Investigation into the effect of some additives on the mechanical strength, quality and thermal conductivity of clay bricks

Adnan I. O. Zaid, A. Qandil[1], M. A. A. Qattous[2]
Mechanical and Industrial Engineering Department,
Applied Science Private University, Amman 11931 Jordan
[1]Civil Engineering Department, Applied Science Private University
Amman 11931 Jordan
[2]Industrial Engineering Department, University of Jordan, Amman, Jordan

E-mail: adnan_kilani@yahoo.com

Abstract. It was repeatedly reported that the clay bricks industry in Jordan is facing both weak mechanical strength and poor quality which caused marketing problems where it is expected to serve the increasing demand of housing in the country especially after the political crises in the neighboring countries Iraq and Syria. It is therefore anticipated that improvement of the mechanical strength and quality of the produced clay evaluation of the brick industry in Jordan is worth investigating. In this paper, theoretical and experimental investigation obtained from field visits to the factories producing clay bricks were carried out. Furthermore, the effect of using some additives from locally available materials namely: Battn El-Ghoul Clay, Suweileh sand and Olive extracts on the mechanical strength, thermal conductivity and surface quality of the produced bricks is investigated and discussed. The experimental results indicated that thermal conductivity, color and durability were all enhanced and the ultimate compressive strength was reduced but remained higher than the acceptable value for brickwork.

1. Introduction and literature review

Brickmaking industry is probably the second earliest industry of mankind after agriculture. The archaeological excavations have shown that the oldest sun-dried bricks have been found beneath the foundations of the old city of Jericho in the Jordan River valley, just a little north of the Dead Sea. This was about 9000 to 10000 years where no molds were used at that time. These excavations indicate that clay has existed in Jordan and have been in use since the old ages, [1-2]. Ever since, the art of brickmaking had advanced to the process of firing. As early as 1955 MILLS [3] published a book about clay bricks from the stage of manufacture to the stage of use. This book seems to be the first book in the field. Later, the mineralogical aspects of clay using differential thermal analysis is given in [4]. Simple manuals for brickmaking to be used with villagers to enable them to make good and cheap bricks by themselves were introduced in [5-6]. The use of bricklaying as a craft is given in references [7-10]. However, the first introduction of the heavy clay technology was forwarded in 1969 in reference [11]. A useful detailed review of brickwork suitable for building based on engineering design and scientific research which provided the recent developments in brickwork technology from which prefabricated and pre-stressed bricks were manufactured are given in [12]. A new trend in the research of brick work was reported in where a good manual which describes a method of stabilizing sun-dried adobe bricks which are water proof and exceptionally strong and have a noticeable quality of durability, where little maintenance and keep-up are necessary were reported in 1972, [13,14]. After 1972, voluminus research papers appeared in the literature on clay bricks all over the world both in indusrial and developing countries in attempts to improve its mechanical strength, durability and surface quality, [15-44].

2. Materials, Equipment and experimental proceadures

2.1Materials

The raw materials used in this paper were taken from three factories producing building clay brick and denoted by A, B and C. Two specimens were taken from each factory and designated as A1, A2 for factory a, B1 and B2 for factory B and C1,C2 for factory C.

2.2 Experimental Procedures

Chemical analysis was carried on each specimen before and after grinding in two different Government Establishments, namely: the Natural Resources Authority, NRA, and the Jordan Phosphate Mines Company as illustrated in Tables 1 and 2 respectively.

Table 1. Chemical Analysis carried out at NRA after grinding raw material (X-ray Fluorescence Analysis)

Sample	MgO%	Al_2O_3%	SiO_2%	%CaO	%Fe_2O_3	%L.O.I
A1	1.01	14.60	44.32	14.40	7.08	17.60
A2	0.24	12.55	74.66	1.70	4.07	5.78
B3	0.97	14.37	39.02	18.20	7.23	19.28
B2	0.19	20.33	70.20	0.60	3.92	7.79
C1	1.11	13.70	38.14	18.10	7.54	19.83
C2	0.43	11.81	51.32	16.90	2.56	16.88
C3	0.90	13.20	49.18	15.30	5.94	7.25

Table 2. Chemical Analysis carried out at Jordan Phosphate Mines Company after grinding Raw

Sample No.	% Na_2O	% MgO	% Al_2O_3	% SiO_2	% P_2O_5	% K_2O	% CaO	% TiO_2	% MnO	% Fe_2O_3
A1	0.0	2.23	12.94	41.30	0.13	1.37	12.37	1.20	0.06	7.21
A2	0.0	0.21	9.92	71.29	0.15	0.81	3.00	1.24	0.03	4.36
B3	0.02	2.38	12.87	33.12	0.05	1.66	16.76	1.13	0.07	7.20
B2	0.03	0.27	16.84	64.34	0.19	0.56	0.11	1.91	0.03	4.85
C1	0.03	2.47	13.10	33.15	0.03	1.66	16.67	1.12	0.07	7.33
C2	0.14	0.87	10.03	51.86	0.18	0.77	12.75	0.96	0.04	2.73
C3	0.70	2.01	14.08	46.09	0.16	1.24	13.88	1.22	0.07	6.51

3. Results and discussions

The results of testing the fired briquettes are shown in Figures 1 to 5 inclusive. The tests which were carried out on the fired briquettes are the compression test, water absorption tests, and the thermal conductivity test. It is worth mentioning that the sample in the first two tests consisted of 5 specimens at least, while in the third test it was ranging from 2 to 3 specimens and in some rare cases it consisted of 4 to 5 specimens. Throughout the measurements taken to establish the data presented in this chapter, care was taken to minimize the error, and as there were many sources of error throughout this work, in the weighing of raw materials and additives, in the mixing and forming stage, in the drying stage, in the firing stage,and finally in testing the fired briquettes. Although, care was taken in manufacturing and testing of all the briquettes of all samples under the same conditions, it was decided to consider a coefficient of variation of 10% as a criterion to accept or reject the specimen from the sample. Normally this percentage will be as low as 2% in metals. In Figure 1, which shows the ultimate compressive strength versus the percentage of each additive, all the additives showed various amounts of decrease in the ultimate compressive strength. For the additive Batn El—Ghoul Clay, the decrease in the compressive strength is minimum and the fired briquettes are still acceptable, for load bearing brickworks even for high percentages of Batn El-Ghoul. Clay. in the case of adding Suweileh Sand the decrease in compressive strength is more pronounced than the previous case. Despite this pronounced decrease, Suweileh Sand is still acceptable for non-load bearing brickworks. In the case of Olive Extracts, still more decrease in the compressive strength was noted; therefore only an additive less than 2% could be used to consider Olive Extracts acceptable for load—bearing bricks and 3% could be considered suitable for non-load bearing bricks.

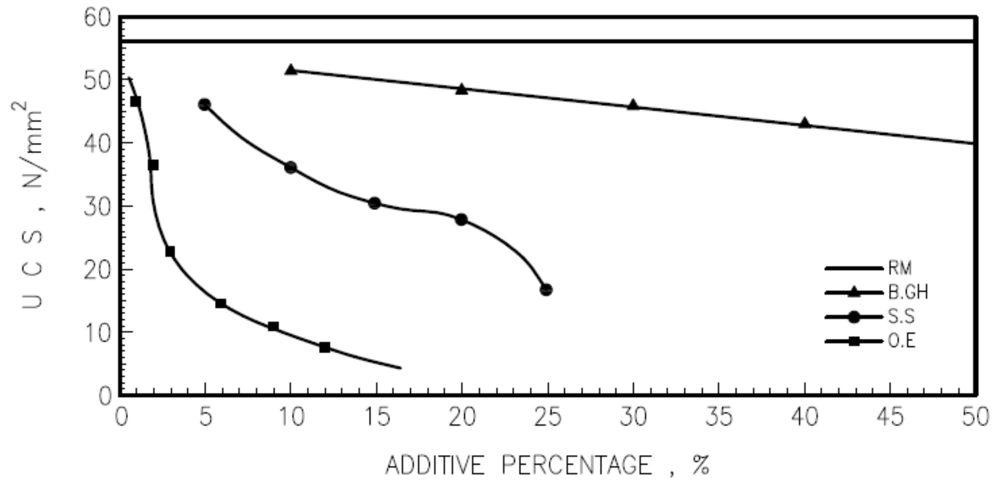

Figure1. Ultimate compressive strength versus additive percentage

Figure 2 shows the percentage of water absorbed (24—hours cold submersion) versus additive percentage for each of the additives. In this Figure it is clear that Batn El-Ghoul Clay shows a small increase over the raw materials, although for additions of 10% and 20% of Batn El—Ghoul Clay the percentage absorbed water is less than that for the raw materials. For Suweileh Sand nearly no great change in the percentage absorbed water occurs when increasing the additive percentage, and all the data points fall a little above those of the raw absorbed is noted for all the percentages, this great increase is clearly noted when the percentages exceeded the 3%. It is. worth mentioning that there is some inflection or turning points at different percentages in the three additives which are due to surface bores or cracks during forming of briquettes, neglecting these inflections will make the trends in the above discussion more clear. Figure 2 shows percentage water absorbed (5-hours boiling) versus additive percentage for each of the additives. In this figure, Batn El-Ghoul Clay starts nearly from the same percentage absorbed by the raw materials and increases until an additive percentage of 30% is reached where it starts to decrease, but still remains above that absorbed by the raw materials, until an additive percentage of 40% is reached. Then it starts to increase again. Suweileh Sand starts above Batn El-Ghoul Clay, then starts decreasing until 10% of additive, then it starts to increase until 20% of additive is reached where it starts to decrease again. Olive Extracts shows a clear sharp increase in the percentage water absorbed. It is worth mentioning that the inflection points of 40% Batn El-Ghoul and the 5% Suweileh Sand could be due to improper mixing of the raw materials and the additives at the aforementioned additive percentages.

IOP Conf. Series: Materials Science and Engineering **146** (2016) 012018 doi:10.1088/1757-899X/146/1/012018

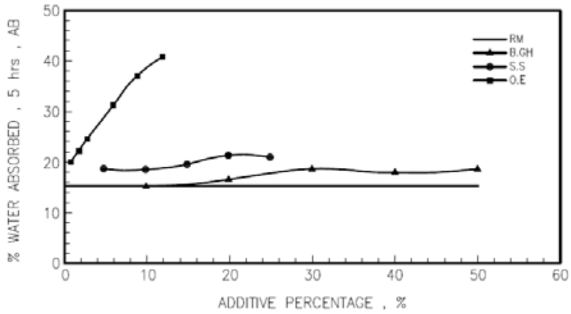

Figure 2. Percentage water absorbed (5-hoursboiling) versus additive percentage

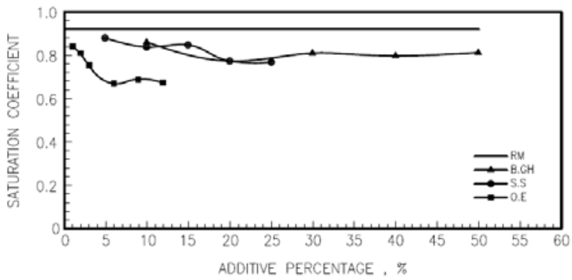

Figure3. Saturation Coefficient versus additive percentage

Figure 3 shows the saturation coefficient versus the additive percentage for each of the additives. In this figure all the three additives start below the raw materials which have a saturation coefficient in the range of negligible weathering (NW). However Batn El—Ghoul Clay shows the best results to be used in sever weathering (SW) nearly for all additive percentages, but Suweileh Sand shows the ability to be used in moderate weathering (MW) if it is added at percentages less than 15%. However, it could be used in severe weathering (SW) if it is added at percentages of 20% or 25%. On the other hand, Olive Extracts could be used in moderate to severe weathering if added at 1,2 and 3% otherwise it will be used in negligible weathering. The above discussion is based on ASTMc62-87(64).

Figure 4, which shows the percentage apparent porosity versus additive percentage for each additive, could be discussed in the same manner as the aforementioned discussion of Figure 3 since the percentage apparent porosity is a function of the absorbed water percentage, after boiling for 5-hours, where the apparent porosity is the product of the specific gravity (GS) by the absorbed boiled water percentage.

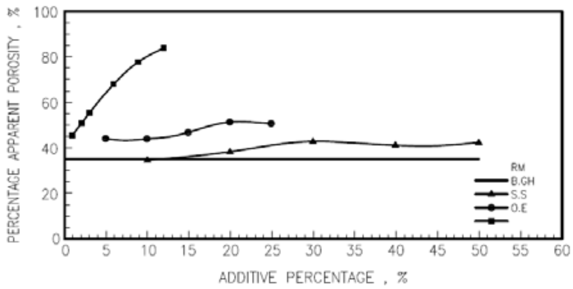

Figure 4. Percentage apparent porosity versus additive percentage

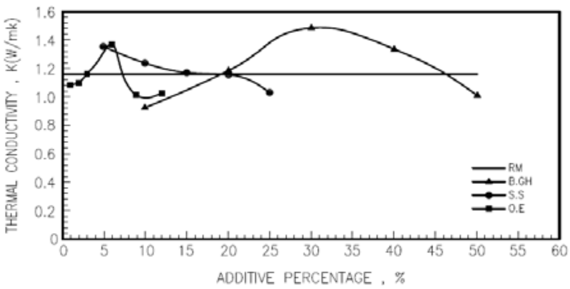

Figure 5. Thermal conductivity versus additive percentage

Figure 5 shows the thermal conductivity versus the percentage for each additive. It can be seen from this figure that increasing the Batn. El-Ghoul clay percentage resulted in increase of the thermal conductivity until 30% addition, then a decrease in the thermal conductivity initiates, the best thermal conductivities were at 10% and 50% of Batn El—Ghoul Clay increase, followed by a decrease in the thermal conductivity. This could be attributed to the presence of mice which behaved as a conductor at this low firing temperature.

When the percentage of apparent porosity was increased the thermal conductivity started to decrease. In case of Suweileh Sand, the thermal conductivity decreases continuously with the increase of Suweileh Sand percentage and a sharp decrease in the thermal conductivity occurred at 20% addition of the sand. This could be due to the increase in porosity upon increase of the percentage of Suweileh Sand. However, the high thermal conductivity at the beginning is due to the large grain size of the

Suweileh Sand. The most interesting additive was Olive Extracts, Figure 5. It is clear that the Olive Extracts starts at lower thermal conductivity than that of the raw materials and starts increasing slowly until 3% of Olive Extracts is reached where an increase in the thermal conductivity was pronounced; after which a sharp decrease starts. The low thermal conductivity at the beginning is due to the high percentage apparent porosity existed even at 1% of Olive Extracts, but increase in the thermal conductivity is attributed to the increase of boreealthough the porosity is still increasing. However, the effect of increase in the bore diameter on the thermal conductivity could not outweigh the effect caused by the high porosity existed, therefore the thermal conductivity started to decrease again. On the whole, it may be concluded and suggested to add Suweileh Sand in a percentage ranging from 15-25, and Olive extracts in percentages between 1-3 or 9-12. One of the main properties tested in this work was the color of the briquettes, where an acceptable red color was obtained when the raw materials were used alone. This red color is the result of using materials under the acceptable Cao: Fe_2O_3 ratio and using fine grinding with proper mixing. The homogeneity in color and mixing is clearly noted when the samples were crushed in the compression test. The effect of adding Batn El-Ghoul Clay on the color produced. The following addition percentages specimens were used:10, 20, 30, 40 and 50% respectively and the produced briquette colors were compared with that produced from the original raw materials. It was found that at 10 and 20% addition of Batn El—Ghoul Clay the color was changed to dark red while at 30% the white scum started to appear and increased more at higher additive percentages, 40 and 50%. The reason for this white scum or efflorescence is the presence of potassium oxide and/or magnesium oxide. Similarly, the effect of adding Suweileh Sand on the produced color was also investigated using the addition percentages of 5,10,15,20 and 25% respectively. The results indicated no great change had occurred, only a little enhancement of the red color was obtained by increasing the sand percentage, in which the percentage of Fe_2O_3 in Suweileh Sand is appreciable, so the overall CaO: Fe_2O_3 ratio is slightly decreased . It is worth mentioning that in these two additives it was noted that the surfaces of the obtained briquettes were fine and smooth. Furthermore, in the case of Suweileh Sand addition early no change in volume was noted. The effect of adding Olive Extracts on the produced color was also investigated but with different percentages namely: 1,2,3,6,9 and 12%. It was noticed that the color was changing between red to pink at the first two percentages, (1 and 2%), whereas at 3% it started to change to pink, this was very clear at 6% addition, and at the 9% a pale color started to appear, which was more pronounced at 12%. This pale color appeared pink in some specimens and yellow in others. The surfaces of the obtained specimens were good and acceptable at the first two percentages, while the appeared bores started to destroy the surface at the 3%. This distortion was more pronounced at higher percentages, (9% and 12%). The large bore diameters and the pale colors are attributed to the burning of the carbon aqueous (organic) matter of the Olive Extracts which includes wood.

3. Conclusions

The following points are concluded:

i) To obtain clay bricks free from line blowing fine grinding of the raw materials is essential to a particle size about 500 microns.
ii) The homogeneous color could be obtained only if proper mixing and homogeneous firing are ensured together with a high temperature enough to allow the iron compounds, mainly the ferric oxide, (Fe_2O_3) to react with the clay ingredients.
iii) Using the three investigated additives which are locally available namely: Batn El-Ghoul clay, Suweileh sand and Olive Extracts, resulted in improvement of the saturation coefficient. This enables the clay brick to be used under severe weather conditions. Batn El-Ghoul may be added with any percentage for severe weather conditions, Suweileh sand is recommended for moderate weather conditions and Olive Extracts if added at percentages less than 3% can be used for severe weather conditions.
iv) The three used additives resulted in decrease of the ultimate compressive strength. However, if they added in the appropriate percentages:10% Batn El-Ghoul, 15% Suweileh sand and less than

3% Olive Extracts they can produce good results i.e. low thermal conductivity, good compressive strength, good saturation coefficient and good red color.

4. Acknowledgment

The first and second authors are grateful to the Applied Science Private University, Amman, Jordan for partial financial support granted to this research (Grant No.DRGS-2015).

5. References

[1] Brownell, W E 1974 Structural Clay Products, Springer Verlag, Wien
[2] Sarraf, F 1982 Clay and Clay Bricks in Jordan, Previous Studies and Existing Situation, Royal Scientific Society, Building Research Center, Amman
[3] Mills A P 1955 Materials of Construction; Their Manufacture and Properties, 6th edition, John Wiley and Sons Inc
[4] Mineralogical Society 1 1957 The Differential Thermal Investigation of Clays, London
[5] Mathur G C 1960 Bricks Making, National Building Organization, Ministry of Work, Housing and Rehabilitation, India
[6] The Brick and Tile Institute of Ontario 1965 Clay Masonry Manual, Ontario, Canada.
[7] McKay J K Brickwork, 2nd edition, Longman, London, 1968
[8] Nash WG 1966 Brickwork One, 1st edition, Hutchinson, Technical Education, London
[9] Nash, W G 1968 Brickwork Two, 1st edition, Hutchinson, Technical Education, London
[10] Hodge J C 1971 Brickwork for Apprentices, 3rd edition, Edward Arnold Publishers Ltd, London
[11] Clews, F H 1969 Heavy Clay Technology, 2nd edition, Academic Press Inc., London
[12] Lancer D 1792 Elements of Load Bearing Brickwork, 1st edition, Pergamon PRESS, London
[13] International Institute of Housing Technology1972 California State University, Fresno Foundation, The Manufacture of Asphalt-Emulsion-Stabilized Soil Bricks and Bricks Makers Manual, California
[14] Appall I S 1972 Low-Cost Durable Shelters, Build International, March/April,100-103.
[15] Swindle- Dressler Company 1972 Feasibility Study for Ceramic Industry, Jordan; Drafts Phase 1 Report, Parts 1 & 2, U.S.A
[16] knizek I 1978 Brickmaking Plant; Industry Profile, UNIDO, Vienna
[17] Krienger M 1978 Home Owners Encyclopedia of House Construction, McGraw-Hill Inc
[18] Kumar A 1979 Building Materials and Components, 2nd edition, MIR Publishing, Moscow
[19] Gupta R B and Sharma, B.R. 1981Insulating Materials, In: Electrical Engineering Materials, 2nd edition, smithSumatraHonda, New Delhi, 126-200
[20] Research on lime Stabilized Soil Building Blocks 1982 Report of Mission, Royal Scientific Society, Amman, Jordan
[21] Country Case Study on Jordan 1982 Draft Report, Royal Scientific Society, Amman
[22] Building Research Establishment (BRE) BREPAK BLOCK MAKING MACHINE , London, 1982
[23] Al-Kass R M, Ha M, Khalil N, AL-Takarli S 1984 Effect of Fine Calcite Grains Present in the Soil on the Properties of Clay Bricks, Journal of Building Research, Building Research Center, Baghdad, 3, 1-31
[24] Al-Saudi N,Mageed I, Ahmad K 1986 Free S well Properties of Bentonite / Kaolinite Mixture, Journal of Building Research, Building Research Center, Baghdad, **5**, , 29-63
[25] Habitat United Nations Centre for Human Settlements (UNCHS), Manual on Basic Principles of Each Application, Nairobi, 1986
[26] Habitat United Nations Centre for Human Settlements (UNCHS) 1986 Manual on Production of Rammed Earth, Adobe and Compressed Soil Blocks, Nairobi
[27] Al-Taie M, Al-Ramadan K 1987 Improving the Refractoriness Under Load of the Fire – Clay Bricks, Journal of Building Research, Building Research Center, Baghdad, 6,60-77

IOP Conf. Series: Materials Science and Engineering **146** (2016) 012018 doi:10.1088/1757-899X/146/1/012018

[28] Al-Kvass R M, Al-Ali B T1988 Lightweight Clay Bricks with Expanded Polystyrene additions, Journal of Building Research, Baghdad, 7,1-10
[29] Jurban B A, Habbali S M, Hamdan M A, ZaidA I O 1988 Some Mechanical and Thermal Properties of Clay Bricks for the Jordan Valley Region, Journal of Materials and Structures, 21, 364-369
[30] Awawdeh M 1991Assessment of BATN EL-GHOUL CLAY, JORDAN, M.Sc. Thesis, Leicester University, U.K
[31] Sultan SA1993 Foam Clay Blocks Industry From Local Material in Jordan, Proceedings of the First International Conference on Implementing Local Material in Industrial Applications, 1, Amman, Jordan, 133-141
[32] Khreis R I 1993 Evaluation of Jordanian Silica Sand for Molding in the Foundry Industry – Shell Process, Proceedings of the First International Conference on Implementing Local Materials in Industrial Applications,1 , Amman, Jordan, 254-311
[33] Dwairi I M, Sallam M 1994 Evaluation of Bentonitic Clays of Azraq for Foundry Sand Uses, The First Jordanian Mining Conference, Amman Jordan, April, 23-25
[34] Raouf ZA , Al-Mousawi MJ 1993The Use of Local Materials in Plastic Concrete Wall for Seepage Control, Proceeding of the First International Conference on Implementing Local Materials in Industrial Applications,1. Amman, Jordan, Sep. 6-9, 72-85
[35] Pierzchlewicz J 1993 New Structural Trends Regarding Clay Hollow-Blocks for External Walls, Proceedings of the First International Conference on Implementing Local Materials in Industrial Applications, 1. Amman, Jordan, 93-102
[36] Ali G A, Pierzchlewicz J, Sivakugan N 1999, Soils and Aggregates in Construction Industry, Conference on Implementing Local Materials in Industrial Applications, 1. Amman, Jordan, 191-201
[37] British Standards Institution, BS 3921: 1958, U.K.
[38] American Society for Testing Materials (ASTM), C62-87, U.S.A
[39] United Nations Industrial Development Organization (UNIDO), 1984 Small-Scale Brick-making, Vienna
[40] Bain J A 1971 A Plasticity chart as an aid to the identification and assessment of industrial clays, Clay Minerals, 9, 1-17
[41] Bain J A, Highly D E 1978 Regional Appraisal of Clay Resources – Challenge to the Clay Mineralogist, Proceedings of the International Clay Conference, 437-446
[42] Bowles J,Liquid and Measurements, 4^{th} edition, McGraw Hill Inc., New York, 1992, 21-32
[43] Cusson Company, usermanual thermal conductivity apparatus, U.K
[44] Grimshaw R W 1971 Miscellaneous Properties of Ceramic Materials, In: The Chemistry and Physics of Clays and Allied Ceramic Materials, 4^{th} edition. John Wiley and Sons, New York, 905-966