OPTIMIZATIONOF MECHANICALPROPERTIES OF FAIR-FACED CONCRETE: ROLE OF WHITE PORTLAND CEMENT

[1]JIHAD MIAH, [2]MOHAMMAD SHAMIM MIAH, [3]SUVASH CHANDRA PAUL, [4]MAMUN HOSSAIN

[1,4]Department of Civil Engineering, University of Asia Pacific (UAP), Dhaka-1215, Bangladesh.
[2]Faculty of Civil Engineering, Dresden University of Technology - TU Dresden, 01187 Dresden, Germany.
[3]Discipline of Civil Engineering, Monash University Malaysia, Malaysia.
E- Mail: [1]jihad.miah@uap-bd.edu, [2]Mohammad_Shamim.Miah@tu-dresden.de, [3]suvash.chandra@monash.edu, [4]omega.mamun@gmail.com

Abstract - The application of Fair-Faced Concrete (FFC) receiving more and more attention in the architectural design of modern buildings due to its aesthetic qualities, infinite range of color tones, natural surface texture, lowering cost by avoiding plastering or veneered, and cladding as well as makes structures more sustainable and easier to recycle.Since the demand of this concrete is increasing day by day, hence it is essential to have exhaustive knowledge about the mechanical properties of FFC. To this purpose, an extensive experimental campaign has been conducted to investigate the mechanical properties as well as aesthetic view of FFC and Normal Concrete (NC) made with burnt clay brick and natural stone aggregates. The FFC was made with a combination of White Portland Cement (WPC) and Ordinary Portland Cement (OPC). In order to optimize the mechanical properties of FFC, five different replacement percentage of OPC by WPC (0, 25, 50, 75, and 100% for brick aggregate and 0, 30, 60, 80, and 100% for stone aggregate) have been investigated.Additionally, an unconstrained nonlinear optimization scheme known as Nelder-Mead Simplex Method was employed for modeling stress-strain behavior of FFC and NC. The experimental results have clearly shown that the compressive strength and modulus of elasticity of FFC is higher than NC (0% WPC). It has been found that up to 50% WPC for brick aggregate and 60% WPC for stone aggregate could be suitably used to obtain maximum mechanical properties of FFC. Furthermore, it has been observed that the outer surface of FFC is smoother, good natural texture of the surface,impressive in color, and brighter than NC.Moreover, a quite good agreement between the measured and the predicted stress-strain curves was observed.

Index terms - Fair-faced concrete, White Portland cement, Aesthetical look, Compressive strength, Stress-strain relation, Optimization.

I. INTRODUCTION

There is a growing trend toward the use of Fair-Faced Concrete (FFC) in Europe and America as well as in Bangladesh due to its outstanding aesthetic look, good surface texture, cost saving due to no decoration process as plastering, and coating after concrete formed, long-term durability under the most severe environmental conditions as well as for its superior mechanical properties [1-3]. For its attractive properties, FFC has been used extensively from the twentieth century in the construction of precast panels, private and public buildings, works of art, bridges, and parking structures, basement walls, stairwells, retaining walls, facades, etc. The use of FFC is very common in the Europe and America. Also in Bangladesh, it is a recent trend to use FFC, however, it not yet commercially taken so important due to the lack of research study compared to normal concrete (NC).

In the existing literature, a detailed study has been conducted by PERI 2002 [4] and a guideline has been proposed for FFC. Additionally, Doka 2013 [5] has reported a list of successfully completed projects in a different location in Europe. Also, it has been reported that the texture can be formed as per the client's/designer's choice.
Indeed, a successful finishing and good aesthetic appearance of FFC depends on several factors, such as the quality of the concrete mix and additives, water to cement ratio, tightness of the formwork, quality of compaction or vibration, and the weather condition in the casting place as well as curing condition. Furthermore, the color of the FFC is affected by the selection of the cement, aggregate type (both coarse and fine aggregates), chemical admixture used in the mix. In order to achieve as homogeneous a color as possible, the mixture (cement, both fine and coarse aggregates) and the water quality should be as consistent as possible. Hence, all materials such as cement and aggregates should come from the same site or factory.

In the past, an enormous number of research works have been focused on the properties of OPC concrete, since it is the most widely used binding material for concrete worldwide. The scanty results are available in the literature on the FFC made with White Portland Cement (WPC). Despite that, some investigations (Sun et al. 2012, Schlaich and Zareef 2008, Li et al. 2012, PERI 2002,Doka 2013 and Netoet al. 2016) deal with FFC, there still seems to be a dearth of published data on it, especially in Bangladesh. The lack of published test results, limited information, and knowledge, as well as the presence of some evidence of the good performance of the FFC, provides the motivation for this research work.
Within this framework, the first objective of this research project was to investigate the optimum

amount of WPC to be used to obtain good aesthetical outlook and maximum mechanical properties of FFC. This preliminary research study has been conducted (Islam et al. 2016 and Shovon et al. 2016) at the University of Asia Pacific (UAP), Dhaka, Bangladesh. While the second important goal of this research project was to develop an unconstrained nonlinear optimization scheme known as Nelder-Mead Simplex Method [9] to evaluate the actual stress-strain behavior of the FFC and NC. In this model, the experimentally measured data were used for optimization of the stress-strain curve.

II. EXPERIMENTAL METHOD

In order to study the optimization of the mechanical properties of FFC role played by WPC, five concretes made with differentreplacement percentage of OPC by WPC (0, 25, 50, 75, and 100% for brick aggregate and 0, 30, 60, 80, and 100% for stone aggregate) have been investigated. The same mix design was used for all concretes; the only difference is the percentage of WPC. The control concrete (FFCB0/FFCS0, B indicates brick and S indicates stone aggregate) was made with 100% OPC and the other four concretes, named as, FFCB25/FFCS30,FFCB50/FFCS60, FFCB75/FFCS80, and FFCB100/FFCS100 were made with replacement percentage of OPC by WPC of 25/30%, 50/60%, 75/80%, and 100%, respectively, see Table 1.

In this experimental campaign, the first class burnt clay bricks (commonly used in Bangladesh) and locally available natural stones were used as coarse aggregates, while natural river sand (locally called Sylhet sand, which fineness modulus and specific gravity were 2.68 and 2.56, respectively) was used as a fine aggregate. The maximum size of coarse aggregate was 20 mm and the grading of the coarse aggregates was controlled as per ASTM C33 [10]. The volumetric mix ratio (commonly practiced mix ratio used in Bangladesh) of 1:1:2 (cement: fine aggregate: coarse aggregate) and water to cement ratio (by weight) of 0.40 were used for both FFC and NC. Total mixing time of fresh concrete was controlled at 5.5 minutes. After completion of mixing, the cylindrical (100 mm in diameter and 200 mm long) concrete specimens were made and demolded after 24 hours of casting. Then all the concrete specimens were cured under water up to the day of the tests (i.e., 28 days).

Within the scope of this study, a total of 300 concrete cylindrical specimens (150 specimens per mix (1:1:2 and 1:1.5:3) and 15 specimens for each case)has been designed and tested. Due to thepage limitation, only the results of mix 1:1:2 are presented here in this paper. While the part of the results of mix 1:1.5:3 have already been published by Miah et al. 2017 [11]. The summary of the experimental program for the compressive strength is presented in Table 1.

Table.1Global view of the experimental program (Note: FFCB and FFCS indicate the FFC made with brick, B,and stone, S, aggregates, respectively)

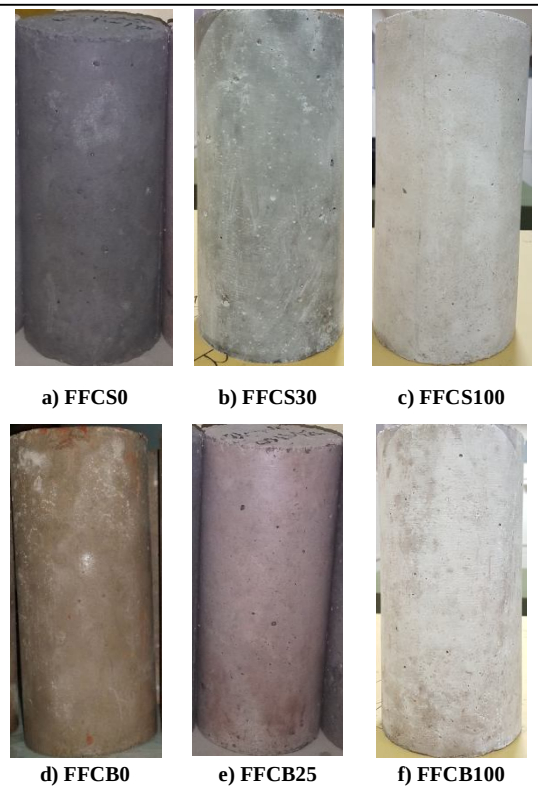
	Mix 1:1:2		Mix 1:1.5:3	
Case	WPC (%)	OPC (%)	WPC (%)	OPC (%)
NCB/FFCB0	0	100	0	100
FFCB25	25	75	25	75
FFCB50	50	50	50	50
FFCB75	75	25	75	25
FFCB100	100	0	100	0
NCS/FFCS0	0	100	0	100
FFCS30	30	70	30	70
FFCS60	60	40	60	40
FFCS80	80	20	80	20
FFCS100	100	0	100	0

The compressive strength tests were performed at 28 days as per ASTM C39 [12] by using Universal Testing Machine (UTM). During compression test, the deformation of concrete specimens was measured by a strain measurement setup with two dial gauges. The gauge length was 100 mm in the central part of the specimen. After crashing, the failure surfaces of concrete were also observed carefully. The modulus of elasticity of concrete specimens was calculated from the stress-strain curves. The stress of concrete at strain level 0.002 was used to determine the modulus of elasticity of concrete.

III. RESULTS AND DISCUSSION

Aesthetical Outlook:

The color of the concrete structure is a key design feature of any face concrete surface, which could influence depending on the type of cement, aggregates, selecting chemical admixture (water reducing admixture), and water quality used in the mix. Indeed, white cement is a key ingredient in architectural and decorative concrete.This evidence can be clearly seen in Figure 1;the brightness of the concrete is increased with the increasing percentage of WPC. While the concrete made with stone aggregate is brighter than the concrete made with brick aggregates, see Figure 1. Also, it can be seen that the outer surface of the FFC specimens are smoother (i.e. fewer voids and less water absorption capacity, means, less chance for corrosion), good natural texture of the surface, and uniform colorthan normal concrete (FFC), which is in good agreement with the existing literature results [1-5].



a) FFCS0 b) FFCS30 c) FFCS100

d) FFCB0 e) FFCB25 f) FFCB100

Figure 1: Image of the fair-faced concretesmade with different percentage of WPC of stone (a-c) and brick (d-f) aggregates.

As a result, FFC could be more durable than NC because of the extra protection from the environmental actions at all seasons such as sand blown by the wind, washing of acid rain (i.e. less chances of erosion due to less pH penetration), exposure to blazing sunlight, salt-fog, carbonization, and freeze-thaw. Even if in worst weather condition, the FFC need less effort and easy to remove any scruffy form the surface of the concrete without affecting the original surface of the FFC, thus contributing to improve its durability.

Indeed, the initial cost of fair-faced concrete could be higher than conventional concrete, but if theright controls are used, FFC will offer much lower maintenance cost during the entire life of the structures. As an example, since the outer surface of the FFC specimens are smoother, i.e. fewer voids and less water absorption capacity, hence, the structural elements may not need the extra cost for paint, decoration process as plastering, putty, and coating and chemical protections as well as the extra cost for repairing the plastering and painting which could decrease the total life-cycle cost of the structures.

Additionally, reducing the amount of construction waste by avoiding plastering and painting, which conducive to the protected environment. And also FFC avoids the plaster cracking, blistering, and hollowing, resulting in reducing the structural construction leakage, cracks on the floor, which could decrease the durability of the structures. As a result, it could be indirectly said that by using FFC has an environmental benefit than NC.

Mechanical Properties:

A total of 150 concrete cylindrical specimens (100 mm in diameter and 200 mm long) were cast and tested at 28 days according to ASTM C39 [12]. The stress-strain curves of FCC made with brick aggregate containing 25% of WPC is shown in Figures 2. Due to the page limitation, only 15 specimens are shown in Figure 2 since a quite good repeatability of the tests were observed from one case to another. Almost no significant change in the development of stress-strain has been observed from one test to another.

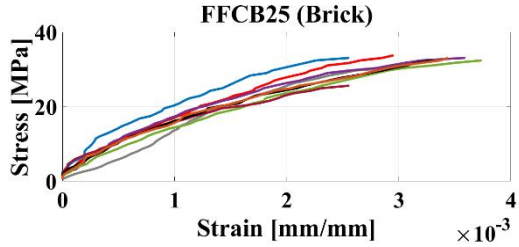


Figure 2: Stress-strain curve of FFCB made with 25% of WPC.

However, in order to deeper analyze the effect of replacement of OPC by WPC on the compressive strength of concrete, Figure 3 has been drawn for stone and brick aggregates based on the average compressive strength form 15 specimens of each case.

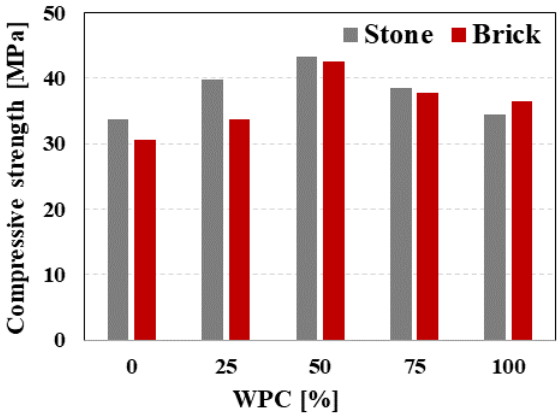


Figure 3: Theaverage compressive strength of concrete made with stone and brick aggregates as a function of thedifferent percentage of WPC.

It can be clearly seen that the compressive strength of FFC is higher than the NC (0% WPC), especially the concrete made with stone aggregates. As the percentage of WPC in the mixture increased, the compressive strength increased up to a certain levelfor brick and stone aggregates, after that the strength decreased. These results are in good agreement with the development of the stress-strain curves, which is not presented in this paper. The maximum compressive strength of FFC made with

brick and stone aggregates are, respectively, 42.5 MPa (6165 psi) for 50% WPC and 43.3 MPa (6300 psi) for 60% WPC. While the maximum compressive strength of NC (0% WPC) made with brick and stone aggregates are, respectively, 30.5 MPa (4420 psi) and 33.7 MPa (4886 psi). It is important to notice that none of the FFC samples made with stone and brick aggregates exhibited lower strength than NC of same aggregates, see Figure 3.

In order to understand better the mechanical properties e.g. compressive strength of concrete, it is worthwhile to study the variation in compressive strength. Therefore, a normalization with respect to reference concrete strength, i.e., $f_c'^{WPC(\%)} / f_c'^{100\%OPC}$ is performed for concrete containing brick and stone aggregates. The representation of the normalized compressive strength is shown in Figure 4.

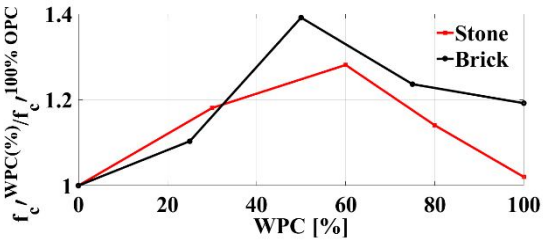


Figure 4: Normalized compressive strength as a function of the amount of WPC concretes made with brick and stone aggregates.

The experimental results showed that the compressive strength of FFCB is about 30% (for 60% WPC) higher than the NC for stone aggregates and about 40% (for 50% WPC) higher for brick aggregates, see Figure 4. This behavior could be due to the higher percentage of the total silicates (C_3S + C_2S) and the higher percentage of dicalcium silicate (C_2S), leading to more C-S-H and less calcium hydroxide in the WPC concrete [13]. From this study, it has been found that up to 50% WPC for brick aggregate and 60% WPC for stone aggregate could be suitably used to obtain maximum mechanical properties of FFC.

The normalized modulus of elasticity of concrete is plotted in Figure 5 as a function of the amount of WPC concretes made with brick and stone aggregates. It is worth noted that FFC concrete has a higher modulus of elasticity than NC, especially concrete made with stone aggregate. The modulus of elasticity of FFC is about more than 5 times (for 30% WPC) higher than the NC for stone aggregates and about more than 2 times (for 100% WPC) higher for brick aggregates, see Figure 5. This behavior is in good agreement with the stress-strain relation and the magnitude of compressive strength. The modulus of elasticity of FFC made with stone aggregate is higher than the brick aggregate, which could be due to the formation of a stronger interfacial transition zone (ITZ) around stone aggregates than brick aggregates as well as higher hardness properties of stone aggregates than brick aggregates.

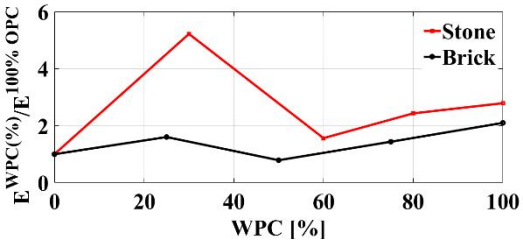


Figure 5: Normalized modulus of elasticity as a function of the amount of WPC concretes made with brick and stone aggregates.

Optimization of Stress-Strain Modeling:

An unconstrained nonlinear optimization scheme known as Nelder-Mead Simplex Method [9] was employed for modeling the stress-strain behavior of FFC and NC, aimed at evaluating the actual stress-strain behavior of the FFC and NC. In this model, the experimentally measured data were used for optimization of the stress-strain curve. The predicted optimization results were compared against the experimental data of stress-strain curve. In addition, the predicted optimized results also compared with Tsai 1988 [14] and Collins 1993 [15] models. Herein, a nonlinear optimization so-called the multidimensional unconstrained nonlinear minimization (Nelder-Mead) is employed for the optimization. The efficacy of the aforementioned optimization has been verified by several researchers (Lagarias, 1998 [9]; Miah, 2015 [16]). The basic principle of the optimization is given below by

$$\min_x y = f(x) \qquad (1)$$

where $f(x)$: $\mathbb{R}^n \rightarrow \mathbb{R}$ is the objective function that needs to be minimized for the variable x. Also, the function f is widely known as cost function.And, the cost functions of this study has been defined as follows for Collins (1993) via Eq. (2) and for Tsai (1988) by Eq. (3).

$$\sigma_c^{opt} = \frac{\sigma_c \times \alpha \times \varepsilon_{ini}}{\varepsilon'_{max} \times (\alpha - 1) + (\varepsilon_{ini} / \varepsilon'_{max})^{\alpha k}} \qquad (2)$$

where $\varepsilon'_{max} = \frac{\alpha \times \sigma'_c}{(\alpha - 1) \times E_c}$; $E_c = 40000\sqrt{\sigma'_c} + 1000000$.

$$\sigma_t^{opt} = \frac{mx}{1 + \left(m - \frac{n}{n-1}\right)x + \frac{x^n}{n-1}} \times \sigma'_c \qquad (3)$$

where m, n are the scaling parameters. Additionally, a fitness function is also essential that is given by

$$\text{Residual} = \frac{\left\| \sigma^{true} - \sigma_c^{opt} or \sigma_t^{opt} \right\|}{\left\| \sigma^{true} \right\|} \qquad (4)$$

where σ^{true} represents the experimentally measured data, σ_c^{opt} indicates the optimized data by Collins model, σ_t^{opt}represents the optimized data via Tsai model.

Predicted optimized and experimentally measured stress-strain curves of NC and FFC made with brick aggregates are presented in Figure 6.Due to the page limitation, the model of stone aggregate is not shown

here in this paper. It can be seen that the predicted optimized stress-strain curves are in very good agreement with the experimentally measured stress-strain curve for both NC and FFC made with brick aggregate. Similar behavior was found for the stone aggregate model which is not presented here.

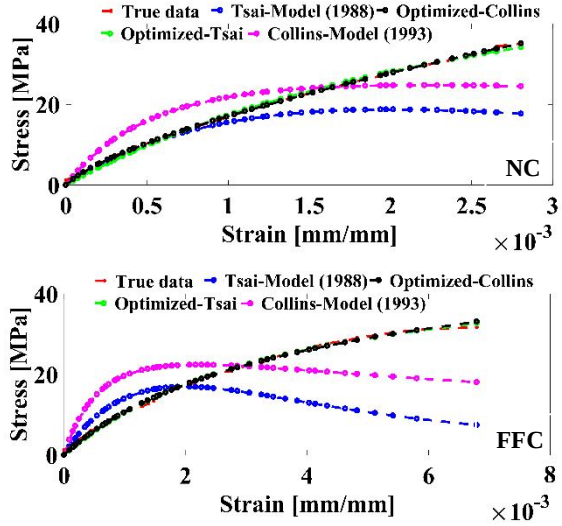


Figure 6: Predicted optimized, Tsai 1988 [14], Collins 1993 [15], and experimentally measured true stress-strain curves of normal concrete (NC or FFC0) and FFC (25% WPC) made with brick aggregate.

It seems that the predicted results are in good agreement with Tsai model than Collins model, especially at the beginning of the trend. Almost linear increment has been observed for both optimized and the experimental data, while an increasing trend up to a certain level and then almost stabilized for both Tsai and Collins models were found. However, more data are needed to perform the regression analysis in order to propose a generic model for NC and FFC made with different aggregates.

CONCLUSION

The main findings regarding the influence of WPC on the mechanical properties and aestheticoutlook of FFC can be summarized as follows:

- The outer surface of the FFC specimens are smoother, good natural texture of the surface, uniform color, and brighter than NC, resulting inless pores in the surface may lead to increase durability.
- Due to its smooth surface of FFC, the structural elements may not need extra cost for decoration process as plastering, putty, and coating, which could decrease the total life-cycle cost of the structures.
- The experimental test results have shown that the compressive strength and modulus of elasticity of FFC is higher than NC (0% WPC) due to higher percentage of C_2S and total silicate (C_3S + C_2S) of WPC than NC [13].
- It has been found that up to 50% WPC for brick aggregate and 60% WPC for stone aggregate could be suitably used to obtain maximum mechanical properties of FFC.
- Even though the data are limited to propose a generic model for NC and FFC made with different aggregates, a very good agreement between the measured and the predicted stress-strain curves was observed.

ACKNOWLEDGMENT

The authors would like to express gratitude to the Engineering Materials Laboratory for experimental support and for the financial assistance of the Department of Civil Engineering, University of Asia Pacific, Dhaka, Bangladesh to carry out this study.

REFERENCES

[1] Y.Sun, Y.Wang, L.Cheng, and X.Zhu,"Construction technology and benefit analysis of fair-faced concrete in high-rise building."Advanced Materials Research. ISSN: 1662-8985; vols. 446-449, pp. 3690-93, 2012.

[2] M.Schlaich, and M E.Zareef,Infra-lightweight concrete. Tailor Made Concrete Structures – Walraven&Stoelhorst (eds), London, ISBN 978-0-415-47535-8; pp. 707-13,2008.

[3] X.Li, X.Ma, and X.Zhang,"Experimental Study on Mix Proportion of Fair-faced Concrete,"Advanced Materials Research, ISSN: 1662-8985; vols. 450-451, pp. 383-386, 2012.

[4] PERI. Reference Booklet Fair-face Concrete, PERI, Issued 10/2002, PERI GmbH Postfach 12 64, 89259 Weißenhorn, Germany,pp. 1–88, 2002.

[5] Doka G. Fair-faced concrete, Doka GmbH, Josef UmdaschPlatz 1, 3300 Amstetten, Austria, 2013. www.doka.com, Art. no. 931176002//05/2013en-GB.

[6] E.Neto,S.Magina, A.Camões, A.Begonha, D. V.Evtuguin, and P.Cachim,"Characterization of concrete surface in relation to graffiti protection coatings,"CBM, vol. 102,pp. 435–444, 2016.

[7] A. T. M. T.Islam, M.Mohibullah, and M.Rahaman,"Evaluation of Mechanical Properties of Fair-Faced Concrete: Bangladesh Perspective – I,Undergraduate Thesis, University of Asia Pacific, Dhaka, Bangladesh, 2016.

[8] K. M. M. I. Shovon, M. Akon, and S. Islam,"Evaluation of Mechanical Properties of Fair-Faced Concrete: Bangladesh Perspective – II, Undergraduate Thesis. University of Asia Pacific, Dhaka, Bangladesh, 2016.

[9] J. C.Lagarias, J. A.Reeds, M. H.Wright, and P. E.Wright,"Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions,"SIAM Journal on Optimization,vol. 9, no. 1,pp.112–47, 1998.

[10] ASTM International. ASTM Standard C33, Specification for Concrete Aggregates, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03

[11] M. S.Miah, M. J.Miah, M. M.Hossain, and S. C.Paul,"Preliminary Experimental Investigation on Influence of Cement Types on Fair-faced Concrete: Bangladesh Perspective," Proceedings of 14th Global Engineering and Technology Conference 29-30 December 2017, Bangladesh, ISBN: 978-1-925488-60-9

[12] ASTM International. ASTM Standard C39, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, West Conshohocken, PA, 2005.

[13] B. S.Hamad,"Investigations of Chemical and Physical Properties of White Cement Concrete,"AdvnCem Based Mater J ,vol. 2, pp. 161-167, 1995.

[14] W. T.Tsai, "Uniaxial Compressional Stress-Strain Relation of Concrete,"Jour. of Structural Engineering,vol. 14, no. 9, pp. 2133–2136, 1988. http://doi.org/10.1061/(ASCE)0733-9445(1988)114:9(2133)

[15] M. P.Collins, D.Mitchell, and J. G.Macgregor,"Structural Design Considerations for High-Strength Concrete,"Concrete International, American Concrete Institute, vol. 15, no. 5, ISSN: 0162=4075; pp. 27-34, May 1993.

[16] M. S.Miah, E. N.Chatzi, V. K.Dertimanis, F.Weber,"Nonlinear modeling of a rotational MR damper via an enhanced Bouc–Wen mode,". Smart Mat. and Str,,vol. 24, no. 10: 105020, 2015.

★★★