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WATER PERMEABILITY AND CHLORIDE AND SULPHATE RESISTANCE OF RUBBERISED FIBRE MORTAR

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Abstract — Non-biodegradable solids such as waste tyres and oil palm fruit fibre (OPFF) would cause environmental problems if not disposed properly. This research studied the water permeability and chloride and sulphate resistance of mixes with addition of OPFF and sand replacement with Treated Crumb Rubber (TCR). The mix known as Rubberised Fibre Mortar (RFM) is a composite of 10% to 30% of TRC and addition of 1% to 1.5% of OPFF. In total sixteen different mixes, with water to cement ratio of 0.48 were prepared and subjected to related tests up to 56 days. The specimens are separated to two water curing types; immersion and spraying. The results show immersion cured specimens is less permeable and more resistance to chloride and sulphate than spraying specimens. The TCR does reduce the water permeability of the mix when 20% and less replacement made, while addition of less than 1% OPFF allows medium permeability. The moderate chloride resistance is achieved in mix with less than 10% TCR replacement and OPFF is not added. While sulphate resistance of RFM with less than 30% TCR is acceptable but addition of OPFF must be limited to 1% to prevent large strength reduction. In conclusion, for indoor mortar applications such as partition wall, RFM made of less than 10% TCR and less than 1% OPFF is recommended.

***Keywords*:** Curing Method, Durability, Oil Palm Fruit Fibre, Rubberised Fibre Mortar, Treated Crumb Rubber

1.0 INTRODUCTION

Natural waste materials such as sludge, rice husk ash (RHA) and groundnut husk ash (GHA), coconut shell and oil palm shell are mainly used as cement or fine and coarse aggregates replacer. These alternative materials are used to reduce the waste and to provide alternative and greener materials in making concrete. Cement replacements are carried out using sludge, rice husk ash (RHA) and groundnut husk ash (GHA) [1,2]. While, natural aggregate replacements were either by using waste or agricultural by-products or solids such as coconut and palm oil shells, sawdust, recycled aggregates, mining tiling waste and tyre [3,4,5].

In Malaysia more than 50,000 tons of worn automobile tyres are generated annually, while in the UK is about 40 million, Nigeria has about 15 million and United States more than 270 million scrap-tyres [6]. These has increased over the years and if unmanaged, scrap tyre poses environmental and health associated risks through tyre stockpile fires and as a breeding ground for disease carrying mosquitoes, rats, mice and vermin [7,8]. Hence, the use of rubber waste shredded tyres in concrete was studied in by many researchers in various forms such as crumb, chips, or particles and in the form of fibres [4,7,8]. The potentialities of utilising waste crumb tyres in various mechanical properties of mortar and concrete shows that the compressive strength, density, and modulus of elasticity were decreasing as the percentage of waste crumb tyre replacement increased. On the same note, the initial water absorption capacity was decreasing but later it increased in line with the addition of percentage of crumb tyres replacement, with no significant change in slump height during the process. The abrasion resistance, noise and thermal insulation were also increased as the percentages of replacement were increasing. Based on these properties, the use of waste crumb tyres are recommended for non-structural concrete applications such as floor rips, partitions, back stone concrete, concrete blocks, and other non-structural uses [9].

Waste from scrap tyres is considered as one of the most crucial environmental problems of the world, because they are non-biodegradable. These discarded tyres can be recycled into various forms of rubber particles for use in the construction industries. It can be used as an aggregate in cement based products, fuel in cement kilns and incinerators for production of electricity. Many researches had shown that use of crumb tyres particles as coarse aggregates will significantly reduce the mechanical properties of concrete) but its usage in granular and powdered form will minimize the loss in mechanical properties. Although, there was a general reduction in compressive strength over conventional concrete, the strength is adequate for medium load bearing structural elements [10,11,12].

Natural fibres are another waste material that have potential to enhance the properties of concrete and to produce a sustainable 'green' concrete material. Fibres are usually used in concrete to control plastic and drying shrinkage cracking. Examples of natural fibres are sisal, coconut, jute, bamboo, palm, industrial hemp, banana leaves, Oil Palm Fruit Fibre (OPFF), oil palm trunk, coconut fibre, bamboo, sisal fibre, coir fibre and wood fibres. These fibres have always been promising as reinforcement of cement composites because of their availability, low cost and low energy consumption. Besides, some types of fibres produce a greater impact, abrasion and shatter resistance in concrete [13].

OPFF is the most available natural fibre in Malaysia, about 4 million hectares of land is used for oil palm plantation annually yielding about 19 million tons of palm oil in Malaysia, which placed as the world's second largest producer; as the production accounts for about 80% of the world's production. There gives significant impact in the environment as they require proper disposal technique. The OPFF has been tested and it proves to improve mechanical properties of concrete and mortar matrix when added as an additive in concrete [14, 15,16]. However, works utilising OPFF mainly focuses on the mechanical properties of concrete with little or none on durability properties.

Ismail and Hashim [14] studied the strength development of concrete using palm oil fibre of lengths 1cm, 3cm, and 5cm used with fibre percentages of 0.25% and 0.50% of cement weight to fibre respectively. The results revealed that at fibre content 0.25% and 0.50%, for both percentages the optimum fibre lengths were 5cm and 3cm respectively which ultimately led to the increase in strength development by 39% in contrast to OPC specimens.

The utilisation of OPFF as a greener and a more cost-effective approach in improving the strength of the composite crumb rubber mortar was employed by Aziz et. al. [16]. The mortar mechanical properties with addition of 0%, 0.5%, 1% and 1.5% OPFF and crumb rubber replacement of 0– 40% by volume of aggregate were reported. The addition of 0.5% OPFF to the composite was found to improve the mechanical properties of the mortar composites. But, research on durability of the product of cement-based matrix incorporating OPFF is not known to the authors knowledge.

As rubber is an insoluble and do not absorbed water, therefore the depth of water penetration is high for rubber concrete mixtures hence, the capillary porosity is low [11, 17]. Amount of absorbed water is closely related to the porosity of the concrete structure giving a picture of the internal microstructure surface. Addition of 10% of rubber particles by total volume of aggregate caused average increase of almost 100% in water permeability depth. It is also observed that mixtures containing pre-treated rubber absorb less water, indicating better adhesion of rubber particles to matrix. Thus, pre-treatment is necessary to ensure better bond between rubber particles and other concrete materials [18].

Uses of crumb rubber in concrete as replacement materials for aggregates are well reported in many articles. Aziz et. al. [16] reported the mechanical properties of mortar with 0%, 0.5%, 1.0% and 1.5% oil palm fruit fibre (OPFF) additions and tyre-crumb replacement of 0–40% at 10% increment by volume of fine aggregate was investigated. The influence of pre-treatment of tyre crumb on the strength of mortar was emphasised from which it was concluded that the tyre crumb must be pre-treated before use in the matrix mix to enhance the bond between particles. However, the works are only on the mechanical properties of the composite. In durability aspects, Ahmad et.al. [19] had only reported the carbonation effect of OPFF and TCR mix compositions but other durability aspects are yet to discuss.

Durability of concrete or mortar is defined as the ability of concrete to resist weathering action, chemical attack such as chloride and sulphate and abrasion while maintaining its designed properties without deterioration for a great number of years. Part of durability or known as permeability is water penetration. Many factors influence these aspects of concrete such as cement content, compaction, curing method, cover thickness and exposure conditions. In some situations, high strength is not necessary, but the conditions of exposure are such that high durability is vital. Hence it is important to study the durability of mortar or concrete composition containing waste and agriculture materials. How these wastes influence durability parameters under different curing conditions and most importantly how waste treatment can enhance the durability performance of this mortar is a question that must be addressed.

Based on the senario, this research will focus on some part of durability, namely water penetration and chloride and sulphate resistance of RFM. Mix design proportions by Farah et al. [15], who reported the mechanical properties of the mix, will be followed. Success of this study is a supplementary information of RFM as the strength behaviour is already known.

2.0 METHODOLOGY

This study is concerned with the durability performance of the RFM by assessing the effect of OPFF and TCR within the RFM under different curing conditions. The effect of replacing fine aggregate with treated crumb rubber (TCR) at 10 - 30% and the effect of adding oil palm fruit fibre (OPFF) at 0.5 - 1.5% respectively. The RFM specimens were produced and then subjected to different curing methods (Immersion and spraying) for 28 days before laboratory assessments were made on the durability properties in accordance with standard codes of civil engineering laboratory practices. In total, 1248 RFM specimens were prepared and investigated comprising of 960 mortar cubes, 96 cylinders and 192 prism and the results presented. As mentioned in the introduction, the potential use of this mixture is as non-structural construction building product that is specifically planned for block or brick production and curing method is one of the factors influencing the durability of mortar or concrete, hence two potential curing methods which are practical for brick or block production were studied, namely immersion and spraying curing methods.

2.1 MATERIALS

In this study, the mortar mixes were produced using Ordinary Portland Composite Cement CEM II/B-M (V-L) 32.5R conforming to ASTM C150[20]. Stone dust with maximum particle size passing sieve no.4 in accordance with ASTM C33[21] having a specific gravity, density and absorption of 2.63, 1702 kg/m3 and 2% respectively. In addition, the granulated TRC has particle sizes ranging between 0.15 – 2.36 mm; a compacted density and fineness modulus of 668 Kg/m3 and 0.9 respectively in accordance with ASTM C128[22] was used after it had been treated. The crumb rubber pre-treatment process was carried out by soaking it in water for 24 hours, then air dried until a saturated surface dry (SSD) condition was reached. Thereafter it was mixed with dry composite cement powder in a tilting concrete mixer until a homogeneous mix was achieved, the TCR was then air dried. The TCR was pre-treated with the aim of ensuring the existence of adequate bonding between it and other constituents, the pre-treatment with cement helps in the creation of surface roughness/friction in conformity with Farah et al. [15]. Cement was chosen because it provides better effect over other chemicals such as hydrochloric acid and sodium hydroxide etc. which could be detrimental to the cement mortar matrix. Combined grading for the fine aggregate and granulated TCR is shown as upper and lower limits and used, respectively in Figure 1. The OPFF was obtained from Seri Ulu Langat Palm Oil Mill Sdn. Bhd at Dengkil, Malaysia.

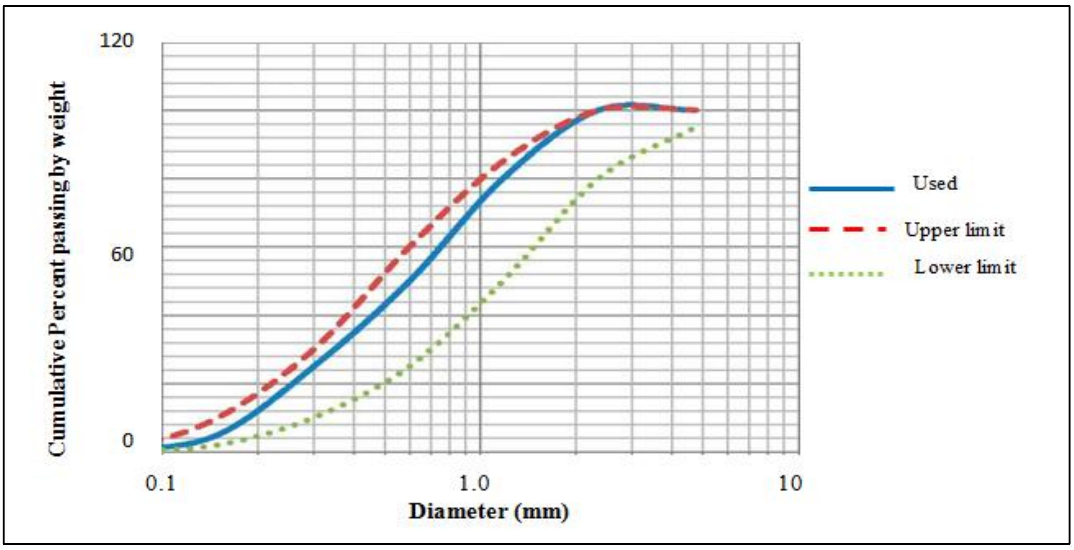

Figure 1 Combined grading for sand and crumb rubber

2.2 MIX PROPORTIONS

The adopted mix design was in accordance with ASTM C 270 [23] having a water cement ratio of 0.48 and cement to FA ratio of 1: 2.75 in line with Farah et.al. [15] and Ahmed et.al. [19]. Minimum target strength of 17 MPa is designed as the control mortar mix. The crumb rubber substitution was at 0%, 10%, 20% and 30% by volume fraction of aggregate. While addition of oil palm fibre (OPFF) of 0%, 0.5%, 1.0% and 1.5% are by weight of cement content. In total, 16 mortar mixes were prepared (Table 1) whilst noting that water content (in column 5, Table 1) is inclusive of 2% water absorption of the fine aggregate.

Table 1 Composition of Plain and Rubberised Fibre Mortar Mixture

Mix Ref./ Percentage	Cement Content (kg/m^3)	Fine Aggregate (kg/m^3)	Crumb Rubber (kg/m^3)	Water Content (kg/m^3)	Fibre (kg/m^3)
F0 CR0	740.0	2035.0	0.0	399.6	-
F0 CR10	740.0	1831.5	80.0	395.5	-
F0 CR20	740.0	1628.0	159.8	391.5	-
F0 CR30	740.0	1424.5	239.8	387.4	-
F0.5 CR0	740.0	2035.0	-	399.6	3.7
F0.5 CR10	740.0	1831.5	80.0	395.5	3.7
F0.5 CR20	740.0	1628.0	159.8	391.5	3.7
F0.5 CR30	740.0	1424.5	239.8	387.4	3.7
F1.0 CR0	740.0	2035.0	-	399.6	7.4
F1.0 CR10	740.0	1831.5	80.0	395.5	7.4
F1.0 CR20	740.0	1628.0	159.8	391.5	7.4
F1.0 CR30	740.0	1424.5	239.8	387.4	7.4
F1.5 CR0	740.0	2035.0	-	399.6	11.1
F1.5 CR10	740.0	1831.5	80.0	395.5	11.1
F1.5 CR20	740.0	1628.0	159.8	391.5	11.1
F1.5 CR30	740.0	1424.5	239.8	387.4	11.1

Note: *The F0 CR0 notations under mix ref./percentages in col. 1 of Table 1 is for ease of identification where; 'F' is OPFF, the first '0' is % content of fibre, 'CR' is crumb rubber and the second, '0' is the % content of the crumb rubber. The same notations are applied in explaining the samples for every batch.*

2.3 MIXING AND CURING METHODS

The dry materials used in the mix such as cement; fine aggregate; and TCR aggregate were first mixed for 2 mins in a bowl mixer in order to prevent balling effect associated with the conventional mixing technique. Then OPFF and one - third (1/3) of water were added and further mixed for 2 mins, the remaining water was gradually added, and mixing continued for about 5 mins until a homogeneous mixture was achieved and samples produced. These samples were cured by either water immersion or water spraying methods. The latter is carried out by covering the specimens with wet burlap clothes and water spraying at alternate day. This method is an effective method of curing particularly for brick or block. In both methods the temperature is of 25 – 30 0C and about 100% relative humidity (RH) for 28 days before the appropriate durability tests were conducted.

3.0 TESTING

The standards for test methods adopted in this study refers to a condition of a tropical temperature ranging between 28 – 300C, except where modifications are required as appropriately stated. To measure the fresh mortar properties, flow table test of hydraulic cement mortar as per ASTM C1437[23] was performed. Average of three measurements of each mortar mixes were plotted. Besides, the density is measured in accordance with BS 1881- 114 [24] by weighing specimens' masses (kg) which defines it as the mass of a unit volume of hardened concrete expressed in kilograms per cubic metre. Hence, the densities of the mortar cubes were calculated by dividing the weight (kg) by the dimensions of the cubes (m3) using equation 1:

$$Density, \rho = \frac{M}{V} \qquad (1)$$

where M is mass of specimen (kg) and V is volume of specimen calculated from cube dimensions (m^3). Besides, the workability and density, the following permeability aspects are carried out:-

3.1 WATER PERMEABILITY

This was investigated according to the BS EN 12390-8 [25] based on the penetration of water under hydrostatic pressure. The diffusion depths into the samples after the water penetration were determined by splitting the samples into two halves and the diffusion depth measured.

3.2 RAPID CHLORIDE PENETRATION TEST (RCPT)

Chloride – induced corrosion of reinforcing steel due to chloride ingression is one of the most common environmental attacks that lead to the deterioration of concrete structures. Therefore, the ability of concrete to resist the penetration of chloride-ions is a critical parameter in determining the service life of a steel reinforced concrete structure exposed to marine environments or water containing chlorides or sulphates. This test method measures the ease with which the mortar allows charge to pass through it by recording current as a function of time which then gives an indication of the mortar's resistance to chloride-ion penetration. Unlike water permeability which measures the ease with which fluid flow through concrete/mortar under hydrostatic pressure. The resistance of the RFM to chloride-ion penetration was evaluated by the rapid chloride penetrability test (RCPT) in accordance to ASTM C1202 [26]. The PROVE'it RCPT instrument was used by allowing electrical charge to travel between 2-sides of the specimen during a 6-hour period and the charge passed is correlated to the chloride – ion travelling through the pore system of the specimen. Total of 288 short cylinders cured under two different curing mediums.

3.3 SODIUM SULPHATE INGRESSION TEST

After 28 days of curing, the specimens were kept under laboratory atmospheric condition for 24 hours to dry its surface water prior to weigh. After that, all samples were submerged in a 2.5% sodium sulphate (Na2SO4) solution with pH of 6 for another 7, 28 and 56 days, following the test procedure reported by James [27], and Bala and Mohammad [28]. The mass of the specimens was weighted, and the appearances of the specimen were observed to ensure no deterioration at the edges as well as any colour changes before the compression test was conducted. Effect of sulphate attack on compressive strength of samples with TCR and OPFF are shown Kfi, resistance to corrosion coefficient of compressive strength and is expressed by eq. 2 [29].

$$K_{fi} = \frac{f_{ci}}{f_{co}} \times 100 \qquad (2)$$

Where fci is a compressive strength at the stage i, and fc0 is a compressive strength at 28 days.

4.0 RESULT AND DISCUSSION

4.1 WORKABILITY

The important behaviour for an acceptance of any waste materials used in concrete or mortar is its workability. The results for the RFM flow table test were compared to control as shown in Figure 2. The workability of TCR samples reveals the largest flow diameter of 143 - 147 mm, which is similar to the control samples of 146 mm. These show the nature of TCR, which is a non-absorbent had been improved by the cement coating treatment, which had successfully reduced the non-absorbent nature and allowing water to flow in-between its grain. Indeed, this is in line with findings reported by Gupta, Chaudhary, & Sharma [30]. With addition of OPFF, RFM mixes obtained the lowest workability with flow diameter of 106 mm. The physical characteristic of OPFF that had high water absorption capacity may affect the friction between solid particles [31], hence less water shared by other matrix and subsequently reduced the workability to about 38% of the control specimen.

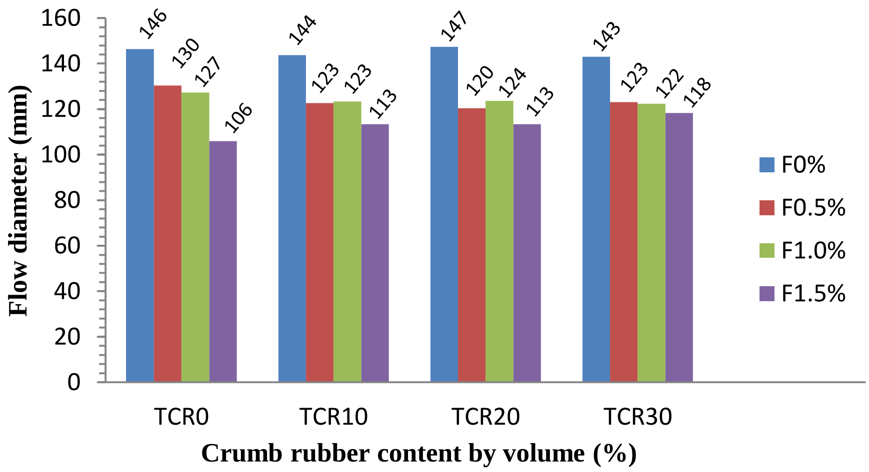

Figure 2 Workability of RFM as a function of rubber and oil palm fibre content

4.2 DENSITY

Aggregates both, fine and coarse are about 75% of the concrete density, hence their replacement with low density material will greatly result in the self-weight reduction of the concrete elements. The TCR utilised in this study has density of 688kg/m3 which is similar to that of Pierce and Blackwell [4] and Benazzouk et al. [17]. The density results for RFM specimens cured by water immersion and spraying are presented in Figure 3(a) and in Figure 3(b), respectively, where all are above 1350 kg/m3. Generally, both curing methods showed density decreases with addition of both TCR and OPFF. The low unit weight of TCR leads to the development of a lighter mortar. The density of all the specimens containing 30% TCR and 0% - 1.5% of OPFF falls within the density for structural lightweight concrete as in Table 2 except specimen containing 20% TCR and 1.0% OPFF which had 5.6% greater than the maximum value for structural lightweight concrete category. Only RFM containing 10% TCR ranged between 1960-2128Kg/m3 which is above 1900 Kg/m3 i.e. normal weight concrete.

Table 2 Practical Range of Lightweight Concrete [32]

Categories	Density Range (kg/m3)	Minimum Strength (MPa)
Structural lightweight concrete	1350 – 1900	17
Moderate strength concrete	800-1350	7-17
Low density concrete	300-800	Use for non-structural purposes such as insulation panel, blocks, pavements, etc.

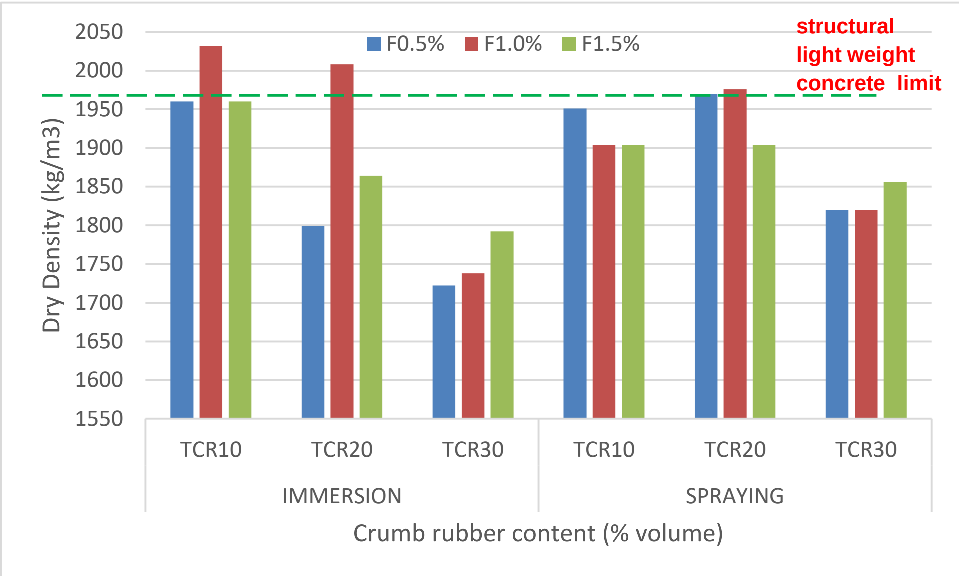

Figure 3 Density of RFM specimens

4.3 WATER PERMEABILITY

The durability of concrete is mainly dependent on the fluid ability to penetrate the concrete microstructure which is referred as permeability or, more importantly penetrability. The permeability results of RFM are shown in terms of water penetration depth in Figure 4 and are compared to the water permeability classification in accordance with DIN 1048[33]. General observation shows spraying curing method cause higher permeability than immersion. Also based on the specimen density, the immersion cured samples (2128 kg/m3) are less porous than spraying specimens (2048 kg/m3). This shows that the earlier curing method allows full hydration of sample and subsequently produced a denser specimen, hence prevent less penetration of water.

Referring to Figure 4, an increase of TCR replacement from 10 to 30 percent cause inconsistent permeability depth on immersion samples, while spraying samples shown medium depth for 10 and 20

% TCR replacement but very high when 30% replacement is made. This is due to lack of good bonding between rubber particles and cement paste where the interface surface between cement paste and rubber grains act as the bedding for pressurised water to flow in the concrete containing rubber [11]. Similar patterns were observed when 0.5 to 1.5% OPFF are added, with the highest permeability depth is when 1.5% OPFF is added. From these results, it can be concluded that when 1.5% OPFF and 20-30% TCR are added, RFM produce a porous mortar which allows high water penetration, and when 0.5-1% OPFF with 10% TCR are used, RFM with medium penetration is obtained.

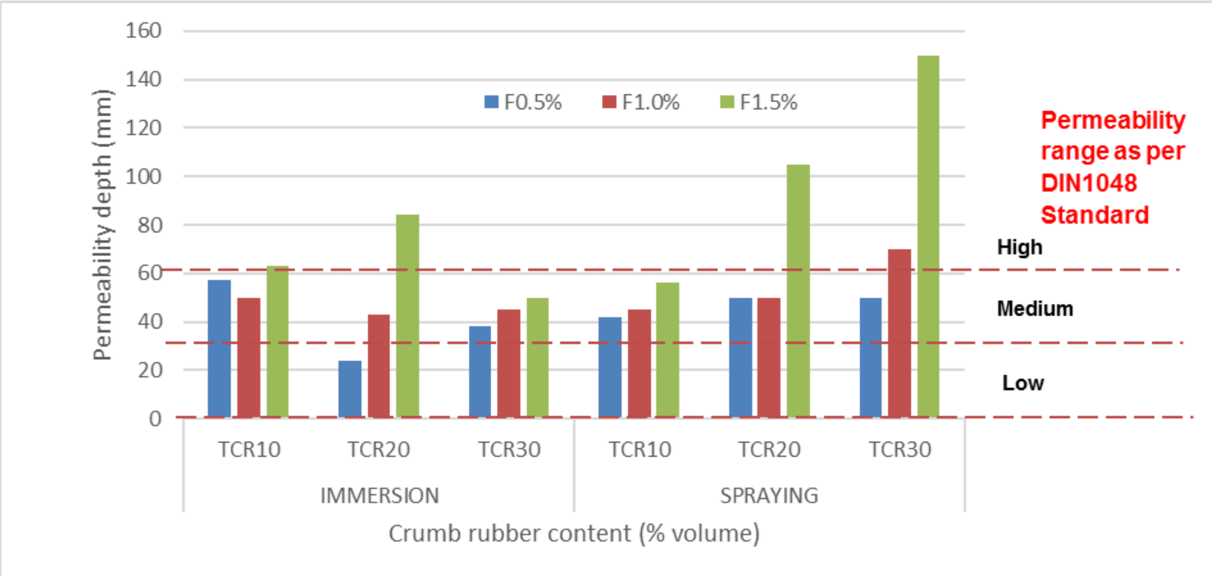

Figure 4 Water penetration depth of RFM samples

4.4 RAPID CHLORIDE PENETRATION

Chloride– induced corrosion of reinforcing steel due to chloride ingression the most common environmental attacks that lead to the deterioration of concrete structures. The ease with which the mortar allows charge to pass through it gives an indication of the mortar's resistance to chloride-ion penetration. The effect of TRC onto the chloride-ion penetration of the specimens is as shown in Figure 5. The resistance to chloride ion penetration of RFM specimens made of 10% TRC and are subjected to immersion curing is better than the control specimens. This probably due to good interaction between rubber particles and mortar composites preventing the chloride penetration to about 30% less than the control. However, as the rubber content increases the penetration of chloride ions also increases. This is in contrary to other works reported in [34], in which the percentage of TRC is not more than 15%. This shows that addition of more than 15% TCR replacement will caused many pores and weak bond between particles in the mix which allows high charge passed the mix and lower the mix resistance to chloride attack.

On the other hand, regardless of the curing methods, the addition of OPFF at 0.5-1.5% as shown in Figure 6 had categorised the mixes as high penetrability where the charge passed are more than 4000 coulombs. High absorption capacity of the OPPF had significantly cause large chloride penetration into the mixes. Hence, even the mechanical properties of RFM with OPFF addition shows acceptable strength as reported by Aziz et.al. [16], OPPF addition in the mix are not recommended when durability is the main concern. In conclusion, only 10% TCR replacement subjected to immersion curing is classified as moderate penetrability of chloride by ASTM C1202 [26], that is suitable for reinforced concrete application as low chloride-ion permeability is necessary to reduce the potential for corrosion of embedded reinforcement.

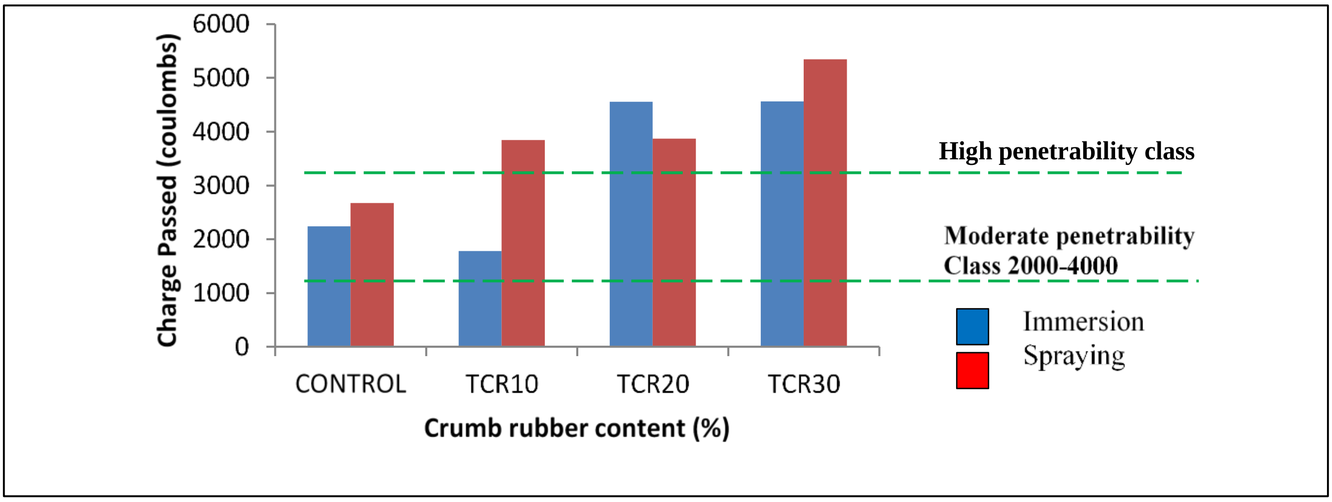

Figure 5 TRC effect on Chloride-ion penetration

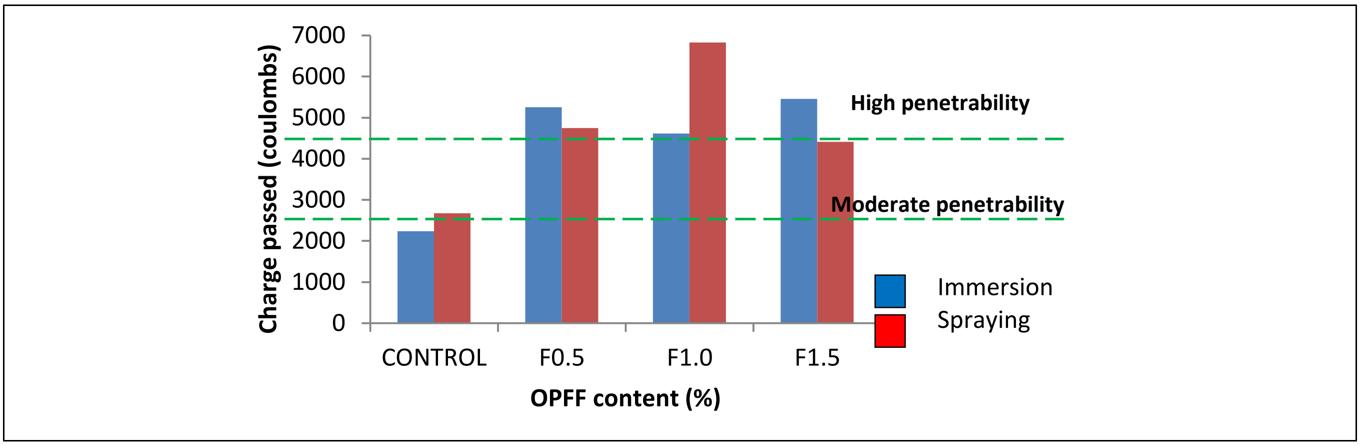

Figure 6 OPFF effect in Chloride-ion penetration

4.5 SULPHATE RESISTANCE

In total 192 cube specimens are prepared, in which half were cured by immersion and another half by water spraying for 28 days before being submerged in the Na2SO4 solution. The average compressive strength of immersion and spraying samples are tabulated in Table 3a and Table 3b, respectively. By observation, no eroded residues of either fine aggregate or crumb rubber particles or cement were observed before 56 days, however after that, salt scaling precipitate was noticed as shown in Figure 7.

Table 3a shows samples with increasing percentages of TCR, obtained good resistance to sulphate attack with resistance coefficient factor Kfi of more than 100%. This explains that TCR content of less than 30% can sustained the strength when exposed to sulphate. While addition of 1.5% OPFF reduces the resistance to corrosion coefficient of compressive strength to less than 100%. On the other hand, Table 3b shows spraying curing specimens obtained inconsistent interaction of matrix to the sulphate attack with percentages of Kfi between 98-116, this could due to its higher permeability and more porous structure of the mixes.

Table 3a: Compressive Strength of immersion curing specimens before and after sulphate attack

IMMERSION	F0% (EFFECT OF TCR)				TCR10 (EFFECT of OPFF)			
	TCR0	TCR10	TCR20	TCR30	F0%	F0.5%	F1.0%	F1.5%
At 28 days (MPa)	37.1	34.0	25.9	26.3	34.0	32.4	34.2	32.6
After sulphate attack of 28 days (MPa)	49.3	40.3	34.4	27.5	40.3	37.8	37.5	29.2
Resistance to corrosion coeff.% K_{fi}	133	119	133	105	119	117	110	90

Table 3b: Compressive Strength of spraying curing specimens before and after sulphate attack

SPRAYING	F0% (EFFECT OF TCR)				TCR10 (EFFECT of OPFF)			
	TCR0	TCR10	TCR20	TCR30	F0%	F0.5%	F1.0%	F1.5%
At 28 days (MPa)	34.0	35.0	32.7	24.3	35.0	31.0	33.2	28.0
After sulphate attack of 28 days (MPa)	53.0	37.3	32.0	26.2	37.3	34.5	37.6	32.6
Resistance to corrosion coeff. % K_{fi}	156	107	98	108	107	111	113	116

Figure 7 Salt scaling on samples surface before and after Na_2SO_4 immersion

5.0 CONCLUSION

The water permeability and chloride and sulphate resistance of RFM discussed above can be concluded as below:

1. The mixes behavior are more predictable on specimens cured by immersion than spraying technique.
2. The workability is not affected by TCR but largely reduced by addition of OPFF as compared to the control specimens. While the density showed reduction in RFM specimens.
3. Water permeability of RFM specimens are classified as high and not recommended for structural applications except for specimen made of 10% TCR and less than 1% OPFF, is classified as medium.
4. Addition of OPFF is not recommended when chloride resistance is required while only less than 10% TCR replacement can be classified as moderate penetrability to chloride.
5. Sulphate resistance of RFM with less than 30% TCR is acceptable but addition of OPFF must be limited to 1% to prevent large strength reduction. 5. Seismic performance has been improved as the modal period increases beyond the typical site period in Bangladesh.

6.0 ACKNOWLEDGEMENT

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