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# Bending strength estimation equations of green binder mortar for global research

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## Abstract

*New regression equations for estimating the bending strength of green mortar composite from pH of green cement containing fine marble particle (MP) is discussed in this experimental study. The tested properties are the bending strength of MP-green cement mortar composite at 7d, 28d, and 90d as well as pH of MP-green cement. Estimation of bending strength gain from pH is explained as new non-destructive method. In the light of the result, the substitution of marble particle up to 35% for Portland cement does have effect the performance of green cement, green mortar composite, and Portland cement positively. Green cement and green mortar composite containing up to 35% MP exhibits enhancement in pH and bending strength at 7d, 28d, and 90dwhen compared to the Portland cement and mortar composite. For that reason, the new regression equations are necessary for estimating the bending strength of MP-green cement mortar composite from pH of MP-green cement.*

**Keywords:** Green cement, marble particle, mortar composite, pH, corrosion, bending strength.

## Introduction

Some regression equations to estimate the bending strength from compressive strength are suggested by plenty of much scientific research since estimation of the bending strength of cement-based non-resilience reinforced-concrete structural composite is significant feature for both non-destructive testing industry and construction industry[1]. As the aforementioned regression equations need to measure the bending moment of material destructively, sample material does not use in any other testing repeatedly, this destructive method also causes to increase the workload in cement laboratory and construction industry. There is a need for comprehensive study so that the bending strength is estimated from pH that is already measured by cement laboratory in a daily routine testing. Since this research uses the pH data of hydraulic green cement, it also presents new regression equations for science, non-destructive testing industry, and construction industry. On the other hand, the rust that is of chemical reaction including the flowing of ion and electron is another significant characteristic for cement-based structural element, such as beam, column, floor, and foundation, in reinforced-concrete and reinforced-concrete structure, it can be prevented by pH level of cement which covers construction steel with a wiry protective layer[2-8]. As this study measures the pH of MP-green cement, it also explains effect of MP on the pH of hydraulic cement and cement composite. Corrosion of inset metal is not affected the replacing of pure cement with by-product providing a rust resistance for cement-based material due to high alkaline level. Researchers also wonder to know whether by-products, such as marble particle, fuel ash, silica fume, etc, do have effect on pH of hydraulic cement positively before they use it in cement research. In other words, it is important to understand whether the by-product and hydraulic cement is suitable each other.

Additionally, marble particle is a by-product originated from cutting of marble stone for manufacturing of marble kitchen counter top, marble column, and marble tile, and so on. The particle is a natural latent hydraulic cementitious material due to its high calcium mono oxide (CaO) content, but disposal of it leads varying harmful problems environmentally[9-12]. Table-1 states the chemical compound of marble particle. In untreated condition, this MP generated is over 2 600 000 tons annually. The particle does not finds any application in construction industry. An alternative way is that the use of marble particle, like limestone dust, employed in many European countries, Canada, and USA is as blending, intergrinding and/or substitution material for cement. However, because of the effect of MP on the pH of hydraulic cement, few research has preferred this alternative method. Since the-MP-study demonstrates that the marble particle does not reduce the alkalinity of hydraulic cement, this experimental non-budget research is carried out to more effective explain relationship between pH of MP-green cement and bending strength of MP-green cement mortar composite. As explained in this study, the article also presents new polynomial regression equations between pH of MP-green cement and bending strength of MP-green cement mortar composite[12-15].

**Aim of this work:** This study objects to estimate the bending strength of MP-green cement mortar composite and the pH of MP-green cement with regression equations. However, this study also presents the cement alkalinity by pH testing method. As reliability interval of the regression equations is 0.95, those could be used by non-destructive testing industry. This study also shows that the pH testing may be used for estimating the bending strength nondestructively as it is more practical, faster, and cheaper. Therefore, the regression equations presented may become an alternative method for the destructive method of bending strength determination.

## Materials and methods

**Materials:** Construction applications use traditional mortar materials, such as lime mortar, lime + mineralogical material mortar, lime + cement mortar, cement mortar, and cement + mineralogical material mortar, for laying brick, infrastructure, structure building, renewal and retrofit of construction. Difference of this mortarcomposite from traditional one aforementioned is that it uses new green cement that also contains marble particle as latent hydraulic additive and/or substitution material in order to explain effectiveness of MP on bending strength gain of hydraulic green mortarcomposite and pH of green cement[16-22]. Table-1 gives the chemical composition of MP to better explain its effect on pH of hydraulic cement.

SMP-GC stands for substituted marble particle-green cement prepared in the study. Mortar composite is mixed with water: cement: sand ratio of 1:2:6. Table-3 presents types of substituted-cement mortar (SCM) composite, reference cement mortar (RCM) composite, and mixture proportion of the mortar composite for one standard 3-gand mold (0.000768 $m^3$).

**Test Methods: Preparation of green cement and green mortar composite for testing:** Table-2 presents groups and types of cement, proportion of by-product, and pure CEM type I42.5 (MPa at 28d)normal cement as percentage.

**Table-1:** Chemical structure of marble particle.

| Chemical Structure (%) | Marble Particle (MP) |
|---|---|
| CaO | 53.7 |
| $SiO_2$ | 0.3 |
| $Al_2O_3$ | 0.1 |
| $FeO_3$ | 0.04 |
| MgO | 0.7 |
| $SO_2$ | 0.05 |
| $K_2O$ | 0.01 |
| $Na_2O$ | 0.3 |
| LOI | 44.1 |
| pH | 12.01 |

**Table-2:** Groups and types of cement, proportion of by–product and pure CEMI42.5N cement.

| Cement | | Proportion of By–product and Binder | |
|---|---|---|---|
| Groups | Types | Marble Particle | CEM type I 42.5 Normal Cement |
| Group 1 | SMP-GCI | 6 | 94 |
| | SMP-GCII | 20 | 80 |
| | SMP-GCIII | 21 | 79 |
| | SMP-GCIV | 35 | 65 |
| Group 2 | CEMI42.5 (Reference) | 0 | 100 |

**Table-3:** Types of substituted-cement mortar (SCM) composite, reference cement mortar (RCM) composite, and mixture proportion of the mortar composite for one standard 3-gang mold.

| Types of Mortar Composite | | Mixture proportion of cement mortar composite | | | | |
|---|---|---|---|---|---|---|
| | | Substituted-Green Cement Proportion | | Tap water (mL) | CEN Standard Sand (g) | Water-to-binder ratio |
| | | MP (g) | CEM I 42.5N (g) | | | |
| SCM | SC–MP6M | 27 | 423 | 225 | 1350 | 0.5 |
| | SC–MP20M | 90 | 360 | 225 | 1350 | 0.5 |
| | SC–MP21M | 94.5 | 355.5 | 225 | 1350 | 0.5 |
| | SC–MP35M | 157.5 | 292.5 | 225 | 1350 | 0.5 |
| RCM | CEMI42.5M (Reference) | 0 | 450 | 225 | 1350 | 0.5 |

**pH experiment of Portland cement and of green cement:** TS 12072 standard method measures the alkalinity level of green cement and of reference cement (Table-2) by a pH meter having specification according to the TS 5133 standard[23-25]. Image of pH meter for measuring of cement alkalinity is seen in Figure-1.

**Bending strength experiment of Portland cement and of green mortar composite:** Standard method of TS EN 196-1 examines the bending strength of prism mortar (40x40x160 mm) at 7d, 28d and 90d (Table-3)[26]. The article presents average value for the bending strength of mortar composite as the descriptive result for reference mortar composite and hydraulic green mortar composite. Equipment for mortar composite preparation is seen in Figure-2, left to right, the automatic-minute-controlled mixer, the bending moment testing machine, computer controlled water curing cabinet, bending moment testing of mortar composite containing MP.

## Results and discussion

Table-4 presents the pH of MP-green cement and of reference cement, bending strength of MP-green cement mortar composite and of reference cement mortar composite at 7d, 28d, and 90d. It also gives types of cement and of mortar composite. Following Figure-3, Figure-4, and Figure-5 give new polynomial regression equations to show the relationships between the pH of MP-green cement and bending strength of MP-green cement mortar composite. These figures also present the R-squared values, coefficients, and the polynomial regression equations that show strong relationship for estimating of 7th-d, 28th-d, and 90th-d bending strength of MP-green cement mortar composite from pH of MP-green cement.

**Figure-1:** Image of pH meter for measuring of cement alkalinity.


**Figure-2:** Equipment for preparation and testing of mortar composite, left to right, the automatic-minute-controlled mixer, the bending moment testing machine, curing cabinet whose relative humidity and water temperature is controlled by computer, bending moment testing of mortar composite containing MP.

**Table-4:** The pH of MP-green cement and of reference cement, bending strength of MP-green cement mortar composite and of reference cement mortar composite at 7d, 28d, and 90d, and the types of cement and of mortar composite.

| Types of Cement | Chemical Properties | | Types of Mortar Composite | Mechanical Properties | | |
|---|---|---|---|---|---|---|
| | | | | Bending Strength (MPa) | | |
| | pH | | | 7th-d | 28th-d | 90th-d |
| SMP-GCI | 12,51 | | SC–MP6M | 6,44 | 6,87 | 6,2 |
| SMP-GCII | 12,50 | | SC–MP20M | 5,05 | 5,67 | 5,59 |
| SMP-GCIII | 12,49 | | SC–MP21M | 4,7 | 5,2 | 4,32 |
| SMP-GCIV | 12,46 | | SC–MP35M | 4,49 | 4,5 | 4,13 |
| CEM I 42.5N (Reference) | 12,72 | | CEMI42.5M | 5,37 | 6,25 | 5,39 |

**pH of Portland cement and of MP-green cement:** Table-4 states the pH of reference cement and of green cement containing marble particle. Since this study replaces MP with pure Portland cement, the green cements prepared to meet the 97%-pH of conventional Portland cement. As 6%-MP is replaced with pure cement, this new cement shows the 98.5% pH of Portland cement. The average loss on pH is only 3% in the pH of pure cement when the replacement ratio is increased from 6% to 35%. This means that the alkaline structure of MP-green cement proceeds to provide a protective thin layer for construction steel since the natural tendency of construction soft malleable steel is to undergo corrosion reaction which causes volume expansion and micron-level-fatigue in cement based material. This high alkalinity level of the MP-green cement, like pure Portland cement, covers on the steel with a thin oxide protective layer. This layer prevents metal atoms from corrosion volume expansion and fatigue, it reduces the corrosion rate in a negligible level, like 0.1(μm) per year. The destruction of protective layer occurs since the alkalinity of the MP-green cement is reduced with negative side effect. Additionally, the highest reduction of alkalinity is in SMP-GCIVwith decreasing ratio of 2.1% while the lowest reduction of alkalinity is in SMP-GCI with decreasing ratio of 1%. New findings also mark that the substitution effect of MP does not cause to break down the preventive pH alkalinity level of pure cement and of green cement (Figure-1 and Table-4).

**Bending strength of Portland cement mortar composite and of MP-green cement mortar composite, and new regression equations for estimating the bending strength from pH:** Table-4 presents the bending strength for mortar composite prepared with SMP-GC and/or reference cement at 7d, 28d, and 90d (Figure-2). Additionally, as explained scientific literature, strength growth of hydraulic binder composite depends on the fluctuation of varying chemical compound of cement paste, such as loss on ignition (LOI) and alkali. Figure-3 specifies a relationship between pH of MP-green cement and $7^{th}$-d bending strength of MP-green mortar composite.

Since this comprehensive study substitutes MP with Portland cement to mix the green mortar composite, this substitution leads to the reduction of 4% bending strength at 7d, except SC-MP6M. The SC-MP6M shows over 19% greater bending strength than that of CEMI42.5M at 7d. This growth means that the MP have effect on the mechanism of initial bending strength as by-product substitution activator. Plus, bending strength of SCM is placed in a relatively wide range of 4 to 6 (MPa) at 7d. This wide range points that high substitution ratio of MP for cement causes the reductionfor7th-d bending strength of hydraulic green cement mortar composite, nevertheless once again, the 6%-MP substitution shows the most pronounced enhancing effect on bending strength gain at 7d (Table-4). Moreover, Figure-3also reveals relationship between pH of MP-green cement and $7^{th}$-d bending strength for MP-green cement mortar composite. As the figure exhibits important relationship between pH of MP-green cement and 7th-d bending strength of MP-green mortar composite, an intelligent artificial neural system may estimate a specified bending strength by testing at least one of the pH of MP-green cement (Figure-3). However, the result supports previous studies when considering the changes of chemical composition at 7d, 28d, and 90d. Effect of admixture containing high calcium mono oxide on strength gain deals with fluctuation of some chemical compounds, like silicon oxide ($SiO_2$), sodium oxide ($Na_2O$), and alkali, as well as increasing of LOI. This knowledge also marks that more than 6% of admixture containing high calcium mono oxide, like marble particle, has positive effect on early bending strength gain of green mortar composite. Figure-4 unveils a relationship between pH of MP-green cement and $28^{th}$-d bending strength of MP-green cement mortar composite.

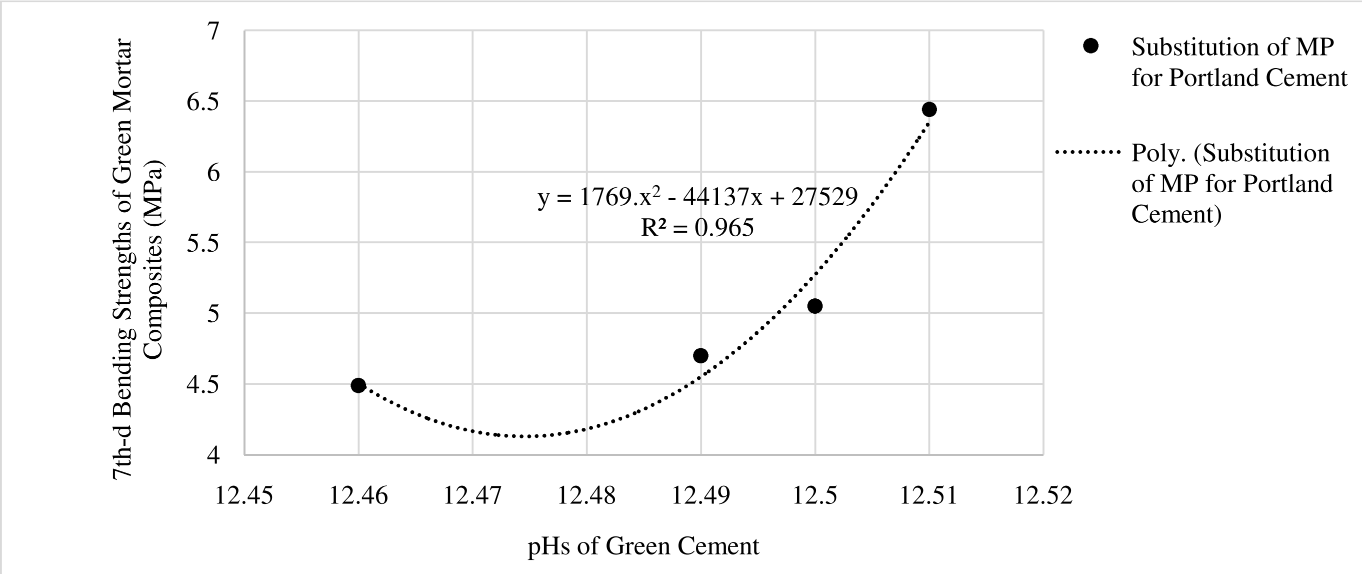


**Figure-3:** Relationship between pH of MP-green cement and $7^{th}$-d bending strength of MP-green cement mortar composite.

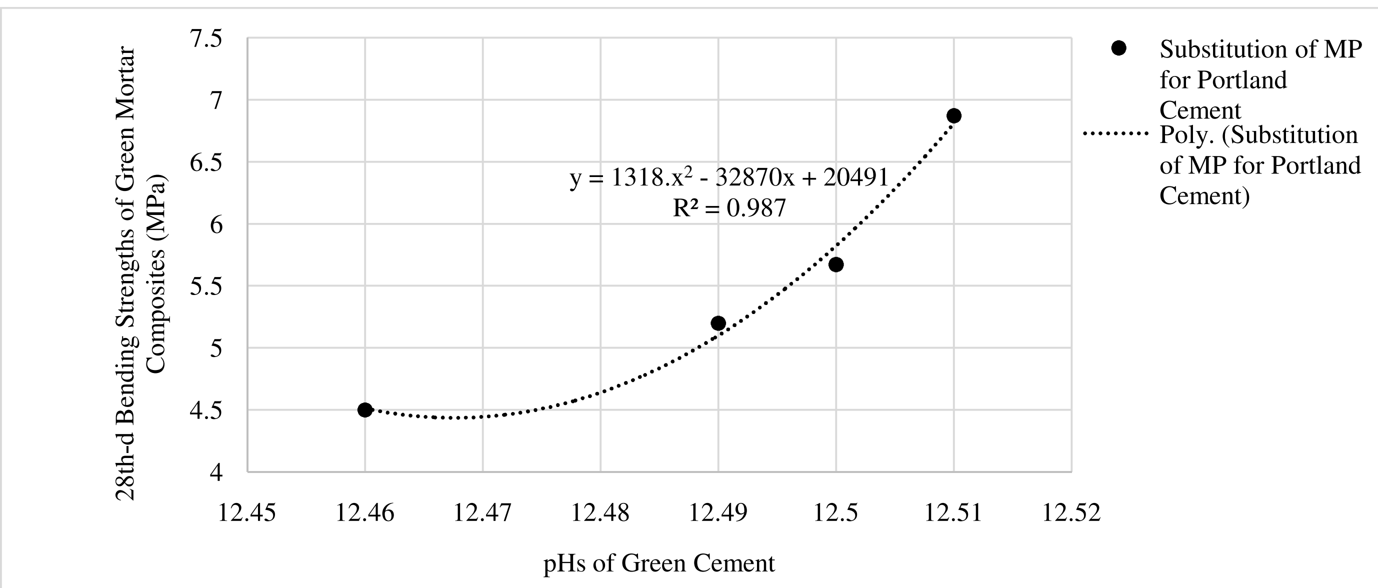


**Figure-4:** Relationship between pH of MP-green cement and $28^{th}$-d bending strength of MP-green cement mortar composite.

As this study substitutes MP with Portland cement, this substitution leads to the reduction of 12% for bending strength at 28d, except SC-MP6M. The SC-MP6M has over 9% greater $28^{th}$-d bending strength than that of CEMI42.5M. Plus, bending strength of SCM composite is located in a relatively wide range of 4 to over 6.5 (MPa) at 28d. Once again, this wide range indicates that high substitution ratio of MP for cement causes the reduction for 28th-d bending strength of hydraulic green cement mortar composite. The result also reveals that the 6%-MP substitution shows a pronounced enhancing effect on bending strength gain at 28d (Table-4). Moreover, Figure-4 shows a meaningful relationship for estimating of 28th-d bending strength of green mortar composite from pH of MP-green cement. As the figure exhibits influential relationship between pH of MP-green cement and 28th-d bending strength of MP-green cement mortar composite, an intelligent artificial neural system may estimate a specified bending strength by testing at least one of the pH of MP-green cement (Figure-4). However, the result fortifies previous studies when considering the changes of chemical composition at 7d and 28d and 90d. The chemical composition change of cement paste explains the mechanism for admixture containing high calcium mono oxide, like marble particle. Blending of high calcium mono oxide-based admixture provides the growth for the bending strength in mortar after 28d since it activates hydrations of calcium-based compound in cement paste. Figure-5 reveals a significant relationship between pH of MP-green cement and $90^{th}$-d bending strength for MP-green cement-mortar composite.

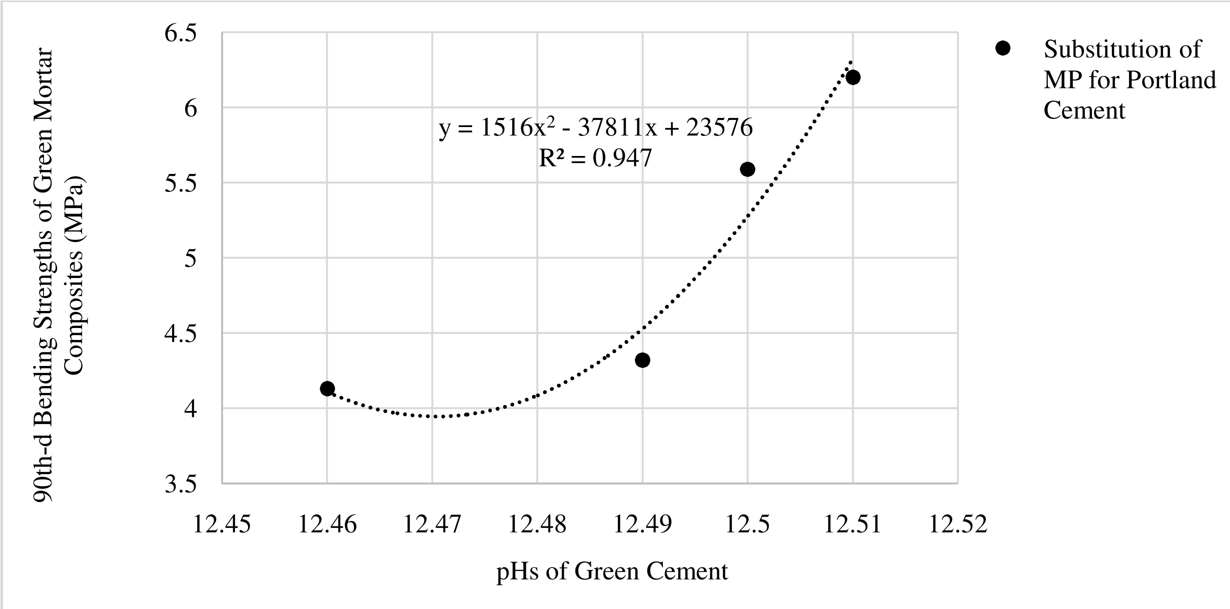


**Figure-5:** Relationship between pH of MP-green cement and 90th-d bending strength of MP-green cement mortar composite.

As MP is substituted for Portland cement, this substitution creates the reduction of 6% for bending strength at 90d, except SC-MP6M. This SC-MP6M presents over 15% greater $90^{th}$-d bending strength than that of CEMI42.5M. In addition, average of 90th-d bending strength for SCM composite is located in a relatively wide range of 4 to over 6 (MPa). This wide range points that the low substitution of MP provides strength gain for hydraulic cement at later age, like at 7d and 28d. The result also points that high substitution ratio of MP for cement causes the reduction for $90^{th}$-d bending strength of SMP-GC mortar composite; nevertheless, the 6%-MP substitution shows the pronounced enhancing effect on bending strength gain at 90d (Table-4).

Moreover, Figure-5 shows the strongest relationship for estimating of 90th-d bending strength of green mortar composite from pH of MP-green cement. As the figure exhibits significant relationship between pH of MP-green cement and 90th–d bending strength of MP-green cement mortar composite, an intelligent artificial neural system may use it to estimate a specified bending strength by testing at least one of the pH of MP-green cement (Figure-5).

## Conclusion

This comprehensive non–budget research presents new regression equations to estimate bending strength gain of MP-green cement mortar composite from pH of MP-green cement. The pH of MP does not reduce the alkalinity level of conventional Portland cement. Furthermore, the use of MP as substitution constituent provides sustainability for pure Portland cement and saves the future of cement manufacturing. Economic and environmental benefits by reducing $CO_2$ emissions are as well known in literature. However, the experimented properties verify that the MP enhances the bending strength gain of green mortar composite as well as pH of green cement. MP-green cement mixture prescription prepared with MP and pure Portland cement meets the required bending strength gain of standard mortar as well as pH of cement for saving the inset metal from rust in reinforced concrete structure. Moreover, the result presents some substantial relationships between bending strength gain of MP-green cement mortar composite and pH of MP-green cement to estimate bending strength gain from pH of MP-green cement. Additionally, MP can be described as initial bending strength gain accelerator according to the result. In view of conclusion, the MP can be used as prepared in this research for the large-scale productions of substituted-green cement and of MP-green cement mortar composite. Moreover, these significant regression equations presented in the article could be used by the construction industry and the non-destructive testing industry.

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