can be categorized as lime mortar, cement mortar, gypsum mortar and cement lime mortar. The selection of mortar for construction greatly depends on the type of a structure, exposure conditions, expected loads and stresses. Cement sand mortar is the strongest mortar of all due to its early strength development, high resistance to impacts and knocks, low permeability and water absorption, which makes it suitable for plastering and flooring in aggressive environments like moist conditions. The strength and durability of cement sand mortar depends upon many factors including water to cement ratio used. Water to cement ratio affects workability, final strength, porosity and water permeability of mortar matrix.

The workability and strength of mortar depends on the water to cement ratio used, but it has been noted that in some construction sites it is a normal practice to improve workability of mortar mixes by adding more water (Makunza 2022). The addition of more water leads to too porous mortar matrix that cannot be used for neither water proofing nor water retaining purposes. The desire to achieve strong and durable structures should put much emphasis on the use of high workability mixes without affecting water to cement ratio, this can only be achieved with the addition of high range water reducers termed as superplasticizer.

1.2 The problem

Cement sand plaster mortar is mainly used as water proofing layer for water retaining structures. But the current practice of using standard mortar for plastering has shown some limitations due to observed leakages and low durability of water retaining structures. These problems have caused materials engineers to use artificial chemicals like Zypex to control leakages in the effort of improving the durability of the said structures (Elisante 2010). This study concentrates on the assessment of high workability plaster mortar as a solution to meet serviceability requirements for water retaining structures. The observed problems of water leakages and cracks in water retaining structures are clearly shown in Figure 1.

Figure 1. Leakage of an underground water tanks (Source: Bulyanhulu Gold Mine)

1.3 Objectives

The main objective of the study was to establish high workability cement sand mortar by adding plasticizer for plastering water retaining structures. With regard to this objective, the specific objectives were: (1) To determine the properties of ingredients of mortar through; (a) Organic matter content test; (b) Particles density test; (c) Cement tests (Setting times, fineness, soundness and strength); (2) To develop various standard plaster mortar mixes using cement, sand and water; (3) To develop various high workability plaster mortar mixes using cement, sand, water and superplasticizer with varying dosages (0.00%, 0.2%, 0.3%, 0.4% and 0.5%); (4) To test mortar mixes in both plastic and hardened states; and (5) To make comparison between standard plaster mortar to high workability plaster mortar.

2. Review on Mortars

Mortar is an intimate mixture of binding materials; fine aggregate, cement and water although admixtures can be added to improve its properties. Benaicha et al. (2019) states that when water is added to the dry mixture of binding material and the inert material, binding material develops the property that binds the inert material. The other name of the mortar is fine aggregate concrete or sandcrete, for with the addition of coarse aggregates it becomes concrete. Akers (2000) in his study advocates that the properties of mortars vary depending on properties and ratio of cement or binder materials to sand, characteristics and grading of sand and water to cement ratio of the mortar mix. A good building mortar should meet the following properties:

- It should easily be workable, and should develop adequate strength in tension, compression and bond for the work it is used.
- It should be durable and should not affect the durability of other materials.
- It should set quickly so that the speed of construction is ensured.
- It should be cheap.
- It should bind bricks or stones to give tight joint through which water can't penetrate.
- The joints formed by mortar should not develop cracks, and should be able to maintain their appearance for long period (Rajput 2009).

Mortar is used for different purposes, which include:-

- Masonry works, pointing and plastering works, and forming joints of pipes.
- Concrete works as a matrix and improving general appearance of the structure.

A good mortar must have appropriate workability, have sufficient water retention, and ability to withstand stresses both compressive and tension stress according to BS 4551, Part 1: 2005+A2:(2013).

2.1 Types of mortar due to cementious materials used

The binders that make up mortars lead to various categories of mortars, therefore mortar mixes are named according to the binder that is applied in it. The ingredients of cement mortar include cement, sand, water and admixtures. Sand particles are bound together by cement paste which results from hydration reaction between cement and water. The workability of the mixture greatly depends on water to cement ratio used. Various types of mortars and their main constituent materials, ratios and expected strengths are given in Table 1.

Table 1: Requirements for mortar to BS 5628-1:2005[**7**]

	Mortar designation	Type of mortar (proportion by volume)			Mean compressive strength at 28 days	
		cement: lime: sand	masonry cement: sand	Cement : sand with plasticizer	Preliminary laboratory test	Site test
1* 2*					N/mm^2	N/mm^2
↑ ↓	i	1: 0 to …:3	-	-	16.0	11.0
	ii	1:│:4 to 4│	1:2│ to 3│	1: 3 to 4	6.5	4.5
	iii	1:1:5 to 6	1:4 to 5	1:5 to 6	3.6	2.5
	iv	1:2:8 to 9	1:5│ to 6│	1:7 to 8	1.5	1.0
Direction of change in properties is shown by arrows		Increasing resistance to frost attack during construction →				
		← Improvement in bond and consequent resistance to rain penetration				

1* = Increase strength
2* = Increase ability to accommodate movement, e.g. due to settlement, temperature and moisture changes.

2.2 Superplasticizer

Super-plasticizers for production of concrete or mortar should conform to ASTM C494-05a(**2016**) as type F for superplasticizers with normal setting times and type G for superplasticizers with retarded setting times. The examples of superplasticizers with their physical and chemical properties are shown in Table 2.

Table 2. Superplasticizers with their chemical and physical properties to ASTM C494-05a.

Physical/Chemical Property	Pozzolith Standard	Bevetol – SPL
Colour	Dark Brown Liquid	Dark Brown
Specific Gravity	1.188	1.15
PH	9.15	9.1±1.0
Maximum Chloride Content	Chloride free	Chloride free
Maximum Alkali Content	Alkali free	Less than 6%

3. Materials Testing

Ingredient materials that make up mortar, which include cement, sand, water and admixtures were collected and tested at the laboratory to ascertain their physical properties as summarized below.

Cement: The adopted cement was Portland Cement known as Twiga Cement 42.5N. Physical tests for cement were conducted as confirmatory tests to check the compliance of the cement to its relevant standard. The tests were conducted at the University of Dar es Salaam building materials laboratory according to BS EN 197-1(2011) and ISO 679:2009(R2015). The obtained test results showed that the initial setting time and the final setting time were 78 and 153 minutes respectively as given in Table 1. The compressive strength at 28 days was observed to be within the allowable values of not less than 42.5 N/mm². Generally, the values in Table 3 obtained from laboratory tests are acceptable with regard to cement specifications and conformity. The strength and expansion values obtained complied with cement specifications. Thus, as regard to these results the type and class of cement tested qualify as cement class 42.5N according to BS EN 197-1(2011) and was found to be acceptable for concrete works.

Table 3. Physical Properties of Cement used to BS EN 197-1

Cement Test Results				
Sample	Setting Times		Soundness	Strength Tests
	Initial.	Final.	Expansion	28 Days
	Min.	Min.	mm	N/mm^2
Twiga Plus 42.5N	78	153	1.0	46
Requirements: BS EN 197 – 1: 2000				
PLC 42.5 N	$\geq$ 60	$\leq$ 10 hrs	$\leq$ 10	Min 42.5 N/mm^2 Max 62.5 N/mm^2

Fine Aggregates: Fine aggregate tests were performed in the laboratory according to BS 812:Part 2: (**1995**) in order to establish their engineering properties. The tests carried out included specific gravity, bulk density and organic impurities content. The bulk density was found to be 1415 kg/m³, particles density was 2600 kg/m³ while the organic impurities amount was found to be 0.26%. In general, the fine aggregates were found to be conforming to the standard.

Superplasticizer: The superplasticizer of brand name POZZOLITH STANDARD was used as the chemical admixture during the investigation. It was type F high range water reducing admixture complying with ASTM C494-05a (**2016**).

4. Experimental Procedures and Results

4.1 Mortar preparation and measurement of flow values

The mortar constituents were mixed at three different ratios of 1:2, 1:3 and 1:4 (cement: sand) with different water-cement ratios. The thoroughly mixed mortar matrix was filled in the standard mould on the flow table in 2 layers, compacted in each layer with 20 number of blows with a 25mm diameter mild steel bar rod of around 350 mm length. The tamping pressure was just sufficient to ensure uniform filling of the mould. Then the mould was upward removed and the flow table was vibrated in 15 seconds. Lastly, the result of increased base diameter of mortar mass was measured and divided by the original diameter to get the flow value. The aim was to achieve an average flow of 120%. Figure 2 presents the pictorial views of the flow table test. The Flow Table test was done in accordance to ASTM C230 / C230M – 21(2021).


Figure 2. Flow table test as conducted at UDSM Building Materials Laboratory

Addition of Doses of Superplasticizer

The dosage of superplasticizer reduced the water- cement ratio through maintaining the average flow value(Akiije **2021**). Mixes were of three different cement to sand proportions, with and without superplasticizer. In each mix, superplasticizer dosage was utilized with an increment 0.1% by weight of cement from 0.20%, 0.30%, 0.40% and 0.50%. Throughout this step, mortar flow was maintained at an average value of 120%. The results for the dosage of superplasticizer and water to cement ratios are as tabulated in Table 4.

Table 4. Effect of Superplasticizer dosages to Mortar requirements

S.P (%)	Mix					
	1:2		1:3		1:4	
	W/C	Flow	W/C	Flow	W/C	Flow
0.0	0.50	125	0.70	121	0.95	120
0.2	0.45	120	0.61	118	0.85	115
0.3	0.44	120.5	0.59	120	0.83	118
0.4	0.43	119	0.58	123	0.80	125
0.5	0.42	121	0.57	120	0.78	121

As the dosage of superplasticizer increased, water demand to achieve average flow was decreasing accordingly as indicated in table 4 and Figure 3. The average mortar flow value obtained was 120% which was adequate for plastering. The water to binder ratio required to ensure an average flow of mortar of 120 % depended on the mix proportion and the dosage of the superplasticizer as water reducing agent.

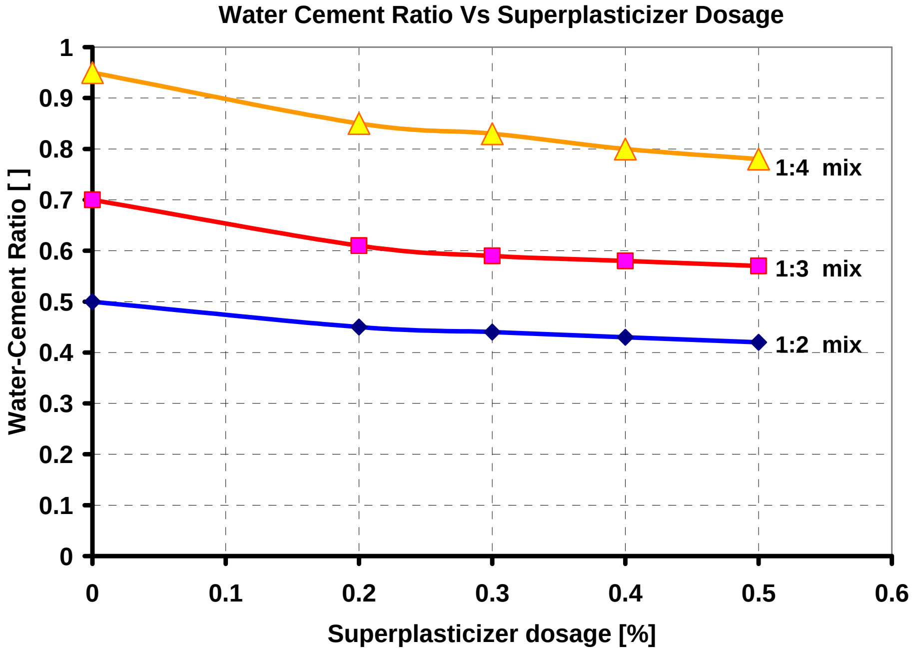

Figure 3. Water cement ratio and Superplasticzer relationship

Casting of Mortar Prisms

All materials including water were weighed prior to mixing of the materials. The mixing was performed in accordance to ASTM C305-20 (**2020**). Then prism specimens of standard size of 40 x 40 x 160 mm length were cast as shown in Figure 4. The filled and compacted mixture in the moulds were covered with wet gunnysacks at the top to control the hydration and allowing good hardening process. After 24 hours, the specimens were remolded and cured in water for 28 days. Figure 4 shows remolded mortar prism samples ready for curing in a curing tank.

Figure 4. Moulds – top left, samples after casting (right –top), and mortar prisms (bottom)

Tensile Strength Test of Mortar Specimens

The mortar specimens were tested for tensile strength at 7 days and 28 days ages. Tensile strength test was the major concern in this study as low tensile strength would result in cracks formation at low hoop stresses in water tanks. The prism specimens were tested using tensile testing machine available at the University of Dar es Salaam Building Materials Laboratory.

Tests were conducted as per the specifications of BS 4551 Part 1:2005+A2(**2013**) at the prescribed ages of testing. The specimens were withdrawn from the curing tank five hours before the testing to achieve surface dry of samples and were cleaned properly with dry cloth to remove loose particles if any. Before conducting the test, all the specimens were checked for any kind of defects such as broken edges and cracks. In order to investigate the effect of superplasticizer on tensile strength of mortar, standard plaster mortar with no super-plasticizer was kept as reference mortar. The test was then carried out on five batches for each mortar mix. From Figures 5 to7, it was noted a wide range of tensile strength ranging from 1.10 MPa to 12.81 MPa was exhibited by high workability mortars depending on the mix proportion and superplasticizer dosage adopted. Comparing the strength with respect to given mortar with no superplasticizer content, mortars with 0.40% of superplasticizer dosage showed the highest tensile strength of 12.81 MPa for mortar with mix ratio of 1:2. The analyzed results in Figures 5, 6 and 7 showed the same trend for mortar mix ratios 1:2, 1:3 and 1:4 respectively at the dosage of 0.40%.

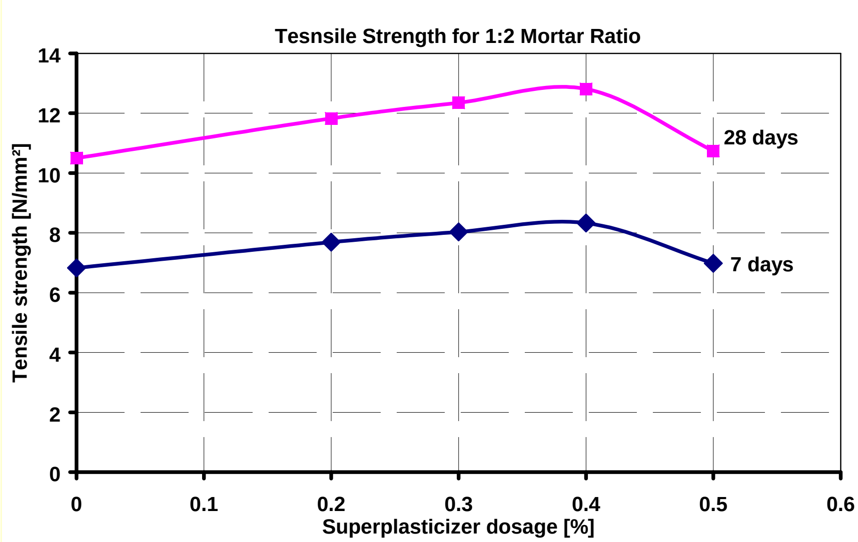

Figure 5. Tensile Strength for mortar ratio versus Superplasticizer Dosage (1:2 Cement Sand mortar, 120% mortar flow).

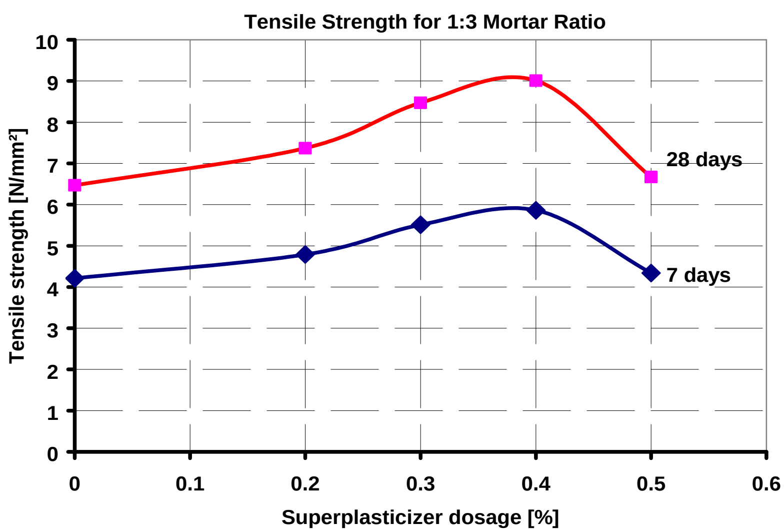

Figure 6. Tensile Strength for mortar ratio versus Superplasticizer Dosage(1:3 Cement Sand mortar, 120% mortar flow).

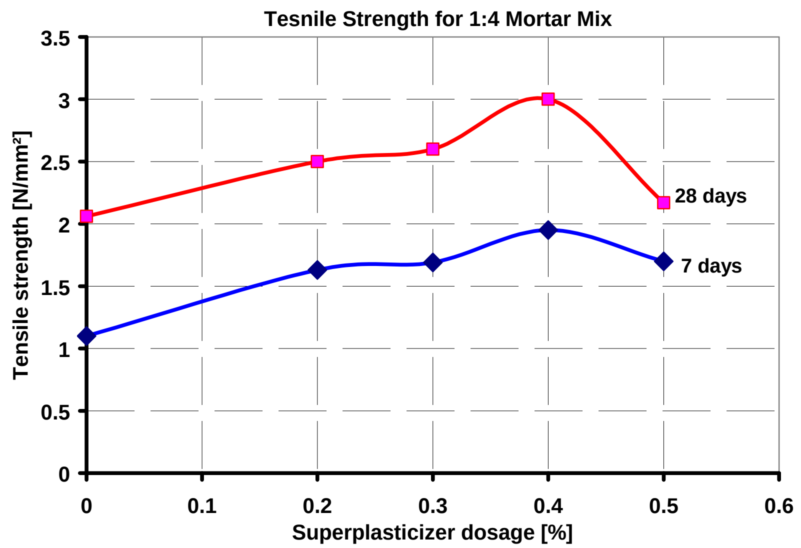

Figure 7. Tensile Strength for mortar ratio versus Superplasticizer Dosage(1:4 Cement Sand mortar, 120% mortar flow).

The increase and decrease in Tensile Strength values of mortar specimens for 28 days of age with varied superplasticizer dosage were calculated with respect to the standard plaster mortar and the results are depicted in Figure 8. With respect to Figure 8, it can be observed that the highest increase was when the superplasticizer dosage was 0.40%.

Compressive Strength Test of Mortars

Prism specimens were tested using universal compressive testing machine available at the University of Dar es Salaam, Building Materials Laboratory. The tests were conducted as per the specifications of ISO 679:2009(R**2015**) at the prescribed ages of testing. During the test, visible cracking and the failure modes were monitored carefully and the ultimate failure load was recorded. From the ultimate failure loads, the compressive strengths were calculated using Equation (1), thus

$$f_c = \frac{F_i}{A_{ci}} \quad (1)$$

Where f_c = Compressive Strength (N/mm2)

F_i = Ultimate Load (N)

A_{ci} = Cross sectional area perpendicular to load direction (mm^2)

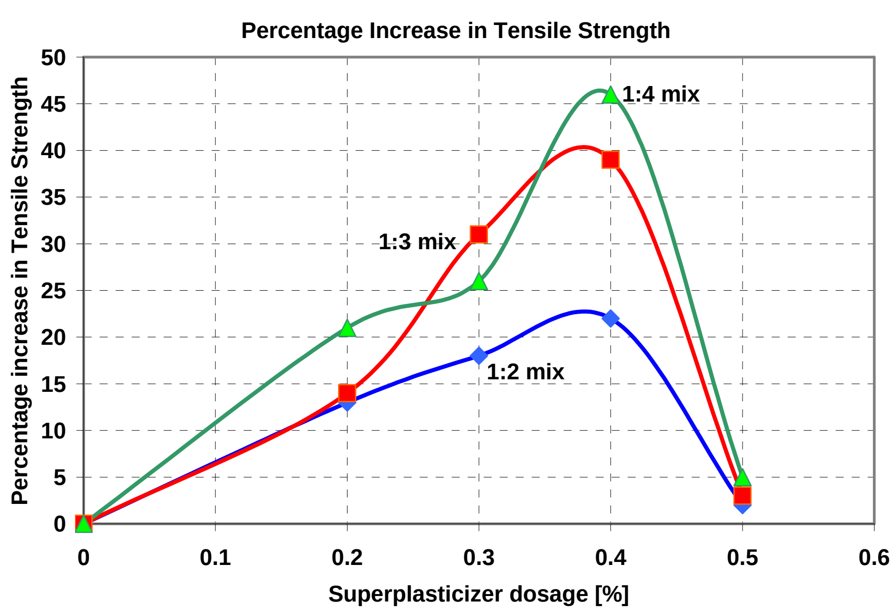

Figure 8: Increase and decrease %age of tensile strength due to superplasticizer dosage

The analyzed 7 days and 28 days compressive strength test results are shown in Figure 9. The increase and decrease in compressive strength values for 28 days of age as per superplasticizer dosage variation were calculated with respect to the standard plaster mortar, where by the obtained results are presented in Figure 10. With regard to Figure 10, it is evident that mortar mixes with 0.40% superplasticizer dosage revealed the highest strength development for each mix. The graph suggests that the optimum dosage of the superplasticizer is 0.40%. The above results are in agreement with those obtained by Muhit (2013) when he studied about the effects of superplasticizer on the compressive strength of concrete although he used different dosage of the chemical.

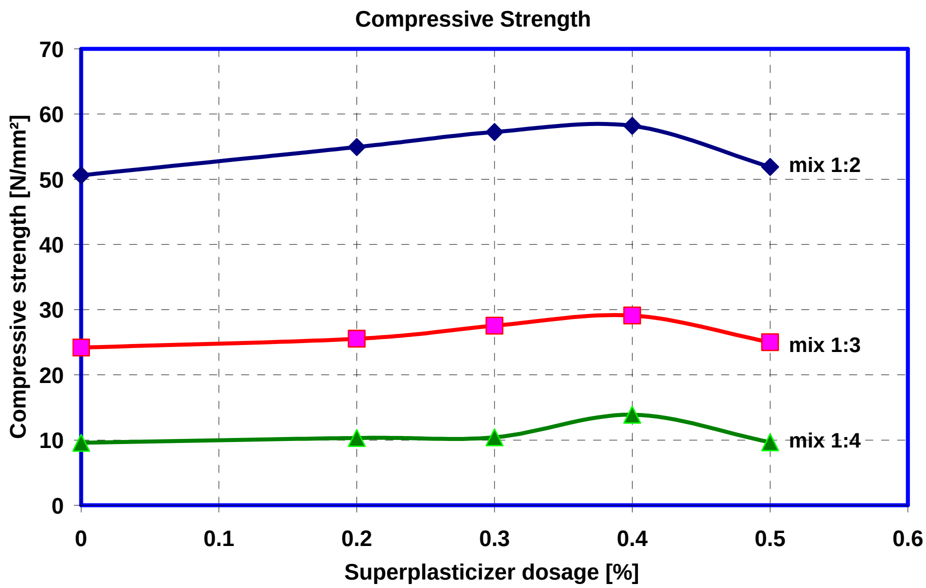

Figure 9: Compressive strength of mortar specimens

Water Absorption Test

Water absorption test was conducted as per specifications of ASTM C 642-13(2013). This method is also known as water immersion method. Three representative samples from each batch were air dried for 24 hours to 48 hours until the change in mass was less than 5%.

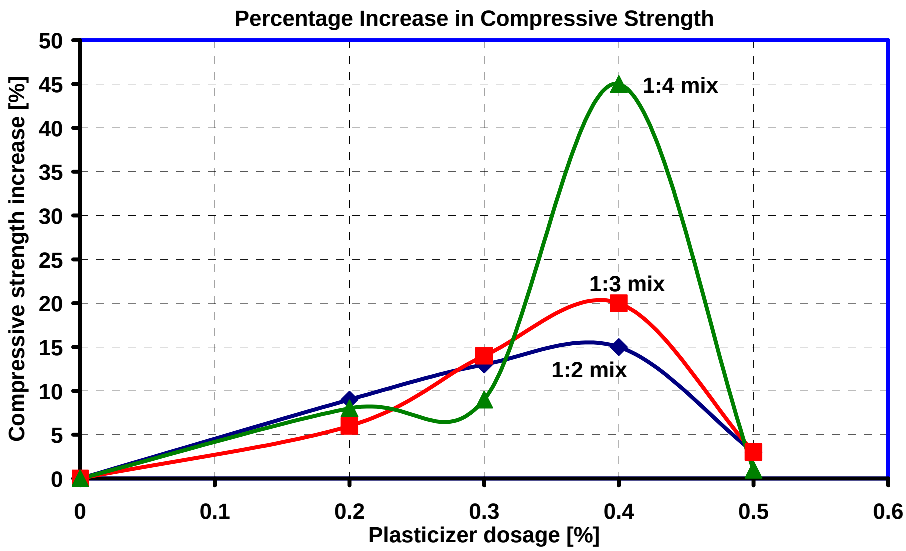

Figure 10: Percentage increase of compressive strength due to SP dosage

The specimens were then weighed, recorded and immediately immersed in water tank to a depth ensuring 25±5mm of water over the top of specimens. The specimens remained in water for 24 hours, followed by withdrawal from water. Then the specimens were dried with a cloth in order to remove surplus water on the surfaces and were weighed again. The water absorption value was then calculated as the increase in the mass resulting from the water immersion process expressed as a percentage of the mass of the dry specimen. The calculations were made as per Equation (2) as specified by ASTM C 642-13 (2013);

$$W_a = \frac{W_w - W_d}{W_d} \times 100\% \quad (2)$$

Where W_a = Percentage of water absorption

W_w = Weight of Wet Specimen

W_d = Weight of Dry Specimen.

The test was carried out on all specimens of mortar mixes developed and the test results obtained were recorded, analyzed and presented in Figure 12.

Figure 11. Prism specimens after Water Absorption test.

According to ASTM C1585 – 20(2020), the typical values of the water absorption of concrete are defined as noted below:

Very low absorption concrete	< 3%
Low absorption concrete	3% – 4%
High absorption concrete	> 4%

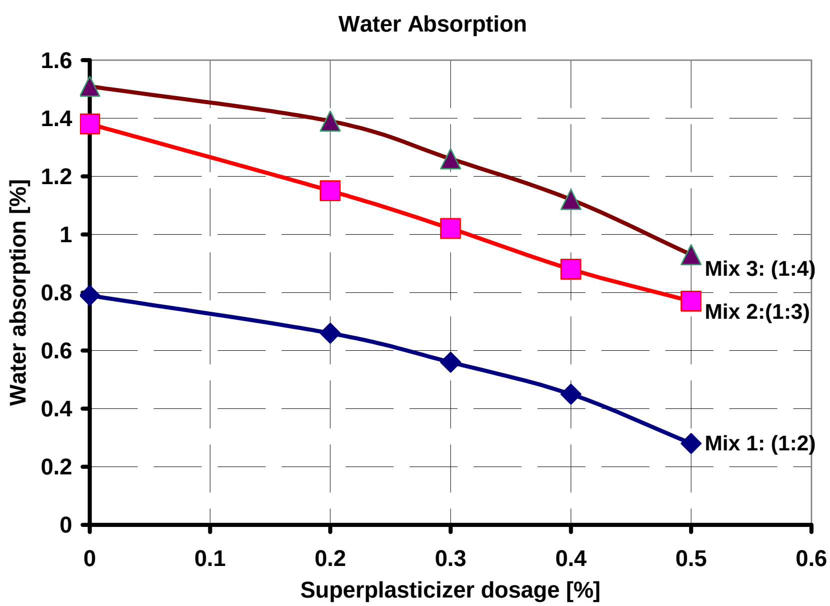

Figure 12: Water Absorption versus Superplasticizer dosages(120% mortar flow).

Unit Weight

It was important to investigate if the addition of superplasticizer had an effect to the unit weight of mortar or not. Due to this reason, the mortar specimens were subjected to density test according to ASTM C 642- 13(**2013**), in which it was noted that as the dosage was varied from 0.00% to 0.50% by weight of cement, the unit weight was increasing with the dosage. The density was observed to be varying within the range of 1800kg/m^3 to 2100kg/m^3 for all three mortar mixes. The results are as summarized in Figure 13, and they indicate that superplasticizer causes an increase to the density of mortar as it causes the fines to fill most of the voids in the concrete.

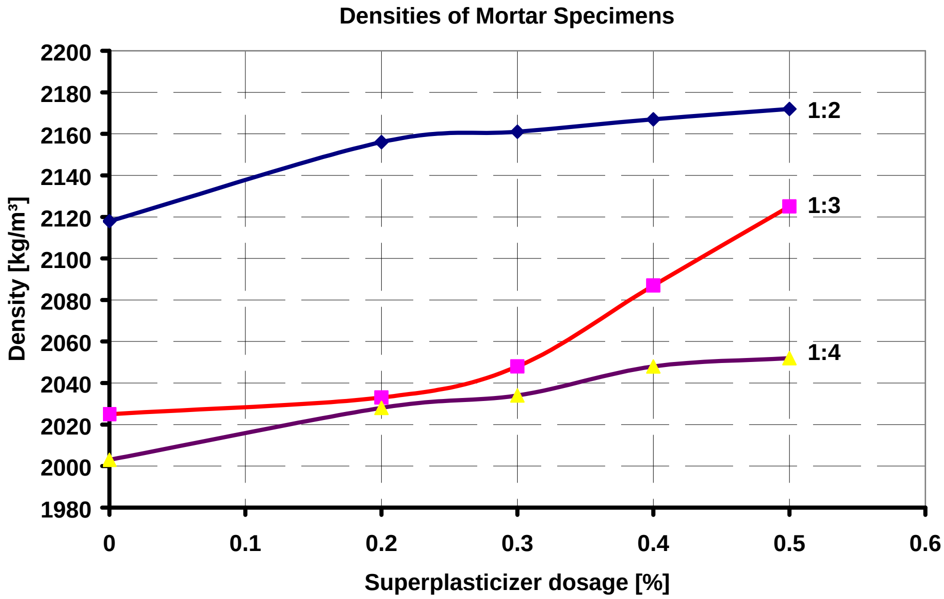

Figure 13. Relationship between density and superplasticizer dosage

4.2 Discussion of the results

The experimental investigations were aimed at developing high workability cement sand mortar using cement, sand, water and superplasticizer for efficient plastering of water retaining structures. This would results in achieving serviceability requirements of similar structures. From the test results, it can be discussed as follows:

Dosage of Superplasticizer Versus Water Demand of Mortar Mixes

The values obtained of water demand for various superplasticizer dosages have shown that water requirement for good workability mortar mixes decreased as the dosage of superplasticizer increased as illustrated in Figure 3.

Tensile Strength

From Figures 5, 6 and 7, tensile strength of mortar prisms is observed to be highly affected by the addition of Pozzolith Standard chemical admixture into mixes. The optimum value of dosage is observed to be around 0.40% of superplasticizer by weight of cement.

Compressive Strength

Mortar with around 0.40% of Pozzolith Standard superplasticizer dosage showed high compressive strength. For example, a value as high as 58.18 MPa of compressive strength at 28 days was achieved for a mortar of mix ratio of 1:2 with 0.40% superplasticizer dosage. The strength enhancement ranges from 6% to 15% over the standard cement sand plaster mortars depending upon the mix proportion. The optimum level of superplasticizer dosage of 0.40% yielded the highest compressive strength in all mix proportions.

Water Absorption

Standard or traditional plaster mortar mixes were observed to have high water absorption values as compared to high workability plaster mortar mixes. In Figure 13, it can be seen that, although all the high workability mortars exhibit low rate of water absorption, the plaster mortar of mix 1:2 with 0.50% superplasticizer dosage exhibited the lowest water absorption.

5. Concluding Remarks

Basing on the investigation results as well as the discussions given above, the following concluding remarks are deduced, thus:-

- High workability plaster mortar mixes exhibited tensile strength values ranging from 2.17 MPa to 12.81 MPa. The compressive strength values ranged from 9.58 MPa to 58.18 MPa and water absorption values ranged from 0.28% to 1.39% which is better performance as compared to standard plaster mortar mixes.
- High workability plaster mortar mix with cement to sand proportion of 1:2 was observed to have the best performance of all mortar mixes and the optimum dosage of superplasticizer was observed to be 0.40% by weight of cement for all investigated mixes.
- Generally, it is recommended that the selection of mix for plastering water retaining structures should be based on the wall to be plastered. Walls made up of concrete should be plastered using cement-sand proportion of 1:3 with 0.40% of superplasticizer dosage, while walls made up of masonry should be plastered using cement-sand proportion of 1:4 with 0.40% of superplasticizer by weight of cement. This will reduce the demand of cement, and enhance environmental sustainability by reducing the amount of carbon dioxide in air resulting from relatively less cement production.
- Further study on thermal resistance of high workability mortar is suggested.

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