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Methods of Processing Efflorescence of Clay Brick

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Abstract— *The current work involves an experimental investigation of the efflorescence processing in clay brick. The experimental program consists of forming and testing forty-two specimens. The main variables considered in this study were: the effect of using artesian wells water, the amount of salts in the soil used, use silica fume, use dates vinegar, use kaolin, use waste glass powder and clay brick burning temperature on the phenomenon of efflorescence. The second part of this study is concerned with how to remove the efflorescence after completion of construction or during construction. From the results of this work, it was concluded that the average of efflorescence was reduced by a very large percentage of about 92.02% when the addition of silica fume 15% of soil weight. It was found that the best technique to processing efflorescence was used dates vinegar because this technique was highly decreased an average of efflorescence (about 89.69%), simple and cost-effective. Also, the best efflorescence removal techniques were washing clay brick by using dates vinegar.*

Keywords— *Efflorescence, Clay brick, Silica fume, Dates vinegar, Waste glass powder.*

I. INTRODUCTION

Clay brick is still a basic material in construction work in many countries, including Iraq. Bricks are considered to be important manufactured building materials and were known [1]. The most used bricks in Iraq are clay bricks. This is because of a number of factors, the most important of which is the availability of raw material almost everywhere, the cost of its small production, its strength, isolation of heat, its resistance to fire and atmospheric changes [2]. There are many problems in the manufacture of clay brick. One of the most important of these problems is the Efflorescence that will be studied in this research [3].

Efflorescence can be defined as a crystalline deposit of soluble salts, generally white in color that appears on the surfaces of clay brick [4]. The salts of efflorescence are generally potassium, sodium, magnesium, iron and calcium; silicate; or carbonates of calcium and sodium; or sodium bicarbonate. On the other hand, all soluble salt that finds its way into the materials may appear as efflorescence [5].

Efflorescence needs three conditions for it to happen [6], the presence of soluble salts in the materials, the presence of moisture to dissolve soluble salts, and take them to the surface and hydrostatic pressure or evaporation must reason the solution to be in motion. Efflorescence cannot happen if any one of these conditions is not present [7].

The efflorescence phenomenon has a significant impact on the performance and properties of clay brick in engineering structures, the most important of which are most of the salts are salts of alkaline metals or sulphate and alkaline dust carbonate, although the chlorides sometimes appear with a small amount of efflorescence and the future effect of these salts is negative on the properties of bricks [8], resulting in cracking and fragmentation of the walls as a result and transform it into a fragile material. The appearance of the salts on the bricks faces to the destruction of the terminations and the appearance of yellow spots [9]. The reaction of these salts to the aluminate tricalcium in the cement and in the presence of water. This reaction is accompanied by an expansion of the volume leading to the fragmentation of the cement's joints [10]. The efflorescence affects the beauty of the facades of buildings and especially the buildings of historic bricks such as the ancient city of Babylon [11].

The efflorescence in clay brick was initially explored in 1903 by Merrigan [12]. After that, several other investigations made by Grogan and Conway [13], Beall [14], Robinson [15], Grimm [16], Hurd [17] and London [18]. A good beginning point is surely the paper from Bowler and Winter. Bowler and Winter [19], were two of the first and possibly most significant contributions with regard the efflorescence in clay brick. Okunade A. Emmanuel [20], studied The influence of the addition of wood ash admixtures and sawdust (for burning out) to a seventy, thirty percentage by wt. clay. It was exposed that the main the sawdust admixture contribution is the decrease in the density of the burnt clay brick produce (as of 1750 kg/m^3 for the blend without sawdust admixtures to 1510 kg/m^3 for blend with 12% sawdust admixture). The wood ash admixture was capable to give in attaining denser products by upper softening coefficients, upper compressive strengths, the lesser absorpt- ion of water, lower efflorescence. Increasing sawdust in blends shaped the reverse results in burnt clay brick products. On the other hand, Xie Min [21], studied the manufacture of sintered clay brick by using fly ash and waterworks sludge as major raw materials with the adding of quartz sand and feldspar powder. The experimental results show that 65%- 75% of waterworks sludge can be utilized to manufacture sintered clay brick. The compressive strength is upper than 25MPa and the absorption of water is about 25% and the efflorescence is lower than 23%. Bilgin [22], investigated that amounts of dust of marble additive had a positive influence on the efflorescence, physical, chemical, and mechanical properties of artificial bricks. With the rising demands of the building manufacturing, cost and quality of bricks become extra significant from day to day. In adding, the practice of waste of marble for the manufacture of manufacturing brick has a significant role in the recycling marble waste in the clay brick manufacture along with a large contribution to the economy and ecology of the country.

This study planned to treatment efflorescence in locally produced brick. The main aims of this research are studying the effect of dissolved salts in water and/or soil used in the manufacture of clay brick on the phenomenon of efflorescence. Also, processing efflorescence in brick by adding silica fume or dates vinegar or kaolin or waste glass powder at different ratios (5%, 10%, 15%) of the weight of soil. Find out the effect of the change in the burn temperature of clay brick on the phenomenon of efflorescence. Finally, processing of the efflorescence post-construction operation by washing the brick building with dates vinegar.

II. EXPERIMENTAL PROGRAM

2.1 Materials Properties

2.1.1 Soil

Table 1,2 explain the test results of chemical and physical properties and chemical analysis of oxides of soil.

TABLE 1. Chemical and physical properties of the soil

Properties of soil		Values
Content of moisture %		23
Specific gravity		2.76
Atterbeerg limit	L.L%	32
	P.L%	19
	P.I%	13
Grain size of soils	Sand%	20
	Silt%	32
	Clay%	48
Sulphate %		2.36
Gypsum%		3.12
Chloride%		0.15
Carbonate%		22
Total soluble salts		0.019
PH		7.4
Organic matter%		0.44

2.1.2 Water used

Water used in this work is brought from the (Al-Sadjad brick plant). This plant uses the water of artesian wells to manufacture clay brick. The reason for using this water in this study is to simulate the industrial reality of clay brick in this plant. The percentage of dissolved salts in this water and distilled water was measured in the amount of 750 ppm (part per million), 20 ppm, respectively.

TABLE 2. Chemical analysis of soil oxides.

Oxides	Content (%)
SiO_2	33.67
Fe_2O_3	8.04
Al_2O_3	11.91
TiO_2	0.93
CaO	16.45
MgO	3.45
Na_2O	1.90
K_2O	2.08
SO_3	3.09
CL	0.34
P_2O_5	0.27
L.O.I	17.87

2.1.3 Silica fume

Silica fume utilized was German manufacture bought from local markets in this work. Table 3 and Table 4 explain the physical properties of silica fume utilized and its chemical composition respectively (depending on the producer) [23]. The experimental results explained that it was adapted to the chemical and physical boundary of ASTM C1240-05 [24].

TABLE 3. Physical properties of silica fume [23].

Physical property	Silica fume
Specific surface area , (m^2/ kg)	24500
Density (kg / m^3)	478
Specific gravity	2.18
Color	Gray dust

2.1.4 Dates vinegar

Dates vinegar is a fluid that is manufactured from the fermentation of ethanol into acetic acid. The fermentation is approved out by bacteria. Dates vinegar consists of acetic (CH3COOH) [25]. Table 5 show the physical properties of dates vinegar [26].

TABLE 4. Chemical analysis of silica fume used in this work.

Oxides	Content (%)	Requirement of pozzolan ASTM C1240-05
SiO_2	95.68	≥ 85
Al_2O_3	0.5	-
Fe_2O_3	-	-
Na_2O	-	-
CaO	1.30	-
MgO	0.43	-
SO_3	0.31	≤ 4
L.O.I	1.55	≤ 6

TABLE 5. Physical properties of dates vinegar used [26].

Physical property	Dates vinegar
Density (g/ml)	1.01
Boiling point (degrees celsius)	100.6
Freezing point (degrees celsius)	– 2
pH	2.4

2.1.5 Kaolin

The used kaolin clay were brought in from the geological survey, which abound in Al-Gaara area of Al-Rutba city in Al-Anbar province. Table 6 shows the physical properties and chemical analysis of kaolin [27, 28].

2.1.6 Fine waste glass and coarse waste glass

Fine waste glass and coarse waste glass in diameter (0.5-2) mm are obtained from the cool-drinks bottles which is formed by grinding. The ground waste glass is taken to the laboratory for mixing with the clay to form bricks [29].

TABLE 6. The physical properties and chemical analysis of kaolin used

Physical analysis	Kaolin %
Sand	8.5
Silt	17
Clay	74.5
Chemical analysis	**Kaolin %**
SiO_2	49.4
Al_2O_3	35.33
Fe_2O_3	1.24
CaO	-
MgO	-
SO_3	0.14
L.O.I	13.89

2.*2 Preparing and Description of Clay Brick Specimens*

Soil is cleaned well from the organic material and other materials, crushed ,Softened then additional the water by (19% of weight of soil) to give a mixture of acceptable plasticity.

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The specimens of brick were prepared by putting the mix with complete homogeneity, Manual compaction continued strong in a steel mold with dimensions of (1.875, 2.875, 6) cm (height, width, length) respectively. These dimensions represent a scale length of 1/4 of the dimensions of the real bricks (7.5, 11.5, 24) cm. The surfaces of the mold were greased with special oils, at the fullness and access to the surface specimens the removal of surplus mix by using a piece of metal, then the surface well settled by (manually trowels), specimens were left for a time of seven days for the purposes of ensuring the dry-out and ensure that for a crack in brick. Then placed in a furnace at a temperature (1000°C) for the purpose of on fire it. The burning program was including the increasing of temperature by 500 °C/h to burning temperature. Then the specimens were left at the burning temperature for two hours at the stay time, then decreasing of temperature by 500 ºC/h. Table 7 explains the symbols of clay brick specimens.

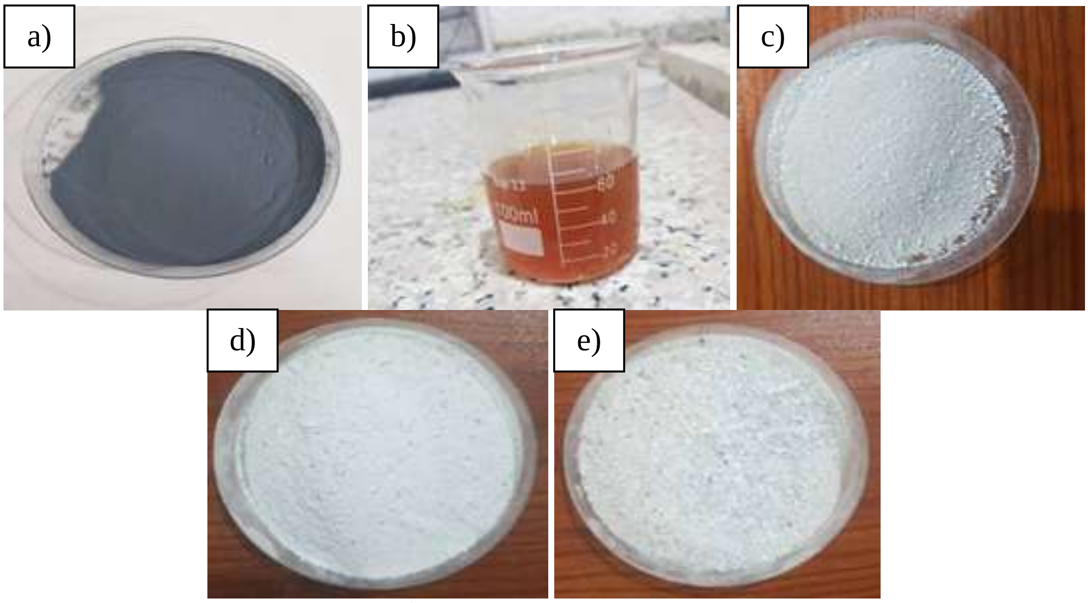

Fig. 1. Materials used during this work a) Silica fume, b) Dates vinegar, c) Kaolin, d) Fine waste glass and e) Coarse waste glass.

TABLE 7. Symbols of tested clay brick specimens.

Symbols	Refer to
A1, A2	Two specimens made of plant water + plant soil.
B1, B2	Two specimens made of distilled water + plant soil.
W1, W2	Two specimens made of plant water + Washed plant soil.
SF1, SF2	Two specimens made of plant water + plant soil+5% Silica Fume.
SF3, SF4	Two specimens made of plant water + plant soil+10% Silica Fume.
SF5, SF6	Two specimens made of plant water + plant soil+15% Silica Fume.
V1, V2	Two specimens made of plant water + plant soil+5% Dates Vinegar.
V3, V4	Two specimens made of plant water + plant soil+10% Dates Vinegar.
V5, V6	Two specimens made of plant water + plant soil+15% Dates Vinegar.
700C1, 700C2	Two specimens made of plant water + plant soil+ burnt at 700C°.
900C1, 900C2	Two specimens made of plant water + plant soil+ burnt at 900C°.
1100C1, 1100C2	Two specimens made of plant water + plant soil+ burnt at 1100C°.
K1, K2	Two specimens made of plant water + plant soil+5% Kaolin.
K3, K4	Two specimens made of plant water + plant soil+10% Kaolin.
K5, K6	Two specimens made of plant water + plant soil+15% Kaolin.
FG1, FG2	Two specimens made of plant water + plant soil+5% Fine Waste Glass.
FG3, FG4	Two specimens made of plant water + plant soil+10% Fine Waste Glass.
FG5, FG6	Two specimens made of plant water + plant soil+15% Fine Waste Glass.
CG1, CG2	Two specimens made of plant water + plant soil+5% Coarse Waste Glass.
CG3, CG4	Two specimens made of plant water + plant soil+10% Coarse Waste Glass.
CG5, CG6	Two specimens made of plant water + plant soil+15% Coarse Waste Glass.

Fig. 2. Forty-two clay brick specimens.

2.3 Efflorescence Test

Efflorescence test is made depending on ASTM C67–02c [30]. Every two specimens in the same group are put on its ends in a flat, small plastic container containing distilled water for one week, and is additional the water when its dry to keep the water depth is 0.6 cm, then left in the same room without water for 3 days for the purposes of drying up, and a growth of the efflorescence phenomenon, after that determined the sum efflorescence area in every sample. The rate of the two specimen test results for every group is taken. The ratio of efflorescence is determined by follow law:-

$$\text{Efflorescence ratio \%} = \frac{\text{Total areas of efflorescence}}{\text{Total areas of brick sides}} \times 100 \quad (1)$$

2.4 Removal of Efflorescence

The second part of this study is concerned with how to remove efflorescence after completion of construction or during construction. A field study has been conducted on some of the work sites built with locally produced clay brick that suffer from the phenomenon of efflorescence. The initial step in the removal of efflorescence must be trying to identify the salt. If the salt is water soluble, the better removal technique is with a dry brush. Washing with water or the usual weathering process might be too effective. Alternatively, hand rinsing by a stiff bristle brush and a mild detergent will often prove sufficient if the efflorescence is in limited areas or small patches. Washing by using dates vinegar may be needed for some cases of efflorescence. But, forever soak the surface with water before utilizing dates vinegar in order to keep the cleaner from penetrating into the brick and further opening voids that encourage efflorescence.

The steps of the processing efflorescence with the technique of washing the dates vinegar is explained as follows and shown in fig. 3.:-

1) The walls are cleaned using brooms to be swept from above to below and equip the face of the wall to paint.
2) Coating the walls with the solution (1 part dates vinegar: 8 parts water) using the brushes of the pigment with all the requirements of protection and safety because of the effect of the solution on the human body.
3) Leaves the wall for a day and repaint again and so until completion 3 times with a day left between the coating layer and the other.
4) After completing 3 layer coating and after leaving it for the last day, sprinkle the brick with water and the work of the spray using cement and water with a little sand.
5) The wall is ready to complete the finishing layers such.

Fig. 3. Removal of efflorescence by using dates vinegar after completing 2 layer coating

III. RESULTS AND DISCUSSION

3.1 The Effect of Using Artesian Wells Water and the Salts in the Soil

Table 8 shows the efflorescence test results for A1, A2, B1, B2, W1and W2 clay brick specimens to investigate the effect of the use of artesian wells water and the amount of salts in the soil utilized in the production of clay brick on a phenomenon of efflorescence. It can be noted from Table 8 and Fig. 4 that the average of efflorescence of two clay brick specimens A1, A2 was 51.61%. This average of efflorescence is very high because the water of artesian wells contains a high percentage of soluble salts and Iraqi soils contain a high amount of the metal clisite and when treated thermally the metal dissociates to free calcium oxide released carbon dioxide and the latter leads to the generation of internal stresses and pathways and channels [31,32], which causes it to get cracking sometimes, depending on the percentage of calcium carbonate and its softness in the soil while the free calcium oxide reacts to the water vapor found in the atmosphere absorbed by the brick forming calcium hydroxide because the last compound has the size of its molecules twice the size of free calcium oxide molecules also causes stress and leads to cracking and breaking in its location the decomposition of soft, free calcium oxide molecules leads to increased weight loss during burning, causing low density, increased porosity, water absorption and low durability. Increased permeability facilitates the function of water absorption, thus melting the soluble salts present in the brick cavity and moving towards the surface causing what is known as the phenomenon of efflorescence. When the water of artesian wells was replaced with distilled water used in the manufacture of clay brick specimens B1, B2, the average of efflorescence was reduced by 30.13% due to the decrease in the percentage of soluble salts. From the foregoing, it can be concluded that using artesian wells in the clay brick industry causes a high amount of efflorescence to have a large amount of dissolved salts. So it is not used in a clay brick industry. When the used soil was washed in clay brick specimens W1, W2, the average of efflorescence decreased by 18.85% due to the decrease in the amount of soluble salts found in the soil. A low rate of efflorescence decrease due to soil washing results in the loss of fine soil granules resulting in a large number of pores in the clay brick produced, so the process of exit the dissolved salts of the brick surface is easy, which causes a high rate of the efflorescence phenomenon. See Fig. 5

3.2 The Effect of Using Silica Fume

Table 8 shows the efflorescence test results for SF1, SF2, SF3, SF4, SF5 and SF6 clay brick specimens to investigate the effect of using silica fume in different ratios (5%, 10%, 15%) on the phenomenon of efflorescence. From Table 8, Fig. 4 and Fig. 6, It can be observed that the average of efflorescence was reduced by a very large percentage of about 92.02% when the addition of silica fume 15% of soil weight and this decrease ratio in efflorescence reduces at lower the percentage of silica fume added and the reason is that silica fume decrease the pores inside the clay brick at a temperature of 1000C$^{\circ}$ and thus less the water absorption of the clay brick and decrease of the average of efflorescence.

3.3 The Effect of Using Dates Vinegar

The dates vinegar has a noticeable effect on decreasing efflorescence by about 89.69% when it was added to the soil by about 15% of the soil weight as shown in Table 8, Fig. 4 and Fig. 6. The clay brick specimens with different addition ratios (5%, 10%, 15%) for the dates vinegar (V1, V2, V3, V4, V5 and V6) showed lower efflorescence when compared with the clay brick specimens without dates vinegar (A1, A2) by about (62.35%, 69.81% and 89.69%, respectively) because the dates vinegar reacts to the soluble salts found in the brick cavity and reduces the amount of those salts and thus decreases the efflorescence. From the experimental results exposed in Fig.4 and Table 8, it can be noted that the best addition to the dates vinegar to reduce the efflorescence is 15%. See Fig. 5.

3.4 Effect of Brick Burning Temperature

The percent ratio of increase and decrease in average of efflorescence is presented in Table 8 for clay brick specimens (700C1, 700C2, 900C1, 900C2, 1100C1 and 1100C2) when compared with control clay brick specimens (A1, A2). From Table 8, Fig. 4 and Fig. 6, It can be noted that the average of efflorescence was reduced by a large percentage of about 30.05% when the burning temperature of brick increased from 700C$^{\circ}$ to 1100C$^{\circ}$ because a raise in the burning temperature so increases the phase of glassy of bunted brick bodies and radically decrease a total pore volume in the brick bode and decrease in water absorption parameters and efflorescence. See Fig.5.

TABLE 8. Efflorescence test results for clay brick specimens.

Specimens No.	Efflorescence %	Average of Efflorescence %	Decrease ratio in Efflorescence %
A1	50.45	51.61	-
A2	52.76		
B1	35.56	36.06	30.13
B2	36.55		
W1	42.67	41.88	18.85
W2	41.09		
SF1	12.95	12.42	75.93
SF2	11.89		
SF3	10.04	9.96	80.70
SF4	9.88		
SF5	4.66	4.12	92.02
SF6	3.57		
V1	18.27	19.43	62.35
V2	20.58		
V3	16.81	15.58	69.81
V4	14.34		
V5	6.30	5.32	89.69
V6	4.33		
700C1	68.55	67.17	- 30.15
700C2	65.78		
900C1	54.38	53.91	- 4.46
900C2	53.44		
1100C1	48.22	47.66	7.65
1100C2	47.09		
K1	13.88	14.39	72.12
K2	14.90		
K3	9.99	10.00	80.62
K4	10.06		
K5	4.88	5.25	89.83
K6	5.61		
FG1	30.00	31.44	39.08
FG2	32.87		
FG3	25.86	26.54	48.58
FG4	27.22		
FG5	6.02	5.73	88.90
FG6	5.44		
CG1	40.02	41.29	20.00
CG2	42.55		
CG3	36.19	35.80	30.63
CG4	35.41		
CG5	15.93	14.77	71.38
CG6	13.61		

3.5 The Effect of Using Kaolin

The effect of changing the added ratios of kaolin on the phenomenon of efflorescence is presented in Table 8, Fig. 4, Fig. 5 and Fig. 6. When treated thermally, Kaolin is characterized by the loss of crystallized water, which is approximately(15%) of its composition

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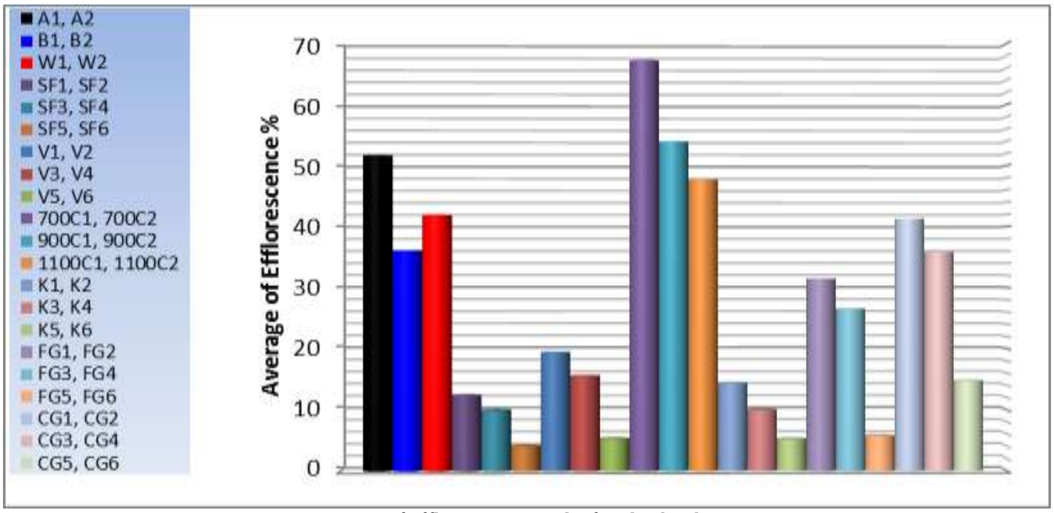

Fig. 4. Average of efflorescence results for clay brick specimens.

Fig. 5. Efflorescence of clay brick specimens.

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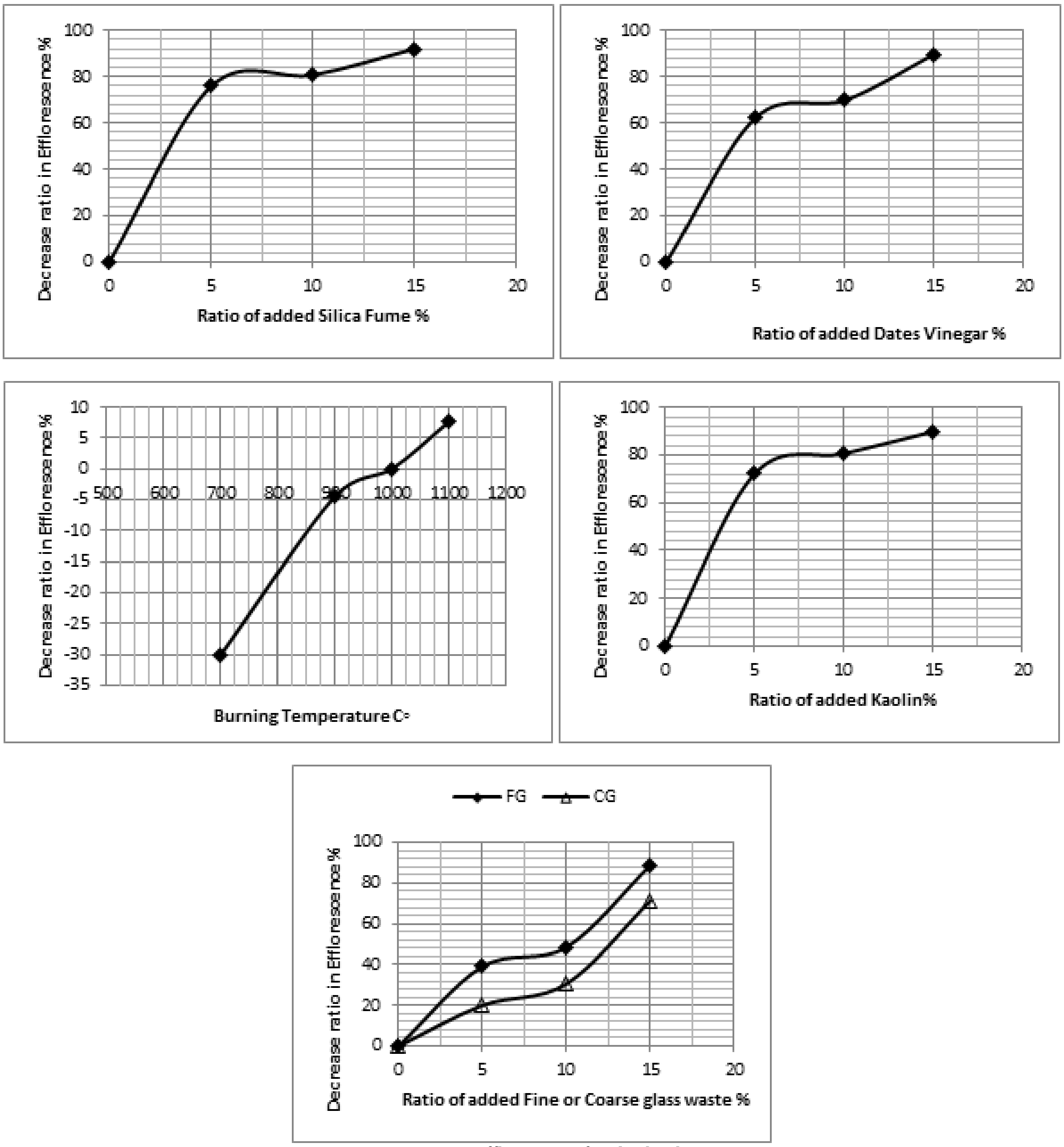

Fig. 6. Decrease ratio in efflorescence for clay brick specimens.

where it works to lower permeability and absorb water with an increased burning heat that helps to decrease the percentage of the efflorescence of the last to be associated with the bricks permeability and its link to the concentration of dissolved salts. From Table 8, Fig. 4 and Fig. 6, It can be observed that the average of efflorescence was reduced by a very large percentage of about 89.83% when the addition of kaolin 15% of soil weight and this decrease ratio in efflorescence reduces at lower the percentage of kaolin added and the reason is that kaolin decrease the pores in the clay brick and thus less the water absorption of the clay brick and decrease of the average of efflorescence. See Fig. 5.

3.6 The Effect of Using Fine Waste Glass and Coarse Waste Glass

The percent ratio of decrease in the average of efflorescence is presented in Table 8 for clay brick specimens (FG1, FG2, FG3, FG4, FG5, FG6, CG1, CG2, CG3, CG4, CG5 and CG6) when compared with control clay brick specimens (A1, A2). It can be observed that the average of efflorescence was reduced by a very large percentage 88.90%, 71.38% when the addition of fine waste glass 15% of soil weight or coarse waste glass 15% of soil weight, respectively. This decrease ratio in efflorescence reduces at lower the percentage of fine or coarse waste glass added. Experimental results show that the effect of fine waste glass in decreasing the average of efflorescence is more than the effect of coarse waste glass. This can be attributed to the melting of fine waste glass faster than the coarse waste glass which causes the pores in the brick to be blocked.

3.7 Evaluation of the Best Technique for Processing Efflorescence

To select an appropriate technique for processing efflorescence, the relative effectiveness of different techniques for processing efflorescence for improving the performance (average of efflorescence, cost and simplicity in use) of clay brick are shown in Table 9. The least effective and the most effective alternatives were indicated with numbers 8 and 1, respectively for techniques to treatment efflorescence. It must be reaffirmed that the objectives do carry unequal weights. The weight of every objective (decreasing an average of efflorescence, cost and simplicity in use) was (50%, 30% and 20%), respectively. From Table 9, the best technique for processing efflorescence in clay brick was used dates vinegar followed in a second place use silica fume followed in a third place use fine waste glass followed in a fourth place use kaolin followed in a fifth place use coarse waste glass followed in a sixth place use distilled water followed in a seventh place increased burning temperature followed in the last place soil washing.

TABLE 9. Final evaluation of different techniques for processing efflorescence.

Techniques for processing efflorescence	Objectives			Final evaluation
	Decreasing average of efflorescence 50%	Cost 30%	Simplicity in use 20%	
Use distilled water	3	1.2	1.4	5.6
Soil washing	3.5	2.4	1.6	7.5
Use silica fume	0.5	1.5	0.4	2.4
Use dates vinegar	1.5	0.3	0.2	2.0
Increased burning temperature	4	1.8	1.2	7.0
Use kaolin	1.0	2.1	1.0	4.1
Use fine waste glass	2	0.6	0.6	3.2
Use coarse waste glass	2.5	0.9	0.8	4.2

IV. CONCLUSIONS

Depending on the experimental results of this study of the tested clay brick specimens, the following main conclusions can be summarized:-

1. Do not allow the use water of artesian wells in the manufacture of local clay brick because of their high percentage of soluble salts that cause very high efflorescence where the average of efflorescence is less than 30.13% when replacing artesian wells water with distilled water.
2. A low rate of efflorescence decrease by about 18.85% due to soil washing results in the loss of fine soil granules resulting in a large number of pores in the clay brick produced, which causes a high rate of the efflorescence phenomenon.
3. The average of efflorescence was reduced by a very large percentage 92.02% when the addition of silica fume 15% of soil weight and the reason is that silica fume decrease the pores inside the clay brick at a temperature of 1000C° and thus less the water absorption of the clay brick and decrease of the average of efflorescence.
4. The best technique to reduce the efflorescence of clay brick is to add the dates vinegar by 15% of the weight of the soil, where the efflorescence decreased by about 89.69% when added the dates vinegar in addition is an easy and low cost technology.
5. The average of efflorescence was reduced a large percentage 30.05% when the burning temperature of brick increased from 700C° to 1100C° because a raise in the burning temperature so increases the phase of glassy of bunted brick bodies and radically decrease a total pore volume in the brick body and decrease in water absorption and efflorescence.
6. The average of efflorescence was reduced by a very large percentage of about 89.83% when the addition of kaolin 15% of soil weight.
7. Experimental results show that the effect of fine waste glass in decreasing the average of efflorescence is more than the effect of coarse waste glass. This can be attributed to the melting of fine waste glass faster than the coarse waste glass which causes the pores in the bricks to be blocked.
8. The best technique for processing the efflorescence after completion of construction or during construction is to wash the clay bricks by the dates vinegar or dipping the bricks with water basins containing dates vinegar.

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