LATERITE, PLASTIC, FLY ASH AND SAND COMBINATION AS A NOVEL COMPOSITE MATERIAL IN CONSTRUCTION APPLICATIONS

P.T. S. Pallege[1], H.P.T.S. Hewathilake[1], Kelum Priyankara[2],

[1] *Department of Applied Earth Science, Faculty of Applied Sciences, Uva Wellassa University, Badulla, Sri Lanka.*
[2] *CCCC, China Harbour Engineering Co. LTD. Middle East.*

ABSTRACT

Natural aggregates sources are depleted due to high demand in construction industry. Therefore, researchers are exploring the use of alternative materials to preserve natural resources while recycling the disposed waste. Similarly, waste plastic has become a critical environmental issue. Hence, the present study introduces a composite material with laterite, sand, chemically unmodified Polyethylene Terephthalate (PET) and fly ash (FA) admixture. Initially X-ray Diffraction (XRD) analysis was conducted for laterite, FA and sand to identify major mineral phases. Four sample series have prepared by keeping one component constant at a time. Prepared sample bricks were tested with slandered Compressive Strength (CS) in both dry and wet conditions and water absorption (WA) analysis. XRD analysis of FA and laterite have confirmed the presence of crystalline silica and kaolinite as major phases respectively and sand has responsible peaks for quartz and feldspar as obvious. The high CS in wet and dry conditions has recorded for the series which has the constant PEP weight percentage of 35%. Higher PEP content more than 35% weight percentage, leads for the higher plasticity that is preventing the obtain of breakeven point. Though the building materials with higher plasticity is suitable for the constructions in seismically active areas, there is a potential risk since the highly flammable nature of the polymers. However, the highest CS in wet and dry conditions has recorded for the combination of 35% of PEP, 25% FA and 20% of both laterite and sand. Hence, it can be presented as favorable and novel combination for the production of bricks in construction applications.

Keyword: - *Laterite, Fly ash, PET, Compressive strength and Water absorption*

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1. INTRODUCTION

Novel technological advancements have introduced the various building materials to the construction field. However, building materials based on natural resources are still maintaining its high demand. In many countries, it is difficult to overemphasize the need for locally manufactured building materials because there is an imbalance between housing requirements and expensive conventional building materials coupled with the depletion of traditional building materials. Clay, Sand and Laterite based building materials are commonly used in local construction industry.

Laterite is derived from a wide variety of parent rocks that have weathered for millions of years, related to the warm and tropical/ subtropical climates. Further, chemical weathering produces a wide variety of soil thickness, grade, chemistry and ore mineralogy. Generally, laterite contains oxides and hydroxides of aluminum, silica, iron and small amounts of calcium, magnesium, titanium and potassium. Almost all laterites are rusty-red due to iron oxides [1]. Laterites in Sri Lanka are mainly located in the south-western part, particularly in the Colombo and Gampaha districts. Though the chemical composition varies with the location, Silicon dioxide, Aluminum oxide and Hematite are the main chemical agents in Sri Lankan laterites.

As a local and conventional brick production material, laterite has several advantages such as plentiful availability, low production cost, high workability with less time and mortar consumption, and low heat capacity [2]. Nevertheless, highly porous nature, low compressive strength and low tensile strength have limited the application of laterite [3]. Further, laterite bricks cannot be accurately cut and separated from the deposits with equal dimensions. Hence, they are composed with poor finishing. Recently, lateritic soil has used to produce compressed stabilized earth bricks **[4].**

Sand is major construction material considered as naturally unconsolidated granules that comprises of solid grains ranging in size from 1/16 to 2 mm (62.5 - 2000 microns). Sand grains are either mineral particles, rock fragments or of biogenic nature. The bulk of sand is mainly composed of silicate minerals and silicate rock fragments by far, quartz is the most popular mineral in sand. River sand mining in Sri Lanka is being fulfilled the needs of construction field however, the depletion of the available sources and high environmental damage are presently become a critical issue.

Fly Ash (FA) is obtained as the by-product of coal combustion and generally composed with high concentrations of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO) and magnesium oxide (MgO). Chemically, it is pozzolana, when combined with lime (calcium hydroxide), the pozzolana combine to form cement compounds. Hence, several research studies have focused on the utilization of FA for construction industry. FA produced by the Norochcholai coal power plant in Sri Lanka became a critical environmental issue such that it acts as polluting agent for air, water and soil. Further FA is interrupting the natural processes and thereby triggering environmental hazards. However, fly ash mixed with laterite cement bricks have many advantages such as, light weight, high compressive strength and minimal environmental impact of direct disposal [5, 6].

Similarly, Polyethylene Terephthalate (PET) based products have also associated with environmental issues regarding the irrespective disposal. PET is a clear, robust, lightweight plastic. The basic building blocks of PET are ethylene glycol and terephthalic acid, which are combined into a polymer chain. The resulting PET spaghetti-like strands are extruded, quickly cooled and cut into small pellets. The resin pellets are then heated to a molten liquid that can be easily extruded or molded into objects of almost any shape. Presently, more than half of the world's synthetic fibers are made of PET, for use in fiber or fabric applications. The technology for blowing PET into bottles was developed in the early 1970s and PET bottles were patented in 1973 [7].

Nevertheless, clay bricks and sandcrete blocks are commonly used for the construction applications. However, clay bricks are associated with the failures in large sizes due to incomplete firing and high water absorption. The manufacturing cost of a sandcrete block is very high due to the high material cost. The strength of sandcrete blocks is considerably low and applying river sand to produce sandcrete blocks causes serious environmental problems. Therefore, present study is focused to develop a composite material with high compressive strength and low water absorption, for the brick production by the combination of laterite and plastics as major components and fly ash and sand as minor components.

2. Methodology

Laterite samples were collected from Radawana area of Gampaha district, Sri Lanka where the mining is conducted for the conventional laterite bricks. Collected laterite samples were initially dried for three days and the size of the fragments were reduced using the laboratory jaw crusher. Crushed laterite soil was then sieved using a mechanical sieve shaker and the mass retained in 0.15 mm mesh was used for the preparation of bricks. River sand samples were obtained from the construction site and 0.5 mm particle size was taken for brick preparation.

Waste plastic bottles were collected from the municipal garbage collection points at Badulla, Sri Lanka. Labels and caps of the collected bottles were removed and washed thoroughly with water. Then cleaned PET bottles cut into small pieces.

Fly ash samples were collected from the Norochcholai coal power plant in Sri Lanka. There are two class of FA such as *Class C* and *Class F*. *Class C,* FA shows a significant amount of calcium oxide and *Class F,* FA consists of less than 20% of calcium oxide [8]. Class F FA has selected for this study.

2.1 Composite Brick Preparation

Four sample series namely "A", "B", "C", and "D" have prepared by keeping one component constant at a time (see Table -1). Initially, weighted PET bottle pieces were re-melted ~290 ºC until converted into a viscous solution. Then selected proportions of laterite, fly ash and sand fractions were added and stirred continuously to obtain a homogeneous mixture. Mixture was poured into a stainless steel mold which has the dimensions of 62 mm (length) × 42 mm (width) ×19 mm (height). Once, the mold is cooled down to the room temperature, the solidified bricks were slowly unmolded. Same procedure was repeated for the each and every combination.

However, in "*Series B*", "*Series C*", "*Series D*", combinations that consist of below 25% of PET, have failed due to attenuated amount of binding content (see Table 01).

Table -1: Raw Materials Combination in Different Sample Series

Series A	**PET %**	**Laterite %**	**FA %**	**Sand %**			***Series B***	**PET %**	**Laterite %**	**FA %**	**Sand %**	
A1	35	0	0	65	✓		**B1**	65	35	0	0	✓
A2	35	10	10	45	✓		**B2**	45	35	10	10	✓
A3	35	20	20	25	✓		**B3**	25	35	20	20	✓
A4	35	30	30	5	✓		**B4**	5	35	30	30	✗
A11	35	0	65	0	✓		**B11**	0	35	65	0	✗
A22	35	10	45	10	✓		**B22**	10	35	45	10	✗
A33	35	20	25	20	✓		**B33**	20	35	25	20	✓
A44	35	30	5	30	✓		**B44**	30	35	5	30	✓
A111	35	65	0	0	✓		**B111**	0	35	0	65	✗
A222	35	45	10	10	✓		**B222**	10	35	10	45	✗
A333	35	25	20	20	✓		**B333**	20	35	20	25	✓
A444	35	5	30	30	✓		**B444**	30	35	30	5	✓
Series C	**PET %**	**Laterite %**	**FA %**	**Sand %**			***Series D***	**PET %**	**Laterite %**	**FA %**	**Sand %**	
C1	65	0	35	0	✓		**D1**	65	0	0	35	✓
C2	45	10	35	10	✓		**D2**	45	10	10	35	✓
C3	25	20	35	20	✓		**D3**	25	20	20	35	✓
C4	5	30	35	30	✗		**D4**	5	30	30	35	✗
C11	0	65	35	0	✗		**D11**	0	65	0	35	✗
C22	10	45	35	10	✗		**D22**	10	45	10	35	✗
C33	20	25	35	20	✓		**D33**	20	25	20	35	✓
C44	30	5	35	30	✓		**D44**	30	5	30	35	✓
C111	0	0	35	65	✗		**D111**	0	0	65	35	✗
C222	10	10	35	45	✗		**D222**	10	10	45	35	✗
C333	20	20	35	25	✓		**D333**	20	20	25	35	✓
C444	30	30	35	5	✓		**D444**	30	30	5	35	✓

Note- "✓" and "✗" symbols denote the possible and failed sample series in molding for the preparation of bricks.

2.2 Characterization

X-ray Diffraction analysis

Initial phase analysis for the Laterite, Sand and “Class- F” FA samples were conducted by X-Ray Diffraction (XRD) analysis with “Rigaku-Ultima IV” X-ray diffractometer, using CuKα1 radiation (λ = 1.54 Å) and 4deg/min scanning rate.

Compressive strength analysis

The compressive strength test was conducted for the prepared composite bricks in both dry and wet conditions by CTM 2000 universal compressive strength machine. The testing procedure was performed according to the Sri Lankan Standards 39: 1978 [9], which is similar to ASTM C67-05 [10].

Water absorption analysis

Water absorption analysis was conducted for the prepared composite bricks. Initially, dry weight of composite bricks was recorded after keeping them in dryer, for 24 hours at 60 ^{0}C. Then the bricks were immersed in water for 24 hours (temperature of 20 °C to 23 °C) and weight was recorded and percentage of water absorption was calculated.

3. RESULTS AND DISCUSSION

3.1 X-ray Diffraction Analysis

Phase identification of raw materials were completed with XRD analysis. Generally, laterite is rich with the oxides and hydroxides of aluminum, silica and iron. Similarly, X-ray diffractogram of laterite (Chart -1A) has confirmed the presence of Kaolinite (K) [11], Quartz (Q) [12], Goethite (Go) [13] and Gibbsite (Gi) [14].

Chart -1B, illustrates the X-ray diffractogram of river sand sample. The observed peaks are confirmed that the sand mainly contained Quartz (Q) [15], Kaolinite (K) [16], Feldspar (F) [17], Rutile (R) and Monazite (Mo) [18, 19].

XRD analysis of Class F FA (Chart -1B) shows the crystalline phases of Mullite (M) [20], Quartz (Q) [21], Hematite (H) and Zeolite (Z) [22, 23]. Further, the previous chemical analysis of Class F FA obtained from Nuraichcholai coal power plant also confirmed presence of 52% of SiO_2 and 32.3% of Al_2O_3 with 7.0% of Fe_2O_3, 5.6 % of CaO, 1.3% of MgO and 1.0% of Na_2O [5].

Commonly, all the selected raw ingredients for the composite material have SiO_2 and Al_2O_3 as major constituents. Hence, major contribution towards higher strength can be obtained from FA and laterite while minimizing the utilization of river sand.

3.2 Compressive Strength

Compressive Strength (CS) analysis were conducted for four sample series in both wet and dry conditions. The combinations of *A3*, *A33* and *A333* in “*Series A*” has the maximum dry and wet strength (Chart -2A). *A333* has highest dry strength value of 6.8 N/mm^2 while *A111* has a minimum dry and wet strengths of 2.2 N/mm^2 and 1.31 N/mm^2 respectively. Further, *A1*, *A11* and *A111* which has single raw ingredient with PET binder have low CS in both dry and wet conditions.

Chart -2B shows the CS analysis for all the possible combinations of “*Series B*”. The maximum strength is shown in sample B333. Comparably, “*Series B*” has higher values of strength than “series A” due to the lower amount of PET content with 35% of laterite. *“Series C”* has the constant 35 weight % of FA and C1 combination (65% PET + 35% FA) has the highest dry state CS (see Chart -2C). In *“Series C”* significantly low CS can be observed when compared with “*Series B*”.

The possible combinations in *“Series D”* (Chart -2D) also has the high CS and shows the similar behavior compared with “*Series C”.* D444 composite with high content of sand, FA with low laterite, has the highest CS.

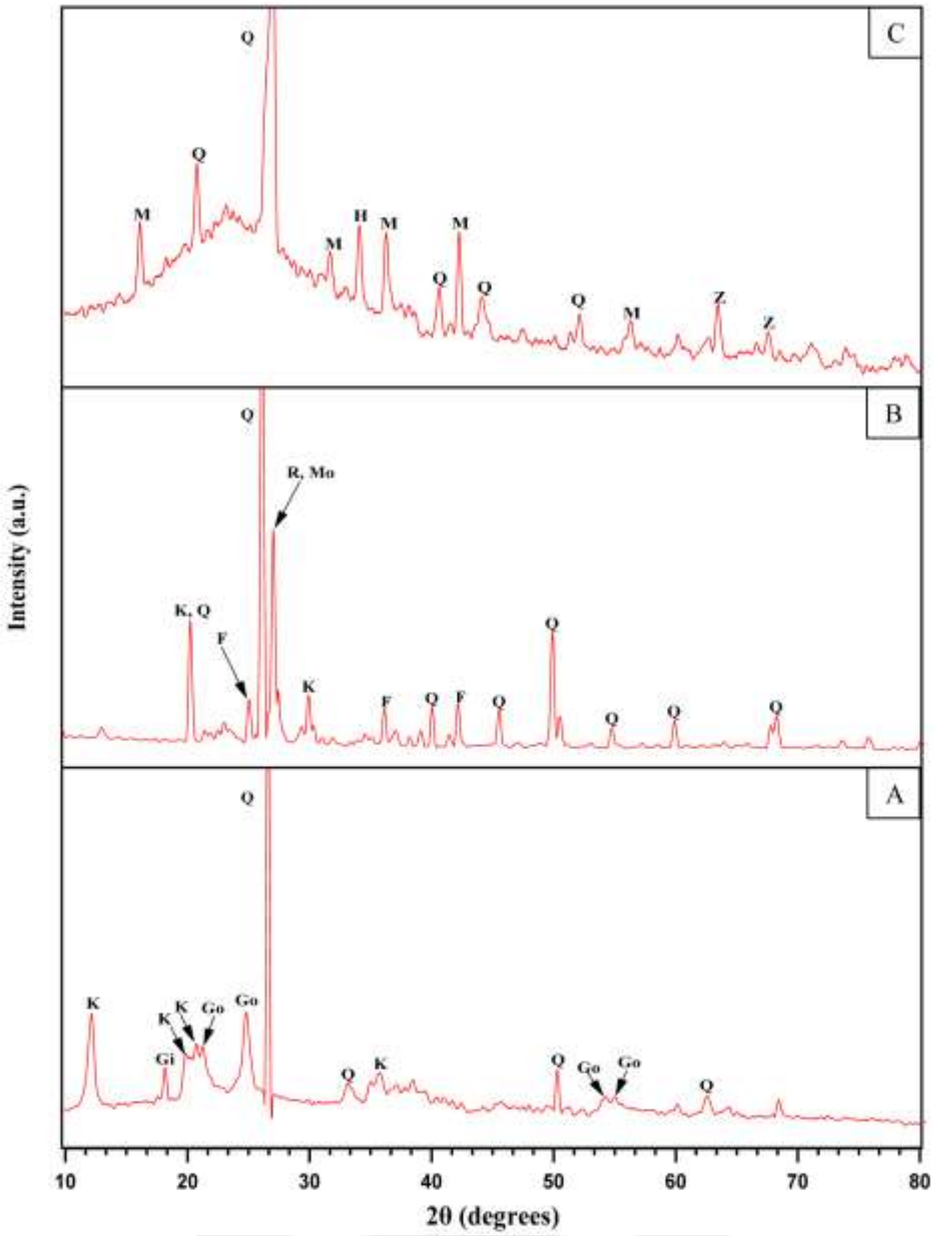

Chart-1: XRD Diffractogram of Laterite (A), Fly ash (B) and Sand (C). The prefixes, K, Q, F, Go, Gi, R, M, Mo, H, and Z stand for the Kaolinite, Quartz, Feldspar, Goethite, Gibbsite, Rutile, Mullite, Monazite, Hematite and Zeolite, respectively.

However, A333 combination in "*Series A* "has the highest CS in both dry and wet conditions with compared to the all other combinations in *Series B, C, and D".* The combination A333 and B333 have the same FA weight % and A333 has highest PET content than B333.

C1 combination is significantly different with other three selected combinations since it composed only 65% of PET and 35% FA. Further, it has the maximum CS in wet condition. Further, in D444 combination has the maximum sand weight.

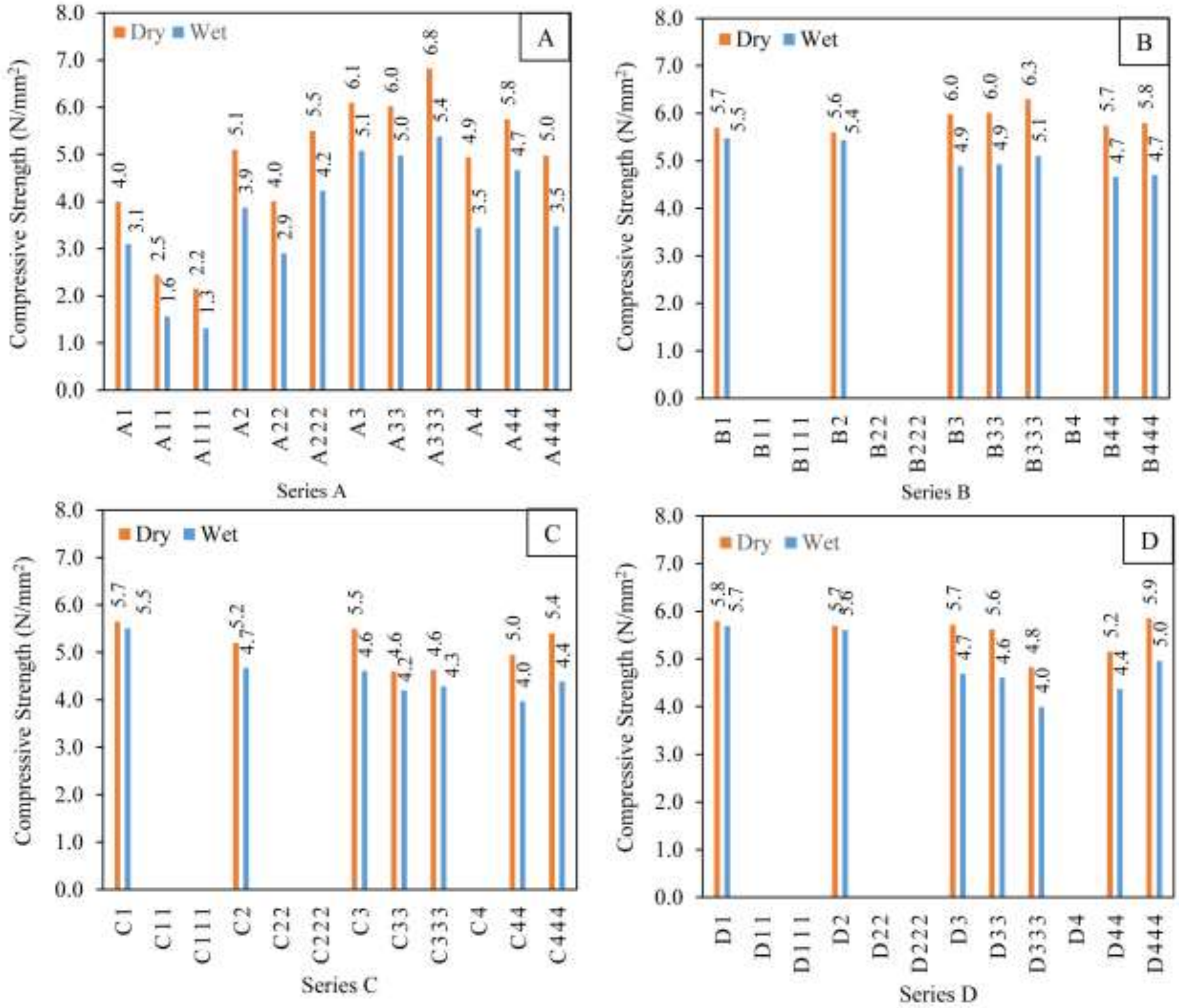

Chart-2: Compressive strength analysis of in both dry and wet conditions

3.3 Water absorption

The variation of the Water Absorption (WA) in "*Series A*" has illustrated in chart -3A. All the combinations have WA percentage within the range of 0.28% - 0.36%. The constant amount of PET might be affected for the narrow range variation of WA in "*Series A*". Chart 3B shows the WA of all the possible combination of "*Series B*". WA varies from 0.10 % to 0.50%. B1 and B333 composites have the lowest and highest WA in "*Series B*". Further, it has depended on the PET content, since the higher PET content reduces the WA.

"*Series C*" with constant weight % with FA has wide range variation in WA (see chart 3C) from 0.08 % to 0.48%. C1 with 65% PET and 35% FA has the lowest WA since the higher amount of PET combines only with fine particles of FA. Further, "*Series D*" also shows the wide range variation in WA, from 0.12% to 0.51% (see chart 3D). Similarly, the highest PET weight of 65% with 35% weight of sand has the lowest WA. However, the lowest WA values were recorded for the combinations of A333, B333, C1 and D444 in each series.

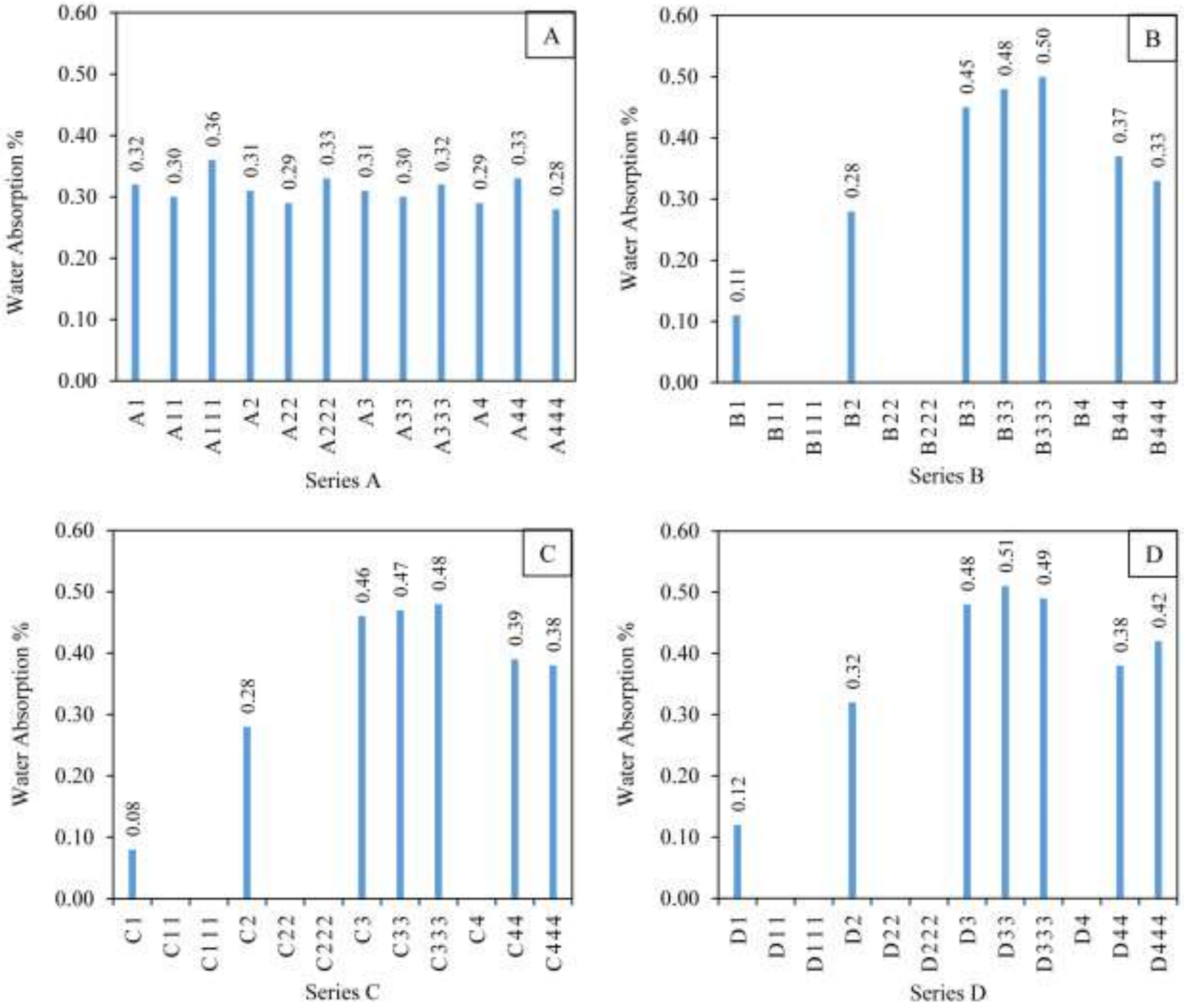

Chart-3: Water absorption of the sample series "*A*", "*B*", "*C*" and "*D*".

Comparably, A333 and C1 combinations have high CS in both dry and wet conditions with low WA. However, C1 has the highest PET content of 65% with 35 weight % of FA. Though, higher plastic building materials are very suitable for the constructions in high seismic areas, the highly flammable nature might enhance the potential risk. Hence, C1 combination is less confident as brick material. Nevertheless, this composition is suitable for outdoor applications such as paving blocks, ponds and swimming pools.

A333 combination in *"Series A"* would be the best combination as brick material, since it has the maximum CS in dry condition and comparably high CS in wet condition. The WA of A33 is comparably low. Further, it contains 35% of PET, 25% of laterite with 20 % of FA and sand respectively. Hence A333 combination is able to maintain the high amount of PET, laterite and FA while minimizing the sand usage.

4. CONCLUSIONS

XRD analysis of fly ash and laterite have confirmed the presence of crystalline silica and kaolinite as major phases respectively and also sand has responsible peaks for quartz and feldspar as obvious.

The highest compressive strength in wet and dry conditions has recorded for the combination in "*Series A"* which has 35% of PET, 25% laterite and 20% of both fly ash and sand. This combination has 6.82 N/mm^2 and 5.38 N/mm^2

of compressive strength under dry and wet conditions respectively. Further, the increasing fly ash content able to increase the compressive strength in both wet and dry conditions. Under the higher PET content breakeven point cannot be detected due to the high plasticity nature.

The composite with highest PET with only fly ash has lowest water absorption of 0.08% but its' compressive strength is lower than the afore said combination in *"Series A"* and this combination has 0.32% of water absorption which is still below the standard water absorption with respect to reference.

Nonetheless, higher plastic building materials are very suitable for use for construction purposes in high seismic areas. However, since polymers are highly flammable, there is a potential risk that these composites will be affected by fire hazards. However, 65% of PET + 35% of fly ash, composition is suitable for outdoor applications such as paving blocks, ponds and swimming pools

Therefore, 35% of PET, 25% laterite and 20% of both fly ash and sand can be taken as the favorable and novel combination for the production of bricks in construction applications.

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