EVALUATION OF TELLOL AL-KIEND CLAY IN MOSUL CITY FOR THE PRODUCTION OF LIGHT WEIGHT AGGREGATES

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ABSTRACT

In this research a representative sample from Tellol Al-Kiend clay deposit (Injana Formation), Naenava Governorate, Iraq, was evaluated for lightweight aggregates preparation. Two methods of heat treatment were carried out. Iso-thermal treatment conducted at (1180 – 1200) °C range, for aggregates made from clay only, using different socking time. Whiles, rapid (or flush) firing, were carried out at 1200 °C, for aggregates made from clay with different types and amounts of additives (dolomite, waste engine oil, and straw). The iso-thermal tests reveal that bloating can occurs at 1180 °C only for 45 minutes holding time. The aggregates obtained, have a specific gravity of about 1.38 and 0.8% water absorption. In rapid firing, it was found that, the bloating of the clay can be significantly improved by the addition of dolomite. The results obtained indicated that aggregates having 1.35 specific gravity with about 1% water absorption value could be produced from aggregates made of clay and 5 wt.% dolomite. The firing time has been about 5 minutes. Thereupon, it can be suggested that, Tellol Al-Kiend clay can be used for the production of lightweight aggregates by rapid firing. Concrete made from these lightweight aggregates shows a compressive strength (28 days) of about 173 kg/cm^2, which can be designated as structural and insulating concrete.

صلاحية أطيان تلول الكند في الموصل لإنتاج الركام الخفيف

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المستخلص

جرى في هذا البحث تقييم نموذج ممثل لترسبات أطيان تلول الكند (تكوين إنجانة) في محافظة نينوى لإنتاج الركام الخفيف، وجربت طريقتان للمعالجة الحرارية. جرى في الطريقة ألأولى معالجة الركام المحضر من الطين فقط في درجات حرارة تتراوح مابين (1180 - 1200) °م وزمن استبقاء مختلف. أما الركام المحضر من الطين مع كميات وأنواع مختلفة من المواد المضافة (دولومايت، مخلفات زيت المحركات والقش) فقد تم معالجتها بالحرق السريع (أو المفاجئ) عند درجة حرارة 1200 °م مع زمن استبقاء 2 أو 3 دقائق. بينت نتائج حرق الركام المحضر من الأطيان فقط بأن الانتفاخ يمكن أن يحصل فقط عند حرارة 1180 °م وبزمن استبقاء 45 دقيقة، وإن الركام الناتج من هذه العملية أعطى كثافة نوعية بحدود 1.38 ونسبة امتصاص للماء 0.8%. ولكن وجد أنه باستخدام الحرق المفاجئ فإن انتفاخ ركام الطين يتحسن بشكل ملحوظ عند إضافة الدولومايت وبينت النتائج المستحصلة من هذه العملية إمكانية إنتاج ركام يمتلك كثافة نوعية بحدود 1.35 ونسبة امتصاص للماء 1% عند إضافة 5% وزناً من الدولومايت للطين وإن الزمن اللازم للحرق هو بحدود 5 دقائق. وعليه يمكن استخدام أطيان تلول الكند في إنتاج الركام الخفيف بإتباع الحرق السريع. كما بينت نتائج فحص الكونكريت المحضر من الركام الخفيف بأن مقاومة الانضغاط بعد 28 يوم بحدود 173 كغم/ سم^2 والذي يمكن أن يستخدم في تحضير الخرسانة الإنشائية العازلة.

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INTRODUCTION

Lightweight aggregates (LWAs) are defined as natural or artificial materials, which are granular and distinctly more porous than sand, gravel or ground rocks and posses lightweight characters (have considerably low apparent specific gravity). They can originate from different natural resources such as volcanic rocks (pumice and tuffs), sedimentary and metamorphic rocks (claystones, slates and shale) or from waste materials and industrial byproducts (Prokopovich and Schwartz, 1957; Ramme *et al*., 1995; De Gennaro *et al*., 2004 and Fakhfakh *et al*., 2007). These lightweight aggregates will range from extremely light materials used for insulators and non – structural concrete all the way to that used for structural concrete (Tommy and Cui, 2002 and Sousa *et al*., 2004). It has been pointed out that any aggregate, with bulk density not exceeding 1.2 g/cm^3 or with particle density not more than 2 $g/cm^3$are defined as lightweight aggregates (Rattanachan and Loprayoon, 2005 and corrochano *et al*., 2009).

However, the most widely used artificial lightweight aggregates are expanded clays, perlite, vermiculite, shale and slate (Arioz *et al*., 2008). Clays, however are a complex group that consist of several mineral commodities (known as clay minerals). Each possesses 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 (Fisher and Garner, 1965). Clays that expand or bloat upon firing have been for long used in manufacturing of lightweight aggregates. Vast literatures of academic and applied topics related to its manufacture, properties, mechanism of formation and engineering aspects were nationwide published (Bauer, 1948; Riley, 1951; Das and Lebdetter, 1968; Valsangkar and Holm, 1990; Khan, H. and Khan, S., 2000; Sousa, *et al*., 2004; Rattanachan and Lorprayoon, 2005; Al-Bahar and Bogahawatta, 2006; Fakhfakh, *et al*., 2007; Arioz, *et al*., 2008 and Al-Ajeel, *et al*., 2010 and 2011).

LWAs however, become of great interest in making concrete of substantial strength and lower weight. They offer a range of technical, economical and environmental enhancing and conserving advantages (Fakhfakh *et al*., 2007 and Wang and Sheen, 2010). These LWAs may range from extremely light in weight (unit weight and compressive strength not exceeding 800 kg/m^3 and 70 kg/cm^2 respectively) employed chiefly for insulators and non-structural concrete all the way to that used for structural concrete. Minimum compressive strength is of about 176 kg/cm^2, and possessing unit weight not exceeding 1.8 g/cm^3 (Tommy and Cui, 2002; Sousa, *et al*., 2004; ACI Committee, 1999 and Al-Khalaf and Abed Usef, 1984).

The objective of this experimental work is to evaluate the clay deposit from Tellol Al-Kiend area in Naenava governorate (north Iraq) which belongs to Injana Formation for the production of lightweight aggregates (LWAs). The deposit is located between Mosul city and Alqosh town (about 30 Km to the north of Mosul and 10 Km south of Alqosh). The area is bounded from the east by the main road between Mosul city and Alqosh town, and from the south by a paved way leads to Hatared village.

MATERIALS AND METHODS

▪ Materials

A representative clay sample of Injana Formation from Tellol Al-Kiend deposit in Naenva Governorate was used for the preparation of lightweight aggregates.

Additives such as; dolomite $CaMg(CO_3)_2$, straw and waste engine oil were also used as gas forming materials.

▪ Methods

― Mineralogical and Chemical Composition: The mineralogical composition (qualitative) of the clay and dolomite was identified by the X-ray diffraction (XRD), using Shimadzu 7000 defractometer, where as the chemical composition was determined by X-ray fluorescence using Shimadzu 1800. The cation exchange capacity (CEC) of the clay was determined by methylen blue absorption method (Schenning, 2004).

― Lightweight Aggregate Preparation: The raw clay sample as received from Tellol Al-Kiend area was prepared to pass 150 micron and the non-clay material (dolomite) was made to pass 75 micron by successive crushing, grinding and screening. The clay powder with or without the additives (dolomite, oil and straw) was mixed with water and kneaded by hand until it was sufficiently plastic. The kneaded mix was extruded in meat mincing machine to form cylindrical bars, from which granules in the range of (– 9.5 to + 4.7) mm size were prepared. The granules were dried at room temperature for at least 48 hr, and then dried in oven for 24 hr, at 100 °C. Further heat treatment was also made at 600 °C for about 15 min.

Next, the aggregates were fired in a muffle furnace at a pre-determined temperature and holding time. The clay aggregates (granules) were heat treated by an isothermal firing mode, whereby the aggregates were introduced in the muffle furnace from ambient temperature and heated up to the pre-determined firing temperature at a rate of 10 °C/min. The aggregates were, then removed from the furnace in due time. In this course of treatment, the firing temperature was in the range of (1180 – 1200) °C using different socking time (10 – 45) min. On the other hand, rapid or flash firing was used for the treatment of the aggregates made from clay and additives, (aggregates made from clay only were also tested). The dried aggregates were directly introduced into a muffle furnace pre-heated at 1200 °C for maximum 5 min. In both firing methods, the cold aggregates were tested for their bulk density and water absorption according to (ASTM, C330-80). The prepared aggregates, however, were made of four groups according to the type of additives used. Table (1) shows these groups and the amounts of each additive used (as wt.% of the clay dried weight).

Table 1: The type of aggregates made from clay and different additives

Group No.	Material	Sample code	Raw clay (%)	Additives (wt.%)		
				Dolomite	Waste oil	Straw
1	Clay	C	100	–	–	–
2	Clay + Dolomite	CD1	100	4	–	–
		CD2	100	5	–	–
		CD3	100	6	–	–
3	Clay + Oil	CO1	100	–	1	–
		CO2	100	–	2	–
		CO3	100	–	3	–
4	Clay + Straw	CS1	100	–	–	1
		CS2	100	–	–	2
		CS3	100	–	–	3

▪ Concrete Mixes

Mix design of proportion 1: 2: 2 (cement: sand: gravel) was chosen in order to achieve the greatest compressive strength value. This mix was prepared by weight proportions for normal concrete, and by volume for lightweight concrete) crushed aggregates of – 9.5 mm size were used), in this mix design. Trial mixes in the laboratory, had been performed to fix the exact amount of water needed to prepare the concrete (normal and lightweight), and it was found to be of 0.7 water/cement. The freshly prepared concrete was placed in the mold in two layers; each layer was compacted manually, using a steel tamping road of 1 inch diameter. Subsequently the specimens were carefully removed from the molds after 24 hr, labeled, immersed in tap water and kept for curing for 28 days (age of testing of compressive strength according to ASTM, C330-80). Both normal and lightweight concrete were tested.

RESULTS AND DISCUSSION

- **Mineralogical and Chemical Composition**

The qualitative mineralogical composition of Tellol Al-Kiend clay and the dolomite are summarized in Table (2), and present in the X-ray diffraction pattern (Figs.1 and 2) for clay and dolomite respectively. It can be seen that montmorillonite, palygorskite and kaolinite are the predominant clay minerals present. Other predominant minerals are calcite and quartz. Feldspar and rutile are also detected, but in minor amounts. The chemical composition of the clay and dolomite are shown in Table (2). As can be noted that the main constituents of the clay material are: SiO_2, Al_2O_3, CaO and Fe_2O_3. These elements are a reflection of the mineralogical composition of the clay as seen in Fig. (1) and Fig.(2).

Table 2: Mineralogical and chemical composition of the clay and dolomite

Mineralogical composition

Clay: Quartz, Calcite, Montmorillonite, Palygorskite, Kaolinite, Rutile and Feldspar
Dolomite: Mainly Dolomite with trace of Quartz

Chemical composition

Sample	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	L.O.I.	Na_2O	K_2O
	(%)								
C1ay	43.83	5.69	12.18	13.34	4.05	0.09	18.26	0.17	1.55
Dolomite	–	0.13	0.16	30.69	20.75	–	46.73	0.11	0.02

The chemical analysis, however, showed that the clay contains a high amount of CaO (13.34%), which is obviously related to the abundance of calcite ($CaCO_3$) as identified by the XRD (Table 2 and Fig.1). Na_2O and K_2O contents are mainly attributed to the presence of feldspar. MgO is related to the presence of montmorillonite and palygorskite clay minerals and the same is true for the presence of Fe_2O_3.

However, CaO, MgO, Fe_2O_3, Na_2O and K_2O which are associated with the clay as essential or exchangeable cations are considered as fluxing constituents (Riley, 1951; Rattanachan and Lorprayoon, 2005 and Fakhfakh, *et al.*, 2007). The sum of these elements represents about 25% of the clay composition. This high value of fluxing elements may enhance the softing and melting temperature of the clay constituent, henceforth adversely affect the bloating behavior of the clay. The chemical and mineralogical analysis, however, indicated that the dolomite used is of a high purity (Table 2 and Fig.2).

The CEC value of the raw clay was found of about 30 meq/100 gram. This indicated that, the clay contains low amounts of montmorillonite. For clarity, it is worth to point out that the CEC of Ca-montmorillonite claystone (with 65% montmorillonite) deposit in Western Desert, used by Al-Ajeel and his team (Al-Ajeel *et al*., 2011) for the production of lightweight aggregates, was of about 70 meq/100 gram. According to (Grim, 1968) the higher the CEC value the higher the montmorillonite content. This Claims that the bloating of clay progressively increasing with the increase in the content of the montmorillonite up to 50% and a larger amount does not increase the probability of bloating.

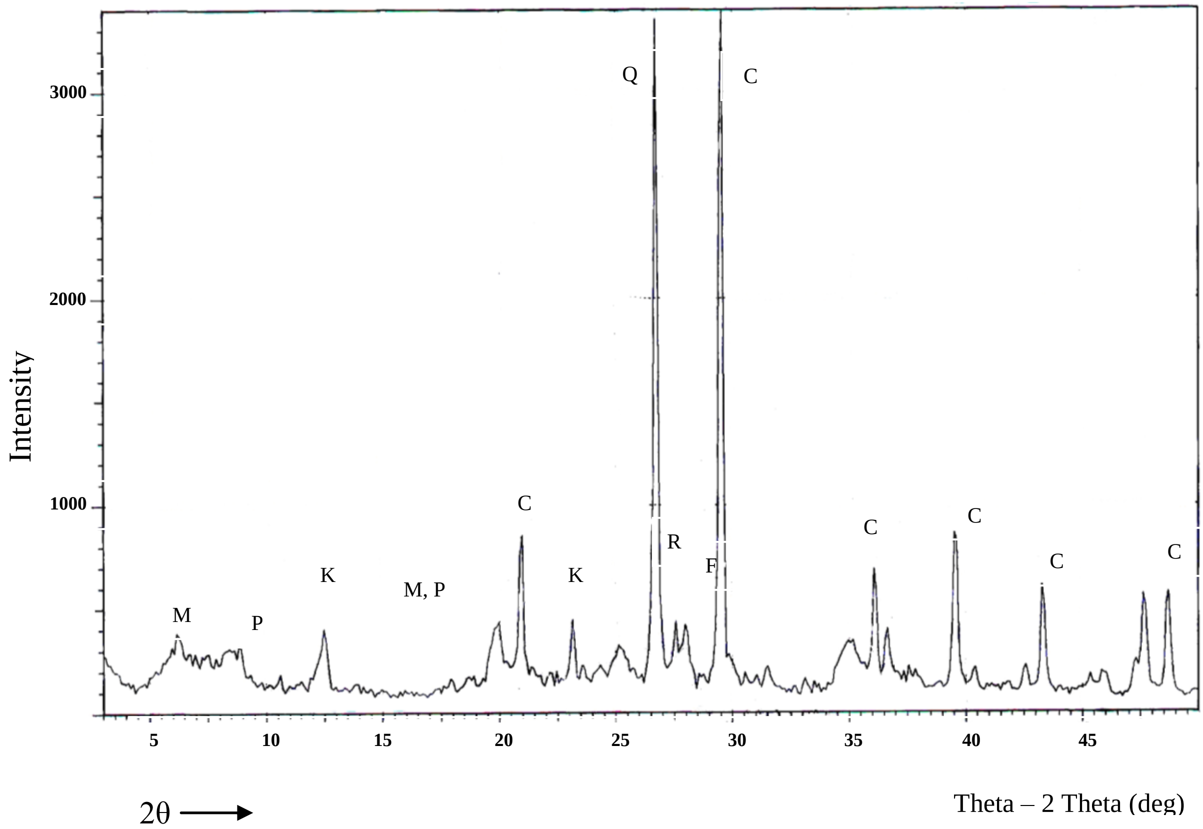

Fig.1: XRD pattern of the raw clay
Q: Quartz, C: Calcite, M: Montmorillonite, P: Palygorskite, K: Kaolinite, R: Rutile, F: Feldspar

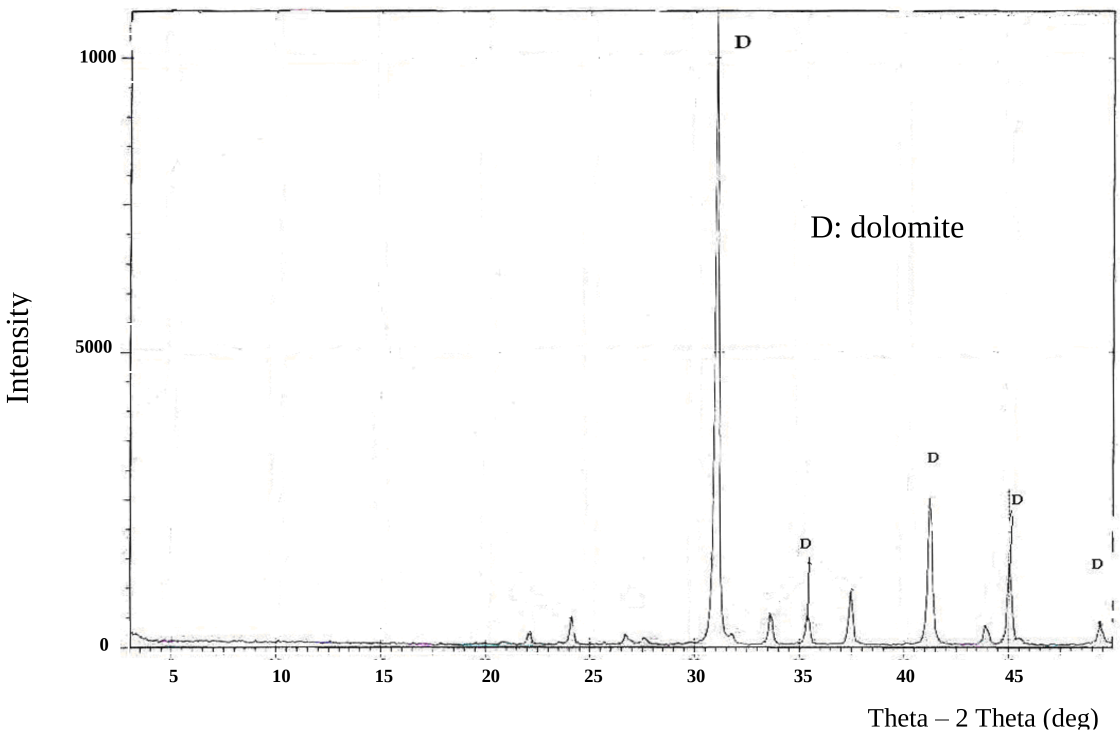

Fig.2: XRD pattern of dolomite

▪ **Bloating of Raw Clay**

In general, the temperature range used for commercial bloating usually between (1050 – 1200) °C, and the highest economically allowed temperature for conducting bloating of clays is not over 1300 °C (Arioz *et al*., 2008 and Viackelionis *et al*., 2011). Also in the investigation of Al-Ajeel *et al*. (2011) to evaluate the bloating behavior of Iraqi low grade calcareous Ca-montmorillonite claystone, it was found that bloating occurs at (1180 – 1200) °C. We noticed that, the mineralogical and chemical composition of this claystone has some resemblance to that of Tellol Al-Kiend clay, particularly the clay minerals present, as well as the type and amount (20%) of the fluxing components. Therefore, the bloatability trials for the aggregates made from clay only, were conducted at 1180 °C to 1200˚C range (slow isothermal firing mode). The results of this test which was carried out at different socking times, are shown in Table (3). It is worth to mention that, the bloating characteristic results given in Table (3) were based on the visual examination of the fired aggregates. From these results, it can be noted that, bloating of the clay was occurred only at 1180 °C and 45 minutes soking time. The specific gravity of the produced aggregates was of about 1.38, which is well below the starting materials (1.96). The water absorption value was very low (0.8%), which is due to the formation of a glassy shell around the aggregates, and hence hindered water penetration into the aggregates. Firing of the aggregates, at 1180 °C for less than 45 minutes does not show any significant changes in the appearance of the aggregates, while at temperature of 1200 °C, the aggregates show a poor bloat for the whole of the socking times tested (Table 3).

Table 3: Physical properties of lightweight aggregate made from clay only

Run No.	Temp. (°C)	Time (min.)	Bulk specific gravity	Water abs. (%)	Bloating appearances
T_1R_1	1180	10	–	–	no bloat
T_1R_2	1180	15	–	–	no bloat
T_1R_3	1180	30	–	–	no bloat
T_1R_4	1180	45	1.383	0.8	good bloat
T_2R_1	1200	10	1.648	2.04	poor
T_2R_2	1200	15	1.567	1.574	poor
T_2R_3	1200	20	1.704	1.923	poor
T_2R_4	1200	25	1.740	1.149	poor
T_2R_5	1200	30	2.155	0.288	poor
F_1 (Rapid firing)	1200	10	1.470	0.89	good bloat

Close examination of these aggregates indicated that melting and sintering have occurred, and accordingly the specific gravity was increased (progressive increase in specific gravity with increase in socking time). Obviously, this can be attributed to the high amounts (25%) of the fluxing components ($CaO + MgO + Fe_2O_3 + Na_2O + K_2O$) present in the clay, which led to sintering incidence.

According to Riley, (1951) two conditions are necessary for bloating of clay. Enough components should be fused and produce a viscous material within the temperature range (1100 – 1300) °C so that, the formed gases will be trapped. The second condition is that, some constituents must be present in the clay, so that these constituents will dissociate and liberate a gas at the time when the mass of the clay has fused to a viscous melt. In this study the XRD analyses (Fig.1) revealed the presence of calcite $CaCO_3$ as an accessory mineral which is a gas producer when heated above 800 °C (CO_2 gas is liberated). From these results, it seems that, a proper viscosity condition of the fused materials at 1200 °C for trapping the evolved gas, does not created, hence no bloat occurs. Obviously neither very high, nor too low viscosity of the viscous phase is acceptable. In the first case a high resistance to the gas evolution is created, while in the second case the gaseous products escape freely without producing bloating. Accordingly, it appears to be no doubt that the bloating of Tellol Al-Kiend clay during the isothermal firing at 1200 °C is principally determined by the viscosity of the melt which is unable to entrap the evolved gas (from decomposition of calcite), and thus no bloat occurs.

Rapid (flush) firing at 1200 °C was also done to observe whether Tellol Al-Kiend clay is bloated at this condition. It can be seen from Table (3) that a good bloat was occurred and a specific gravity of 1.47 was attended.

- **Characteristics of Clay Mix (Rapid Firing)**

It was claimed that, the bloat ability of natural clay can be improved by employing additives such as carbonic materials, heavy fuel oil, straw, saw dust and carbonate (dolomite)…etc (Al-Marahleh, 2005). Therefore, attempts were made to find the effect of the additives (dolomite, straw and heavy oil) that could increase the bloatability of the clay, and hence producing acceptable lightweight aggregates. The raw aggregates mixes, which were made from different proportions of the additives to the clay shown in Table (2) were fired for (3 and 5 minutes) at 1200 ˚C. The properties of produced aggregates are shown in Table (4).

Generally, it can be seen that, among each group neither the firing time, nor the amounts of additives have a significant effect on the specific gravity of the fired aggregates. On the other hand, the type of additive significantly affect the bloatability of the clay. From what have been displayed discussion, it is apparent that, all aggregates made from clay and dolomite can produce good bloated aggregates with specific gravity ranging from (1.49 – 1.35). The lower specific gravity value (1.35), however, was obtained from the aggregates made of 5 wt.% dolomite with clay. Also, the results of Table (4), show that good bloated aggregates can be obtained from mixtures of clay with (1 and 2 wt.%) of either oil (CO and CO_2), or straw (S_1 and S_2) with rather higher specific gravity Other mixes, however, show a poor bloating with a high specific gravity too.

Table 4: Physical properties of lightweight aggregates made from mixed materials

Aggregates mix	Sample code	Temp. (°C)	Socking time (min.)	Density (g/cm^3)	Water absorption (%)	Bloating appearances
Clay + Dolomite	CD1	1200	3	1.424	1.1	good
	CD2	1200	3	1.367	0.934	v. good
	CD3	1200	3	1.49	0.392	good
	CD1	1200	5	1.470	0.4	good
	CD2	1200	5	1.350	0.996	good
	CD3	1200	5	1.4	1.73	good
Clay + Oil	CO1	1200	3	1.605	0.546	good
	CO2	1200	3	1.559	0.543	good
	CO3	1200	3	1.644	1.01	poor
	CO3	1200	5	2.035	0.584	poor
Clay + Straw	CS1	1200	3	1.56	1.2	good
	CS2	1200	3	1.512	1.49	good
	CS3	1200	3	1.60	1.54	poor
	CS1	1200	5	1.625	1.958	poor
	CS2	1200	5	1.61	1.6	poor
	CS3	1200	5	1.621	1.41	poor

However, comparing the properties of the aggregates obtained from the rapid firing of (clay + 5 wt.% dolomite) with that obtained from the isothermal firing (using clay only). It can be noted that, the aggregates produced from the isothermal firing for (45 min at 1180 °C) show no significant differences than that of rapid firing. This, however, is an economical matter, but surely from economic point of view, the rapid (flush) firing is most significant.

From the foregoing experiments, it seems that, a number of factors may determine the bloating characteristics of clays including clay mineralogy, accessory (non-clay mineral composition) and chemical composition. The importance, however, is not only the type of minerals present in the clays but also their quantity.

However, the lightweight aggregate prepared from clay + 5 wt.% dolomite, and clay only by rapid firing was tested for lightweight concrete. The compressive strength of 28 days of the prepared lightweight concrete was determined and compared as shown in Table (5). It is obvious that the compressive strength of the lightweight concrete is much lower than that of the normal concrete. Beside, the density of the lightweight concrete made from clay

aggregates does not show any significant difference. Therefore, this could not be considered as lightweight concrete. On the other hand, concrete made from clay + 5% dolomite lightweight aggregate, resulted with lower density (1.76 g/cm^3) as well as low compressive strength. According to RILM (The Reunion International des Laboration d' Essais et de Recherches sur les Materiaux et les Constructions), this property which fall mid-way between low density and structural concrete can be designated as structural and insulating concrete (Sousa *et al*., 2004).

Table 5: Physical and mechanical properties of cube of concrete

Concrete	Compressive strength (kg/cm^2)	Density (g/cm^3)	Water absorption (%)
Normal aggregate	270	2.16	3.7
Clay lightweight aggregate	172.6	1.98	5.9
Clay + 5% dolomite lightweight aggregate	125.4	1.76	6.9

CONCLUSIONS

On the bases of the present experimental work, the following can be concluded:

- The firing method (isothermal or rapid) and some additives can influence the bloating behavior of Tellol Al-Kiend clay.
- It is possible to produce lightweight aggregates considerably lighter (specific gravity 1.38 – 1.35 range) than the conventional aggregates by: **a)** iso-thermal firing of clay aggregates for 45 min. at 1180 °C, and **b)** rapid firing for no more than 5 min. at 1200 °C of aggregates made of clay + 5 wt.% dolomite.
- Economically, rapid firing method is most recommended for the production of lightweight aggregates from Tellol Al-Kiend clay.
- The concrete made from the lightweight aggregates (LWAs) produced in this study has a compressive strength of about 172.6 kg/cm^2, which is intermediate between low density (insulator or non-structural) and structural concrete.

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