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EFFECT OF QUARRY DUST AND BILLET SCALE ADDITIONS ON THE PROPERTIES OF FLY ASH BRICKS*

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Abstract– This paper reports the effect of addition of quarry dust and billet scale on the properties of fly ash bricks. Bricks were made with fly ash and cement and varying percentages of quarry dust and billet scale. All the mixtures were made to be flowable in fresh state. The bricks were then tested for strength, modulus of rupture, ultrasonic pulse velocity, initial rate of suction, water absorption, and efflorescence. The strength of bricks ranged from 0.8 MPa to 18.9 MPa, modulus of rupture ranged from 0.13 MPa to 3.7 MPa, water absorption from 15 to 32 %, and initial rate of suction between 0.27 and 2.21 kg/m^2.min. All the bricks were categorised as non-efflorescent. It is concluded that the optimum ratio of fly ash and billet scale and quarry dust and billet scale is 1:1 to get improved strength. Furthermore, it is shown that fly ash bricks incorporating 25% of quarry dust and billet scale gives reduction in the various properties observed.

Keywords– Fly ash brick, quarry dust, billet scale, strength, water absorption

1. INTRODUCTION

Fly ash is burnt residue of pulverized coal and is siliceous in nature. It consists of much unfixed SiO_2 and Al_2O_3, and hence possesses comparatively high potential activity [1]. The useful effects of fly ash in concrete are often called morphologic effect, pozzolanic effect, and micro aggregate effect. The morphologic effect states that there are many micro beads in fly ash working as "lubricating balls" when incorporated in fresh mix; hence it benefits the fluidity. The micro aggregate effect of fly ash states the micro beads in fly ash can disperse well in concrete and combine firmly with gel produced in cement hydration, and thus promote concrete density. Recycling fly ash in building sector will not only alleviate the disposal problem but also converts a waste material into a marketable commodity [2].

Fly ash has been used in many applications such as bricks and blocks, cellular concrete products, lightweight aggregates, manufacture of cement and asbestos, road construction and embankment, backfill, and land development [2, 3]. Various researches have been carried out on recycling fly ash in many applications. It was mixed with limestone powder waste to produce composite material without the addition of Portland cement [4], fly ash was mixed with hematite tailings and clay to produce clay brick [5]. The cementitious binder of fly ash–lime–gypsum finds extensive application in the manufacturing of bricks, hollow bricks and structural concrete to solve the problems of housing shortage and at the same time to build houses economically by recycling industrial waste [6-10].

Quarry dust is crushed dust, produced during the breaking of stone boulders in stone crusher for producing coarse aggregates. The quarry dust consists of excess fines and hence is considered as waste material. The quarry dust produced in crusher plants is dumped in bulk quantities around the quarry plants and causes environmental pollution. Both billet scale and quarry dust are available in bulk quantities

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which can be recycled. Billet scale is an iron oxide which is formed on the surface of the steel during continuous casting, reheating and hot rolling operations for steel processing. The scale is removed by water sprays and then disposed by dumping.

Accumulation of unmanaged wastes, especially in developing countries has resulted in an increased environmental concern. Recycling of such wastes as building materials appears to be a viable solution which offers various benefits such as eliminating pollution, economic design of buildings, less use of virgin natural resources, and reduction in cost of waste disposal [11-13]. This study is an attempt to develop bricks using fly ash, quarry dust, and billet scale.

2. MATERIALS AND METHODS

a) Materials

Ordinary Portland cement (OPC) obtained from Lafarge Cement Sdn Bhd, Petaling Jaya, Malaysia conforming to MS522 Part1: 2006 [14] was used for all mixtures in the investigation. When tests on Ordinary Portland cement were held according to ASTM C150, 2006 [15] the specific gravity was 3.15 and specific surface area was 2910 cm^2 g^{-1}. Fly ash was obtained from Kapar Energy Ventures Sdn Bhd, Kapar thermal power station, Kapar, Selangor, Malaysia. The specific gravity of fly ash was 2.323 and specific surface area was 2423 cm^2 gm^{-1} determined according to ASTM C618, 2006 [16]. Billet scale was obtained from Amsteel Mills, Klang, Selangor, Malaysia. Quarry Dust was obtained from Hanson Quarry Products, Batu 11, Cheras, Kuala Lumpur, Malaysia. The chemical and physical properties of the constituent materials are given in Table 1. The specific gravity of quarry dust 2.69 and the fineness modulus was 3.0. The specific gravity of billet scale was 2.97 and the fineness modulus was 2.57.

Table 1. Physical and chemical properties of the constituent materials used to manufacture fly ash

Material	Chemical composition %							Physical properties			
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	MnO	LOI (%)	Blaine fineness (cm^2/gm)	Density (kg/m^3)	Specific gravity
Fly ash	56.58	27.83	4.0	4.30	1.40	-	-	2.53	2423	1155	2.323
Billet scale	1.37	0.09	94.61	0.111	0.03	-	1.03	0.56	-	1746	2.97
Quarry dust	69.94	14.60	2.16	2.23	0.38	-	0.07	0.74	-	1630	2.69
Cement	21.54	5.32	3.6	63.60	1.00	2.1	-	2.48	2910	1367	3.15

b) Casting

The mixture proportions are indicated in Table 2. The ratio of billet scale and quarry dust was done based on trial mixtures. Fly ash and billet scale were first placed in a mixer and dry mixed for 2 minutes. Cement and quarry dust were then added and mixed for another 2 minutes. The mixer was kept covered with burlap while mixing to avoid the volatility of material [17]. Water was then added and the contents were mixed for another 2 minutes. The sample was then tested for flow consistency according to ASTM D 6103 [18]. The mixture is considered flow able when the spread diameter is 200 ± 20 mm [19]. Water content was adjusted until the required consistency was achieved. Mixture was tested for fresh density according to BS 1881:part108:1985 [20]. The mix was then poured in brick moulds of size (200×90×60) mm. The moulds were covered with wet burlap overnight and then transferred to curing environment in plastic storage boxes at a temperature of 22°C and a relative humidity of 95% [21]. The constituent materials were weighed according to the given ratio as shown in Table 2. Two series were studied in this paper, namely series C and D. In series C 10% of cement, 40% of fly ash and 50% of quarry dust and billet scale were mixed. However, in series D cement was reduced to 5%, fly ash was increased to 70% and quarry dust and billet scale were reduced to 25%. The quarry dust was replaced with billet scale in this investigation based on past works on billet scale [22-24].

Table 2. Mix proportion used for series C and series D fly ash bricks

Mix ID	Ratio (%)				w/c	Fresh density (kg/m^3)
	C	FA	QD	BS		
C1	10	40	50	0	2.42	1872
C2	10	40	37.5	12.5	2.10	2013
C3	10	40	25	25	2.05	2026
C4	10	40	12.5	37.5	1.94	2133
C5	10	40	0	50	1.91	2156
D1	5	70	25	0	7.07	1648
D2	5	70	18.75	6.25	7.07	1696
D3	5	70	12.5	12.5	7.07	1716
D4	5	70	6.25	18.75	7.07	1736
D5	5	70	0	25	7.07	1768

c) Test methods

Fly ash bricks were tested for compressive strength, ultrasonic pulse velocity (UPV), water absorption, initial rate of suction (IRS), modulus of rupture (MR), and efflorescence. Three samples were used for each test and the average value reported. The compressive strength test was done according to ASTM C67–07a, 2003 [24] at 7, 14, 28 and 56 days by using universal testing machine of 1000 kN capacity. Modulus of rupture was determined according to ASTM C67–07a, 2003 [25]. It was determined by three-point bending test using Universal Testing Machine with a supporting span of 175 mm, a height of 60 mm and a width of 90 mm.

UPV through a material is a function of elastic modulus and density of material and therefore it can be used to assess the quality and uniformity of material [26]. UPV test was conducted according to BS1881-203 [27] at 7, 14, 28 and 56 days. Water absorption of a brick is defined as the weight of water absorbed by brick is expressed as a percentage of the dry weight of the brick. It varies roughly from (4.5-21) % and the variation is mainly due to the variable raw material. The determination of water absorption was done at day 28 according to BS3921 [28].

IRS denotes the amount of water sucked by the brick upon contact with mortar during laying. IRS results from the presence of capillary mechanism of small pores in the bricks. It is an important property in masonry construction since it affects the bond strength between the brick and mortar, thus affecting water tightness and durability of masonry. IRS test was done according to BS3921 [28] by placing two pieces of metal 100 mm and 75 mm in water dish and the brick was placed on its bed face downwards on the pieces of metal. The depth of immersion of the brick is maintained at 3 ± 1 mm. IRS was conducted by subtracting the mass of bricks before and after immersing the bricks in the water dish for one minute. Efflorescence test was conducted according to ASTM C67 –07a, 2003 [25]. The bricks were placed on their header face in distilled water for 7 days and the depth of immersion was maintained at 25.4 mm. The bricks were then heated in an oven at 110°c for 24 hr. The faces of each specimen were examined by an observer with normal vision from a distance of 3 m.

Tests were also carried out on clay bricks and cement bricks. Clay bricks were obtained from Puchong Brick Mfr Sdn Bhd, Petaling Jaya, Malaysia and cement bricks were obtained from Cribwall (M) Sdn Bhd, Petaling Jaya, Malaysia.

3. RESULTS AND DISCUSSION

Results for mechanical properties are reported in Table 3. Figures in this paper were normalized by dividing the values on y-axis by the maximum value on y-axis for getting better clarity in the discussion. Fresh density ranged from 1648 kg/m^3 to 2156 kg/m^3 as shown in Table 2. It can be observed that the fresh density is less for all mixtures of D series than for all mixtures of C series. This is due to the increased fly ash content in series D. Fly ash content in series D is 70 %, whereas the same is 40 % in series C. Cement is reduced to 5 % from 10 % in series D. Hence the major constituent in series D is fly ash. Relationship between fresh density and quarry dust and billet scale (QD+BS) is indicated in Fig. 1. It is clear that the fresh density increased with the increase in quarry dust and billet scale. Quarry dust and billet scale are heavy and hence contribute to the increase in fresh density of the mixture [24], [25].

Table 3. Mechanical properties of fly ash bricks

Mix ID	Strength (MPa) at day				UPV (km/s) at day				WA (%)	IRS (kg/m^2. min)	MR (MPa)
	7	14	28	56	7	14	28	56			
C1	6.09	7.67	12.42	17.55	2.47	2.58	2.67	2.78	19.17	0.55	2.55
C2	6.46	9.25	13.53	18.87	2.31	2.36	2.45	2.53	17.67	0.55	3.11
C3	6.66	11.67	15.97	20.32	2.10	2.13	2.33	2.68	15.90	0.55	3.78
C4	4.70	7.23	11.54	16.63	1.90	2.12	2.30	2.60	16.52	0.55	3.47
C5	4.38	6.55	10.53	14.57	1.64	1.66	1.88	2.58	15.4	0.55	2.89
D1	0.65	0.78	0.90	1.40	0.67	0.78	0.80	0.82	32	2.21	0.18
D2	0.84	0.96	1.59	1.78	0.62	0.69	0.76	0.79	32	2.21	0.21
D3	0.89	1.55	2.01	2.11	0.51	0.57	0.61	0.66	32	2.21	0.25
D4	0.51	0.62	0.87	1.30	0.48	0.51	0.55	0.58	32	2.21	0.15
D5	0.43	0.60	0.80	1.0	0.45	0.48	0.50	0.54	32	2.21	0.13

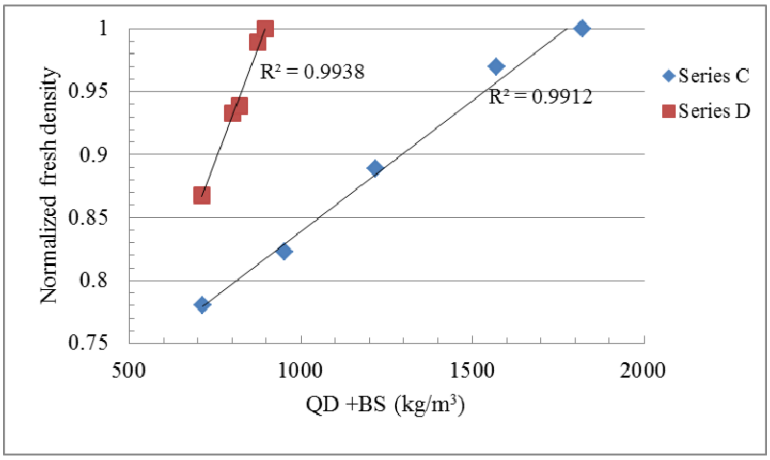

Fig. 1. Relationship between fresh density and QD+BS

Result for compressive strength at 28 days ranged between (10.5-15.9) MPa for series C and between (0.8-2.01) MPa for series D. Range of compressive strength according to BS3921, 1985 [25] is (5-50) MPa. According to Australian standard AS 1225, 1984 [29], range of compressive strength is (4-7) MPa. Singapore Standard SS 103, 1974 [30] recommended that the compressive strength of bricks should range between (5-35) N/mm^2. Compressive strength test was performed on conventional bricks such as clay brick and cement bricks giving compressive strengths of 15 MPa and 12 MPa respectively. It was shown that the fly ash bricks from series C fall within the limits of the standards and approach the results for the conventional bricks. However, fly ash bricks from series D did not fit the standards requirements and recorded lower values as compared with the conventional bricks.

Fly ash as powder material may reduce the compressive strength of the hardened matrix due to reduced pozzolanic reaction [31]. On the other hand, cement content reduction from 10% in series C to merely 5% in series D plays a role in compressive strength reduction since the compressive strength is linearly correlated with cement content [10].

The relationship between compressive strength and quarry dust and billet scale (QD+BS) is shown in Fig. 2. Compressive strength increased with the increase of (QD+BS) and peaked when the ratio of quarry dust and billet scale was 1:1. Hence it is concluded that the optimum compressive strength can be achieved at a quarry dust and billet scale ratio of 1:1. This is explained as billet scale is granular and capable of disintegration upon crushing, hence the strength is reduced when recycled solely in the mix [22]. On the other hand, quarry dust is about 16% fine below 150 µm which fill the voids and hence enhances the compressive strength [33]. A similar trend was observed in Fig. 3 which illustrates the relationship between compressive strength and fly ash and billet scale (FA+BS).

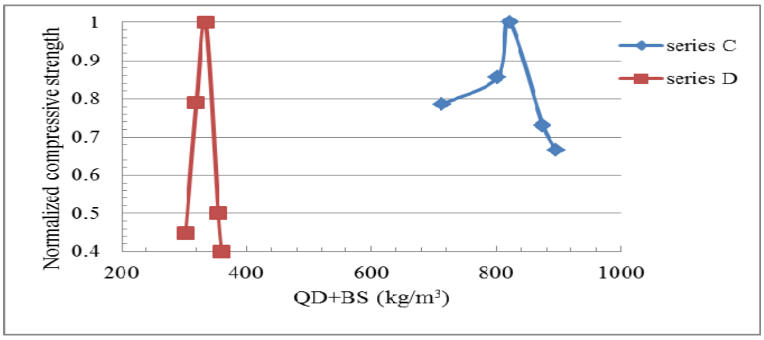

Fig. 2. Relationship between compressive strength and QD+BS

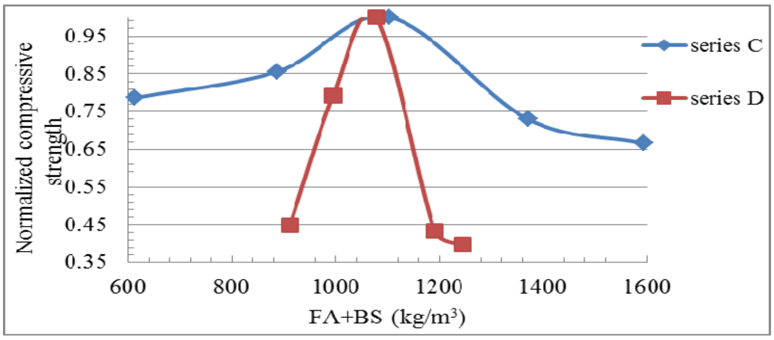

Fig. 3. Relationship between compressive strength and FA+BS

Modulus of rupture ranged between (2.5-3.7) MPa for series C and in (0.13- 0.25) MPa for series D. The minimum permissible limit of modulus of rupture of brick is 0.65MPa [2]. Modulus of rupture test was performed on clay brick and cement brick and the results were 1.6 MPa and 1.8 MPa respectively. Therefore, fly ash bricks produced from series C showed higher values for modulus of rupture. However, fly ash bricks from series D showed less values of modulus of rupture than that of conventional bricks. Modulus of rupture increased with the increase of fly ash and billet scale and optimized at 1:1 fly ash and billet scale as indicated in Fig. 4. Recycling of billet scale solely in the matrix may reduce the modulus of rupture as it may disintegrate due to attrition between the constituent materials during mixing, thereby weakening the bond. However, further tests are necessary to confirm this. Consequently, modulus of rupture will be reduced since it is more sensitive than compressive strength to voids and micro-crack [24]. However, fly ash as powder material may fill the voids in the mix when mixed with billet scale enhancing the modulus of rupture [23]. A similar trend was found in Fig. 5 which illustrates the relationship between modulus of rupture and QD+BS.

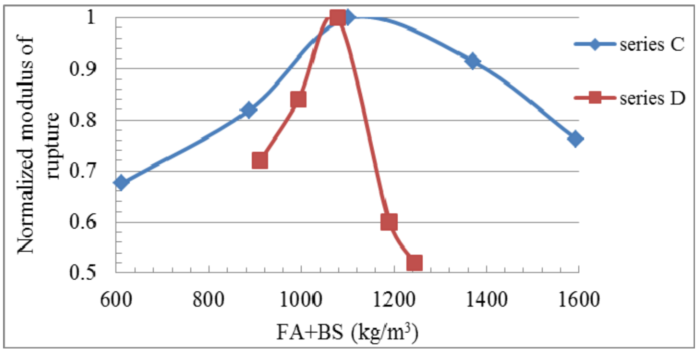

Fig. 4. Relationship between modulus of rupture and FA+BS

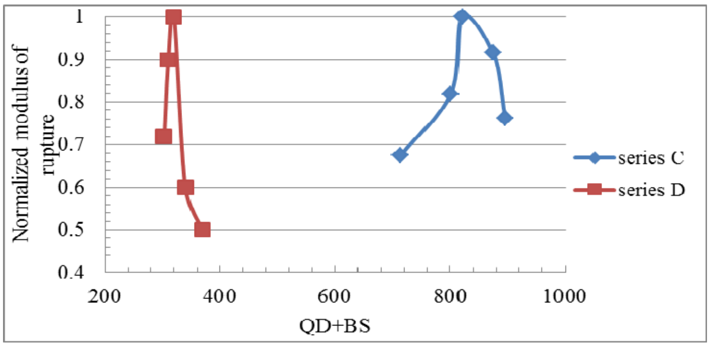

Fig. 5. Relationship between modulus of rupture and QD+BS

Result for UPV at 28 days ranged between (1.8-2.6) km/s for series C and between (0.5-0.8) km/s for series D as shown in Table 3. The acceptable range of UPV of brick is (1.453-2.758) km/s [13]. UPV test was performed on clay brick and cement brick and results were 0.793 km/s and 1.501km/s respectively. It was indicated that UPV for fly ash bricks developed from series C satisfy the requirement standards of UPV for bricks and was higher than conventional bricks, whereas fly ash bricks from series D did not fit the requirements for UPV regulations for bricks. UPV was linearly correlated with fly ash and quarry dust (FA+QD) as demonstrated in Fig. 6. On the one hand, fly ash as powder material reduces the number of micro pores in the mix [31] and then enhances UPV [4]. On the other hand, quarry dust is about 16% of fines below 150µm [32] and plays a role in filling the voids in the matrix, hence UPV will be increased accordingly. However, UPV distinctly decreased with the increase of quarry dust and billet scale (QD+BS) as shown in Fig.7. Adding more billet scale with less quarry dust reduces UPV because billet scale may be disintegrated due to attrition and create voids in the matrix, hence reducing UPV. Further investigation needs to be conducted to confirm this.

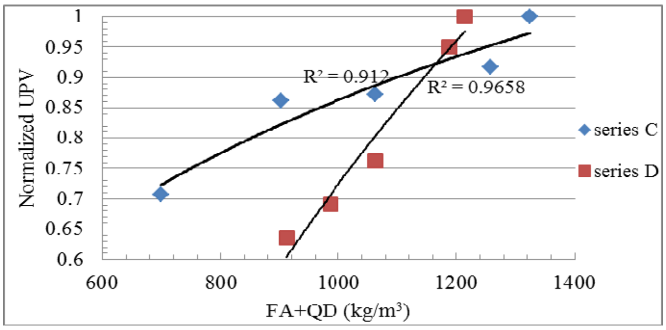

Fig. 6. Relationship between UPV and FA+QD

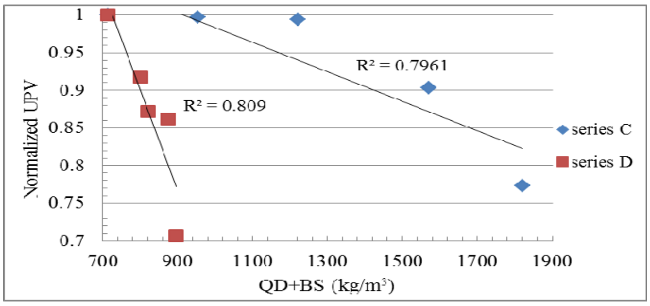

Fig. 7. Relationship between UPV and QD+BS

Results for water absorption of bricks ranged from 15.4% to 19.1 % for series C and were 32% for series D, which was constant along the series as given in Table 3. It is clear that the water absorption increased for series D as compared with series C. It may be attributed to the increase in fly ash content from 40% in series C to 70% in series D. Fly ash is water absorbent material; it increased the water absorption capacity of hardened matrix when recycled in it [2], [4] and[32]. Water absorption peaked for series D at 32 %. It is shown in Table 3 that water absorption increased along series C. Thus, it may be related to the quarry dust fines which are around 16 % of quarry dust having high affinity for water, caused water absorption increment, and created high water demand in the hardened matrix [33], [34]. However, water absorption for series D was consistent along the series since the ratio of quarry dust in series D is small, varying from 25% to 0% which is incapable of increasing the water absorption. Water absorption significantly decreased with the increase of quarry dust and billet scale (QD+BS) for series C as demonstrated in Fig. 8. This is because adding more billet scale with less quarry dust will reduce the water absorption since billet scale is non-water absorbent [35]. The relationship between water absorption and fly ash and quarry dust (FA+QD) is shown in Fig. 9. It is demonstrated that water absorption is linearly correlated with (FA+QD) in series C since both fly ash and quarry dust have high water affinity as mentioned previously. The influence of billet scale and quarry dust in water absorption for D series needs further investigation.

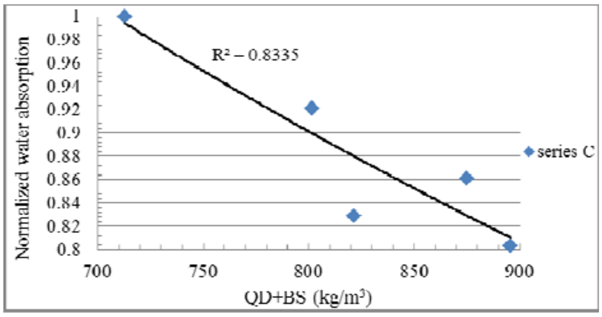

Fig. 8. Relationship between water absorption and QD+BS

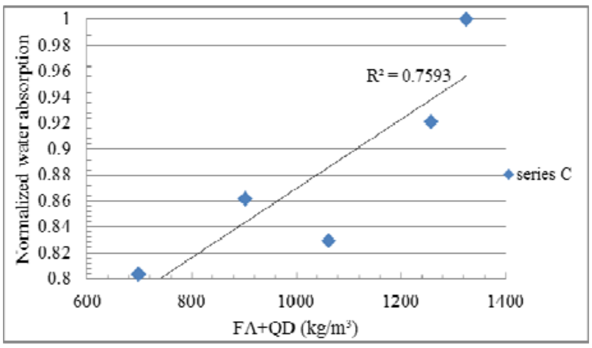

Fig. 9. Relationship between water absorption and FA+QD

Initial rate of suction ranged between (0.55-2.21) kg/m^2.min. Bricks with IRS less than 0.25 kg/m^2.min are considered as low suction bricks whilst bricks with IRS more than 1.5 kg/m^2.min are regarded as high suction bricks [35]. Bricks in series C showed acceptable IRS but the bricks in series D did not fit the requirement of the acceptable limit of IRS and they can be considered as high suction bricks. Efflorescence in this study was investigated in accordance with ASTM C67-07a, 2003 [24]. All the bricks studied in the investigation were found to be non efflorescent.

4. CONCLUSION

Following conclusions can be made from the investigation:

1. Fresh density of fly ash bricks ranged between (1648-2156) kg/m^3 and was linearly correlated with (QD+BS), compressive strength generally ranged between (0.8-15.9) MPa, and modulus of rupture ranged between (0.13-3.7) MPa UPV is linearly correlated with (FA+QD). Water absorption is adversely correlated with (QD+BS).
2. The optimum ratio of constituents of fly ash bricks developed in this study was 1:1 by mass of fly ash: billet scale and 1:1 quarry dust: billet scale by mass for optimum mechanical properties.
3. The mechanical properties of fly ash bricks incorporated with 50% by weight of quarry dust and billet scale were significantly enhanced and showed higher performance than conventional bricks. Therefore, they could be used as an alternative to conventional bricks in the building sector. However, fly ash bricks incorporated with 25% by weight of quarry dust and billet scale did not fit the requirement of the relevant standard. Therefore, they are not safe to be used in place of conventional bricks. It is concluded that recycling industrial wastes such as billet scale and quarry dust in fly ash brick contributed to improving the quality of fly ash bricks produced by the unusual methodology used in this study.

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LIST OF ABBREVIATION

FA	fly ash.
C	cement
BS	billet scale
QD	quarry dust
W	water
w/c	water to Cement ratio
FA+BS	fly ash + billet scale
QD+BS	quarry dust + billet scale

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