International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Determination of Optimized Flexural and Split Tensile Strengths of PSA-MSA-Cement Concrete (PMCC) Using Scheffe's (6, 2) Model

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ABSTRACT

The increasing rise of cost of cement has given room for agitation for incorporation of innovative binders to partially replace cement in the cement production. Periwinkle Shells Ash (PSA) and Mussel Shells Ash (MSA) are important environmentally friendly innovative binders capable of partially replacing cement with promising design strengths. This research work is aimed at applying Scheffe's (6, 2) Model to optimize the Flexural Strength and Split Tensile Strength of PMCC. PMCC is a concrete mixture where cement is partially replaced with PSA and MSA. In this work, only 60 per cent (%) of cement is replaced. Using, Scheffe's (6, 2) simplex model, the Flexural and Split Tensile Strengths of PMCC were obtained for different twenty- one mix proportions at the initial experimental test points[IETP]. The mix proportion of PSA- MSA was in 50% - 50% ratio. Twenty- one control experiments were also carried out and the design strengths at the experimental (control) test points [ECTP] determined. By using the Student's t-test statistics, the adequacy of the model was validated .The 28th day optimum (Maximum) design strengths of PMCC are 8.98 MPa for the flexural strength and 2.74 MPa for the split tensile strength. Thus, the maximum PMCC design strengths based on Scheffe's models can adequately sustain the construction of both light-weight and heavy-weight structures such as construction of walkways, pavement slabs ,building , bridges etc, still maintaining the best possible economic, safety and environmentally friendly advantages.

Keywords: PMCC, PSA, MSA, Scheffe's (6, 2) Model, Flexural Strength, Split Tensile Strength, Mixture Design, Mix Ratio, Polynomial/Mathematical/Regression Model.

1.INTRODUCTION

Cement is a very important construction material, without it, majority of construction works would not have been possible. It is one of the major component of concrete, another construction material, which according to Ishaya and others (2016), is described as the widely used construction material globally. The history of cement materials, according to Shetty (2006), is as old as the history of engineering construction. From past experience in the construction industries, Cement Cost Factor (CCF) constitutes almost 50 per cent of the Overall Building Cost Factor (OBCF). As the cost of cement has been on the increase nowadays, the researchers across the academic and construction sectors have been attracted to brainstorm on the workable ways of partially replacing the cement with less expensive binders so that the low income earners in the society would build their own houses. The suggestion would be to incorporate the use of these innovative binders to partially replace the cement conventional main raw materials like limestone in the cement manufacturing industries so that the cost of production of cement would be drastically reduced. In other to demonstrate the efficacy of this idea, PSA and MSA binders are incorporated in the PMCC mixture so that the design strengths (flexural and split tensile strenghts) could be ascertained for further consultations.

As we all know, concrete as a homogeneous mixture of cement, sand, gravel and water. It is very strong in carrying compressive forces and as result, is gaining increasing importance as building materials throughout the world (Syal and Goel, 2007). According to Oyenuga (2008), concrete is a composite inert material comprising of a binder course (cement), mineral filter or aggregates and water. Furthermore, concrete, according to Neville (1990), plays an important part in all building structures owing to its numerous advantages which ranges from low built in fire resistance, high compressive strength to low maintenance. According to Shetty (2006), concrete, especially plain type possesses a very low tensile strength, limited ductility and little resistance to cracking. This has resulted to continuous search for upgrading the properties of concrete in the tune of economic realities, especially through consideration of partial replacement of its cement component with less expensive binders. Recent researches have shown that both PSA and MSA as less expensive and environmentally friendly binders contain very high quantity of calcium carbonate when calcinated at suitable temperatures and can partially replace cement with utmost promising results in terms of high quality concrete production. The use of these two binders, PSA and MSA can improve both the economic and safety criterion of the cement and henceforth the PMCC mixture due to the outstanding qualities and inherent properties both possess. For this present work, special properties of PMCC under investigation are the flexural strength and the split tensile strength. By definition, flexural strength (usually described as modulus of rupture) is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. It is also defined as the maximum bending stress that can be applied to the material before it yields. The flexural strength test is an important tool for engineers and contractors to evaluate the overall strength and toughness of concrete. The test provides valuable information about the quality and consistency of the concrete mix, and helps to ensure that the concrete meets the required standards and specifications for a particular application. The results of the flexural strength test can also be used to determine the most appropriate type of concrete for a particular project, and to ensure that the concrete will perform as expected over its expected service life. On the other hand, splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete. It is generally carried out to obtain the tensile strength of concrete, and the stress field in the tests is actually a biaxial stress field with compressive stress three times greater than the tensile stress. The tensile splitting strength test is a crucial evaluation method for determining the tensile strength of concrete. Concrete is brittle and weak in tension, making it susceptible to cracking. The splitting tensile strength test is an indirect method of testing the tensile strength of concrete. It involves splitting a cylinder across its vertical diameter to measure the force required to do so. It is generally greater than direct tensile strength and lower than flexural strength.

As in the case of the previous work of Nwachukwu and others (2022i), greater efficiency for the mixture design of concrete made with cement that is partially replaced with PSA and MSA can be carried out through optimization. An optimization problem is one requiring the determination of the optimal (maximum or minimum) value of a given function, called the objective function, subject to a set of stated restrictions, or constraints placed on the variables concerned. Specifically, optimization of the concrete mixture design is a process of search for a mixture for which the sum of the costs of the ingredients is lowest, yet satisfying the required performance of concrete, such as workability, strength and durability. According to Shacklock (1974), one of the objectives of mix design is to determine the most appropriate proportions in which to use the constituent materials to meet the needs of construction work. Another definition by Jackson and Dhir (1996) noted concrete mix design as the procedure which, for any given set of condition, the proportions of the constituent materials are chosen so as to produce a concrete with all the required properties for the minimum cost. Consequently, the cost of any concrete thus includes, in addition to that of the materials themselves, the cost of the mix design, of batching, mixing, placing the concrete and of the site supervision as well as the mix design methods. Thus, the empirical procedures proposed by Hughes (1971), ACI- 211(1994) and DOE (1988) seems to be more complex and time consuming as they involve a lot of trial mixes and complex statistical calculations before the desired strength of the concrete can be reached. Therefore, optimization of the concrete mixture design remains the fastest method, best option, most convenient and the most efficient way of selecting concrete mix proportions for better efficiency and better performance of concrete when compared with usual empirical methods listed above. An example of optimization model is Scheffe's Optimization Model which could be in the form of Scheffe's Second Degree Model or Scheffe's Third Degree Model. Thus, in this present study, Scheffe's Second Degree Model for six components mixtures (namely, water, cement, PSA, MSA, fine aggregate and coarse aggregate) will be in focus.

This present study examines the application of Scheffe's Second Degree Model for six component mixture, Scheffe's (6, 2) in the optimization of the Flexural Strength and Split Tensile Strength of PMCC. Of all the researches related to the subject matter that have been carried out, none has been able to address it sufficiently. For example, on Periwinkle Shells (PS), PSA, Mussel Shells (MS) and MSA other Mollusks Shells works, Agbede and Manasseh (2009) investigated the suitability of periwinkle shell as partial replacement for river gravel in concrete. Bamigboye and others (2021) investigated the prospects and challenges pertaining to the sustainable use of seashells as binder in concrete production. Peceno and others (2019) investigated the substitution of coarse aggregates with mollusc-shells waste in acoustic-absorbing concrete. The works of Alla and Asadi (2021) focused on the experimental investigation of snail shell based cement mortar. Adewuyi and others (2015) examined the utilization of mollusc shells for concrete production for sustainable environment. Mohammad and other (2017) carried out a review on seashells ash as partial cement replacement. Gonzalez and others (2015) investigated the effects of seashell aggregates in concrete properties. Oyedepoo (2016) examined the evaluation of the properties of lightweight concrete using periwinkle shells as a partial replacement for coarse aggregate. Gigante and others (2020) investigated the evaluation of mussel shells powder as reinforcement for PLA-based biocomposites. Melo and others (2019) carried out an extensive work on high- density polyethylene/mollusc shell –waste composites, effects of particle size and coupling agent on morphology, mechanical and thermal properties. Elamah and others (2021) accessed the strength characterization of periwinkle polymer concrete. Soneye and others (2016) carried out a research on the study of periwinkle shells as fine and course aggregate in concrete works. Abdullah and Sara (2015) carried out an assessment of periwinkle shells ash as composite materials for particle board production . Offiong and Akpan (2017) carried out an assessment of physico-chemical properties of periwinkle shell ash as partial replacement for cement in concrete. On works done on Flexural Strength (FS) and Split Tensile Strength (STS) as well as on the application of optimization in concrete mixtures, recent works have shown that many works have been done on FS and STS and many researchers have used Scheffe's method to carry out one form of optimization work or the other. For instance, Nwakonobi and Osadebe (2008) applied Scheffe's model to optimize the mix proportion of Clay- Rice Husk Cement Mixture for Animal Building. Egamana and Sule (2017) carried out an optimization work on the compressive strength of periwinkle shell aggregate concrete. Ezeh and Ibearugbulem (2009) made use of Scheffe's model to optimize the compressive cube strength of River Stone Aggregate Concrete. Scheffe's model was used by Ezeh and others (2010a) to optimize the compressive strength of cement- sawdust Ash Sandcrete Block. Furthermore, Ezeh and others (2010b) optimized the aggregate composition of laterite/ sand hollow block using Scheffe's simplex method. The works of Ibearugbulem (2006) and Okere (2006) were based on the application of Scheffe' model in the optimization of compressive strength of Perwinkle Shell- Granite Aggregate Concrete and optimization of the Modulus of Rupture of Concrete respectively. Obam (2009) developed and applied mathematical model to optimize the strength of concrete using shear modulus of Rice Husk Ash as a case study. The work of Obam (2006) was based on four component mixtures, that is Scheffe's (4,2) and Scheffe's (4,3) where comparison was made between second degree model and third degree model. Nwachukwu and others (2017) developed and applied Scheffe's Second Degree Polynomial model to optimize the compressive strength of Glass Fibre Reinforced Concrete (GFRC). Again, Nwachukwu and others (2022a) developed and used Scheffe's Third Degree Polynomial model, Scheffe's

(5,3) to optimize the compressive strength of GFRC where they compared the results with their previous work, Nwachukwu and others (2017). Nwachukwu and others (2022c) used Scheffe's (5,2) optimization model to optimize the compressive strength of Polypropylene Fibre Reinforced Concrete (PFRC). Nwachukwu and others (2022d) applied Scheffe's (5,2) mathematical model to optimize the compressive strength of Nylon Fibre Reinforced Concrete (NFRC). Nwachukwu and others (2022b) used Scheffe's (5,2) mathematical model to optimize the compressive strength of Steel Fibre Reinforced Concrete (SFRC). Furthermore, Nwachukwu and others (2022e) used Scheffe's Third Degree Regression model, Scheffe's (5,3) to optimize the compressive strength of PFRC. Nwachukwu and others (2022f) applied Modified Scheffe's Third Degree Polynomial model to optimize the compressive strength of NFRC. Again, Nwachukwu and others (2022g) made use of Scheffe's Third Degree Model to optimize the compressive strength of SFRC. In what is termed as introduction of six component mixture and its Scheffe's formulation ,Nwachukwu and others (2022h) developed and use Scheffe's (6,2) Model to optimize the compressive strength of Hybrid- Polypropylene – Steel Fibre Reinforced Concrete (HPSFRC). Nwachukwu and others (2022 i) applied Scheffe's (6,2) model to optimize the Compressive Strength of Concrete Made With Partial Replacement Of Cement With Cassava Peel Ash (CPA) and Rice Husk Ash (RHA). Nwachukwu and others (2022j) applied Scheffe's (6, 2) model in the Optimization of Compressive Strength of Hybrid Polypropylene – Nylon Fibre Reinforced Concrete (HPNFRC) . Nwachukwu and others (2022k) applied Scheffe's Second Degree Polynomial Model to optimize the compressive strength of Mussel Shell Fibre Reinforced Concrete (MSFRC). Nwachukwu and others (2022 l) carried out an optimization Of Compressive Strength of Concrete Made With Partial Replacement Of Cement With Periwinkle Shells Ash (PSA) Using Scheffe's Second Degree Model. Nwachukwu and others (2023a) applied Scheffe's Third Degree Regression Model to optimize the compressive strength of Hybrid- Polypropylene- Steel Fibre Reinforced Concrete (HPSFRC). Nwachukwu and others (2023b) applied Scheffe's (6,3) Model in the Optimization Of Compressive Strength of Concrete Made With Partial Replacement Of Cement With Cassava Peel Ash (CPA) and Rice Husk Ash (RHA)**.** In the work of Nwachukwu and others (2023c), titled Need For Effective Evaluation Of Water Resources Qualities For Sustenance And Attainment Of Construction (Engineering) Development Goals, flexural and split tensile strengths from groundwater sources were determined in other to determine the effectiveness of these water resources in construction works. Nwachukwu and others (2023d) applied the use of Scheffe's Second Degree Model In The Optimization Of Compressive Strength Of Asbestos Fibre Reinforced Concrete (AFRC). Nwachukwu and others (2023e) used optimization techniques in the Flexural Strength And Split Tensile Strength determination of Hybrid Polypropylene - Steel Fibre Reinforced Concrete (HPSFRC). Nwachukwu and others (2023f) applied Scheffe's Optimization model in the evaluation of Flexural Strength And Split Tensile Strength Of Plastic Fibre Reinforced Concrete (PLFRC). Finally, Nwachukwu and H.E. Opara (2023) in the their paper presented at the Conference Proceedings of the Nigeria Society of Engineers, demonstrated the use of Snail Shells Ash (SSA) in the partial replacement of cement using Scheffe's (5,2) optimization model. Based on the works reviewed so far, it appears that the subject matter has not been fully addressed as it can be envisaged that no work has been done on the use of Scheffe's (6,2) Model to optimize the Flexural and Split Tensile Strengths of PMCC. Henceforth, the need for this present research work**.**

2. METHODOLOGY

2.1 MATERIALS FOR PMCC MIXTURES

In this work, the constituent materials under investigation in line with Scheffe's (6, 2) model are Water/Cement ratio, Cement, PSA, MSA, Fine and Coarse Aggregates. The water is procured from potable water from the clean water source and was applied in accordance with ASTM C1602/C1602M-22 (2022). The cement is Dangote cement, a brand of Ordinary Portland Cement obtained from local distributors, which conforms to British Standard Institution BS 12 (1978). Fine aggregate of sizes that range from 0.05 - 4.5mm was procured from the local river. Crushed granite as a coarse aggregate of 20mm size was obtained from a local stone market and was later downgraded to 4.75mm. As a matter of facts, both fine and coarse aggregates were procured and prepared in accordance with ASTM C33/C33M-18 (2018). The PS and MS used in this work were procured as a waste in an aquaculture industry and were washed and sundried for few days. After sufficient drying, the PS and MS were then calcined in a Gallenkamp Muffle Furnace at about 400^0C. The calcined PS and MS samples were allowed to cool in a deciccator and then ground into very fine powder ,otherwise described as PSA and MSA respectively using a ceramic mortar and pestle. The resulted PSA and MSA were later sieved through a BS sieve of 75 microns and kept in air tight container for use in the PMCC mixtures.

2.2. THEORITICAL BACKGROUND ON PMCC SCHEFFE'S (6,2) MODEL

By definition, a simplex lattice is a structural representation of lines joining the atoms of a particular mixture and these atoms are constituent components of that same mixture. For the present PMCC mixture, the constituent elements are the following six components: water, cement, PSA, MSA, fine aggregate and coarse aggregate. It should be noted that mixture components, according to Obam (2009) are subject to the constraint that the sum of all the components must be equal to 1 as stated in Eqn.(1):

$$X_1 + X_2 + X_3 + \dots + X_q = 1 \; ; \quad \Rightarrow \sum_{i=1}^{q} X_i = 1 \qquad \textbf{(1)}$$

where $X_i \geq 0$ and $i = 1, 2, 3 \dots q$, and q = the number of mixtures.

2.2.1. POSSIBLE DESIGN POINTS FOR PMCC SCHEFFE'S (6, 2) MIXTURES

The Scheffe's (q, m) simplex lattice design is characterized by the symmetric arrangements of points within the experimental region and a well-chosen regression equation to represent the response surface over the entire simplex region as stated by Aggarwal (2002). The (q, m) simplex lattice design given by Scheffe, according to Nwakonobi and Osadebe (2008) contains ${}^{q+m-1}C_m$ points where each components proportion takes (m+1) equally spaced values

$X_i = 0, \frac{1}{m}, \frac{2}{m}, \frac{3}{m}, \ldots, 1;\quad i = 1, 2, \ldots, q$ ranging between 0 and 1 and all possible mixture with these component proportions are used, and m is Scheffe's polynomial degree, which is 2 in this present study .For example a (3, 2) lattice consists of ${}^{3+2-1}C_2$ i.e. ${}^{4}C_2$ = 6 points. Each X_i can take m+1 = 3 possible values; that is $x = 0, \frac{1}{2}, 1$ with which the possible design points are: $(1,0,0), (0,1,0), (0,0,1), \left(\frac{1}{2}, \frac{1}{2}, 0\right), \left(0, \frac{1}{2}, \frac{1}{2}\right), \left(\frac{1}{2}, 0, \frac{1}{2}\right)$. In order to evaluate the number of coefficients or terms or design points required for a given lattice, the following general formula is adopted: $k = \frac{(q+m-1)!}{(q-1)!\,.\,m!}$ Or ${}^{q+m-1}C_m$ **2(a-b)**

Where k = number of coefficients/ terms / design points, q = number of components/mixtures = 6 in this present study and m = number of degree of polynomial = 2 in this present work. Using either of Eqn. (2), $k_{(6,2)}$ = 21. Thus, the possible design points for PMCC Scheffe's (6,2) lattice can be stated in Eqn.(3) :

A_1 (1,0,0,0,0,0); A_2 (0,1,0,0,0,0); A_3 (0,0,1,0,0,0); A_4 (0,0,0,1,0,0), A_5 (0,0,0,0,1,0); A_6 (0, 0,0,0, 0, 1); A_{12} (0.67,0.33, 0, 0, 0, 0); A_{13} (0.67, 0, 0.33,0,0,0); A_{14} (0.67, 0, 0, 0.33,0,0); A_{15} (0.67, 0, 0, 0,0.33, 0); A_{16} (0.67, 0, 0, 0, 0, 0.33); A_{23} (0,0.50,0.50, 0,0,0); A_{24} (0, 0.50, 0, 0.50, 0,0); A_{25}, (0, 0.50, 0, 0,0.50, 0); A_{26} (0, 0.50,0,0, 0.50); A_{34} (0.50, 0.50, 0, 0,0,0); A_{35} (O.50, 0,0.50, 0,0,0); A_{36} (0.50,0, 0,0.50, 0, 0); A_{45} (0.50, 0, 0, 0,0.50, 0); A_{46}(0.50,0,0,0,0,0.50);A_{56}(0,0,0.50,0.50,0,0); **(3)**

According to Obam (2009), a Scheffe's polynomial function of degree, m in the q variable: X_1, X_2, X_3, X_4 … X_q is given in the form of Eqn.(4) stated under:

$$P = b_0 + \sum bi\, xi + \sum bij xj + \sum bi\, jxjxk + + \sum bi^{j}{}_2 + \ldots\, i_n xi_2 xi_n \qquad \textbf{(4)}$$

Where ($1 \le i \le q$, $1 \le i \le j \le k \le q$, $1 \le i_1 \le i_2 \le \ldots \le i_n \le q$ respectively) , b = constant coefficients and P is the response which represents the property under investigation. For this present work, the properties under investigation are the Flexural Strength (P^F) and the Split Tensile Strength (P^S). This research work is based on the Scheffe's (6, 2) simplex, but the actual form of Eqn. (4) for six component mixture , degree two has been developed by Nwachukwu and others (2022h) and thus will be applied subsequently.

2.2.2. PSEUDO AND ACTUAL COMPONENTS IN PMCC SCHEFFE'S (6,2) MIX DESIGN

In Scheffe's mix design, the relationship between the actual components and the pseudo components has been established as :

$$Z = A * X \qquad \textbf{(5)}$$

where Z is the actual component; X is the pseudo component and A is the coefficient of the relationship

Re-arranging Eqn. (5) yields: $X = A^{-1} * Z$ **(6)**

2.2.3.FORMULATION OF MATHEMATICAL EQUATION FOR PMCC SCHEFFE'S (6, 2) LATTICE

The polynomial equation by Scheffe (1958), which is also known as response is given in Eqn.(4). But Eqn.(4) has been developed by Nwachukwu and others (2022h) to accommodate six component mixture for Scheffe's second degree model .Hence, the Simplified version of PMCC Scheffe's (6,2) simplex lattice based on Eqn.(4) is shown in Eqn.(7):

$$\begin{aligned} P = {} & ß1X1 + ß2X2 + ß3X3 + ß4X4 + ß5X5 + ß6X6 + ß12X1X2 + ß13X1X3 + ß14X1X4 + ß15X1X5 + ß16X1X6 + \\ & ß23X2X3 + ß24X2X4 + ß25X2X5 + ß26X2X6 + ß34X3X4 + ß35X3X5 + ß36X3X6 + ß45X4X5 + ß46X4X6 \\ & + ß56X5X6 \qquad \textbf{(7)} \end{aligned}$$

2.2.4. COEFFICIENTS DETERMINATION OF THE PMCC SCHEFFE'S (6, 2) POLYNOMIAL

From the work of Nwachukwu and others (2022h), the coefficients of the Scheffe's (6, 2) polynomial are expressed as under. :

$$\beta_1 = P_1;\ \beta_2 = P_2;\ \beta_3 = P_3;\ \beta_4 = P_4;\ \beta_5 = P_5 \text{ and } \beta_6 = P_6 \qquad \textbf{8(a-f)}$$

$$\beta_{12} = 4P_{12} - 2P_1 - 2P_2;\ \beta_{13} = 4P_{13} - 2P_1 - 2P_3;\ \beta_{14} = 4P_{14} - 2P_1 - 2P_4; \qquad \textbf{9(a-c)}$$

$$\beta_{15} = 4P_{15} - 2P_1 - 2P_5;\ \beta_{16} = 4P_{16} - 2P_1 - 2P_6;\ \beta_{23} = 4P_{23} - 2P_2 - 2P_3;\ \beta_{24} = 4P_{24} - 2P_2 - 2P_4; \qquad \textbf{10(a-d)}$$

$$\beta_{25} = 4P_{25} - 2P_2 - 2P_5;\ \beta_{26} = 4P_{26} - 2P_2 - 2P_6,\ \ \beta_{34} = 4P_{34} - 2P_3 - 2P_4;\ \beta_{35} = 4P_{35} - 2P_3 - 2P_5; \qquad \textbf{11(a-d)}$$

$$\beta_{36} = 4P_{36} - 2P_3 - 2P_6;\ \beta_{45} = 4P_{45} - 2P_4 - 2P_5,\ \ \beta_{46} = 4P_{46} - 2P_4 - 2P_6;\ \beta_{56} = 4P_{56} - 2P_{35} - 2P_6; \qquad \textbf{12(a-d)}$$

Where P_i = Response Function (Flexural Strength and the Split Tensile Strength) for the pure component, i

2.2.5. PMCC SCHEFFE'S (6, 2) MIXTURE DESIGN MODEL

By substituting Eqns. (8)-(12) into Eqn. (7), we obtain the mixture design model for the PMCC Scheffe's (6,2) lattice.

2.2.6. EVALUATION OF THE PSEUDO AND ACTUAL MIX RATIOS FOR THE PMCC SCHEFFE'S (6, 2) DESIGN LATTICE AT INITIAL EXPERIMENTAL TEST POINTS AND CONTROL POINTS.

A. AT THE PMCC INITIAL EXPERIMENTAL TEST POINTS [IETP]

Usually, the concrete conventional mix ratio is usually in the form of 1:2:4. However this conventional nomenclature is impossible to actualize in the Scheffes optimization mixture because of the requirement of simplex lattice design based on Eqn. (1) criteria at a given water/cement ratio for the actual mix ratio. Thus, there is need for the transformation of the actual components proportions to meet the Eqn. (1) criterium. Based on experience and knowledge from a typical Scheffe's (4,2) work as well as previous knowledge from literature, the following arbitrary prescribed mix ratios are chosen for the five vertices of Scheffe's (4,2) lattice. They are as follows: A_1 (0.67:1:1.7:2.0); A_2 (0.56:1:1.6:1.8); A_3 (0.5:1:1.2:1.7); A_4 (0.7:1:1:1.8); A_5 (0.75:1:1.3:1.2), and A_6 (0.80:1:1.3:1.2) **(13a)**

From Eqn.(13a), the mix ratios represents water/cement ratio, cement, fine aggregate and coarse aggregate respectively. Now, for the present PMCC Scheffe's (6,2) mixture, where 60 % of cement is replaced with PSA and MSA where the mix proportion of PSA- MSA was in 50% - 50% ratio, the following mix ratio can be formulated from Eqn.(13a) to give Eqn.(13b).

A_1 (0.67:0.4:0.3:0.3:1.7:2.0); A_2 (0.56:0.4:0.3:0.3:1.6:1.8); A_3 (0.5:0.4:0.3:0.3:1.2:1.7); A_4 (0.7: 0.4:0.3:0.3:1.0:1.8); A_5 (0.75: 0.4:0.3:0.3:1.3:1.2), and A_6 (0.80: 0.4:0.3:0.3:1.3:1.2) **(13b)**

For the pseudo mix ratio, the following corresponding mix ratios at the vertices for six component mixtures are always chosen: The rest are listed in Eqn.(3).

A_1(1:0:0:0:0:0), A_2(0:1:0:0: 0:0), A_3(0:0:1:0:0:0), A_4(0:0:0:1:0:0), A_5(0:0:0:0:1:0) and A_6(0:0:0:0:0:1) **(14)**

For the transformation of the actual component, Z to pseudo component, X, and vice versa, Eqns. (5) and (6) are applied. By substituting the mix ratios from point A_1 into Eqn. (5), we obtain:

$$\begin{pmatrix} 0.67 \\ 0.40 \\ 0.30 \\ 0.30 \\ 1.70 \\ 2.00 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} & A_{36} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} & A_{46} \\ A_{51} & A_{52} & A_{53} & A_{54} & A_{55} & A_{56} \\ A_{61} & A_{62} & A_{63} & A_{64} & A_{65} & A_{66} \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad \textbf{(15)}$$

Transforming the R.H.S matrix and solving, we obtain as follows: A_{11}= 0.67; A_{21}= 0.4; A_{31}= 0.3; A_{41}= 0.3; A_{51}= 1.7; A_{61}= 2.0. The same approach is used in obtaining the remaining values as shown in Eqn. (16).

$$\begin{pmatrix} Z_1 \\ Z_2 \\ Z_3 \\ Z_4 \\ Z_5 \\ Z_6 \end{pmatrix} = \begin{pmatrix} 0.67 & 0.56 & 0.50 & 0.70 & 0.75 & 0.80 \\ 0.40 & 0.40 & 0.40 & 0.40 & 0.40 & 0.40 \\ 0.30 & 0.30 & 0.30 & 0.30 & 0.30 & 0.30 \\ 0.30 & 0.30 & 0.30 & 0.30 & 0.30 & 0.30 \\ 1.70 & 1.60 & 1.20 & 1.00 & 1.30 & 1.30 \\ 2.00 & 1.80 & 1.70 & 1.80 & 1.20 & 1.20 \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \end{pmatrix} \qquad \textbf{(16)}$$

Considering mix ratios at the mid points from Eqn.(3) and substituting these pseudo mix ratios in turn into Eqn.(16) yields the corresponding actual mix ratios as follows: At point A_{12} we have: A_{12} (0.67, 0.33, 0, 0, 0, 0). Then substituting Eqn.(16), we have:

$Z_1 = 0.63$; $Z_2 = 0.40$; $Z_3 = 0.30$' $Z_4 = 0.30$; $Z_5 = 1.00$ and $Z_6 = 1.93$. **(17)**

The same approach goes for the remaining mid-point mix ratios. Hence, in order to generate the twenty-one coefficients, twenty-one (21) experimental tests will be carried out and the corresponding mix ratios are as depicted in Table 1.

Table 1: Pseudo (X) and Actual (Z) Mix Ratio For PMCC Based On Scheffe's (6,2) Lattice For IETP

S/N	**IETP**	**PSEUDO COMPONENT**						**RESPONSE SYMBOL**	**ACTUAL COMPONENT**					
		X_1	**X_2**	**X_3**	**X_4**	**X_5**	**X_6**		**Z_1**	**Z_2**	**Z_3**	**Z_4**	**Z_5**	**Z_6**
1	E_I	1	0	0	0	0	0	P_1	0.67	0.40	0.30	0.30	1.70	2.00

2	E_2	0	1	0	0	0	0	P_2	0.56	0.40	0.30	0.30	1.60	1.80
3	E_3	0	0	1	0	0	0	P_3	0.50	0.40	0.30	0.30	1.20	1.70
4	E_4	0	0	0	1	0	0	P_4	0.70	0.40	0.30	0.30	1.00	1.80
5	E_5	0	0	0	0	1	0	P_5	0.75	0.40	0.30	0.30	1.30	1.20
6	E_6	0	0	0	0	0	1	P_6	0.80	0.40	0.30	0.30	1.30	1.20
7	E_{12}	0.67	033	0	0	0	0	P_{12}	0.63	0.40	0.30	0.30	1.00	1.93
8	E_{I3}	0.67	0	0.33	0	0	0	P_{13}	0.61	0.40	0.30	0.30	1.54	1.90
9	E_{I4}	0.67	0	0	0.33	0	0	P_{14}	0.68	0.40	0.30	0.30	1.47	1.93
10	E_{I5}	0.67	0	0	0	0.33	0	P_{15}	0.70	0.40	0.30	0.30	1.57	1.74
11	E_{I6}	0.67	0	0	0	0	0.33	P_{16}	0.71	0.40	0.30	0.30	1.57	1.74
12	E_{23}	0	0.50	0.50	0	0	0	P_{23}	0.53	0.40	0.30	0.30	1.40	1.75
13	E_{24}	0	0.50	0	0.50	0	0	P_{24}	1.41	0.40	0.30	0.30	1.30	1.80
14	E_{25}	0	0.50	0	0	0.50	0	P_{25}	0.66	0.40	0.30	0.30	1.45	1.50
15	E_{26}	0	0.50	0	0	0	0.50	P_{26}	0.68	0.40	0.30	0.30	1.50	1.50
16	E_{34}	0.50	0.50	0	0	0	0	P_{34}	0.62	0.40	0.30	0.30	1.65	1.90
17	E_{35}	0.50	0	0.50	0	0	0	P_{35}	0.59	0.40	0.30	0.30	1.45	1.85
18	E_{36}	0.50	0	0	0.50	0	0	P_{36}	0.69	0.40	0.30	0.30	1.35	1.90
19	E_{45}	0.50	0	0	0	0.50	0	P_{45}	0.71	0.40	0.30	0.30	1.50	1.60
20	E_{46}	0.50	0	0	0	0	0.50	P_{46}	0.74	0.40	0.30	0.30	1.50	1.60
21	E_{56}	0	0	0.50	0.50	0	0	P_{56}	0.60	0.40	0.30	0.30	1.10	1.75

B. AT THE PMCC EXPERIMENTAL (CONTROL) TEST POINTS [ECTP]

Here, twenty- one (21) different control mix ratios were predicted and listed in Table 2, which according to Scheffe's (1958), their summation should not be greater than one. The same approach for component transformation adopted for the initial experimental test points are also adopted for the control points and the results are shown in Table 2.

Table 2:Actual & Pseudo Component Of PMCC Based On Scheffe 's (6,2) Lattice For ECTP

S/N	**ECTP**	**PSEUDO COMPONENT**						**RESPONSE SYMBOL**	**ACTUAL COMPONENT**					
		X_1	X_2	X_3	X_4	X_5	X_6		Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
1	C_1	0.25	0.25	0.25	0.25	0	0	P_1	0.61	0.40	0.30	0.30	1.38	1.83
2	C_2	0.25	0.25	0.25	0	0.25	0	P_2	0.62	0.40	0.30	0.30	1.45	1.68
3	C_3	0.25	0.25	0	0.25	0.25	0	P_3	0.67	0.40	0.30	0.30	1.40	1.70
4	C_4	0.25	0	0.25	0.25	0.25	0	P_4	0.66	0.40	0.30	0.30	1.30	1.68
5	C_5	0	0.25	0.25	0.25	0.25	0	P_5	0.63	0.40	0.30	0.30	1.28	1.63
6	C_6	0.20	0.20	0.20	0.20	0.20	0	P_6	0.64	0.40	0.30	0.30	1.36	1.70
7	C_{12}	0.30	0.30	0.30	0.10	0	0	P_{12}	0.59	0.40	0.30	0.30	1.45	1.83
8	C_{13}	0.30	0.30	0.30	0	0.10	0	P_{13}	0.59	0.40	0.30	0.30	1.48	1.77
9	C_{14}	0.30	0.30	0	0.30	0.10	0	P_{14}	0.65	0.40	0.30	0.30	1.42	1.80
10	C_{15}	0.30	0	0.30	0.30	0.10	0	P_{15}	0.64	0.40	0.30	0.30	1.30	1.77

11	C_{16}	0	0.30	0.30	0.30	0.10	0	P_{16}	0.60	0.40	0.30	0.30	1.27	1.71
12	C_{23}	0.10	0.30	0.30	0.30	0	0	P_{23}	0.60	0.40	0.30	0.30	1.31	1.79
13	C_{24}	0.30	0.10	0.30	0.30	0	0	P_{24}	0.62	0.40	0.30	0.30	1.33	1.83
14	C_{25}	0.30	0.10	0.30	0.30	0	0	P_{25}	0.63	0.40	0.30	0.30	1.41	1.85
15	C_{26}	0.10	0.20	0.30	0.40	0	0	P_{26}	0.61	0.40	0.30	0.30	1.25	1.79
16	C_{34}	0.30	0.20	0.10	0.40	0	0	P_{34}	0.64	0.40	0.30	0.30	1.35	1.85
17	C_{35}	0.20	0.20	0.10	0.10	0.40	0	P_{35}	1.40	0.40	0.30	0.30	1.04	1.59
18	C_{36}	0.30	0.10	0.30	0.20	0.10	0	P_{36}	0.62	0.40	0.30	0.30	1.36	1.77
19	C_{45}	0.25	0.25	0.15	0.15	0.20	0	P_{45}	0.61	0.40	0.30	0.30	1.51	3.16
20	C_{46}	0.30	0.30	0.20	0.10	0.10	0	P_{46}	0.68	0.40	0.30	0.30	1.56	1.96
21	C_{56}	0.10	0.30	0.30	0.30	0	0	P_{56}	1.30	0.40	0.30	0.30	1.31	1.79

2.2.7. MEASUREMENT OF QUANTITIES OF PMCC MATERIALS

The actual components as transformed from obtained from Tables 1 and 2 were used to measure out the quantities of Water/Cement Ratio (Z_1), Cement (Z_2), PSA (Z_3), MSA (Z_4) Fine Aggregate (Z_5) and Course Aggregate (Z_6) using a weighing balance of 50kg capacity in their respective ratios for the concrete beam and cylinder strengths test at the laboratory.

Mathematically, Measured Quantity, M^Q of PMCC Mixture is given by Eqn.(18)

$$M^Q = \frac{X}{T} * Y \qquad \textbf{(18)}$$

Where, X = Individual mix ratio at each test point = 0.67 for Z_1 at E_1 in Table 1, for example.

T = Sum of mix ratios at each test point = 5.37 at E_1 in Table 1, for example

And Y = Average weight of Concrete cube/beam/cylinder

For the Flexural Strength concrete beam mould of 15cm*15cm*60cm, Average Y from experience = 30kg

For the Split Tensile Strength Concrete cylinder mould of 15cm*30cm, Average Y from experience =12.5kg

For the mix ratios at IETP of Table 1, the measured quantities are displaced in Table 3.

Table 3: Measured Quantities Of PMCC Materials In The Laboratory At IETP

S/N	**IETP**	**ACTUAL MIX RATIOS**						**MEASURED QUANTITY IN THE LABORATORY [Kg]**											
								FLEXURAL STRENGHT						**SPLIT TENSILE STRENGHT**					
		Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6
1	E_I	0.67	0.40	0.30	0.30	1.70	2.00	3.7	2.2	1.7	1.7	9.5	11.2	1.6	0.9	0.7	0.7	4.0	4.7
2	E_2	0.56	0.40	0.30	0.30	1.60	1.80	3.4	2.4	1.8	1.8	9.7	10.1	1.4	1.00.	0.8	0.8	4.0	4.5
3	E_3	0.50	0.40	0.30	0.30	1.20	1.70	3.4	2.7	2.0	2.0	8.2	11.6	1.4	1.1	0.9	0.9	3.0	4.8
4	E_4	0.70	0.40	0.30	0.30	1.00	1.80	4.7	2.7	2.0	2.0	6.7	12.0	1.9	1.1	0.8	0.8	2.9	5.0
5	E_5	0.75	0.40	0.30	0.30	1.30	1.20	5.3	2.8	2.1	2.1	9.2	8.5	2.2	1.2	0.9	0.9	3.8	3.5
6	E_6	0.80	0.40	0.30	0.30	1.30	1.20	5.6	2.8	2.1	2.1	9.1	8.4	2.3	1.2	0.9	0.9	3.8	3.5
7	E_{12}	0.63	0.40	0.30	0.30	1.00	1.93	4.1	2.6	2.0	2.0	6.6	12.7	1.7	1.1	0.8	0.8	2.7	5.7
8	E_{I3}	0.61	0.40	0.30	0.30	1.54	1.90	3.6	2.4	1.8	1.8	9.1	11.3	1.5	1.0	0.7	0.7	3.8	4.7
9	E_{I4}	0.68	0.40	0.30	0.30	1.47	1.93	4.0	2.4	1.8	1.8	8.7	11.4	1.7	1.0	0.7	0.7	3.6	4.7
10	E_{I5}	0.70	0.40	0.30	0.30	1.57	1.74	4.2	2.4	1.8	1.8	9.4	10.4	1.8	1.0	0.8	0.8	3.9	4.4

11	E_{I6}	0.71	0.40	0.30	0.30	1.57	1.74	4.2	2.4	1.8	1.8	9.4	10.4	1.8	1.0	0.7	0.7	3.9	4.3
12	E_{23}	0.53	0.40	0.30	0.30	1.40	1.75	3.4	2.6	1.9	1.9	9.0	11.2	1.4	1.1	0.8	0.8	3.7	4.7
13	E_{24}	1.41	0.40	0.30	0.30	1.30	1.80	7.7	2.2	1.6	1.6	7.1	9.8	3.2	0.9	0.7	0.7	3.0	4.1
14	E_{25}	0.66	0.40	0.30	0.30	1.45	1.50	4.3	2.6	2.0	2.0	9.4	9.8	1.8	1.1	0.8	0.8	3.9	4.1
15	E_{26}	0.68	0.40	0.30	0.30	1.50	1.50	4.4	2.6	1.9	1.9	9.6	9.6	1.8	1.1	0.8	0.8	4.0	4.0
16	E_{34}	0.62	0.40	0.30	0.30	1.65	1.90	3.6	2.3	1.7	1.7	9.6	11.0	1.5	1.0	0.7	0.7	4.0	4.6
17	E_{35}	0.59	0.40	0.30	0.30	1.45	1.85	3.6	2.5	1.8	1.8	8.9	11.3	1.5	1.0	0.8	0.8	3.7	4.7
18	E_{36}	0.69	0.40	0.30	0.30	1.35	1.90	4.2	2.4	1.8	1.8	8.2	11.5	1.7	1.0	0.8	0.8	3.4	4.8
19	E_{45}	0.71	0.40	0.30	0.30	1.50	1.60	4.4	2.5	1.9	1.9	9.4	10.0	1.8	1.0	0.8	0.8	3.9	4.2
20	E_{46}	0.74	0.40	0.30	0.30	1.50	1.60	4.6	2.5	1.9	1.9	9.3	9.9	1.9	1.0	0.8	0.8	3.9	4.2
21	E_{56}	0.60	0.40	0.30	0.30	1.10	1.75	4.0	2.7	2.0	2.0	7.4	11.8	1.7	1.1	0.8	0.8	3.1	4.9

The same approach was used for the measured quantities at the ECTP.

2.3. METHOD

2.3.1. METHODS FOR FLEXURAL STRENGTH TEST

A. SPECIMEN PREPARATION / BATCHING/ CURING FOR FLEXURAL STRENGTH TEST

In this experimental investigation, the standard size of specimen (mould) for the Flexural Strength measures 15cm*15cm*60cm. The mould is made of steel metal with sufficient thickness to prevent spreading or warping. The mould is constructed with the longer dimension horizontal and in such a manner as to facilitate the removal of the moulded specimen without damage. Batching of all the constituent material was done by weight using a weighing balance of 50kg capacity based on the adapted mix ratios and water cement ratios. A total number of 42 mix ratios were to be used to produce 84 PMCC prototype concrete cubes. Forty-two (42) out of the 84 mix ratios were as control mix ratios to produce 42 cubes for the conformation of the adequacy of the mixture design given by Eqn. (7), whose coefficients are given in Eqns. (8) – (12). Twenty-four (24) hours after moulding, curing commenced. Test specimens are stored in water at a temperature of 24^0 to 30^0 for 48 hours before testing. They are tested immediately on removal from the water whilst they are still in a wet condition. After 28 days of curing, the specimens were taken out of the curing tank for flexural strength determination.

B. PMCC FLEXURAL STRENGTH TEST PROCEDURE/CALCULATION

Flexural strength testing was done in accordance with BS 1881 – part 118 (1983) - Method of determination of Flexural Strength, ASTM C78/C78M-22 (2022) and ACI (1989) guideline. In this present study, two samples were crushed for each mix ratio. In each case, the Flexural Strength of each sample which is expressed as the Modulus of Rupture (MOR) was then calculated to the nearest 0.05 MPa using Eqn.(19)

$$\mathrm{MOR} = \frac{PL}{bd^2} \qquad \textbf{(19)}$$

where b = measured width in cm of the specimen, d = measured depth in cm of the specimen at the point of failure, where L = Length in cm of the span on which the specimen was supported and P = maximum load in kg applied to the specimen.

2.3.1. METHODS FOR SPLIT TENSILE STRENGTH TEST

A. SPECIMEN PREPARATION / BATCHING/ CURING FOR SPLIT TENSILE STRENGTH TEST

The specimen for the Split Tensile Strength is Concrete Cylindrical specimen measuring diameter 150 mm and length 300 mm. They were cast with plastic fibers and the specimen was loaded for ultimate compressive load under Universal Testing Machine (UTM) for each mix. A total number of 42 mix ratios were to be used to produce 84 PMCC prototype concrete cylinders. Twenty-one (21) out of the 42 mix ratios were as control mix ratios to produce 42 cubes for the conformation of the adequacy of the mixture design given by Eqn. (7), whose coefficients are given in Eqns. (8) – (12). After 28 days of curing the specimens were taken out of the curing tank for the Split Tensile Strength determination.

B. PMCC SPLIT TENSILE STRENGTH TEST PROCEDURE/CALCULATION

The cylindrical split tensile test for the PMCC was done using the universal testing machine in accordance with BS EN 12390-6:2009 and ASTM C 496/ C 496 M-17 (2017). Two samples were crushed for each mix ratio and each case, the Split Tensile Strength of each specimen/sample was then calculated using Eqn. (20)

$$F_t = \frac{2P}{\pi D L} \qquad (20)$$

Where, F_t = Split Tensile Strength, MPa , P = maximum applied load (that is Load at failure, N) ; D = diameter of the cylindrical specimen (Dia. Of cylinder, mm); and L = Length of the specimen (Length of cylinder, mm),

3. RESULTS PRESENTATION AND DISCUSSION

3.1. PMCC RESPONSES (FLEXURAL STRENGTH AND SLIT TENSILE STRENGHT) FOR THE IETP

The results of the Responses (Flexural Strength and Split Tensile Strength) test based on Eqns.(19 and 20) are shown in Table 4.

Table 4: PMCC Response (Flexural Strength, FS and Split Tensile Strength, STS) Test Results From IETP Based on Eqns.(19and 20)

S/N	**IETP**	**EXPT. NO**	**28^{TH} DAY RESPONSE P_I, MPa**		**RESPONSE SYMBOL**	**28^{TH} DAY AVERAGE RESPONSE P, MPa**	
			FS	**STS**		**FS**	**STS**
1	E_I	PMCC/ E_I A	7.88	2.22	P_1	8.00	2.33
		PMCC/ E_I B	8.12	2.44			
2	E_2	PMCC/ E_2 A	5.89	2.09	P_2	6.72	2.18
		PMCC/ E_2 B	7.54	2.27			
3	E_3	PMCC/ E_3 A	6.23	1.99	P_3	6.00	2.00
		PMCC/ E_3 B	5.77	2.00			
4	E_4	PMCC/ E_4 A	9.00	2.76	P_4	8.98	2.74
		PMCC/ E_4 B	8.96	2.72			
5	E_5	PMCC/ E_5 A	4.56	2.66	P_5	5.45	2.56
		PMCC/ E_5 B	6.34	2.45			
6	E_6	PMCC/ E_6 A	6.07	2.34	P_6	6.08	2.42
		PMCC/ E_6 B	6.08	2.49			
7	E_{12}	PMCC/ E_{I2} A	4.28	0.90	P_{12}	4.26	0.96
		PMCC/ E_{I2} B	4.24	1.02			
8	E_{13}	PMCC/ E_{I3} A	7.98	2.34	P_{13}	8.16	2.34
		PMCC/ E_{I3} B	8.33	2.34			
9	E_{14}	PMCC/ E_{I4} A	8.22	2.68	P_{14}	7.94	2.53
		PMCC/ E_{I4} B	7.66	2.37			
10	E_{15}	PMCC/ E_{I5} A	7.68	2.71	P_{15}	7.77	2.69
		PMCC/ E_{I5} B	7.88	2.67			
11	E_{16}	PMCC/ E_{I6} A	4.88	2.25	P_{16}	5.09	2.24
		PMCC/ E_{I6} B	5.29	2.22			
12	E_{23}	PMCC/ E_{23} A	7.28	2.11	P_{23}	7.47	2.18
		PMCC/ E_{23} B	7.65	2.24			
13	E_{24}	PMCC/ E_{24} A	7.23	1.88	P_{24}	7.29	2.22
		PMCC/ E_{24} B	7.34	2.56			

14	E_{25}	PMCC/ E_{25} A	7.39	2.39	P_{25}	7.47	2.41
		PMCC/ E_{25} B	7.55	2.43			
15	E_{26}	PMCC/ E_{26} A	8.00	3.00	P_{26}	8.11	2.56
		PMCC/ E_{26} B	8.21	2.12			
16	E_{34}	PMCC/ E_{34} A	8.13	2.19	P_{34}	8.18	2.32
		PMCC/ E_{34} B	8.23	2.45			
17	E_{35}	PMCC/ E_{35} A	7.55	2.61	P_{35}	7.44	2.42
		PMCC/ E_{35} B	7.32	2.23			
18	E_{36}	PMCC/ E_{36} A	7.83	2.18	P_{36}	7.88	2.45
		PMCC/ E_{36} B	7.93	2.71			
19	E_{45}	PMCC/ E_{45} A	5.65	2.45	P_{45}	5.74	2.44
		PMCC/ E_{45} B	5.83	2.43			
20	E_{46}	PMCC/ E_{46} A	6.89	2.54	P_{46}	7.06	2.44
		PMCC/ E_{46} B	7.23	2.34			
21	E_{56}	PMCC/ E_{56} A	8.29	2.54	P_{56}	8.34	2.55
		PMCC/ E_{56} B	8.38	2.55			

3.2. PMCC RESPONSES (FLEXURAL STRENGHT AND SPLIT TENSILE STRENGHT) FOR THE ECTP

The responses (Flexural strength & Split Tensile Strength) from experimental (control) tests are shown in Table 5

Table 5: PMCC Scheffe's (6,2) Responses (Flexural strength and Split Tensile Strength) From ECTP

S/N	**ECTP**	**EXPT NO**	**RESPONSE (MPa)**		**Z_1**	**Z_2**	**Z_3**	**Z_4**	**Z_5**	**Z_6**	**AVERAGE RESPONSE (MPa)**	
			FS	**STS**							**FS**	**STS**
1	C_1	PMCC/ C_I A	6.68	2.00	0.61	0.40	0.30	0.30	1.38	1.83	7.20	2.16
		PMCC/ C_I B	7.72	2.31								
2	C_2	PMCC/ C_2 A	8.89	2.11	0.62	0.40	0.30	0.30	1.45	1.68	8.05	2.25
		PMCC/ C_2 B	7.21	2.39								
3	C_3	PMCC/ C_3 A	6.47	2.88	0.67	0.40	0.30	0.30	1.40	1.70	7.37	2.44
		PMCC/ C_3 B	8.27	2.00								
4	C_4	PMCC/ C_4 A	8.30	2.21	0.66	0.40	0.30	0.30	1.30	1.68	8.28	2.43
		PMCC/ C_4 B	8.26	2.65								
5	C_5	PMCC/ C_5 A	7.56	2.76	0.63	0.40	0.30	0.30	1.28	1.63	7.35	2.50
		PMCC/ C_5 B	7.14	2.23								
6	C_6	PMCC/ C_6 A	6.47	2.31	0.64	0.40	0.30	0.30	1.36	1.70	6.30	2.44
		PMCC/ C_6 B	6.12	2.56								
7	C_{12}	PMCC/ C_{I2} A	4.21	1.76	0.59	0.40	0.30	0.30	1.45	1.83	4.44	2.04
		PMCC/ C_{I2} B	4.67	2.32								

8	C_{13}	PMCC/ C_{13} A	7.95	2.37	0.59	0.40	0.30	0.30	1.48	1.77	7.64	2.37
		PMCC/ C_{13} B	7.33	2.37								
9	C_{14}	PMCC/ C_{14} A	6.88	2.67	0.65	0.40	0.30	0.30	1.42	1.80	7.28	2.53
		PMCC/ C_{14} B	7.68	2.39								
10	C_{15}	PMCC/ C_{15} A	7.69	2.23	0.64	0.40	0.30	0.30	1.30	1.77	7.34	2.42
		PMCC/ C_{15} B	6.99	2.61								
11	C_{16}	PMCC/ C_{16} A	5.82	2.71	0.60	0.40	0.30	0.30	1.27	1.71	5.68	2.47
		PMCC/ C_{16} B	5.54	2.23								
12	C_{23}	PMCC/ C_{23}A	7.27	2.54	0.60	0.40	0.30	0.30	1.31	1.79	7.53	2.55
		PMCC/C_{23} B	7.78	2.65								
13	C_{24}	PMCC/C_{24} A	7.32	1.89	0.62	0.40	0.30	0.30	1.33	1.83	7.49	2.17
		PMCC/C_{24} B	7.65	2.45								
14	C_{25}	PMCC/C_{25} A	7.21	2.48	0.40	0.40	0.40	0.40	0.40	0.40	7.44	2.40
		PMCC/C_{25} B	7.67	2.32								
15	C_{26}	PMCC/C_{26} A	7.89	2.35	0.61	0.40	0.30	0.30	1.25	1.79	7.95	2.34
		PMCC/C_{26} B	8.00	2.32								
16	C_{34}	PMCC/C_{34} A	8.32	2.27	0.64	0.40	0.30	0.30	1.35	1.85	8.44	2.35
		PMCC/C_{34} B	8.55	2.43								
17	C_{35}	PMCC/C_{35} A	7.57	2.34	1.40	0.40	0.30	0.30	1.04	1.59	7.62	2.45
		PMCC/C_{35} B	7.66	2.56								
18	C_{36}	PMCC/C_{36} A	7.56	2.27	0.62	0.40	0.30	0.30	1.36	1.77	7.69	2.26
		PMCC/C_{36} B	7.82	2.24								
19	C_{45}	PMCC/C_{45} A	6.11	2.35	0.61	0.40	0.30	0.30	1.51	3.16	6.00	2.42
		PMCC/C_{45} B	5.89	2.48								
20	C_{46}	PMCC/C_{46} A	6.80	2.33	0.68	0.40	0.30	0.30	1.56	1.96	6.91	2.44
		PMCC/C_{46} B	7.02	2.55								
21	C_{56}	PMCC/C_{56} A	8.34	2.63	1.30	0.40	0.30	0.30	1.31	1.79	7.71	2.38
		PMCC/C_{56} B	7.07	2.12								

3.3. SCHEFFE’ S (6, 2) POLYNOMIAL MODEL FOR THE PMCC RESPONSES (FLEXURAL STRENGHT AND SPLIT TENSILE STRENGHT).

By substituting the values of the responses (flexural strengths or Split Tensile Strength) from Table 4 into Eqns.(8) through (12), we obtain the coefficients (β_1, β_2 … …. B_{56}) of the Scheffe’s Second degree polynomial for PMCC. Substituting the values of these coefficients into Eqn. (7) yields the polynomial model for the optimization of the flexural strength, P^F or Split Tensile Strength, P^S of PMCC (at the 28th day) based on Scheffe’s (6,2) lattice as stated under:

P^F or P^S = ß1X1 + ß2X2 + ß3X3 + ß4X4 + ß5X5 + ß6X6 + ß12X1X2 +ß13X1X3 + ß14X1X4 + ß15X1X5

+ ß16X1X6 + ß23X2X3 + ß24X2X4 + ß25X2X5 + ß26X2X6 +ß34X3X4+ ß35X3X5+ ß36X3X6

+ ß45X4X5 + ß46X4X6 +ß56X5X6 **(21)**

3.4. SCHEFFE'S (6, 2) MODEL RESPONSES (FLEXURAL STRENGHT AND SPLIT TENSILE STRENGHT) FOR PMCC AT ECTP

By substituting the pseudo mix ratio of points C_1, C_2, C_3, C_4, C_5, … C_{56} of Table 2 into the revised Eqn.(20), we obtain the Scheffe's Second degree model responses (flexural strength and split tensile strength) for the control points of PMCC.

3.5. TEST OF ADEQUACY OF PMCC SCHEFFE'S (6, 2) MODEL RESULTS (FOR FLEXURAL STRENGHT AND SPLIT TENSILE STRENGHT) USING STUDENT'S – T -TEST

In this session, the test of adequacy is performed to determine the correlation between the PMCC flexural and split tensile strengths results (lab responses) given in Tables 4 and model responses from the control points based on Session 3.4. Using the Student's – T – test, the result shows that there are no significant differences between the experimental results and model responses. Therefore, the model results are validated. The procedures involved in using the Student's – T - test have been explained by Nwachukwu and others (2022 c). Thus, the models are adequate for determining the flexural and split tensile strengths of PMCC based on Scheffe's (6,2) simplex lattice.

3.6. RESULTS DISCUSSION

The maximum flexural strength of PMCC based on Scheffe's (6,2) lattice are **8.98** MPa for the 28th day result. Similarly the maximum split tensile strength of PMCC based on Scheffe's (6,2) lattice are **2.74** MPa for the 28th day result .The corresponding optimum mix ratio is **0.70:0.40:0.30:0.30:1.00:1.80** for Water/Cement Ratio, Cement, PSA, MSA, Fine Aggregate and Coarse Aggregate respectively. The minimum flexural strength and split tensile strength are **4.26** MPa and **0.96** MPa respectively for the 28th day results. The minimum values correspond to the mix ratio of **0.63:0.40:0.30:0.30:1.00:1.93** for Water/Cement Ratio, Cement, PSA, MSA, Fine Aggregate and Coarse Aggregate respectively. Thus, the Scheffe's model can be used to determine the PMCC flexural and spilt tensile strength of all 21 points (1 - 56) in the simplex based on Scheffe's Second Degree Model for six component mixtures.

4. CONCLUSION

In this present work, so far the determination of flexural and split tensile strengths of PMCC using Scheffe's Second Degree Model; Scheffe's (6, 2) has been presented. Firstly, the Scheffe's model was used to predict the mix ratio for evaluating both the flexural and split tensile strengths of PMCC. Through the use of Scheffe's (6, 2) simplex model, the values of both strengths were determined at all 21 points (1- 56). The result of the student's t-test shows that the strengths predicted by the models and the corresponding experimentally observed results are highly correlated. The maximum and minimum design strengths predicted by the model based on Scheffe's (6, 2) model are as stated in the results discussion session. Thus, with the Scheffe's (6, 2) model, any desired strength of PMCC, given any mix ratio can be easily predicted and evaluated and vice versa. Subsequently, the application of this Scheffe's optimization model has reduced the problem of having to go through vigorous, time-consuming and laborious empirical mixture design procedures in order to obtain the desired design strengths of PMCC mixture based on Scheffe's (6,2) simplex lattice .

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