BLOATING CHARACTERISTICS OF LOW GRADE Ca-MONTMORILLONITE CLAYSTONE AND THE EFFECT OF SOME ADDITIVES

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ABSTRACT

This study was conducted to assess the bloating characteristics of the calcium montmorillonite claystone from Wadi Bashira in the Iraqi Western Desert and indicate the effect of red kaolinitic claystone and feldspathic sand addition. The materials were formed into pellets, (aggregates) after mixing in different wt% combinations. The results of heat treatment of aggregates formed only from montmorillonite claystone indicated that, bloating incidence occurs at a temperature of (1180 – 1200º C). The bloated aggregates obtained exhibit a considerable low bulk density (1.185) g/cm^3 and low mechanical strength. All aggregates made from the mixtures (montmorillonite claystone, red kaolinitic claystone with, or without feldspathic sand) showed a good to very good bloating. Also the aggregates made of montmorillonite claystone and feldspathic sand (except that made with 5 wt% feldspathic sand) showed a good bloating. The bulk density of the bloated aggregates obtained was appreciably low (0.54 – 0.7 g/cm$^{3)}$ with water absorption value of (4 – 6.8) %. This suggested that these aggregates can probably used, as lightweight materials in civil works.

الخصائص الإنتفاخية للمونتموريلونايت واطئ النوعية وتأثير بعض الإضافات عليها

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المستخلص

جرت هذه الدراسة لتقييم الخاصية الانتفاخية لأطيان المونتموريلونايت من ترسبات وادي بشيرة في الصحراء الغربية العراقية وتأثير إضافة أطيان الكاؤولين الحمراء والرمال الحاملة للفلدسبار عليها. بينت نتائج المعاملات الحرارية المختبرية لمكورات شكلت فقط من أطيان المونتموريلونايت، بان حصول الانتفاخ يتم عند درجة حرارة (1180 - 1200)° م، وان المكورات التي انتفخت تتصف بكثافة حجميه (1.185 غم/سم^3) وصلادة ميكانيكية واطئة. وقد أظهرت المكورات التي تم تشكيلها من مزيج أطيان المونتموريلونايت وأطيان الكاؤولين الأحمر مع الرمال الحاملة للفلدسبار أو بدونها انتفاخاً جيداً إلى جيد جداً. كذلك أظهرت المكورات التي شكلت من أطيان المونتمورلونايت والرمال الحاملة للفلدسبار (ماعدا تلك التي استخدم فيها 5% رمال حاملة للفلدسبار) انتفاخاً جيداً. وقد كانت الكثافة الوزنية التي تم الحصول عليها للمكورات المنتفخة واطئة نسبياً مع قيمة لامتصاص الماء مابين (4 - 6.8) %. توعز هذه النتائج إلى إمكانية استخدام هذه المكورات كركام خفيف في أعمال الهندسة المدنية.

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INTRODUCTION

Claystone is an important raw material with a wide variety of properties and uses. The clays are a complex group that consist of several mineral commodities (known as clay minerals), each possess particular properties, mineralogy, geological occurrence and uses. They are fine grained materials and are composed of alumina and silica structure with additional iron, magnesium and alkaline earth elements (Grim, 1968). Some clays, however, under certain firing conditions have the property of expanding or bloating and become light in weight, with the formation of cellular particles structure (Grosh and Hamlin, 1963; Fisher and Garner, 1965; Kenneth and Harmon, 2009). It has been stated (Riley, 1951; Fisher and Garner, 1965; and Arioz *et al*., 2008) that, for such bloating to occur, the following should be present: (1) compounds that liberate gases during firing must be present in the clay, and (2) that some material must fuse or vitrify during firing temperature to form a proper viscosity; high enough to trap the gases. Riley (1951) in his work provides a number of minerals (hematite, calcite, dolomite, pyrite, gypsum, and feldspar), which would lead to bloating of the clays.

Clays that expand or bloat upon firing have been for long used in manufacturing of lightweight aggregates. Because of their typical properties of lightweight, good thermal and acoustical insulations, as well as fire resistance, they become of great interest in civil works. They offer a range of technical, economical and environmental enhancing and conserving advantages (Bremner *et al*., 2005; Fakhfakh *et al*., 2007 and Wang and Sheen, 2010). In view of these remarkable properties, and recent interest through most of the developed world, a number of studies have been conducted related to the use of clay in lightweight aggregates (Sousa *et al*., 2004; Rattanadhan and Lorprayoon, 2005; Al-Bahar and Bogahawatta, 2006; Fakhfakh *et al*., 2007 and Arioz *et al*., 2008).

In this paper, the bloating behavior of Wadi Bashira montmorillonite claystone as well as the effect of addition in various ratios of kaolinite claystone and feldspathic sand is presented.

MATERIALS AND METHODS

▪ Raw Materials

The clayey materials (Montmorillonite claystone and Kaolinitic claystone) are found in the Western Desert of Iraq. Whereas, feldspathic sand deposit is located in the central part of Iraq (Fig.1). The montmorillonite claystone is from Wadi Bashira deposit, it belongs to the lower part of Digma Formation of Late Cretaceous (Maastrichtian) age (Al-Bassam and Saeed, 1989). The kaolinitic claystone belongs to Amij Formation of Jurassic age (Mahdi and Al-Delaimi *et al*., 1999). The feldspathic sand is from Dibdibba Formation (Al-Najaf Plateu) deposit, which belongs to Pliocene - Pleistocene age (Al-Kaabi, 1999).

▪ Methods

Each material was successively crushed and ground to pass 100 mesh sieve, and then representative sample was drawn from each material for mineralogical (XRD) and chemical analyses. The XRD analysis was carried out by X-ray diffraction using Philips Pw 1480 equipment and Cu target λ for Cu = 1.5 Å Ni filter. Whereas, chemical analysis was conducted, according to GEOSURV Work Procedures, Part 21 (Al-Janabi *et al*., 1992).

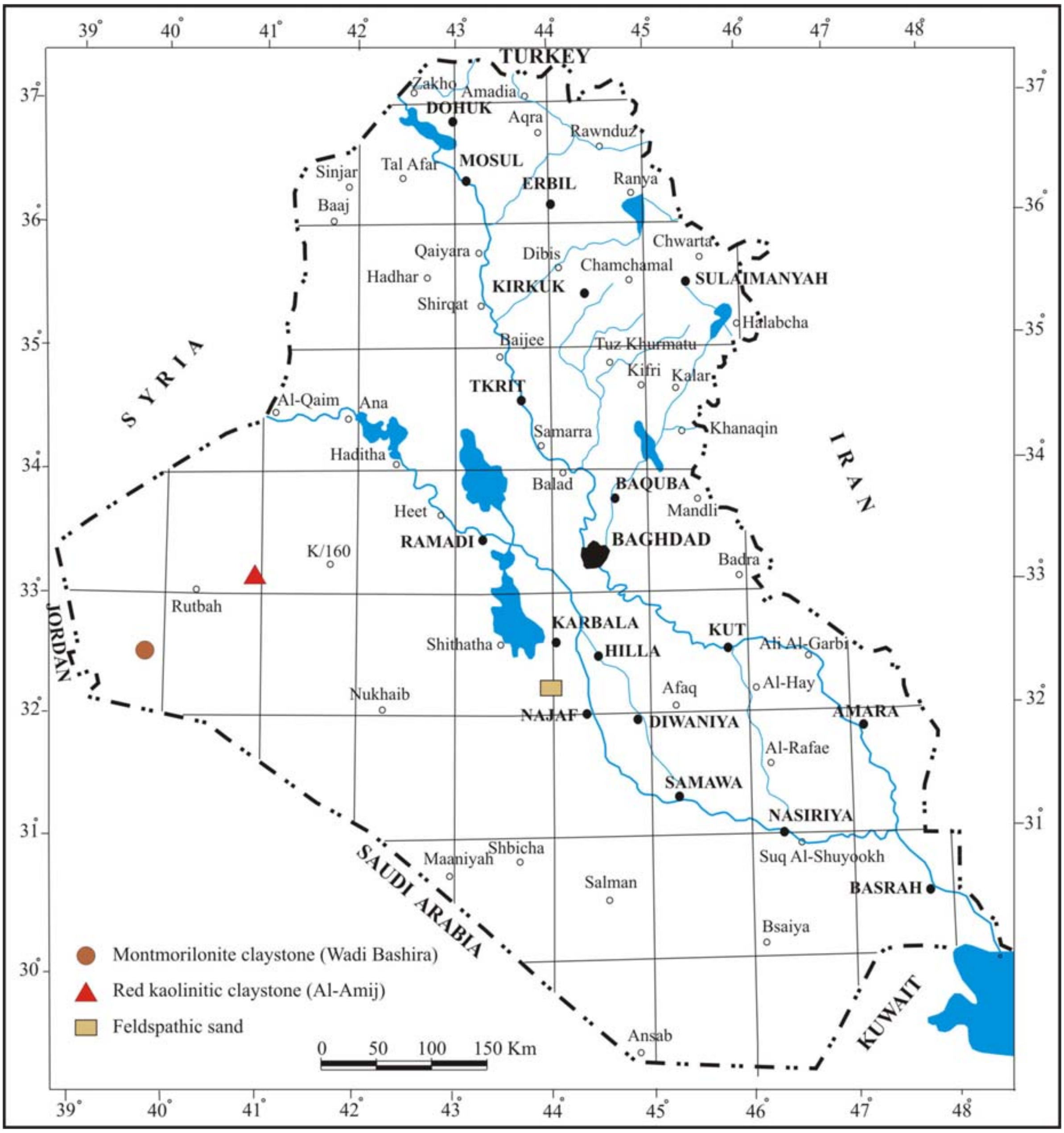

Fig.1: Location of deposits of materials used

Small pellets of (10 – 12) mm in diameter were shaped by hand from fresh, sufficiently plastic paste of the powdered raw materials. These aggregates were made of five groups (Table 1). The first group was made of montmorillonite claystone only, while groups 2 and 3 were made from mixing unit weight of montmorillonite claystone (major proportion) with certain unit weight of kaolinitic claystone or feldspathic-sand, respectively to arrive at 100 unit weight; mix of both materials. Group 4a and 4b were made by mixing a fixed amount of both montmorillonite and kaolinitic claystone in a proportion to arrive at 100 unit weight and then adding feldspar in different wt% of the prepared mix. The same was done with group 5a and 5b, but in this case, the kaolinitic claystone was added in variable wt%. Table (2) shows these material mixes.

Table 1: Mixes of aggregate groups

Group No.	Materials Mixed	Code No.
1	Montmorillonite claystone	M
2	Montmorillonite claystone + Kaolinitic claystone	MK
3	Montmorillonite claystone + Feldspathic-sand	MF
4	Montmorillonite claystone + Kaolinitic claystone + Feldspathic-sand	MKF
5	Montmorillonite claystone + Feldspathic-sand + Kaolinitic claystone	MFK

Table 2: The material mixes for aggregates preparation groups

Group No.	Symbol	Montmorillonite unit weight	Red Kaolinitic claystone unit weight	Feldspar unit weight
1	M	100	–	–
2	MK1	95	5	–
	MK2	90	10	–
	MK3	80	20	–
3	MF1	95	–	5
	MF2	90	–	10
	MF3	80	–	20
4a	MKF1a	70	30	10
	MKF2a	70	30	20
	MKF3a	70	30	30
4b	MKF1b	80	20	10
	MKF1b	80	20	20
	MKF3b	80	20	30
5a	MFK1a	70	10	30
	MFK2a	70	20	30
	MFK3a	70	30	30
5b	MFK1b	80	10	20
	MFK2b	80	20	20
	MFK3b	80	30	20

The prepared aggregates (pellets) were dried at room temperature for at least 24 hr, then in a laboratory oven at 110º C for another 24 hr, in order to prevent their disintegration during the firing process. Each group or sub-group of the dried aggregate was placed in a refractory dish with alumina powder and, then fired in an electric muffle furnace.

Pellets made only of montmorillonite claystone (group-1) were fired at different temperatures (1000 – 1200º C) for different residence times, in order to characterize the bloating behavior of the claystone with respect to variation in temperature; prior to addition of any additives. Groups (2 – 5) were fired at a predetermined temperature of (1180 – 1200)º C. At the end of each test, the aggregates were removed from the furnace, cooled, and then tested for bulk density and water absorption, according to ASTM C127.

RESULTS AND DISCUSSION

- **Raw Materials Characterization**

Table (3) presents the qualitative mineral composition of the used raw materials identified by the X-ray diffraction (XRD). The XRD results show that Ca-montmorillonite is the major clay mineral composing the montmorillonite claystone, and it is associated with other clay (palygoreskite) and non clay minerals (calcite, quartz, gypsum,…etc.). For the kaolinitic claystone, kaolinite represents the main constituent of Al-Amj clay, associated with different non-clay minerals. The feldspathic-sand constitutes mainly of quartz-sand and some feldspar.

Table 3: Mineralogical composition of the studied materials

Raw Material	Mineralogical Composition
Montmorillonite claystone	Ca-montmorillonite (major), Palygorskite, Calcite, Quartz, Iron oxide, Apatite, Gypsum, Halite, and trace of Feldspar
Kaolinitic claystone	Kaolinite (major), Quartz, Iron oxide, Calcite and Dolomite, with trace of Anatase
Feldspathic-sand	Quartz, Feldspar

The Chemical analysis results (Table 4) showed that the main constituents of the clayey materials are silica and alumina, while, the feldspathic-sand is composed mainly of silica (94% SiO_2). Table (4) reveals that, the summation of metals, oxides (Fe_2O_3 + CaO + MgO + Na_2O + K_2O), which are so called fluxing compounds are much higher in montmorillonite claystones than that of the other raw materials used. This, however may influence the softening point of the montmorillonite claystone as well as, the bloating characterization during firing (Rattanachn and Lorprayoon, 2005; and Fakhfak *et al*., 2007).

Table 4: Chemical composition of raw materials

Materials	SiO_2	AL_2O_3	Fe_2O3	CaO	MgO	SO_3	Na_2O	K_2O	Cl	L.O.I
Red Kaolinitic claystone	47.6	25.52	5.72	3.64	0.6	1.4	0.5	0.32	0.84	12.26
Montmorillonite claystone	48.58	14.16	4.54	9.0	4.6	1.4	1.13	0.32	1.16	14.25
Feldspathic-sand	94.37	3.25	0.31	0.18	–	<0.07	0.62	0.94	–	0.58

- **Raw Montmorillonite Claystones Bloating Characterization**

Based on visual observation, the bloating characteristics of raw montmorillonite claystone pellets (aggregates) tested with respect to variation in firing temperature and time are shown in Table (5). The data given in this table discloses that the firing temperature and time have a decisive effect on the bloating of the aggregates. It can be seen, that bloating dose not started below 1150º C and only incipient bloating appeared at 1150º C. At this temperature, the aggregate exhibited some degree of bloating, which is considered as a poor bloat. On the other hand the clay aggregates showed a good bloating at (1180 – 1200)º C, but only at 10 min firing socking time. As the firing time rises to 20 and 30 min, fusion and softening occurs, which resulted in flat bloated aggregate. It have been claimed (Fisher and Garner, 1965; Fakhfakh *et al*., 2007 and Wang and Sheen, 2010) that fluxing materials (CaO, MgO, Fe_2O_3, Na_2O, and K_2O) significantly influences the softening and melting of the clay aggregates and hence the bloating behavior. The montmorillonite claystone of Wadi Bashira is a calcareous material and contains high amount of fluxing compounds (Table 4). This obviously would enhance the chance of melting and softening of the clay, particularly when the time of exposure to high temperature (1180 – 1200° C) is increased. Therefore, flattening of the aggregate occurs, as the firing time exceeded the permissible limit (10 min).

Table 5: Bloating characterization of montmorillonite claystone aggregates at different temperatures and times

Material Identity	Run No.	Temp. (ºC)	Time (min)	Rate (ºC/min)	Appearances
Montmorillonite Claystone (M)	M1	1000	10	15	No bloat
	M2	1000	20	15	No bloat
	M3	1000	30	15	No bloat
	M4	1100	10	15	No bloat
	M5	1100	20	15	No bloat
	M6	1100	30	15	No bloat
	M7	1150	10	15	Poor bloat
	M8	1150	20	15	Poor bloat
	M9	1150	30	15	Poor bloat
	M10	1180	10	15	Good bloat
	M11	1180	20	15	Flat bloat
	M12	1180	30	15	Flat bloat
	M13	1200	10	15	V. good bloat
	M14	1200	20	15	Flat bloat
	M15	1200	30	15	Flat bloat

However, close visual examination of the well bloated aggregate indicated that the structure was slightly vitrified and core of large voids being formed due to liberated gases, (these gases are related mainly to water vapor, carbon dioxide derived from dehydration of montmorillonite and decomposition of calcite). Obviously, this would weaken the structure, and provides a low density material. It was necessary therefore, to use some admixture, which itself, would not bloat, but could provide a better expansion property to the aggregates at the proper firing temperature (1180 – 1200º C). The choice for such material was red kaolinitic claystone and feldspathic-sand.

- **Bloating Behavior Montmorillonite Claystone with Admixture**

The bloating characteristics of the fired aggregates at 1200º C, which were prepared (Table 2) from montmorillonite claystone, red kaolinitic claystone, and/ or feldspathic-sand at different proportions are shown in Table (6).

Table 6: Characterization of aggregates made from mixed material

Group No.	Sample No.	M:F or M:K unit weight	M:F:K unit weight	M:K:F unit weight	Appearances
2	MK1	95:5			Good bloat
	MK2	90:10			Good bloat
	MK3	80:20			V. good bloat
3	MF1	95:5			Good bloat
	MF2	90:10			Poor flat bloat
	MF3	80:20			Poor flat bloat
4a	MFK1a		70:30:10		V. good bloat
	MFK2a		70:30:20		V. good bloat
	MFK3a		70:30:30		V. good bloat
4b	MFK1b		80:20:10		V. good bloat
	MFK2b		80:20:20		V. good bloat
	MFK3b		80:20:30		V. good bloat
5a	MKF1a			70:30:10	V. good bloat
	MKF2a			70:30:20	V. good bloat
	MKF3a			70:30:30	V. good bloat
5b	MKF1b			80:20:10	V. good bloat
	MKF2b			80:20:20	V. good bloat
	MKF3b			80:20:30	V. good bloat

In general (except in aggregates of MF2 and MF3 samples of group-3), all aggregates tested have successfully produced a good to very good bloating development. These aggregates were of a fair spherical shape with brownish appearance (without any incidence of vitrification) and a gray porous core. However, it is worth to point out that the aggregates of MF2 and MF3 (group-3), which show a poor bloating have exhibited a glassy phase surfaces, with incidence of melting and softening that converted the spherical aggregates in to disc like shape.

From the forgoing results, it can be deduced that the expansion or bloating of the claystone is most probably affected by the amount of the fluxing agent, which play an important role in determining the softening a melting phases.

- **Bulk Density and Water Absorption Properties of the Heat Treated Aggregate**

The bulk density and water absorption properties of the aggregates listed in Table (6), with their bloating characteristics, are shown in Table (7). Furthermore, Figs. (2, 3, and 4) present the result of bulk density versus variation in the amount of admixtures (kaolinitic claystone and/ or feldspathic-sand) to the montmorillonite claystone.

Table 7: The results of bulk density and water absorption of the heat treated aggregates prepared from montmorillonite claystone with different ratio of admixtures

Group No.	Sample No.	Bulk Density (gm/cm^3)	Water Absorption (wt%)
2	MK1	0.66	5.3
	MK2	0.65	4.08
	MK3	0.571	4.39
3	MF1	0.678	4.51
	MF2	0.989	3.08
	MF3	1.099	2.89
4a	MFK1a	0.554	5.36
	MFK2a	0.552	4.33
	MFK3a	0.714	4.03
4b	MFK1b	0.607	6.81
	MFK2b	0.674	6.4
	MFK3b	0.637	4.72
5a	MKF1a	0.565	4.02
	MKF2a	0.610	4.70
	MKF3a	0.712	4.48
5b	MKF1b	0.524	4.43
	MKF2b	0.596	4.28
	MKF3b	0.689	4.54

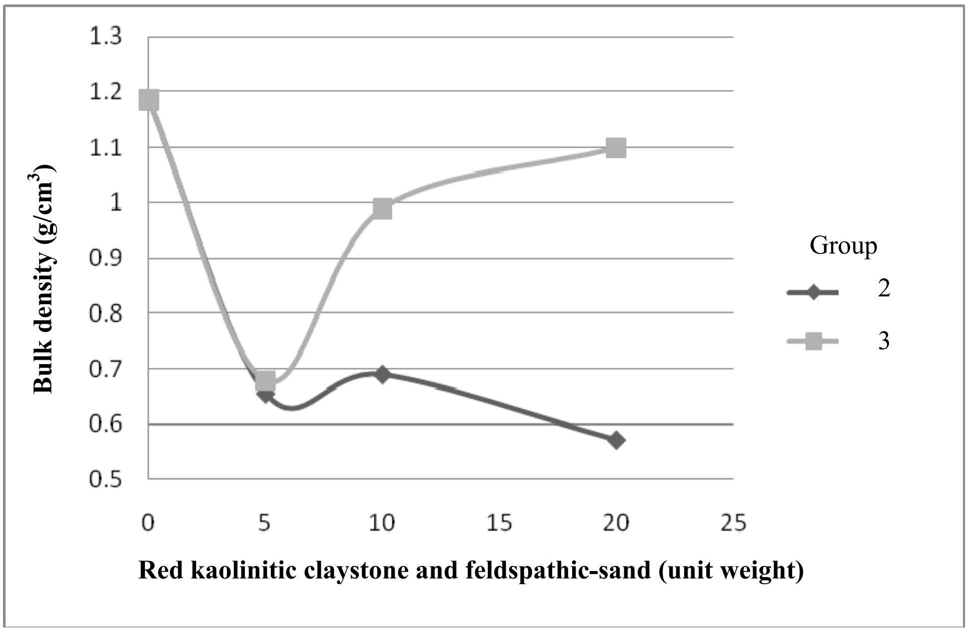

Fig.2: Density of LWA made of montmorillonite claystone (base) with different addition of red kaolinitic claystone and feldspathic-sand (sample MK and MF)

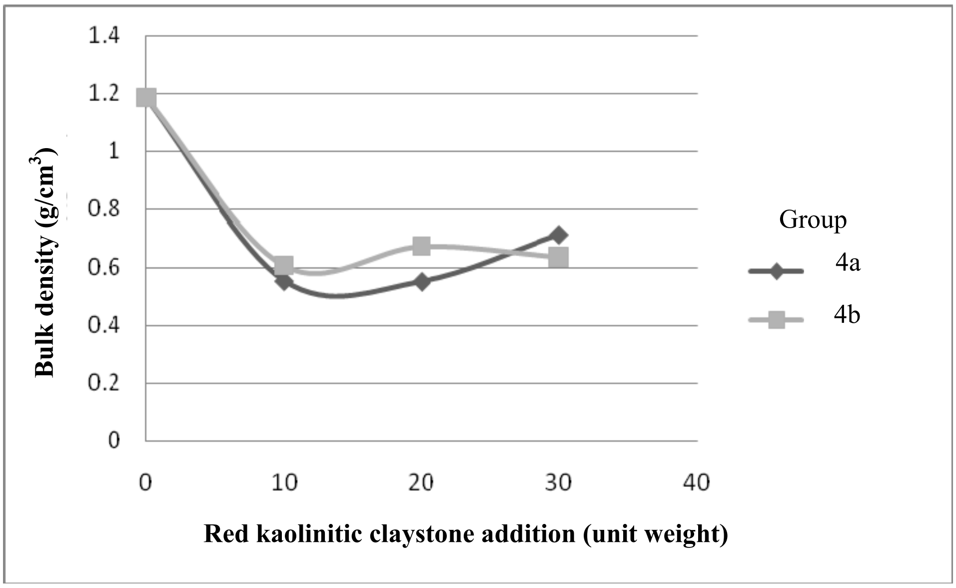

Fig.3: Bulk density verses red kaolinitic claystone addition to montmorillonite and Feldspathic-sand combination (70:30 and 80:20), aggregate (group MFK a and b)

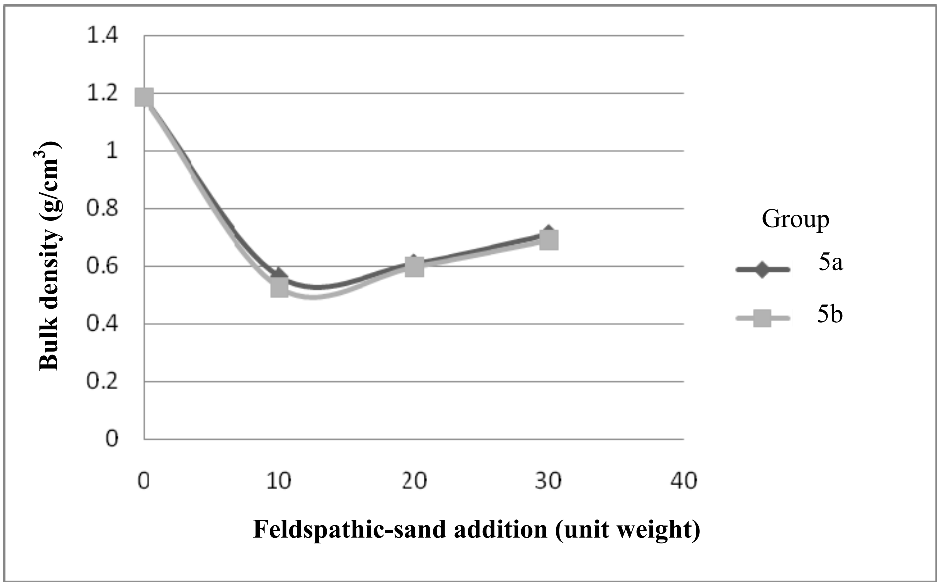

Fig.4: Bulk density versus feldspathic-sand addition to montmorillonite and red kaolinitic claystone combination (70:30 and 80:20), aggregates (group MKFa and b)

Figure (2), presents the relation between the bulk density and the heat treated aggregates, which were prepared from montmorillonite claystone with different amount of red kaolinitic claystone or feldspathic-sand (groups-1, and -2). It can be clearly seen from Fig. (2) that both aggregates (MK and MF) at which 5 wt% of either feldspathic-sand or red kaolinitic claystone was used; resulted almost in identical bulk density. However, the attitudes of the bulk density were diverged with increasing the amount of these admixtures. It can be seen that, increases the amount of red kaolinitic claystone beyond 5 wt%, resulted in slight gradual decreases in the bulk density. The low bulk density, however, obtained was 0.57 g/cm³ at 20 wt% addition of red kaolinitic claystone. In contrary, the bulk density was increased as the amount of feldspathic sand increases, the maximum bulk density was of 1.1 g/cm³, when 20 wt% of feldspathic-sand was used.

However, the relationship between the bulk density results and the addition of red kaolinitic claystone (Fig.3) of the groups 4a and 4b ($MFKa_{1-3}$ and $MFKb_{1-3}$), which indicates no significant difference occurs with increase of red kaolinitic claystone to the limit tested (30 wt%). The bulk densities obtained were in the range of (0.55 – 0.7) g/cm³ for both groups (4a and 4b). Currently, Fig. (4) illustrates the values of the bulk density (Table 7) as a function of feldspathic-sand addition of the groups (5a and 5b) aggregates. It can be seen from Fig. (4) that the bulk densities of these groups are of identical values with respect to the additions of feldspathic-sand. It can be also seen, that there is a slight increase in the bulk density as the amount of feldspathic-sand increases. In general, the bulk densities obtained were in the range of (0.52 – 0.71) g/cm³, which is so analogous to those demonstrated in Fig. (2), for aggregates of group (4a and 4b). It has been claimed, however, that any aggregates with bulk density of less than 1.2 g/cm³ could be defined as light weight aggregates (Rattanachan and Lorprayoon, 2005). Meaning that all the heat treated aggregates, which are presented in Table (6) can be considered as lightweight aggregates. Accordingly, it could be anticipated that these aggregates can be used in civil engineering works.

Nevertheless, the water absorption test result of the light weight aggregates (Table 7) were in the range of (4 – 6.8) % and these values are lower than those characterizing the conventional light weight aggregates, which generally involve a high water absorption about 30% (Fakhfakh *et al*., 2007). In fact, water absorption increases with the increase of the surface porosity, that interconnected with the pores in the core of the aggregates, as well as, the presence of macro and micro cracks that could form during the firing operation.

CONCLUSIONS

According to the laboratory test results of this work, the following conclusion can be highlighted.

- Apart from firing temperature, the bloating of the montmorillonite claystone is highly affected by the amount of flux, and the present of gas forming minerals or compounds.
- The montmorillonite claystone of Wadi Bashira can successfully be used in the preparation of expanded lightweight aggregates. The optimum firing temperature is of (1180 – 1200)º C, at soaking time of 10 min.
- The addition of feldspathic sand in amount of (10 – 20) wt% suppressed to some extent the expandability of the montmorillonite claystone, while very good expansion (or bloating) with red kaolinitic clay addition was obtained.
- Successful lightweight aggregates can be produced from mixing montmorillonite claystone with different proportions of feldspathic-sand and red kaolinitic clay.
- The prepared lightweight aggregates exhibit, low bulk densities (0.54 to 0.7) g/cm³ with water absorption of (4 to 6.8%) lower than the conventional lightweight aggregates.

REFERENCES

Al-Bahar, S. and Bogahawatta, V., 2006. Development of lightweight aggregate in Kuwait. The Arabian Journal for Science and Engineering. Vol.31, Nr 1c.

Al-Bassam, K. and Saeed, L.K., 1989. Mineral investigation of the upper cretaceous Safra montmorillonite claystone deposit, Wadi Bashira, Western Desert. GEOSURV, int. rep. no. 1922.

Al-Janabi, Y., Al-Saadi, N., Zainal, Y., Al-Bassam, Kh. and Al-Delaimi, M., 1992. GEOSURV Work Procedures, Part 21, Chemical Laboratories. GEOSURV, int. rep. no. 0192WRCH01.

Al-Ka'abi, A., 1999. Discovery of feldspathic-sand in Dibdibba Formation, NW Al-Najaf and reservwe estimation. GEOSURV, int. rep. no. 2513.

Arioz, O., Kilinc, K., Karasu, B., Kaya, G., Arslan, G., Tuncan, A., Korkut, M. and Kivark, S., 2008. A preliminary research on the properties of lightweight expanded clay aggregate. Jour. Aust. Ceram. Soc., Vol. 44, No.1, p. 23 – 30.

ASTM C (127 – 73). Specific Gravity and Absorption of Coarse Aggregates.

Bremner, T.W., Ries, J.P. and Wolfe, W.H., 2005. Environmentally uses of lightweight aggregate.

Fakhfakh, E., Hajjaji, W., and Medhioub, M., 2007. Effects of sand addition on production of lightweight aggregate from Tunisian smectite-rich clayey rocks. Applied Clay Science, No.35, p. 228 – 237.

Fisher, W.L. and Garner, B., 1965. Bloating characteristics of east Texas clays. Bureau of Economic Geology, The University of Texas, geological circular, No. 65 – 1.

Grim, R. E., 1968. Clay Mineralogy. McGraw Hill Book Company, 2nd edit., 569pp.

Grosh, W.A. and Hamlin, H.P., 1963. Lightweight aggregates. Expansion properties of clays, shales and argillites of Minnesota, US Bureau of Mines, Report of investigation, Vol.6313, 30pp.

Keneth, S. and Harmon, P.E., 2009. Engineering Properties of Structural Lightweight Concrete. Carolina State Company,United States (report).

Mahdi, M.A. and Al-Delaimi, M.R., 1999. Kaolinitic claystone in Iraq. GEOSURV, int. rep. no. 1902 (in Arabic).

Rattanachan, S. and Lorprayoon, C., 2005. Korat clays as raw materials for lightweight aggregates. Science Asia, Vol.31, p. 277 – 281.

Riley, C.M., 1951. Relation of chemical properties to the bloating of clays. Jour. American Ceramic Society, Vol.34, p. 121 – 128.

Sousa, H., Carvalho, A. and Melo, A., 2004. A new sound insulation lightweight concrete masonry block. Design and experimental characterization. 13th International Brick and Block Masonry Conference, Amsterdam, July 4 – 7.

Wang, H.Y. and Sheen, Y.N., 2010. Performance characteristics of dredged silt and high-performance lightweight aggregate concrete. Internet data.