Use of sugarcane bagasse ash as brick material

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Application of bio-fuel by-product sugarcane bagasse ash (SBA) as a principal raw material for the manufacturing of bricks was studied. The bricks were developed using the quarry dust (QD) as a replacement to natural river sand and lime (L) as a binder. SBA as a principal raw material was characterized using X-ray fluorescence (XRF), thermo-gravimetric analysis (TGA), X-ray diffraction and scanning electron microscopy (SEM). XRF confirms SBA as a cementitious material. TGA confirms thermal stability till 650°C, whereas SEM monograph shows individual ash with a rough surface and numerous fine pores. Elemental analysis of quarry dust and lime was also carried out using XRF and classic wet test. The physical properties of quarry dust and lime were determined using the laboratory test methods. SBA–QD–L combination bricks were designed and developed in different mix proportions. Physico-mechanical properties of the developed bricks were studied according to recommended standards. The results of the SBA–QD–L bricks were compared with physico-mechanical properties of commercially available burnt clay-and-fly-ash bricks. It was observed that SBA–QD–L bricks are lighter in weight, energy efficient and meet compressive strength requirements of IS 1077:1992. The bricks also serve the purpose of solid waste management and innovative sustainable construction material. The bricks can be used in local construction especially for non-load-bearing walls.

Keywords: Bricks, quarry dust, lime, sugarcane bagasse ash.

DUE to limited availability of natural resources and rapid urbanization, there is a shortfall of conventional building construction materials. On the other hand, energy consumed for the production of conventional building construction materials pollutes the air, water and land. Accumulation of unmanaged agro-waste, especially from the developing countries, has an increased environmental concern. Therefore, development of new technologies to recycle and convert waste materials into reusable materials is important for the protection of the environment and sustainable development of the society. Waste materials, including sugarcane bagasse ash (SBA)[1–3], recycled paper mill waste[4], petroleum effluent treatment plant sludge[5,6], billet scale[7], red mud, fly ash[8], granulated blast furnace slag[9], steel industry dust[10] and sewage sludge[11] were used to manufacture brick and other construction materials. The cementitious binder, fly ash–lime–gypsum (FaL–G) finds extensive application in the manufacturing of building components and materials such as bricks[12], hollow bricks[13] and structural concrete[14]. Attempts were also made to incorporate agro-industrial waste in the production of bricks; for instance, the use of straw, cotton waste[15], rice husk ash[16], limestone dust and wood sawdust[17] and processed waste tea[18]. Thermal conductivity was reduced by the addition of pore-forming agents (waste material) to the bricks before firing[19–21]. The need to conserve traditional building materials that are facing depletion has forced engineers to look for alternative materials. Recycling of such wastes by incorporating them into building materials is a practical solution to the pollution problem[22].

The major pollution problems faced by small-scale process industries are due to the huge amount of solid and sludge waste generation and the limited treatment facilities. The use of waste as the brick material is a sustainable solution to solid waste management; it provides alternative raw material and an additional source of revenue. The raw materials used here are otherwise landfilled and thus add to ever escalating cost of disposal. The burnt sugarcane bagasse residue is commonly known as SBA. The potential production capacity of burnt sugarcane bagasse residue is around 7–8% of total bagasse consumed[23,24]. The resulting CO_2 emissions from bagasse are equal to the amount of CO_2 that the sugarcane absorbs from the atmosphere during its growing phase, which makes the process of co-generation greenhouse gas-neutral[25]. The bricks thus manufactured using these wastes are energy-efficient due to zero emission of the principal raw materials. The present communication focuses on the development of SBA–quarry dust (QD)–lime (L) brick combination which is useful for the sustainable development of the construction industry. The automated brick plant was used for brick manufacturing. Optimal composition of the brick with respect to SBA–QD–L was determined from various proportions by evaluating the properties.

The principle raw material, SBA sample, was collected from M/s Shri Satyasai Oil Industries and Refinery, Nanded, Maharashtra, India. Samples were collected during the cleaning operation of the boilers in the factory. In the boiler, the sugarcane bagasse is burnt at a temperature varying from 240°C to 600°C, depending on the moisture content and feed of the bagasse. The SBA thus obtained is used for making building bricks by mixing with quarry dust and lime in different proportions. Raw lime conforming to Bureau of Indian Standards (BIS), IS 712:1984 was used[26]. Crushed quarry dust was obtained from local crusher plants (Metal Quarry, Nagpur, India).

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Particle size distribution analysis of SBA was carried out using the hydrometer test. Chemical analysis of SBA was done using energy-dispersive X-ray fluorescence spectrometer (XRF PANalytical PW2403 MagiX, The Netherlands). Proximate analysis of SBA was carried out using gravimetric methods, X-ray diffraction (XRD) pattern was recorded on a model XRD-Philips PN-1830 with a scan rate of 2°/min. XRD pattern was recorded in the 2θ range 5–100°. Thermo-gravimetric differential thermal analysis (TG-DTA; Diamond TG/DTA, Perkin Elmer, USA) was carried out to determine the thermal stability. The microanalysis was carried out using field emission gun-scanning electron microscope (FEG-SEM, JSM-7600F, Japan).

There is no consistent definition for quarry fines used throughout the quarrying sector or construction industry. The phrases quarry fines, dusts and wastes are used interchangeably and also refer to materials of different particle size range. Quarry dust comprises materials less than 6 mm in size, generated during the crushing activity of stones. Chemical analysis of quarry dust was done using the energy-dispersive X-ray fluorescence spectrometer. The specific gravity was determined using pycnometer test.

The elemental analysis of as-received lime was carried out using the energy-dispersive X-ray fluorescence spectrometer and classic wet methods. X-ray fluorescence (XRF) is the mandated means of final detection; this method requires a homogenized and powdered sample. Classic wet methods use sophisticated instrument for the final parameter analysis. Most wet methods involve gravimetric measurements that assess changes in weight and volumetric measurement, which assess changes in volume. The specific gravity of lime was determined by the Le Chatelier flask method.

In and around the study area, a questionnaire survey of brick plants was carried out regarding the manufacturing processes, materials and practices. As most of the local manufacturers are producing bricks of size $230 \times 110 \times 80$ mm^3, the same dimension was adopted for production of SBA–QD–L bricks. Fully automated commercial brick plant was used to make the SBA–QD–L building bricks. Mixes of SBA quarry dust and lime with various compositions were prepared. SBA and quarry dust weight percentages in the composition mix varied from 80 to 50 and 0 to 30 respectively with 5% variation. Lime percentage was kept constant for all the compositions (20% wt). Twenty samples for each composition (SBA: QD: L) were prepared. In the mixing process of samples, lime contents and water (0.25–0.32 water to dry mix ratio) were placed in a mixing unit of the automated plant and mixed for around 30 sec. In order to obtain a more homogeneous mix, SBA and quarry dust were later added into the lime slurry and the mixer was operated for 2 min. The freshly prepared mix was fed through a conveyor into the pressing unit. The mix was pressed into moulds till the adjustable pressure reaches up to 20 MPa in pressure gauge. After pressing, the bricks were taken out from the moulds automatically and likewise all samples of brick were cast. All the brick samples were kept for drying for 3 days followed by 7 days continuous wet curing and 7 days sun-drying.

The physico-mechanical tests were carried out on a sun-dried product according to recommended Indian standards. The tests were compressive strength IS 3495 (Part-I): 1992 (ref. 27), water absorption IS 3495 (Part-II): 1992 (ref. 28), efflorescence IS 3495 (Part-III): 1992 (ref. 29) and brick density IS 2185 (Part-I): 1979 (ref. 30). The compressive strength was determined using compression testing machine. For each composition, six samples were tested for compression strength, three samples respectively, for water absorption, efflorescence and dry density test after complete drying, and the average was obtained. The advanced physico-mechanical tests like three-brick masonry prism compressive strength[31], three-brick masonry prism shear bond strength[32] and five-brick masonry prism modified bond wrench strength[33] were also carried out on the optimum brick composition. The flexural strength test was carried on the optimum brick composition according to IS 4860:1996 (ref. 34).

The particle size distribution of as-received SBA sample was carried out without any external grinding. Tables 1 and 2 show the physical characteristics and particle size analysis of SBA respectively. Table 3 shows XRF chemical analysis of the SBA sample compared to ordinary Portland cement (OPC). SBA mainly contains silica (59.50%) and CaO (14.75%). Proximate analysis of SBA is indicated in Table 4. FEG-SEM images (Figure 1) of SBA show individual ash with a rough surface and numerous very fine pores. TGA curve (Figure 2) indicates the SBA sample has been thermally pre-treated and mass loss of 2.75% occurs between 500°C and 650°C. This curve reveals the appearance of three distinct mass-loss regions. The first loss (2.176%), between 30°C and 500°C, is attributed to the removal of superficial water molecules or water from the solid pores. At a second mass loss, the

Table 1. Physical characterization

Properties	Specific gravity	Mean particle size, D60 (μm)
Sugarcane bagasse ash (SBA)	2.4	45.0
Quarry dust (QD)	2.7	–
Lime (L)	3.2	–
Ordinary Portland cement (OPC)	3.0	16.9

Table 2. Particle size distribution analysis of SBA

Distribution (%)	Gravel	Sand	Silt	Clay
SBA	0.61	75.15	23.04	1.20

Table 3. XRF chemical analysis of SBA

Elements (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	Reference
SBA	59.50	2.40	3.34	14.75	2.11	0.92	8.90	–
QD	49.10	14.71	13.85	8.48	4.49	0.09	1.84	–
Lime	5.80	1.83	0.62	67.54	13.93	–	7.43	–
OPC	21.00	6.00	3.50	65.00	0.70	1.50	4.00	40

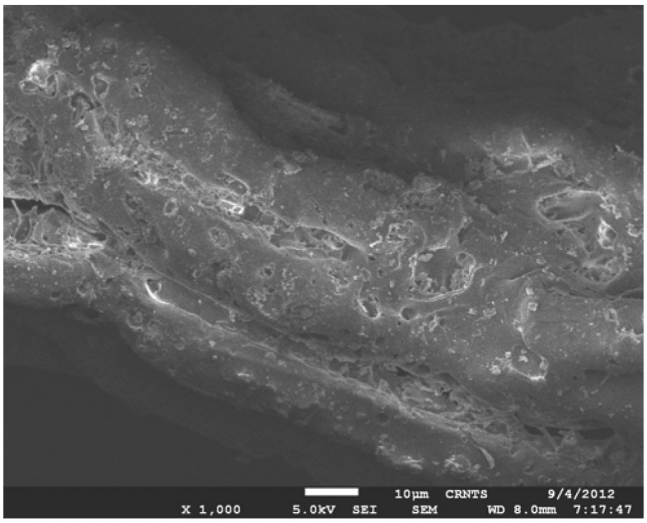

Figure 1. Particle image (SEM) of virgin sugarcane bagasse ash (SBA).

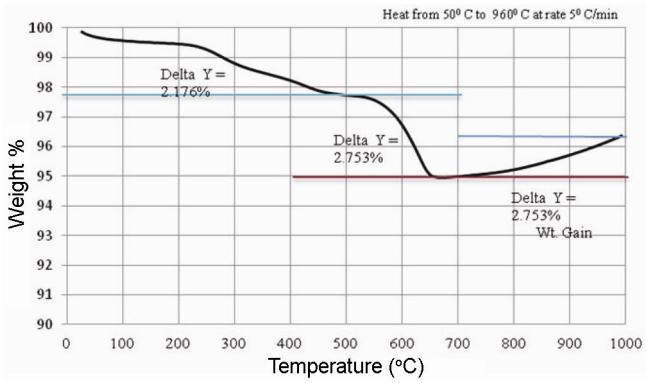

Figure 2. Thermo-gravimetric analysis of SBA.

material gets thermally degraded sintered. The diffraction pattern of virgin SBA (Figure 3) shows that the intensity peak between 20° and 30°, characteristic of amorphous silica, decreases with hydration, which suggests its pozzolanic/cementitious activity. The nature of materials was not modified even after addition of lime in SBA.

The physical characterization of collected sample of quarry dust was carried out without any external grinding. Table 1 shows the physical characteristics of the quarry dust. Table 3 shows XRF chemical analysis of the quarry dust sample. QD mainly contains silica (59.50), Al_2O_3 (14.71), Fe_2O_3 (13.85), CaO (8.48%) and MgO (4.49).

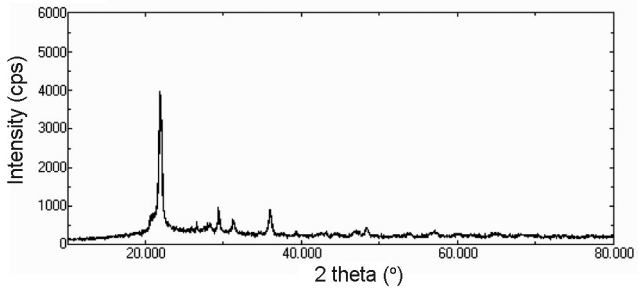

Figure 3. X-ray diffraction pattern of virgin SBA.

The specific gravity of as-received lime was determined. Table 1 shows the specific gravity of lime. Table 3 shows the chemical analysis of lime. Lime mainly contains CaO (67.54%) and MgO (13.93%).

Figure 4 shows the brick manufacturing process of the automated brick plant. The bricks for each composition were manufactured by weighing batch of 50 kg, including all ingredients as mentioned in Table 5. The physico-mechanical tests (Table 6) such as weight, dry density, water absorption, efflorescence and compressive strength were carried out for the developed SBA–QD–L building bricks of all composition and compared with the burnt clay and fly ash–cement bricks available commercially in and around the study area. It was observed that the building bricks made for all other compositions, except trial no. 1, met the compressive strength requirement according to IS 1077:1992 (ref. 35). Hence the composition of trial no. 1 was not considered for further analysis. Apart from the physico-mechanical testing, energy consumed during production of SBA–QD–L building bricks and fly ash brick was determined from the incorporated lime weight percentage and cement weight percentage, excluding the transportation distance of raw materials[36], whereas energy consumption of clay brick was estimated on the basis of consumed quantum of fuel required for firing the kiln[37]. The results obtained are given in Table 7. The optimal compostion of the bricks was decided on the basis of obtained maximum compressive strength. The advanced physico-mechanical properties (Table 8) such as flexural strength, combined compressive strength of three-brick masonry prism, shear bond strength of three-brick masonry prism and modified bond wrench test of five-brick masonry prism were determined for the optimal brick composition and compared with the same properties of burnt clay and fly ash–cement bricks. It was

Figure 4. Brick-making process. ***a***, Weighing and batching; ***b***, Feeding of raw material; ***c***, Mixing of material; ***d***, Mixing unit to hopper; ***e***, Hopper to conveyor; ***f***, Conveyor to brick mould; ***g***, Stacking of wet brick; ***h***, Final brick after curing.

Table 4. Proximate analysis of SBA

Weight (g)	Moisture (%)	Ash (%)	Volatile materials (%)	Free carbon (%)
500	7.10	51.30	40.80	0.80

observed that the flexural strength of the commercially available fly ash bricks was maximum (81.85 kg/cm^2) whereas the SBA–QD–L bricks also met the minimum requirement of Class II bricks (70 kg/cm^2) for flexural strength according to IS 4860:1996. The combined compressive strength of SBA–QD–L bricks was 6.84 MPa, which is approximately equal to the combined compressive strength of commercially available fly ash brick (7.55 MPa) and double the combined compressive strength of commercially available burnt clay bricks. The shear bond strength of SBA bricks was 3.59 kg/cm^2, which is more than the shear bond strength of commercially available fly ash (3.24 kg/cm^2) and burnt clay (3.18 kg/cm^2) bricks. Similarly, the modified bond wrench strength of SBA–QD–L bricks was 2.37 kg/cm^2, which is again more than that of commercially available fly ash (1.27 kg/cm^2) and burnt clay (0.98 kg/cm^2) bricks. Figure 5 shows three-brick and five-brick masonry prism for compressive strength, shear bond and flexural bond test. Figures 6–8 show the test arrangement for flexural strength, shear bond test and modified bond wrench strength test respectively.

The common parameter required in utilizing any material as supplementary cementitious material, mineral admixture or pozzolana depends on the proportion of silica in its by-product[38]. The XRF elemental composition (SiO_2–59.50%) and XRD pattern of amorphous silica show suitability of SBA as cementitious/pozzolanic material. FEG–SEM microstructure image shows the rough surface of SBA with numerous irregular pores, which provide significant binding effect responsible for the compressive strength when mixed with cement and quarry dust. Pores present on the surface hold water inside, which leads to higher water absorption of the developed bricks compared to commercially available fly ash bricks. Physical characterization of SBA shows lower specific gravity than the OPC and quarry dust present in the building bricks, making the bricks lighter in weight. Table 7 shows that the SBA bricks have lower density compared to conventional burnt clay and fly ash bricks. Particle size analysis indicates that 75% of SBA is distributed in the range of fine aggregate which shows the potential of SBA as replacement of fine aggregate material. The QD below 6 mm was used as replacement for fine aggregates. Characterization of QD shows the presence of crystalline silica (59.10%), which imparts compressive strength in the SBA–QD–L building brick. The black colour of quarry dust is due to the presence of Fe_2O_3 (13.85%). The characterization of lime shows the presence of CaO (67.54%) and MgO (13.93%). The CaO present in lime reacts with the amorphous silica present in SBA and imparts adequate binding to the SBA–QD–L bricks. The tests have been carried out in accordance with Indian standards. The compressive strength of the brick samples was determined using the compression testing machine. Various compositions of SBA–QD–L bricks show average compressive strength of 3.69–6.59 MPa compared to conventional burnt clay brick of 3.5 MPa. The average water absorption for various compositions of SBA–QD–L bricks was observed (~20%) to be high compared to fly ash–cement and burnt clay bricks, whereas both the compressive strength and water absorption of SBA–QD–L bricks met the minimum requirement of IS 1077:1992. TGA curve indicates that the bricks made out of SBA can withstand temperature up to 650°C.

Table 5. Details of composition

	20% Lime (constant)				Composition per batch of 50 kg		
Trial no.	SBA (%)	QD (%)	Lime (%)	Total (%)	SBA (kg)	QD (kg)	Lime (kg)
1	80	0	20	100	40.00	0.00	10.00
2	75	5	20	100	37.50	2.50	10.00
3	70	10	20	100	35.00	5.00	10.00
4	65	15	20	100	32.50	7.50	10.00
5	60	20	20	100	30.00	10.00	10.00
6	55	25	20	100	27.50	12.50	10.00
7	50	30	20	100	25.00	15.00	10.00

Table 6. Physico-mechanical properties of SBA–QD–L bricks

Trial no.	Avg dry wt (kg)	Avg wet wt (kg)	Avg water absorption (%)	Avg field density (kg/m^3)	Avg. compressive strength (MPa)	Efflorescence
1	2.127	2.526	19.70	1051	3.29	Nil
2	2.152	2.574	19.61	1063	3.69	Nil
3	2.273	2.727	19.97	1123	3.82	Nil
4	2.312	2.778	20.16	1142	4.08	Nil
5	2.417	2.894	19.74	1194	4.32	Nil
6	2.567	3.097	20.65	1268	5.20	Nil
7	2.805	3.375	20.32	1386	6.59	Nil

Table 7. Embodied energy and physico-mechanical properties of SBA–QD–L brick versus commercially available burnt clay and fly ash–cement bricks

	Material Composition (%; 230 × 110 × 80 mm^3)												
Type of brick	Clay	Fly ash	SBA	Sand	QD	Cement	Lime	Weight (kg)	Density (kg/m^3)	Compressive strength (MPa)	Water absorption (%)	Energy per 1000 bricks equivalent (GJ)	Brick energy (%)
Burnt clay	90	–	–	10	–	–	–	3.250	1600	3.50	15	4.250	100
Fly ash	–	40	–	50	–	10	–	3.640	1800	6.50	10	2.366	56
SBA–QD–L (Trail 7)	–	–	50	–	30	–	20	2.805	1386	6.59	~20	2.244	53
SBA–QD–L (Trial 6)	–	–	55	–	25	–	20	2.567	1238	5.20	~20	2.054	48
SBA–QD–L (Trial 5)	–	–	60	–	20	–	20	2.417	1194	4.32	~20	1.934	45
SBA–QD–L (Trial 4)	–	–	65	–	15	–	20	2.312	1142	4.08	~20	1.850	44
SBA–QD–L (Trial 3)	–	–	70	–	10	–	20	2.273	1123	3.82	~20	1.818	43
SBA–QD–L (Trial 2)	–	–	75	–	5	–	20	2.152	1063	3.69	~20	1.722	41

Table 8. Advanced physico-mechanical properties of SBA–QD–L brick versus commercially available burnt clay and fly ash–cement bricks

Type of brick	Flexural strength (kg/cm^2)	Combined compressive strength (MPa)	Shear bond strength (kg/cm^2)	Modified bond wrench test (kg/cm^2)	Remarks
Burnt clay	60.82	3.53	3.18	0.98	Commercial brick
Fly ash	81.85	7.55	3.24	1.27	Commercial brick
SBA–QD–L (Trail 7)	72.18	6.84	3.59	2.37	Developed brick

A negative sign of slope in Figure 9 indicates that the density of SBA–QD–L bricks is inversely proportional to the weight percentage of SBA in the mix. As the weight percentage of SBA present in the mix increases, the density of the brick decreases. It can be observed from Figure 10 that the density of SBA–QD–L bricks is directly

proportional to their compressive strength, i.e. as the density of the brick increases, the compressive strength increases. Figure 11 shows the relation between density and equivalent energy per 1000 bricks. The density and equivalent energy are directly proportional to each other.

Figure 5. Photograph showing three-brick and five-brick prism for compressive strength, shear bond and flexural bond test.

Figure 6. Flexural strength test.

Figure 7. Shear bond test.

Hence the compressive strength and equivalent energy are both inversely proportional to the weight percentage of SBA present in the mix. As the weight percentage of SBA in the mix increases, the compressive strength decreases with a decrease in the equivalent energy consumption. The optimum composition of any building brick/masonry material is usually decided on the basis of high compressive strength and lowest equivalent energy consumption in manufacturing. From an engineering aspect, physico-mechanical properties like compressive

Figure 8. Modified bond wrench strength test.

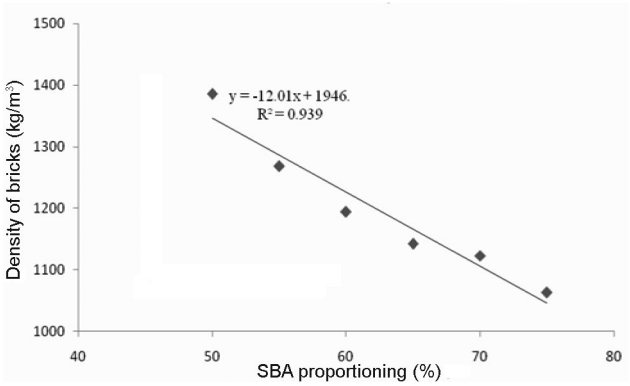

Figure 9. Percentage of SBA in mix versus density of bricks.

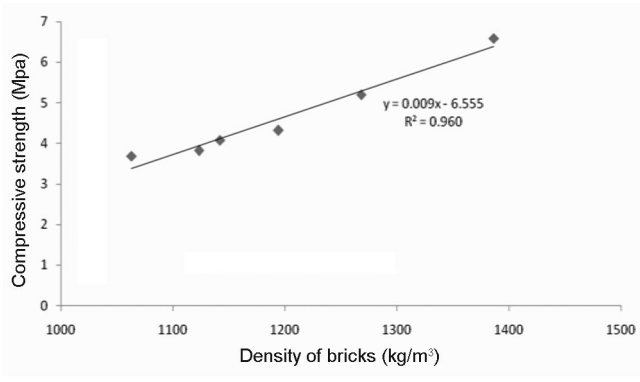

Figure 10. Density versus compressive strength of SBA–QD–L bricks.

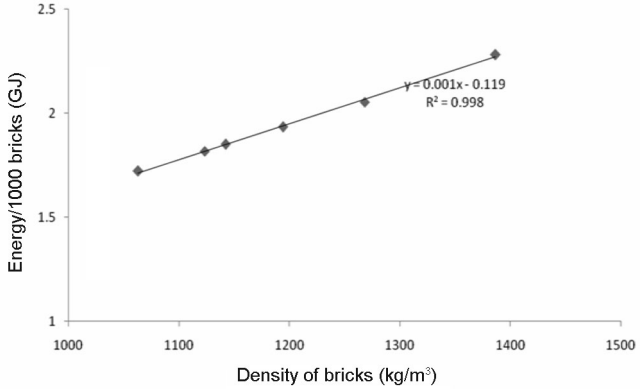

Figure 11. Density versus equivalent energy/1000 bricks.

strength and water absorption play a significant role in the selection of masonry units. From the different compositions of SBA–QD–L bricks, trial no. 7 (SBA: QD : L :: 50 : 30 : 20) shows compressive strength of 6.59 MPa, which is 1.4% and 88.3% more than that of commercially available fly ash–cement bricks and burnt clay bricks. Considering the energy aspect, trial no. 7 of SBA–QD–L bricks consumes equivalent energy of 2.282 GJ, which is maximum among SBA–QD–L brick trials, but 6% and 50% less than the energy consumption of fly ash–cement and conventional burnt clay bricks respectively. Hence the composition in trial no. 7 of SBA–QD–L bricks is optimum among all compositions of SBA–QD–L bricks. From the obtained results of advanced physico-mechanical tests, it is also clear that the masonry bonding with SBA–QD–L bricks is stronger compared to commercially available fly ash and burnt clay bricks.

The bricks prepared in commercial plants using SBA, quarry dust and lime meet all the requirements as described in the Indian standard. The recycling of solid wastes into sustainable, energy-efficient construction materials is the only viable solution for the problem of environmental concerns and natural resources conservation for future generations. The SBA–QD–L combination provided a lighter, new brick material. The bricks with 20% addition of lime to SBA and quarry dust exhibited a compressive strength of up to 6.59 MPa, which is almost double that of the conventional clay bricks (3.5 MPa). The optimum composition of SBA–QD–L brick is 15% and 25% lighter than the commercially available burnt clay and fly ash–cement bricks respectively. It was also observed that masonry bonding of SBA–QD–L bricks is stronger compared to commercially available fly ash and burnt clay bricks. Manufacturing process of SBA–QD–L bricks results in 50% and 6% reduction in energy consumption over the commercially available burnt clay and fly ash–cement building bricks. The results showed significant potential and scope for utilizing the agricultural solid waste for manufacturing of building materials that are energy-efficient, lightweight and sustainable.

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