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The Effects of TiO_2 in the Performance of Mortar

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Abstract. Titanium dioxide (TiO_2) is a material that contains photocatalysic which acts as self-cleansing agents on a material surface. In the application of TiO_2 in the civil engineering construction, it can be mixed with the fresh mortar known as TiO_2 mortar. Hence, a study on the characteristic strength of the TiO_2 mortar needs to be carried out. Moreover, the optimum dosage levels of the TiO_2 in the mortar can be determined. The characteristics of the TiO_2 were identified based on the compressive strength and flexural strength at 3, 7, 21 and 28 days. A total of five sets of specimens with different dosage levels were prepared and compared with the control specimen.

Introduction

Titanium Dioxide (TiO_2) has received considerable attention in recent years as coating for concrete pavement [1,2]. The photocatalytic process of TiO_2 can be used as trap agent to absorb organic and inorganic air. It gives a promising benefit such as reduce the environmental impacts such as acidification, eutrophication, criteria air pollutants and smog formation. It is also practical for self-cleaning [3] and air-purifying concrete pavement [4]. For other material, the effect of TiO_2 on properties of polyethylene nano composites [5], self-cleaning glass [6] and as coating on residential window glass [7] have also been investigated. Effectiveness of TiO_2 in the perspective of environmental friendly building materials such as in the aspect of coating, cement, concrete, wallpaper, glass, porcelain and PVC profile has been investigated by Chen and Xu [8]. They found that, TiO_2 has excellent performance in improving human environment and facilitate the effectiveness of human health to achieve environmental protection. It also has great benefit in improving air quality inside a building [9]. A study on TiO_2 photocatalytic concrete for air purification with different percentage by weight with respect to the binder has been conducted by Husken et al. [10]. The effects of TiO_2 nanoparticles on flexural damage of self-compacting concrete (SCC) have been studied by Nazari and Riahi [11]. In their study, the TiO_2 nanoparticles has been replaced in concrete instead of cement with 4 % weight of SCC and it was found that the replacement of more than 4 % weight of SCC reduced the flexural strength of the SCC. In the production of building materials, the TiO_2 functions as an additive that significantly reduces the consumption of resources such as traditional energy. It is because TiO_2 particles crystallize in three forms, anatase, rutile, and brookite [12]. Anatase is a meta-stable that transforms into rutile at high temperature [13] and has photocatalyst semiconductor in environmental purification [14]. Since the TiO_2 contains an agent which acts as self-cleansing due to photocataclysic composition, it is useful in civil engineering construction. It can be used as a self-cleaning material in order to maintain the surface condition of the structure especially on reinforced concrete structure which is highly exposed to aggressive environment. The application of TiO_2 in such structure can be implemented by a generic study of its performance such as inclusion of TiO_2 in the mortar and concrete. However, the reviews on the inclusion of TiO_2 in both materials are still limited. In this paper, only the mixture of TiO_2 and fresh mortar at various dosage levels is presented. In the present study, only the compressive strength and the flexural strength were identified at 3, 7, 21 and 28 days of harden TiO_2 mortar specimens. The results were then compared with the control specimen and the strength effectiveness of the TiO_2 mortar specimens was identified.

Experimental Programme

The physical properties of the TiO_2 are solid state (powder), slightly odour and white colour. The chemical properties of the TiO_2 are density of 4.05 g/cm^3 and 1800^{0}c melting point. In the preparation of the TiO_2 mortar, the mortar was designed for different proportions by weight of water: cement: fine aggregate and it was 0.5: 1: 3, respectively. Then, 5 % of silica fume based on cement weight was added to the mortar mix to improve the workability of the mortar. Table 1 shows the dosage levels of the TiO_2 used in the mortar mix. For control specimen, no TiO_2 and silica fume were added to the mortar mix. Two sizes of TiO_2 mortar were prepared, 100 mm x 100 mm x 100 mm cubes and 40 mm x 40 mm x 160 mm prisms for compressive strength and flexural strength, respectively. A total of 72 cubes size 100 mm x 100 mm x 100 mm were prepared for the compressive strength at 3, 7, 21 and 28 days. Meanwhile, for flexural strength test, a total of 72 prisms with the size of 40 mm x 40 mm x 160 mm were tested at the age of 3, 7, 21 and 28 days. The fresh mix of the control specimen and TiO_2 mortar is presented in Fig. 1. For each dosage level and age of test for both tests, three cubes were prepared. Then, the results were averaged.

Table 1. Dosage Levels of the TiO_2 in the Fresh Mortar

Mixture	Cement (%)	Titanium Dioxide (%)	Silica Fume (%)
Control	100	0	0
TDM 1	67	0.28	5
TDM 2	65	0.30	5
TDM 3	63	0.32	5
TDM 4	61	0.34	5
TDM 5	59	0.36	5

a) b)

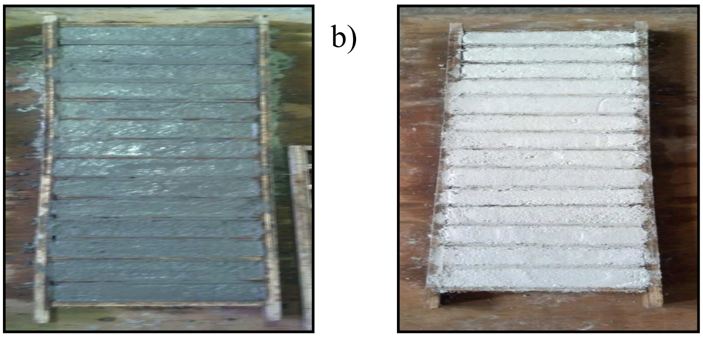

Fig. 1. Fresh mix in the moulds a) control prisms b) TiO_2 mortar prisms

Results and Discussion.

Compressive Strength Results. Fig. 2a shows the results of compressive strength of hardened control specimen and TiO_2 mortar at 3, 7, 21 and 28 days. Five dosage levels of TiO_2 were mixed in the mortar and designated as TDM 1 to 5. From the graph, the compressive strength of TiO_2 mortar for all dosage levels of TDM 1 to 5 increases as the age of the specimen increases. For TDM 1, which contains 0.28 % of TiO_2, the compressive strength is lesser than TDM 2 which contains 0.30 % of TiO_2 at the age of 3 to 21 days. However, the compressive strength increases when it reaches the optimum age of 28 days. It is found that the compressive strength of TDM 1 is 23.32 N/mm^2 and TDM 2 is 21.97 N/mm^2. The compressive strength of TDM 3 which contains 0.32 % of TiO_2 drastically dropped halves than TDM 2 at the age of 3 days. It indicates that the increase of TiO_2 in the mortar mix did not increase the strength at early age of the specimen. Similar case occurred for TDM 4 and TDM 5 which contains 0.34 % and 0.36 % of TiO_2. At optimum age of 28 days, it is found that the compressive strength reduces when the TiO_2 increases. From the Fig. 2a, it is also found that the compressive strength of TiO_2 mortar is lesser than control specimen. The inclusion of TiO_2 in mortar increased the porosity of the mortar and hence reduces the strength of the mortar. In overall, it indicates that the inclusion of TiO_2 did not increase the compressive strength of the mortar especially at the optimum age of 28 days. However, the compressive strength of TiO_2 mortar for specimen TDM 2 at the age of 21 days increases more than the control specimen. The compressive strength effectiveness of the TiO_2 mortar is presented in Fig. 2b. It indicates that the TDM 2 which contains the inclusion of 0.30 % TiO_2 produced more strength effectiveness than the other specimens which have different inclusion of TiO_2 dosage levels at early age of 3 to 21 days. However, the strength effectiveness reduced to 3.3 N/mm^2 when it reached 28 days. It indicates that the optimum inclusion of TiO_2 in mortar is 0.30 %. If higher percentage of TiO2 is used, it reduced the strength of its combination. The compressive strength effectiveness can be used to determine the difference in the strength between the control specimen and the mortar with the inclusion of TiO_2. From the Fig. 2b, the TDM 5 has lower compressive strength effectiveness compared to other specimens. In overall, the compressive strength effectiveness of TiO_2 mortar increases when it reaches the age of 21 days. However, it reduces when reaches to optimum age of 28 days.

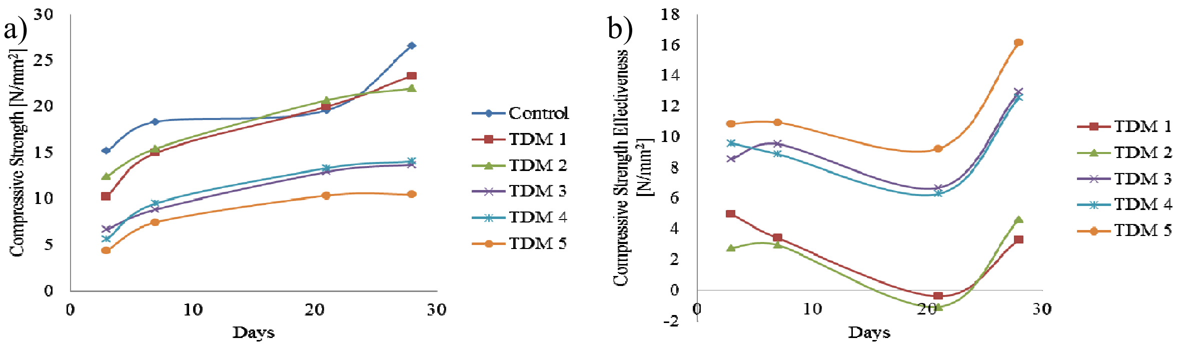

Fig. 2 a) Compressive strength of the control and TiO_2 mortar; b) Compressive strength effectiveness of the various dosage levels of TiO_2 mortar

a) b)

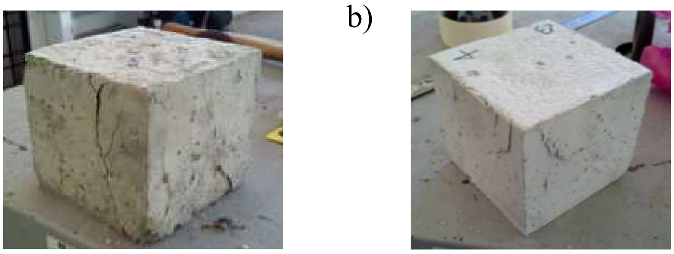

Fig. 3. Condition of the cube surface a) control cube b) mortar with the inclusion of TiO_2

Although the TiO_2 seemingly did not increase the performance of the mortar in terms of its compressive strength, at the age 21 days, the inclusion of TiO_2 at low dosage level such as 0.28 % and 0.30 % TiO_2 in the mortar is found to increase when compared to the control specimen. This depicts that it is still practical to be used if the inclusion of other material in the composition of the mortar can be made. At the same time, the TiO_2 role as self-cleaning agent in the composition can still be maintained. It can be depicted in Fig. 3 that the surface of the TiO_2 mortar cube is brighter or cleaner than the control cube. Hence, the inclusion of TiO_2 in the mortar composition can be used as decorative materials.

Flexural Strength Results. The flexural strength of control specimen and various dosage levels of TiO_2 mortar specimen are depicted in Fig. 4a. It indicates that the flexural strength of the control specimen increases as the age of the specimen increases. The average flexural strength of the control mortar increased from 4.45 N/mm^2, 6.03 N/mm^2, 6.73 N/mm^2 and 7.86 N/mm^2 for age 3, 7, 21 and 28 days, respectively. The flexural strength of TDM 1 at the age 3 days was 5.16 N/mm^2 and increased to 7.40 N/mm^2 when reached the optimum age of 28 days. It indicates that the harden TiO_2 mortar prism specimen when subjected to three point loading increases the flexural strength as the age of the specimen increases. However, the inclusion of the TiO_2 in the mortar mix is found to reduce the flexural strength as the dosage level of the TiO_2 increases. It can be depicted that in Fig. 4a where at optimum age of 28 days, the flexural strength of TDM 1 (0.28 % TiO_2), TDM 2 (0.30 % TiO_2), TDM 3 (0.32 % TiO_2), TDM 4 (0.34 % TiO_2) and TDM 5 (0.36 % TiO_2) were 7.40 N/mm^2, 6.94 N/mm^2, 5.90 N/mm^2, 5.16 N/mm^2 and 4.18 N/mm^2, respectively. It seemingly indicates that the higher the inclusion of TiO_2 in the mortar mix did not improve the performance of the flexural strength. The flexural strength effectiveness of the TiO_2 mortar at various dosage levels is depicted in Fig. 4b. It indicates that the inclusion of 0.28 % TiO_2 and 0.30 % TiO_2 designated as TDM 1 and TDM 2 have better strength effectiveness than the other prisms that has other inclusion of TiO_2. It can be seen especially at the optimum age of the prisms. In overall, the flexural strength effectiveness of TiO_2 is lesser than the compressive strength effectiveness as discussed in preceding section. However, it is confirmed that 0.3 % of TiO_2 is the optimum dosage level can be used to improve the strength of the mortar.

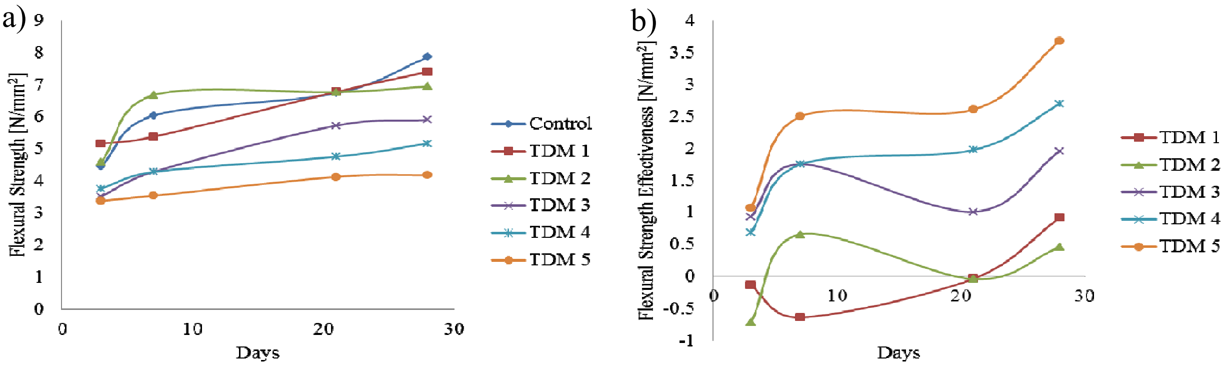

Fig. 4 a) Flexural strength of the control and TiO_2 mortar; b) Flexural strength effectiveness of the various dosage levels of TiO_2 mortar

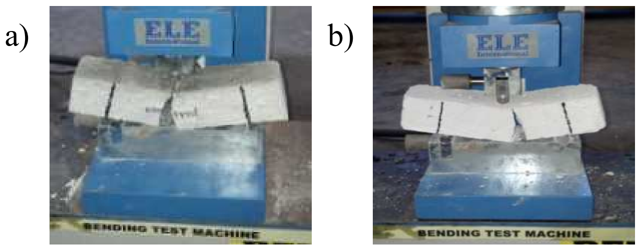

Fig. 5. Prism failure of hardened specimens a) control specimen b) TiO_2 mortar with 0.34% TiO_2

Fig. 5 shows the failure of the prism specimens when subjected to monotonic load where the specimens fail almost halves for control specimen and TiO_2 mortar specimen. From the observation of the appearance of the surface of the specimens, it is found that the specimens of TiO_2 mortar are brighter than control prisms. It is due to the composition of photocataclysic in the TiO_2 which affect to the surface of the specimen. Although the flexural strength of the TiO_2 mortar is lesser than control specimen, this study is useful. It is because the review on the application of TiO_2 in the civil engineering construction is still limited. Hence, this study can be used as a milestone or reference to other researchers who are interested in the application of TiO_2 in the mortar.

Conclusion

In overall, the comparison between TiO_2 mortar specimen and control specimen indicates that the strength of control specimen is higher than TiO_2 mortar. Hence, the inclusion of TiO_2 did not increase the performance of mortar such as compressive strength and flexural strength. Although the strength of the TiO_2 is lesser than control specimen, this study is vital as the inclusion of TiO_2 in the mortar can be used for the structure appearance where it gains brighter feature of the structure's surface. It can be concluded that the optimum dosage level that can be used to improve the strength of the mortar is 0.3 % of TiO_2. For future research, the TiO_2 mortar will be applied in the reinforced concrete structure to investigate the performance of the surface that relates to the self-cleaning structure.

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