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Research paper

Developing Lightweight Clay Brick Units Using Waste Materials

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Abstract

The study aims to develop specific lightweight brick units using locally available clay of traditional burned brick units publically used in the south of Iraq using solid wastes. Throughout the study, chemically inaction and difficult to recycling wastes was considered, they were classified into Poly Vinyl Chloride (PVC) and hardwood solid waste which is used to upgrade lightweight characteristic and maintenance required bricks' characteristics and to be introduced as a smart technical way to recycling solid waste. Solid waste is introduced as additive materials and firing fuel enhanced coefficient in the concept of its energy recovery useful in the production process. An experimental program was considered including five main series of samples, tested and analyzed in the scope of clay bricks units and in the scope of lightweight constructional related to aerated wall construction units. The verified compressive strengths and other properties of tested specimens were found to confirm bricks class C except for specimens of hardwood of 10% although it assigns less dry density (1.18 g/cm3). In general, as light weight bricks, the characteristics of developed units was found to be within the permitted limits of ASTM C 1389.

Keywords: *Clay bricks; Compressive strength; Hardwood, ; Lightweight; Poly Vinyl Chloride; Solid waste.*

1. Introduction

In Iraq, clay brick units production belongs to ancient decades especially in middle and southern regions, the urgency of housing need beside simple techniques of manufacturing and requirement lead to developing this industry with time[1], Plate 1. Shows customary widely spread bricks factory in the south of Iraq.
Clay Bricks are the most common types of bricks because of availability of raw materials, low cost of production, appropriate to bear the forces, heat isolation, resistance to fire and atmospheric changes. The fired product is a ceramic composed pronominally of Silica (SiO_2 (55-65) %, Alumina Al_2O_2 (10-25) % , another 25 %. The common raw materials used for manufacturing bricks could be classified as fine soils which its properties are influenced mainly by clay and silt size particles, clay is a type of soil possessing cohesion and plasticity which normally consists of particles in both the clay size and silt size ranges.
The urgent demand of reducing solid waste environmental dangerous with investing of involving of incineration energy recovery within required firing fuel of manufacturing encourage investigation reproducibility of light weight clay bricks of solid waste materials of significant specific heat capacity. Beside recycling benefit and as pure clay is not fit for the bricks production, solid waste as impurity materials developing paste don't shrink during the drying process and help to prevent cracks of mud in the cases of drying.
The traditional manufacture process is characteristic by controlling heat energy supplying where units fired to a temperature in the range 900 to 1200 co for several days. Solid waste could be severed from various physicals mode with different mechanical properties during firing depending on heat quantities provided during unique firing period. An attempt to applying firing heat by separated period is presented to study optimum firing time conjugated with best units properties.
As lightweight brick units are developing high thermal insulating material with acceptable density and compressive strength, they could be smart construction alternative to be used as brickwork in many construction situations. In 2008, Perapong Tekasakul [2] studied rice husk ash effect on lightweight clay brick characteristics. Various mass ratios of additive from 10-50% were mixed with in raw clay. Higher additive required a higher water content in order to ensure the proper dry density, up to 30% was found to meet standards limits. In 2017, L. Arun Raja[3] investigated using expanded perlite for brick reproducibility as the main material. Parameters such as unit weight, mechanical strength were determined and optimized. They were tested for water absorption, efflorescence, compressive strength, density and sound test as per Indian Standards. Its thermal, acoustic insulation and lightness properties make perlite an excellent option to be utilities as lightweight aggregate in brick production.
Construction developing aim of developing best construction materials alternatives is enhancing construction materials researches. In this study light weight fired clay bricks is developed using two types of solid waste material (polyvinylchloride, and hardwood) as additives so as for upgrading lightweight characteristic and maintenance required constructional properties like compressive strength, water content and efflorescence in addition to raw materials plasticity and to introduce as smart technical way to recycling solid waste in the concept of energy recovery recommended in management of solid waste strategy.

a.Mining

b.Tunnel Kiln

c.Firing Chamber

Plate 1: Customary bricks factory (widely spread out over south of Iraq)

2. Soil Plasticity Characteristics

The proper soil of bricks manufacturing in Iraq consists of 13% pure clay, 17% of fine sand, 45% green silt, 8% coarse sand where pure clay is not fit for the bricks production since other materials help to build a paste doesn't shrink during drying process [4] and as a key property of the clay in relation to brick manufacture is its moisture content at the time of processing, the fine soil with waste additives would be investigated to show plasticity characteristic as well as proper mixing water content. The term plasticity describing the ability of a soil to undergo unrecoverable deformation without cracking or crumbling. The liquid, plastic limits and liquidity, plasticity indexes of fine soil were analyzed by Atterberg limit using British standard specification BS1377 [5]. Plasticity chat of British standard BS 5390 [6] use to classify used fine soil (particle size ≤600 μm) before and after having waste additives.

3. Management of Solid Waste

Brick manufacturing uses readily available raw materials, including some waste products. The primary ingredient, clay, has been termed an "abundant resource" by many authorities including the American Institute of Architects [7], confirming that depletion of clay is not a concern. Nonhazardous waste products from other industries are sometimes used. Examples include using bottom- and fly-ash from coal-fired generators, using other ceramic materials as grog, using lubricants derived from processing organic materials in the forming of brick, and using sawdust as a burnout material [8]. Waste management hierarchy consider as a key element of integrated solid waste management [9]. Although waste incineration not the best option of waste management, but incineration with energy recovery presents an acceptable option to manage solid waste, as shown in Fig.1. Table 1. summarized adopted solid waste characteristics.

Figure 1: Hierarch of management of Solid waste

Table 1: Used solid waste specific characteristics

No.	**Waste type**	**Designation**	**Upper limit of particles fineness μm**	**Specific heat, Cp J/kg.K**	**Density, ρ Kg/m3**
1	Polyvinylchloride (PVC) [10]	Wpvc	300	1050	1600
2	Hardwood [11]	Whw	300	1255	255

a. Traditional waste

b. Polyvinylchloride solid waste, Wpvc

c. Hardwood solid waste, W_{hw}
Plate 1: Solid waste

4. Experimental Methodology

4.1 Sample Preparation

50x50x50 mm fired clay samples made with a composite mixture of clay and solid waste powder. It is poured, strongly compacted, then, it is dried for 20 days before burning by KSL 1100 X burning furnace of 900 co, Plate 2. The materials proportions tabulated in Table .2, five main groups considered, the first to be control of clay without any solid waste, the second and third group involved hardwood solid waste by 5 % and 10% as powder of clay mass while fourth and fifth groups involved PVC solid waste by 5 % and 10% as powder of clay mass. The main characteristics of used KSL-1100X High Temperature Muffle Furnace[12] listed in Table .3. Iraqi specification No. 25 [13] used to determine compressive strength, dry density, water content and efflorescence of developed units, ELE 20 ton compression machine used to tested specimens for compressibility.

a. During peak temperature

b. During cooling

c. Fired specimens

Plate 2: The firing of tested specimens

Table 2: Raw materials proportions

No.	Group	Specimens designation	Clay (%)	W_{hw}(%)	W_{PVC} (%)	Water content (%)	Firing period (hrs)
1		A2		-	-		2
2		A4		-	-		4
3	G1	A6	100	-	-	21.7	6
4		A8		-	-		8
5		A10		-	-		10
6	G2	B#4	95	5	-	23	4
7		B2		10	-		2
8		B4		10	-		4
9	G3	B6	90	10	-	25.9	6
10		B8		10	-		8
11		B10		10	-		10
12	G4	C#4	95	-	5	23	4
13		C2		-	10		2
14		C4		-	10		4
15	G5	C6	90	-	10	21.7	6
16		C8		-	10		8
17		C10		-	10		10

Table 3: The main characteristics of used KSL-1100X High Temperature Muffle Furnace

Item	Specifics
Operating Voltage:	220V AC±10% Single Phase 50/60 Hz
Power:	3500W
Operation Temperature Range:	$100\sim1100^0$C, Maximum Temperature is 1200 ^{0}C
Heating Rate:	≤ 400C /min, Max. Heating Rate is 50 0C /min
Chamber Cubic Capacity:	438 cubic inch , 7.2 Liter

5. Results and Discussion

Firing time, Compressive strength, dry density, specific strength, efflorescence, water absorption, and Atterberg limits were investigated then discussed and analyzed.

Firing time effect on compressive strength, dry density, and water absorption were tabulated in Table .4. The result pointed that firing for 4 hrs. exhibited an optimum firing period for all burned samples, the negative response for extreme firing energy relate to higher porosity formed where dry density decrease with increase firing time as residual of additive waste entirely leave voided between solid particle within the ceramic structure of the burned unit. Firing for two hrs don't satisfy optimum specific compressive strength for all groups, although the water absorption and dry density have gotten proper values.

Figure 2. shows the response of compressive strength developing in term of burning period, the same behavior trend had assigned for all group which indicated negative effect beyond the firing of 4hrs. As dropping of compressive strength related to the effect of regime heat capacity supplied on chemical and physical transformation degree of waste additives within particles structure of fired unit, an optimum the firing period associated to the impurity of raw materials could be assigned for each mass production.

Table 4: The Effect of Firing Time

No.	specimens designation	compressive strength (MPa)	Specific strength*	water absorption (%)	Dry Density (g/cm^3)
1	A2	18.75	8.15	21.95	2.3
2	A4	18.18	11.36	23.53	1.6
3	A6	15.5	10.53	24.6	1.52
4	A8	11.2	6.22	25.71	1.43
5	A10	8.9	5.89	26	1.51
6	B#4	8.91	6.19	25.93	1.44
7	B2	4.25	2.76	40	1.54
8	B4	5.68	4.81	35.71	1.18
9	B6	4.44	4.44	35	1
10	B8	3.56	3.12	35	1.14
11	B10	3.5	2.8	35	1.25
12	C#4	12.28	9.25	21.5	1.327
13	C2	13.82	9.8	26.67	1.41
14	C4	16.05	12.54	24.24	1.28
15	C6	12.05	9.56	22.8	1.26
16	C8	8.21	6.67	21.43	1.23
17	C10	6.43	5.31	21	1.21

** Specific strength introduced throughout this study as compressive strength per dry bulk density*

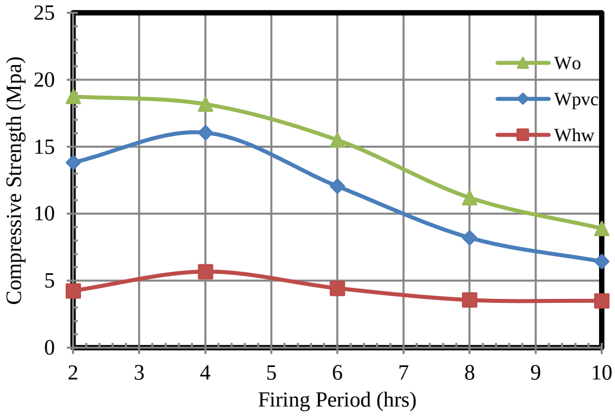

Fig. 2: Compressive strength verse firing period

Water absorption variation in term of firing time shows in Figure.3, burned units produced without waste materials (Wo) exhibited increasing absorption water with firing time, inversed behavior is noted for unit included waste additives where the absorption tends to decrease with firing time.

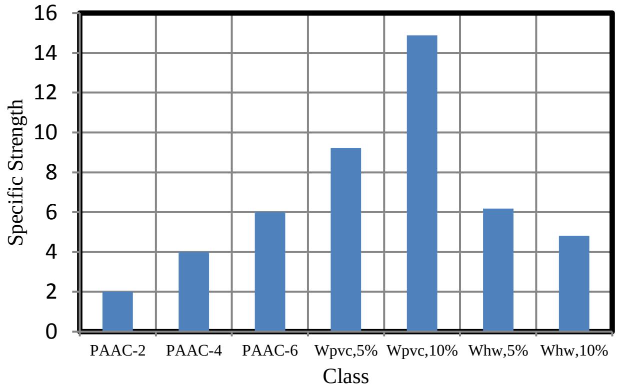

Fig. 4: Specific strength verse solid waste ratio of developed specimens in comparison with traditional classes

Compressive strength as a function of the various ratio of different solid waste shows in Fig. 5. The specimens of PVC waste (W_{pvc}) depicted best strength improvement as waste ratio changed from 5% to 10% where corresponding ratio variation of hardwood waste (W_{hw}) indicated strength dropping, this variation could be related to effect of used waste and its firing response on crystallization structure formed during firing which affected by impurity of raw materials. Dry density as a function of the various ratio of different solid waste shows in Fig. 6. As used waste materials increase, the corresponding density decrease, hardwood waste assign high effect on density.

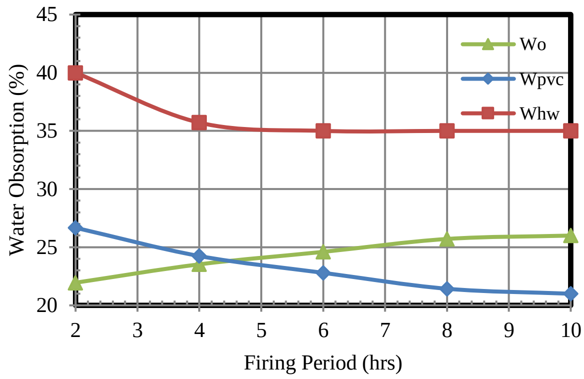

Fig. 3: Water Absorption verse Firing period

ASTM C 1389 [14] specification adopted for comparison in the scope of light weight masonry unit, while Iraqi specification (25/1988) [13] adopted for comparison in the scope of traditionally used clay bricks, Table 5. included these comparisons. Developed unit exhibited high compressive strength and conform to limits assigned by ASTM except for unit of 10% of hardwood waste which is out of PAAC-6 limit, plastic waste as an additive of 10% was the higher improvement while hardwood of 10% was the less one. The compressive strength of tested specimens verified in scope of Iraqi specification found to be confirmed to Iraqi bricks class C except for specimens of hardwood of 10% although it assigns less dry density (1.18 g/cm3). In general, as light weight units, the developed units within permitted limit of ASTM relate to Aerated Concrete (PAAC) Wall Construction Units. The specific strength which is introduced as a strength unit per density shows in Fig.4.

Table 5: Comparison of Strength and Specific Strength with ASTM and Iraqi Specification

Type	PAAC [14]			Clay bricks [13]			Developed light weight clay bricks			
Class	PAAC-2	PAAC-4	PAAC-6	A	B	C	W_{pvc}, 5%	W_{pvc},10%	W_{hw}, 5%	W_{hw},10%
Compressive strength (MPa)	2	4	6	16	11	7	12.28	16.05	8.91	5.68
Dry density (g/cm3)	0.4	0.5	0.6		1.9*		1.33	1.28	1.44	1.18
Specific strength	5	8	10	8.4	5.8	3.7	9.23	14.88	6.19	4.81

***** Iraqi specification does not indicate clear criteria for bricks dry density, the assigned limit present an average value had been gotten by laboratory tests.

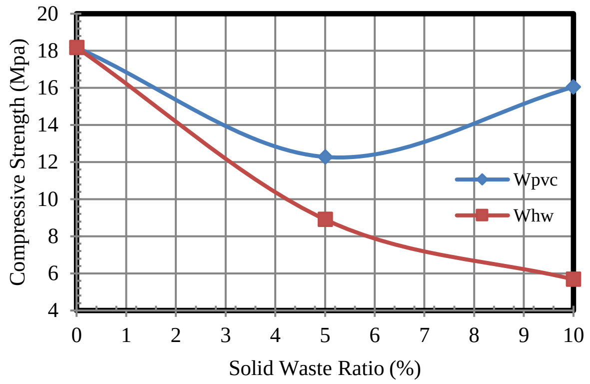

Fig. 5: The compressive strength verse various ratio of different solid waste

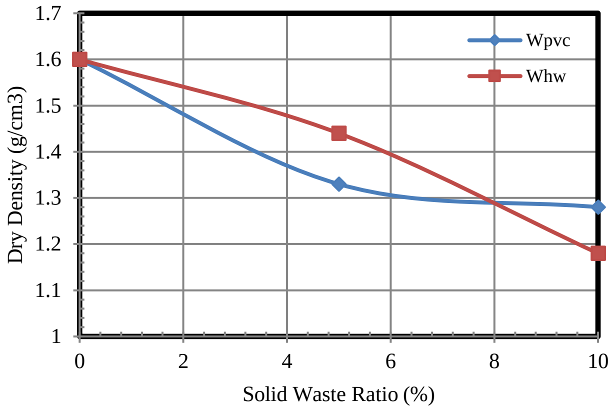

Fig. 6: Dry density verse solid waste ratio

Table 6. assigned Iraqi specification limits of efflorescence and water absorption as well as corresponding properties values of developed specimens, the test observation and results depicted that the efflorescence of tested specimens within customary specification of class B and C of recognized Iraqi bricks while over dosage of hardwood waste (W_{hw},10%) affect water absorption, regime value had been assigned (35.71%). Adsorption of water due to the surface forces on waste particles may be associated with assigned plastic behavior.

Figure 7. Clearly indicated efflorescence variation as a function of solid waste additive type (W_{pvc}, W_{hw}) and them dosage (5%, 10%). It is worth to mention that, lightweight construction unit developing so as to upgrade their thermal insulation, specific strength, dead load reduction and it could be utilized away from moisture movement caused traditional efflorescence problem.

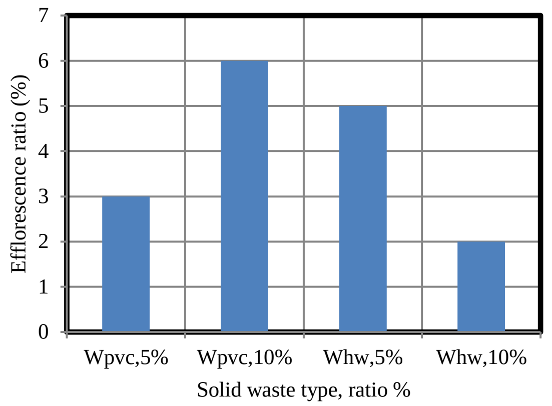

Fig. 7: Efflorescence verse Solid Waste ratio

Plasticity is an important property in the manufacturing process of clay bricks which effect compressive strength. Table 7. shows soil characteristic with a basic plastic description using the plastic chart. The data clearly show that the used waste maintained proper plasticity characteristic of clay soil, the basic classification equivalent to clayey silt soil of low plasticity except for that of high dosage of hardwood powder (10%), its plastic behaviour will be equivalent to pure clay soil which is not fit for clay brick due to drying shrinkage of prepared sample previous firing operation. Plasticity maintenance assigned is due to the presence of waste particles in the mixture. The space between such particles is very small in size with the result that water is held at negative pressure due to developing capillary tension. Cohesion could be produced between the particles, allowing the raw material to be deformed.

Table 6: Efflorescence and Water Absorption in the Scope of Iraqi Specification

Type	Clay bricks			Developed light weight clay bricks			
Class	A	B	C	W_{pvc}, 5%	W_{pvc},10%	W_{hw}, 5%	W_{hw},10%
Efflorescence	(0-10) %	(10-50) %	(>50)	3	6	5	2
Water absorption (%)	22	26	28	21.5	24.24	25.93	35.71

Table 7: Plastic Characteristics

No.	Group	Clay (%)	W_{hw} (%)	W_{PVC} (%)	Atterberg limits [4]				Soil Classification [5]
					Liquid limit L.L	Plastic limit P.L	Plastic Index I.P	Liquidity Index I.L	
1	G1	100	-	-	12.5	5.3	7.2	16.4	clayey silt soil of low plasticity
2	G2	95	5	-	12.6	5.5	7.1	17.5	clayey silt soil of low plasticity
3	G3	90	10	-	15.05	6.8	8.25	19.1	clay soil of low plasticity
4	G4	95	-	5	12.15	5.1	7.05	17.9	clayey silt soil of low plasticity

5	G5	90	-	10	11.8	4.8	7	16.9	clayey silt soil of low plasticity

6. Conclusions

The main conclusions depended on the exploration analysis could be :

1- For specified used raw materials, firing for 4 hrs exhibited an optimum firing period for all burned samples, the negative response for extreme firing energy (firing beyond 4 hrs) relate to higher porosity formed where dry density decrease with increase firing time as residual of additive waste entirely leave voided between solid particle within ceramic structure of burned unit.

2- As for dropping of compressive strength related to the effect of regime heat capacity supplied on chemical and physical transformation degree of waste additives within particles structure of the fired unit, an optimum firing period associated to the impurity of raw materials could be assigned for each mass production.

3- The compressive strength of tested specimens verified in the scope of Iraqi specification (25/1988) found to be confirmed to bricks class C except for specimens of hardwood waste of 10% although it assigns less dry density (1.18 g/cm^3).

4- As a lightweight brick, the developed units within permitted limit of ASTM C 1389 relate to aerated wall construction units with acceptable compressive strength, unit weight and specific strength and could be smart construction alternative to be used as brickwork in many construction situations.

5- The specimens of PVC waste (W_{pvc}) depicted best strength improvement as waste ratio changed from 5% to 10% where corresponding ratio variation of hardwood waste (W_{hw}) indicated strength dropping, this variation could be related to effect of used waste and its firing response on crystallization structure formed during firing which affected by impurity of raw materials.

6- The efflorescence of tested specimens within the customary specification of class B and C of recognized Iraqi bricks while over dosage of hardwood waste (W_{hw},10%) affect water absorption, regime value had been assigned (35.71%)

7- The used waste maintained proper plasticity characteristic of clay soil, the basic classification equivalent to clayey silt soil of low plasticity except for that of high dosage of hardwood powder (10%), its plastic behavior will be equivalent to pure clay soil which is not fit for clay brick due to drying shrinkage of prepared sample previous firing operation.

8- Plasticity maintenance assigned is due to the presence of waste particles in mixture. The space between such particles is very small in size with the result that water is held at negative pressure due to developing capillary tension. Cohesion could be produced between the particles, allowing the raw material to be deformed.

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