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Performance of Concrete Grout under Aggressive Chloride Environment in Sabah

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Abstract**—**Service life of existing reinforced concrete (RC) structures in coastal towns of Sabah has been affected very much. Concrete crack, spalling of concrete cover and reinforcement rusting of RC buildings are seen even within 5 years of construction in Sabah. Hence, in this study a new mix design of concrete grout was developed using locally available materials and investigated under two curing conditions and workability, compressive strength, Accelerated Mortar Bar Test (AMBT), water absorption, volume of permeable voids (VPV), Sorptivity and 90-days salt ponding test were conducted. The compressive strength of concrete grout at the age 90 days was found to be 44.49 N/mm^2 under water curing. It was observed that the percentage of mortar bar length change was below 1% for developed concrete grout. The water absorption of the concrete grout was in between the range of 0.88 % to 3.60 % under two different curing up to the age 90 days. It was also observed that the VPV of concrete was in the range of 0 % to 9.75 and 2.44% to 13.05% under water curing and site curing respectively. It was found that the Sorptivity of the concrete grout under water curing at the age of 28 days is 0.211mm/√min and at the age 90 day are 0.067 mm/√min. The chloride content decreased greatly, 90% after a depth of 15 mm. It was noticed that the site cured samples showed higher chloride contents near surface compared to water cured samples. This investigation suggested that the developed mix design of concrete grout using locally available construction materials can be used for crack repairing of existing RC structures in Sabah.

Keywords**—**Concrete grout, Salt ponding, Sorptivity, Water absorption.

I. INTRODUCTION

CONCRETE has become the material of choice for the construction of structures exposed to extreme conditions [1]. Corrosion, one of the main causes of deterioration in concrete structures, initiates due to its exposure to harmful chemicals that may be found in nature such as in some ground waters, industrial effluents and sea waters. The most aggressive chemicals that affect the long term durability of concrete structures are chloride and sulfate. Concrete immersed in a wet or moist aggressive medium tend to suffer damages and exhibits so in the form of microcracks.

The major cause of these problems is the chloride-induced corrosion of reinforcing steel which, because of the substantial volume increase that accompanies the transformation of iron to rust, can lead to cracking and spalling of the concrete cover. In addition, the corrosion of reinforcing steel bars can also cause a weakening of the bond and anchorage between concrete and reinforcement, which can reduce the shear capacity of reinfroced concrete (RC) beams and affects the serviceability and ultimate strength of concrete elements in RC structures [2].

Deterioration of concrete infrastructures has emerged as one of the most severe and demanding challenges facing the construction industry [3]. Corrosion of embedded steel represents the dominating type of deterioration due to chloride reaction and it represents a major problem for the durability and long term performance of concrete structures. Extensive research in the past few decades has established the mechanisms of seawater attack on cement paste and concrete, and shown that seawater certainly causes deterioration of cement paste as a result of reaction with susceptible components of the paste, and formation of new reaction products such as gypsum, ettringite, brucite,calcium-chloroaluminate. Most of the deteriorated concrete, spalling of the concrete cover is the most frequently occur. The simplest way to repair this type of problem is by patching the affected area by using concrete type of grouting.

Grouting is a construction material used to fill and bond cracks and defects in structural concrete and masonry. Grout is generally composed of a mixture of water, cement, sand, often color tint, and sometimes fine gravel if it is being used to fill voids in concrete, masonry , reinforcing steel, securing the steel in place and bonding it to the masonry. An understanding of grouting durability is fundamental to establish the service life of repaired structures. Knowledge of the grouting durability is the key to the long term performance and although all repaired part of structure is likely to deteriorate to some extent; ensuring good durability is about minimizing the rate of deterioration.

This paper discusses about the effect of aggressive chloride environment on concrete grouting. Most of the type of grout used in repairing and rehabilitation of concrete structures are made of materials that similar to the materials used in producing concrete. Therefore, the property of this type of grout is similar to the properties of concrete. The main objective of this study is to develop the mix design for the concrete grouting using locally available materials so that it can withstand and reduce the damage caused by the chloride that present in the environment. Also aims to determine the compressive strength and the degree of expansion or elongation of the grouting and the degree of resistance of the grout against chloride penetration. In this study Ordinary

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Portland cement, Silica Fume, Fly Ash, and granite stones with the size of less than 4.75 mm are used as ingredients.

II. Experimental Details

The cement used in the grout was Type I ordinary Portland cement conforms to ASTM C-150, and also conforms to Malaysian Standard. The locally available Low calcium fly ash (FA), Class F as per ASTM C-618 and commercially available. W. R. Grace brand silica fume (SF) was used as mineral admixtures. Coarse aggregates composed of crushed granite particles with the size of less than 4.75 mm. Potable water was used during mixing and curing. Superplasticizer (SP) accordance with the ASTM C- 494, type F was used to enhance the workability of grout mix. The detailed mix proportions of the gout are given in Table I. The ingredients of grout were mixed into pan type concrete mixer of 56 liters capacity was used.

TABLE I
Mix Proportion for 1m^3 of Concrete Grout in KG

Cement	SF	FA	Water	Aggregate	SP
440	38.5	71.3	165	1588	9.185

In this study, two types of curing conditions namely full water or water curing (WC) and site curing (SC) were employed to investigate the curing effect on durability of grout [4]. In the water curing condition, after one day the specimens were demould and kept in water till the age on test, whereas in site curing condition, after one day the specimens were demould then cured six days with wet hessian (hessian was kept wet by spraying the water three times in a day) after that exposed to the sun till the date of test. The durability of grout can be assessed by conduct the test on hardened concrete properties such as compressive strength, water absorption, sorptivity, and volume of permeable voids, accelerated mortar bar and 90 - day salt ponding test at the age of 90 days for different curing conditions.

The specimen moulds used in this study were in the size of 100 mm x 100 mm x 100 mm cubes for compressive strength test, sorptivity test, and volume of permeable voids test. The prism of size 25 mm x 25 mm x 279 mm and slab of size 300mm x 300 mm x 75 mm used for accelerated mortar bar test and 90 - day salt ponding test respectively.

The compressive strength of 100 cubes was carried out in accordance to the BS: 1881: part 116: 1983 at age 28, 56 and 90 days. The Volume of Permeable Voids (VPV) and water absorption were conducted in accordance to ASTM C 642 – 97[5]. Sorptivity is a measure of capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. The purpose of this test is to determine the rate of capillary rise through absorption unsaturated concrete surface. The sorptivity test was performed on inner cut surfaces size of 100 mm cube the specimens [6]. The 90 – day salt ponding test that was conducted in accordance to the ASTM C 1543-02 standard [7].

III. Results and Discussions

Workability is defined as the ability of fresh concrete to be mixed, handled, transported and placed with a minimum loss of homogeneity It is important to ensure that the concrete grout mix was workable before investigate the compressive strength and durability. The workability of the concrete grout mix was evaluated by conduct the slump test. The slump value for the mix with water binder ratio 0.4 was 60 mm and well within the range of 50 mm to 180 mm for most structural applications [8].

Compressive Strength is defined as the measured maximum resistance of a concrete specimen to axial loading. Compressive strength is considered the most important properties as an index of its overall quality. The compressive strength of the concrete grout at the age 3, 7, 28, 56 and 90 days for the two water curing conditions is shown in Table II. It was found that the compressive strength of 44. 49 N/mm^2 was obtained under water curing at the age of 90 day. It was observed that the compressive strength of the concrete grout under full water curing increases as the age increased. The same trend was also observed in site curing. However, it was noted that the compressive strength water curing is 11.5 % higher than site curing. This may be due to the insufficient amount of water available for hydration in site curing and also the microcracks developed under site curing cause the strength reduction.

In AMBT method, the lengths of the mortar bars were measured before, during and after the curing. The initial length of mortar bars was taken as zero reading. Whereby, the difference between the zero reading of the sample and the effective measurement length in 0.002 mm sensitivity for each period was calculated. Results were recorded as expansion of the mortar bars for each period and given in Table III. The interpretation of the AMBT result according to ASTM C 1260-05 [9] was given in Table IV. The expansion results show that the average length of change concrete grout was below 1% and any change length below 1% is considered as harmless. The 14-day cumulative length change shown in Table III can be converted as 54.6 microstrain which is less than 80 to 100 microstrain as range for tensile microcrack development for concrete.

TABLE II
Compressive Strength of Concrete Grout

Age on test (Day)	Average compressive strength, N/mm^2	
	Water curing	Site curing
3	13.24	12.42
7	21.65	19.14
14	29.565	27.18
28	35.53	33.79
56	42.97	38.74
90	44.49	39.74

TABLE III
AMBT EXPANSION FOR CONCRETE GROUT AFTER 24 HOUR WATER CURING

Day	Average of length change (%)	Cumulative Average of length change, (%)
0	0	0
1	0.00012	0.00012
2	0.00059	0.00071
3	0.00024	0.00095
4	0.00012	0.00107
5	0.00012	0.00118
6	0.00012	0.0013
7	0.00036	0.00166
8	0.00059	0.00225
9	0.00071	0.00296
10	0.00083	0.00379
11	0.00047	0.00426
12	0.00036	0.00462
13	0.00047	0.00509
14	0.00036	0.00545

TABLE IV
INTERPRETATION OF THE AMBT RESULT ACCORDING TO ASTM C 1260-05

Expansion Percentage	Degree of Reactivity
Less than 0.10 %	Harmless
More than 0.20 %	Harmful
Between 0.10 % to 0.20 %	Potential Harmful

It was observed that the percentage of length change was below 1% for developed concrete grout. According to ASTM C1260, any change length noticed below 1% is considered as harmless and highly durable concrete.

Water absorption is particularly important in concrete as well as being important for durability to resist corrosion [10]. The water absorption of the concrete grout in different curing condition up to the age 90 days are given in Table V. As it is expected the reduction in water absorption is observed when the age of concrete increased. The same trend followed in the compressive strength was observed in water absorption of the concrete grout in water curing and site curing. It is well known that the water absorption of concrete below 3 % considered low permeable and good durability [11].

TABLE V
WATER ABSORPTION FOR CONCRETE GROUT (90 DAYS)

Age on test	Water absorption in Water Curing, (%)	Water absorption in Site Curing, (%)
28 days	3.28 %	3.60 %
56 days	1.80 %	2.78 %
90 days	0.88 %	0.89 %

The Volume of Permeable Voids (VPV) has been recognized as important property of concrete as it affects the transport mechanism through the concrete such as ingress of aggressive gases and solutions. Safiudin and Hearn [12] mentioned that the permeable porosity affects the transport properties and durability of concrete because the porous medium of concrete permits the transport of water and other chemical compounds. Dinakar et al. [13] have found that the water absorption is directly proportional to the volume of permeable voids of the concretes.

TABLE VI
VOLUME PERMEABLE VOIDS AT VARIOUS AGES FOR THE CONCRETE GROUT

Age on test (days)	Volume Permeable Void s in %	
	Water curing	Site curing
28	9.75	13.05
56	2.41	7.96
90	0.00	2.44

It was observed that the VPV of concrete was in the range of 0% to 9.75% and 2.44% to 13.05% under water curing and site curing respectively. The VPV keep reducing as the concrete age grows. According to Gambhir [14] the hardened state of concrete when its age grows makes the concrete less permeable and hence VPV is very low at late ages.

Sorptivity is defined as rate of movement of a wetting front through a porous material under the action of capillary force. Generally, the concept of water sorptivity is a property describing the rate of water penetrating into the concrete due capillary action. Good quality of concrete would have a low sorptivity rate. Sorptivity test gives an indication of the possibility for the penetration of deleterious materials like chloride and sulfate ions which can lead to deterioration in concrete structures. The sorptivity for the concrete grout at the age up to days under two curing conditions is given in Table VII.

TABLE VII
SORPTIVITY OF THE CONCRETE GROUT

Age (Days)	Sorptivity (mm / √min)	
	Water curing	Site curing
28	0.211	0.237
56	0.147	0.161
90	0.067	0.098

It was observed the sorptivity of the concrete grout decreases from the age of 28 days to the age of 90 days. This is because of the reduction in pore diameter as the age of concrete grout increased. Also it is well known that mineral admixtures such as fly ash in concrete attain a maximum strength at the age of 90 days. Normal strength concretes had sorptivity values of about 0.09 $mm/min^{0.5}$ with a water cement ratio of 0.4 and 0.17 $mm/min^{0.5}$ with a water cement ratio of 0.6 [15]. The concrete grout under water curing at the age of 90 days showed very low sorptivity

The 90 - Days Salt ponding test is a long term test for measuring the penetration of chloride into concrete. The chloride profile can be used to produce characteristic information about a particular concrete which include all mechanism of chloride ingress [16]. The powdered sample was extracted from the two specimens according to the specified depth and was analyzed by using a Spectrophotometric method. In this method indicator solutions of mercury thiocyanate and ferric ion solution which reacted with the chlorides ion to produce a color complex and was measured against non-standard using the spectrophotometer to quantify the concentration. The percentage of chloride by weight of the concrete grout for the water curing and site curing samples are reported in Table VIII and Table IX

TABLE VIII
PERCENTAGE OF CHLORIDE BY WEIGHT UNDER WATER CURING

Penetration Depth (mm)	Water Curing		
	Concentration Cl (mg/L) every 100 mg/L of concrete	% by Concrete	% by Cement
0-5mm	10.3	1.03	5.08
5-10mm	5.7	0.57	2.81
10-15mm	3.1	0.31	1.53
15-20mm	0.9	0.09	0.44
20-25mm	0.05	0.005	0.02

TABLE IX
PERCENTAGE OF CHLORIDE BY WEIGHT UNDER SITE CURING

Penetration Depth (mm)	Site Curing		
	Concentration Cl (mg/L) every 100 mg/L of concrete	% by Concrete	% by Cement
0-5mm	12.1	1.21	5.97
5-10mm	8.2	0.82	4.04
10-15mm	4.2	0.42	2.07
15-20mm	1.1	0.11	0.54
20-25mm	0.08	0.008	0.03

It was measured that the unit weight of concrete grout is 2172 kg/m^3, mass of cement content is 440 kg/m^3. It is well known that the chloride content near the top surface is higher and consistently decreases with increasing penetration of drilling depth interval. From the chloride profile, it can be observed that the chloride content decreased with increasing the penetration depth. The ingress of chloride by diffusion process due to the gradient concentration is controlled by the porous structure of concrete grout. It was noticed that the site cured samples shows higher chloride contents near surface compared to water cured samples. This may be due to the site cured samples lost the moisture during early period therefore pore structure affected causing more chloride content near the surface.

IV. CONCLUSION

This study presents the design of concrete grout mix for structural applications and also the experimental evaluation to determine the volume stability of the concrete grout and the resistance against chloride penetration. It is concluded that the developed mix design of concrete grout have adequate compressive strength and highly durable. Based on the results, the following conclusions can be drawn:

The compressive strength of concrete grout at the age of 90 days was found to be 44.49 N/mm^2 under water curing. The compressive strength water curing is 11.5 % higher than site curing. This may be due to the insufficient amount of water available for hydration in site curing.

It was observed that the percentage of length change was below 1% for developed concrete grout. According to ASTM C1260, any change length noticed below 1% is considered as harmless and highly durable concrete.

The water absorption of the concrete grout was in the range of 0.88 % to 3.60 % under two different curing up to the age 90 days. BS 1881 specifies concrete with typical absorption values less than 3% is low absorption concrete. This low water absorption level is a good indicator of limited open porosity that can inhibit the high flow of water into the concrete.

It was observed that the VPV of concrete was in the range of 0 % to 9.75 and 2.44 % to 13.05 % under water curing and site curing respectively. The VPV decreased with the increasing of concrete age. According to VicRoads classification for concrete durability the VPV of the concrete less than 11 % is excellent and in between 11 and 13 % means good durability.

It was found that the sorptivity of the concrete grout under water curing at the age of 28 days was 0.211mm/√min and at the age of 90 days was 0.067 mm/√min. Also for site curing it was 0.237 mm/√min and 0.098 mm/√min at the age 28 days and 90 days respectively. It is observed the sorptivity of the concrete grout decreased from the age of 28 days to age 90 days. This is because of the reduction in pore diameter as the age of concrete grout increased.

The chloride content decreased greatly 90% after a depth of 15mm. It was noticed that the site cured samples showed higher chloride contents near surface compared to the water cured samples. This may be due to the site cured samples lost the moisture during early period therefore pore structure affected causing more chloride content near the surface.

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