



## Assessment of Suitability of the Beduh Deposits (Lower Triassic) for Lightweight Aggregates, North Amadyia, Kurdistan Region - Iraq

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### Abstract

This study deals with the assessment of deposits of the Beduh Formation (Lower Triassic) for lightweight aggregate. It is carried out on channel samples of three exposures (Beduhe, Sararu and Nazdur) at north of Amadyia. Lithologically, the formation consists of alternation of reddish purple, reddish brown and greenish grey shale with subordinate thin sandstone beds and some siltstone streaks.

XRD analysis revealed that the studied samples are composed mainly of clay minerals such as illite in major proportion with kaolinite, chlorite, smectite and mixed-layer illite-smectite in minor proportions. The non-clay minerals are quartz and calcite, in major proportions and minor proportions of feldspar and hematite. Grain size analysis showed that the raw materials are composed mainly of clay and silt, with subordinate sand. The plasticity index of these shales is high due to high clay content. Chemical analyses show that the raw materials are composed essentially of silica, alumina, calcium oxide and relatively a less proportion of iron oxide, and appreciable amounts of MgO, K<sub>2</sub>O, Na<sub>2</sub>O, TiO<sub>2</sub> and MnO.

The raw materials are ground and sieved to two sizes: fine size (less than 0.075 mm) and coarse size (less than 1.00 mm). Water is added (about 12-15 %) to the sieved samples and thoroughly mixed, pelletized by hand to lumps named here pellets (about 18-20 mm diameter). The pellets are dried and fired at different temperatures with different soaking times. The evaluation physical tests (bloating, porosity, water absorption and bulk density) shows that the best results achieved through flash firing at 1120°C with soaking time 30 minutes and rapid cooling, after pre-heating to about 300 to 350°C for 10 to 15 minutes. The coarse raw materials (less than 1.00 mm) show better results than the finer size (less than 0.075 mm).

### Introduction

Beduh Formation is an Early Mesozoic siliciclastic lithostratigraphic unit that crops out in many areas at the Northern Thrust Zone of Iraq, near the Iraqi-Turkish borders. The formation was described for the first time by Wetzel in 1950, near Beduhe Village (Bellen *et al.*, 1959) as "a red-brown and purplish shale and marl with thin ribs of limestone and sandy streaks" (Bellen *et al.*, 1959). Hakeem (2012) described the lithology of Beduh Formation as alternation of reddish purple, reddish brown and greenish grey shale with thin sandstone beds and some siltstone streaks.

The development in construction industry together with obtaining the best alternatives for construction materials is behind the expansion in the studies of construction materials. Since most of the lithology of Beduh Formation is red shale; therefore, the deposits of the formation need to be assessed for

utilization in various ceramic industries (Hakeem, 2012). This research deals with the assessment of some clayey deposits from Beduh Formation for lightweight aggregate. Lightweight aggregates are defined as natural or artificial materials, which are granular, porous and lightweight, and can be divided into two categories: 1) Those occurring naturally and are ready to use only with mechanical treatment, i.e. crushing and sieving, such as pumice and volcanic tuffs. 2) Those produced by thermal treatment from either naturally occurring materials or from industrial by-products materials. The natural materials used for producing lightweight aggregate of second categories can be manufactured from igneous, sedimentary, and metamorphic rocks such as (perlite, vermiculite, clay, shale, slate). On the other hand, they can also be manufactured from wastes and industrial by-products such as glass and fly ash (Riley, 1951; Burwell, 1954; Heiner and Loskamp, 1966; Gennaro *et al.*, 2005; Yen *et al.*, 2008; Corrochano *et al.*, 2009). Artificial lightweight aggregates are formed by the rapid heating at high temperature of materials that have the ability to expand (bloating), and the temperature interval over which the bloating of a sample occurs is called its bloating range.

Two conditions are necessary to achieve an appropriate expanded material; first, it must contain substance that release gases at high certain temperature. Second, a plastic state with the appropriate viscosity must be produced so that it can trap the released gases at this temperature (Riley, 1951). Most natural aggregates have a particle density between 2.4 and 2.8 g/cm<sup>3</sup>, typically 2.6 g/cm<sup>3</sup>, while lightweight aggregates have a particle density between 0.8 and 2.0 g/cm<sup>3</sup> (Cheeseman *et al.*, 2005; Cheeseman, 2011). Bates (1969) stated that the density of lightweight aggregates ranges between 2/3 - 1/3 from density of ordinary aggregates, and Klinefelter (1960 in Gennaro *et al.*, 2005) determined it as less than water density. The benefits associated with these low densities, which are due to the formation of voids and pores, are very good thermal and acoustic insulating and materials with a good resistance to fire (Fakhfakh *et al.*, 2007).

This study focuses on investigation of the possibility of producing good quality expanded aggregate with and without additives, from the channel samples collected from Beduh Formation in the studied outcrop sections. Its objective is to assess the deposits of Beduh Formation for lightweight aggregate industry.

### **Geological setting:**

Tectonically, Iraq has been divided into many zones according to Buday (1980), Buday and Jassim (1987) and Numan (1997). Jassim and Buday (2006) divided Iraq into three tectonic areas, namely the Stable Shelf Zone with no surface anticlines, the Unstable Shelf with surface anticlines, and the Zagros Suture which comprises thrust sheets of radiolarian chert, igneous and metamorphic rocks. The studied samples are collected from the exposure of the Beduh Formation at the Northern (Ora) Thrust Zone (Fig. 1). Structurally, the studied sections are located at two asymmetric anticlines trending E-W called Ora and Nazdur anticlines (Fig. 2). The northern and southern limbs of these anticlines comprise Paleozoic and Mesozoic strata (Al-Brifkani, 2008). Beduhe and Sararu sections are located at the southern limb of Ora anticline whereas Nazdur section is located at the northern limb of Nazdur anticline (Fig. 2). Stratigraphy, almost the entire Phanerozoic succession is exposed at the Northern Thrust Zone of Iraq. Beduh Formation is of Lower Triassic age and is in conformable and gradational contact with both the underlying Mirga Mir Formation and the overlying Geli Khana Formation (Bellen *et al.*, 1959).

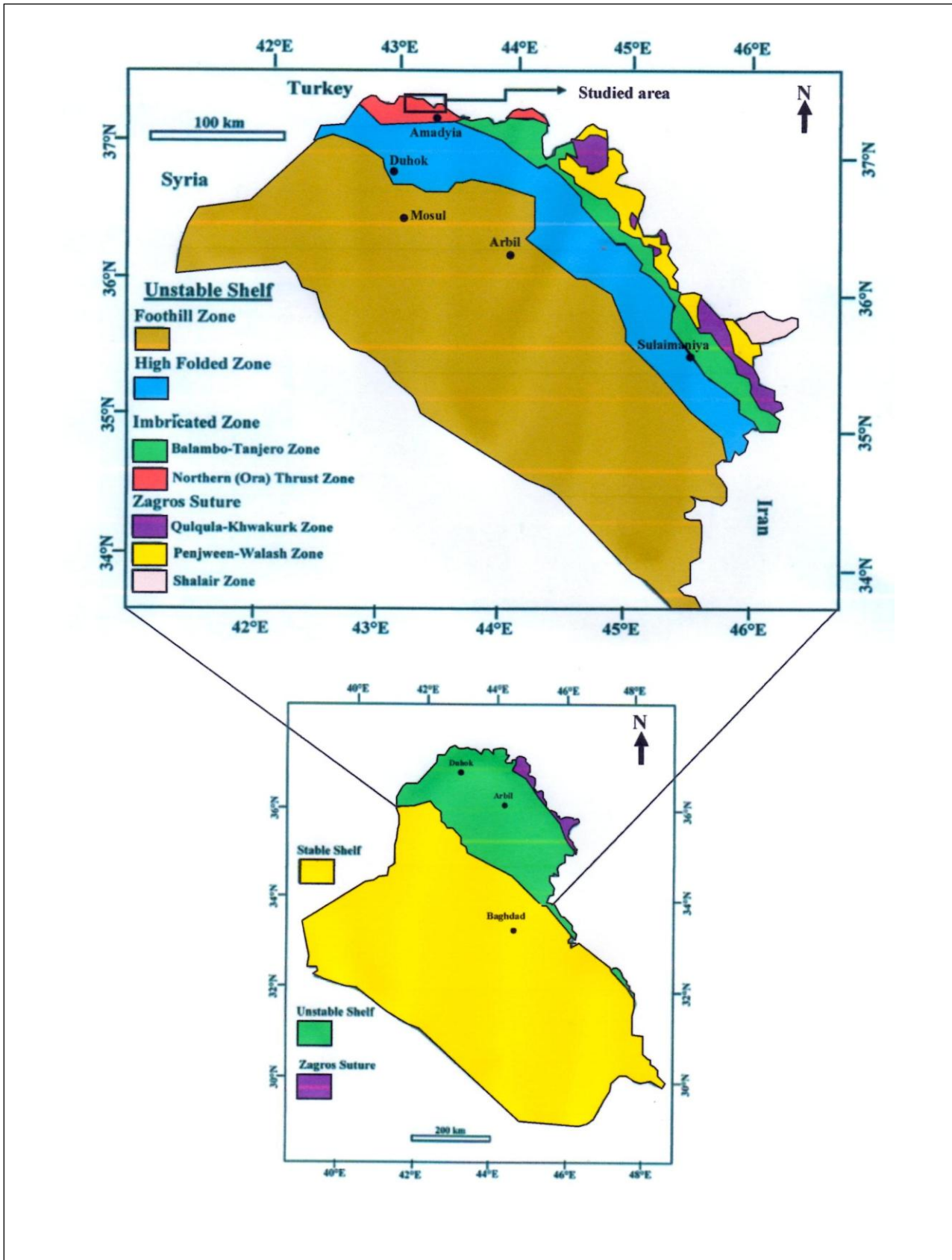


Figure-1: Tectonic map of Iraq showing the studied area (from Jassim & Buday, 2006).

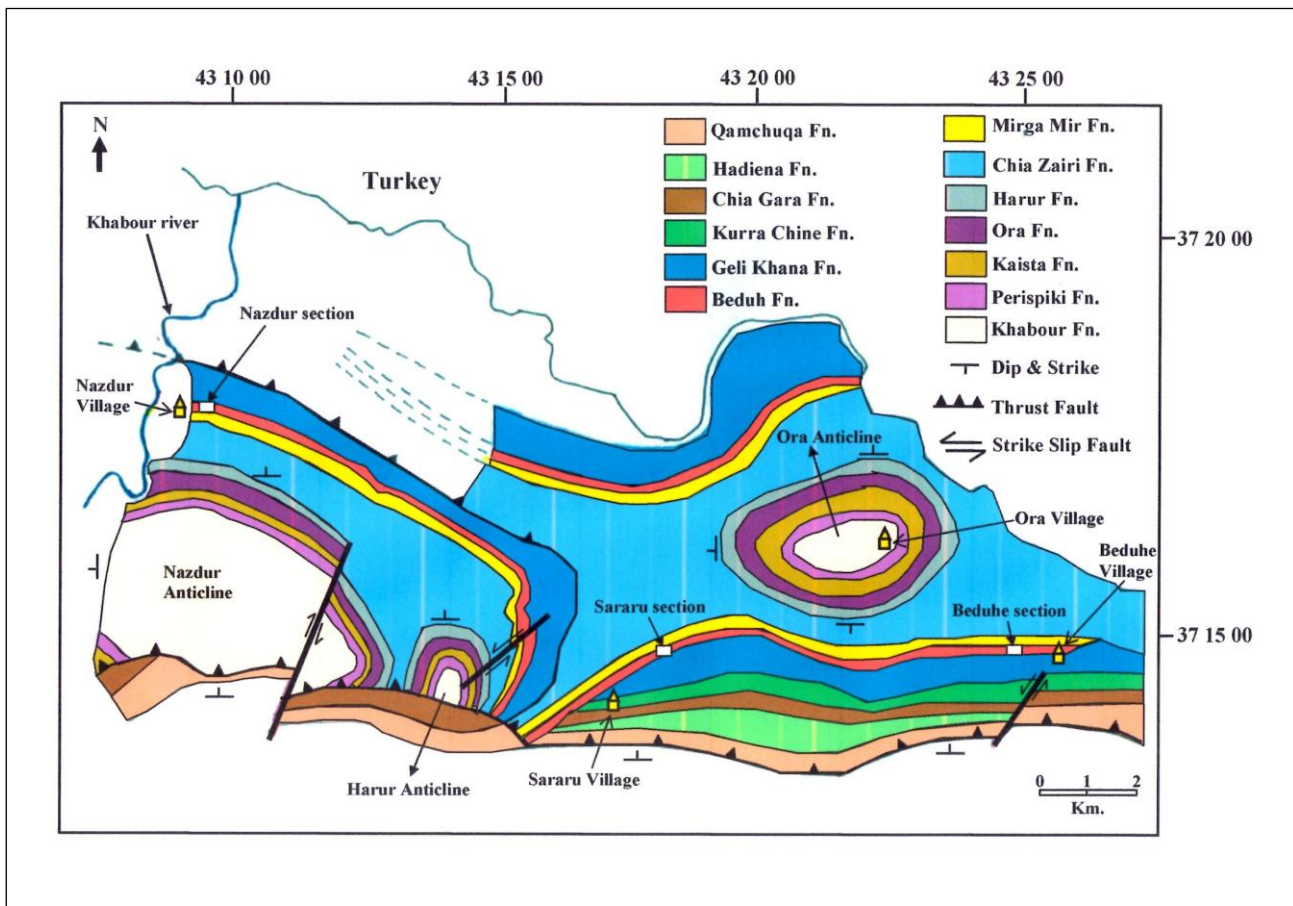


Figure-2: Geological map of the area and the studied sections (after Al-Brifceni, 2008).

### Sampling and methods:

The study involves field and laboratory investigations. The laboratory work incorporates assessment of the raw material (mineralogical, physical and chemical), preparation of the pellets (before and after firing) and assessment of the results.

#### Field work:

In this study, three outcrop sections are selected. All these sections are located in the Northern Thrust Zone. Channel sampling was used for collecting samples from each sections (about 10 kilograms). Lithology and location of studied sections are described in detail below:

1- Beduhe section (BB): Beduhe section is the type section of the formation and is located at about 20 km northwest of Amadiya city. This section is exposed at 1 km to the west of the Beduhe village, along the valley, and 5 km southeast of Ora village with Lat. 37° 15' 26" N and Long. 43° 23' 35" E (Fig. 2).

2- Sararu section (SB): Sararu section is located at about 26 km northwest of Amadyia city. This section is exposed near the road between Ora and Sararu villages, at about 1.5 km to the northeast of Sararu village, and 6 km to the southwest of Ora village with Lat. 37° 15' 02" N and Long. 43° 18' 19" E (Fig.2).

3- Nazdur section (NB): Nazdur section is located at about 42 km northwest of Amadyia city. This section is exposed at about 500 m north of the intersection of two unpaved roads; one goes to the foot bridge to cross the Khabour river and the second climb down to the Khabour valley near Nazdur village with Lat. 37° 18' 44" N and Long. 43° 08' 45" E (Fig. 2).

**Laboratory works:**

Mineralogy of the raw materials, of all channel samples, was studied using XRD technique. The analysis is carried out in the laboratories of the Iraq Geological Survey-Baghdad. Four slides are prepared: one powder slide to recognize the non-clay minerals, and three oriented smears (by pipette method) to recognize the clay minerals. The percentage of carbonate minerals in the studied samples are calculated according to the procedure proposed by Carver (1971), i.e., by adding 10 % hydrochloric acid (HCl) to a pre-weighted sample and left for 24 hours to allow complete reaction. Then the carbonate percentage was calculated using the following equation:

$$\text{Carbonate \%} = \frac{\text{Weight loss}}{\text{Wt. of sample}} \times 100$$

Grain size analysis is carried out using pipette method. The samples are treated with 5% HCl to dissolve the carbonate cement material and facilitate the disintegration process. This method is more reliable and gives accurate results (Friedman and Johnson, 1982). Atterberg limits (Plastic limit, liquid limit and plasticity index) are carried out according to B.S. 1377-1967. Chemical analyses of major and minor oxides (SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, CaO, MgO, MnO, SO<sub>3</sub>, Na<sub>2</sub>O, K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub>) are carried out by X-ray fluorescence (XRF) in the laboratories of the Iraq Geological Survey-Baghdad, to determine the major oxides content.

**Forming method:**

The studied sample are ground to a fine size by ring crusher and well mixed. The pulverized studied samples are sieved into two sizes (less than 0.075 mm and less than 1.00 mm) before forming process. Water is added, in about 12-15 %, to the sieved fraction until it was sufficiently moldable, and then pelletized by hand into size of about 18-20 mm diameter (Fig. 3). Other samples are formed by addition of about 10 % of water with about 5 % of motors waste oil, for an attempt to improve the bloating ability. Using oil as admixture in clays leads to a significant reduction in density in the resulting aggregates with lower firing temperature (Al-Bahar and Bogahawatta, 2006). For this purpose, one mixture sample is prepared from mixing the three samples (BB, SB, and NB) in equal proportion, and then mixed with the mentioned percentage of motors waste oil.



Figure-3: Pellets molded by hand for lightweight Aggregate preparation (before firing).

**B. Drying and firing:**

The molded pellets are air-dried for two days and placed in an oven at 105 °C for 24 hours, to prevent the cracking during firing. During firing, various temperatures and soaking times are tried (1040°C, 1060°C, 1080°C, 1100, and 1120 °C with soaking times 10, 30, and 60 minutes for each temperature) in order to obtain the optimum conditions for bloating, and get the best lightweight aggregate specifications. In addition, two methods of firing and cooling are followed, gradual and flash (rapid). Furthermore other prepared samples are pre-heated to about 300 to 350°C for 10 to 15 minutes, to prevent explosion during firing at high temperatures, and without affecting on the bloating characteristics for the product. The latter technique is recommended by many researchers such as Al-Kass and Al-Khalissi (1979), Fakhfakh, *et al.* (2007), Al-Awjar (2008) and Yen, *et al.* (2008).

**Evaluation tests:**

The evaluation of the prepared pellets for the lightweight aggregate preparation is carried out too. The most important tests are the following:

1. Bloating (volume increase): Bloating ability is the most important property in the lightweight aggregate industry and has been determined by the following equation:

$$\text{Bloating (volume increase)\%} = \frac{V_a - V_b}{V_b} \times 100$$

Where:  $V_a$  = Volume of the sample after firing.

$V_b$  = Volume of the sample before firing.

2. The weight loss is calculated by the following equation:

$$\text{Weight loss \%} = \frac{\text{Weight of pellet before firing} - \text{Weight of pellet after firing}}{\text{Weight of pellet before firing}} \times 100$$

3. True (total) porosity: The true (total) porosity of the fired pellets is calculated according to the following equation:

$$\text{True porosity \%} = \frac{\text{Volume of certain weight of sample} - \text{Volume of same weight as powder}}{\text{Volume of certain weight of sample}} \times 100$$

4. Water absorption: The water absorption of the fired pellets is calculated according to ASTM C373-72.

5. Bulk density: The bulk density of the fired pellets is calculated according to ASTM C373-72.

**Results and discussion:**

**Raw materials:**

The mineralogical analysis of the raw materials, as revealed by XRD technique, showed that they are composed of clay and non-clay minerals. Illite is the major clay mineral in the studied samples whereas kaolinite, chlorite, smectite, and mixed layer are subordinate (Fig. 4). Individual clay particles have an important influence on ceramic properties, as well as they have generally appropriate properties in ceramic industries, which give a suitable plasticity, moldable when wet, hard when dried and vitrified when fired (Kingery, 1967). The non-clay minerals in the studied raw materials are essentially of quartz and calcite, with subordinate proportion of feldspars and hematite (Fig. 4). These minerals has an important role in the ceramic industries because some of them contribute as a flux materials like calcite, feldspar, and hematite; while quartz mineral is responsible to form a glass melt. They are therefore contributing to the mechanical and physical properties of the end product (Kingery, 1967). Calcite is present in the clay deposits in varying proportions. Increase of these minerals and passing certain limit will adversely affect the properties of ceramic body due to the decomposition during firing and tend to cracking and fracturing, and on the other hand, these minerals acts as flux materials (Al-Kass, *et al.*, 1985; Al-Obaidi, 1999). The decomposition of carbonate minerals during firing will also increase the porosity and decrease the bulk density of the ceramic body.

The percentage of carbonate minerals in the studied samples ranged between 9.26 and 18.27 % (Table 1). This percentage is suitable for ceramic industries especially for construction products like brick, because clays will become unsuitable for ceramic industries if the carbonate percentage exceeds 35 %, especially when it present in coarse grain size and not distributed homogenously (Al-Dawaf, 1969).

The results of grain size analysis showed that the three raw materials are composed mainly of clay (< 4  $\mu\text{m}$ ) and silt (4-63  $\mu\text{m}$ ) portions, with a minor proportion of sand (63  $\mu\text{m}$ -2 mm) as shown on Table 2. The percentages of these components are plotted on the Folk's (1980) classification triangle in order to classify the samples. The Beduhe channel sample plots on the mud field, whereas Sararu and Nazdur channel sample plot on the sandy mud field (Fig. 5).

Atterberg limits, i.e. plastic limit, liquid limit, and plasticity index are calculated according to B.S. 1377-1967 ( Table 3). The plastic limit ranges between 24.31 to 27.72 %, the liquid limit ranges from 44.82 to 52.06 % and plasticity index ranges from 20.51 to 24.34. The high limits of plasticity are due to high proportion of clay portions in the all studied samples (Table 2).

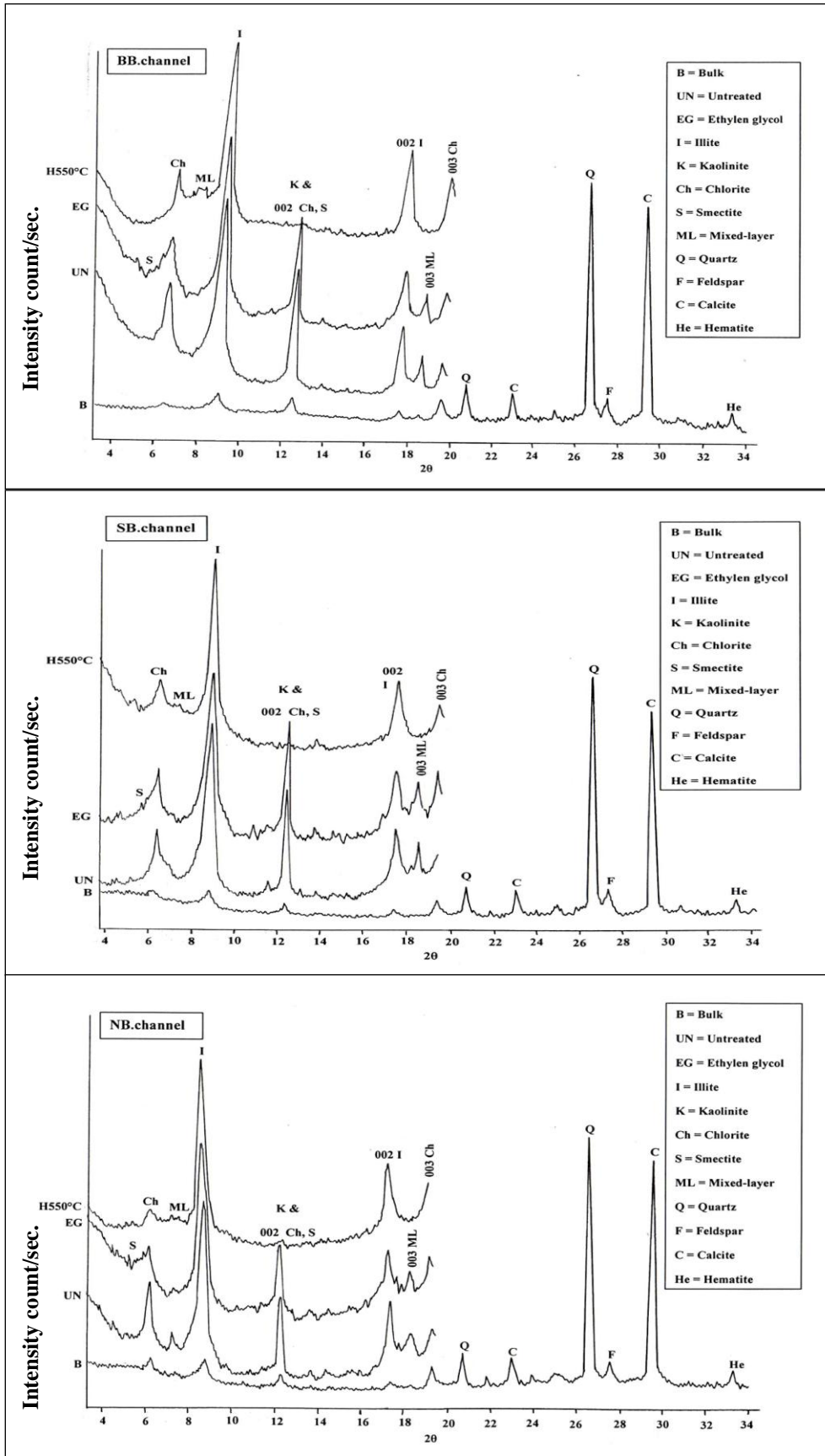


Figure-4: X-ray diffractograms of clayey deposits from Beduh Formation.

Table-1: The percentages of carbonate minerals in studied samples.

Sample	Carbonate %
BB	18.27
SB	16.63
NB	9.26

Table-2: Grain size analysis of the raw materials showing their contents of sand, silt and clay.

Sample	Sand %	Silt %	Clay %
BB	9.32	32.23	58.45
SB	11.79	37.00	51.21
NB	15.09	37.56	47.35

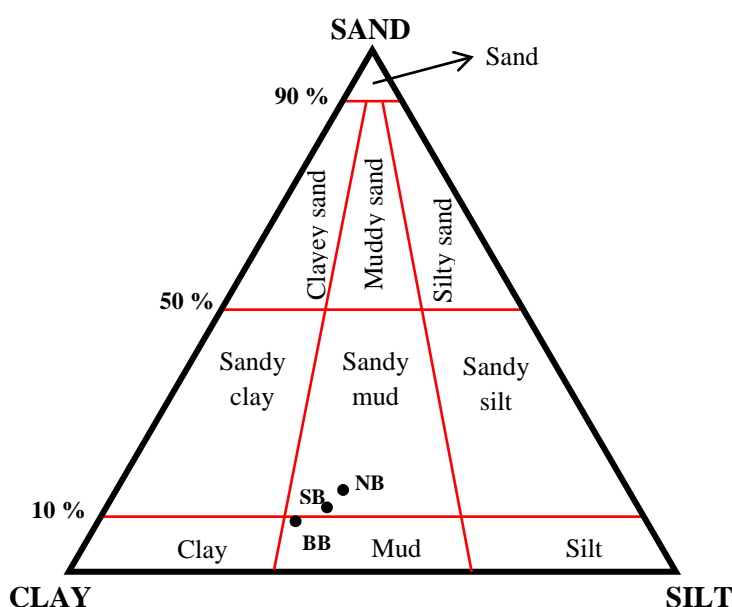


Figure-5: Relative distribution of sand, silt, and clay portions of the Beduh deposits (using Folk’s terminology, 1980).

Table-3: Atterberg limits for studied samples according to B.S. 1377-1967.

Sample	Plastic limit %	Liquid limit %	Plasticity index
BB	27.72	52.06	24.35
SB	26.11	49.63	23.52
NB	24.31	44.82	20.51

The results of chemical analysis are shown on Table 4. It shows that the raw materials are composed essentially of silica ranging between 44.67 and 48.06 %, because silica is considered the main component of clay minerals, as well as it is present in the form of quartz mineral in channel samples (Fig. 4). Also there is relatively a considerable proportion of alumina ranging between 14.79 and 15.67 % in the studied samples. This oxide is also a major part of the structure of clay minerals. Both these oxides are considered refractory

materials in the ceramic industries (Kingery, 1967). In addition to that, there is a high proportion of calcium oxide (CaO) ranging between 10.84 and 12.56 %, and this proportion is mainly due to presence of calcite in the raw materials (Figs. 6-1 and 2). Calcium may also be present in the clay minerals structure. There are relatively a less proportion of iron oxides ranging between 3.17 and 3.50 %. The iron oxides have a major role in determining the colour of ceramic specimens during firing. Also the chemical analysis for raw materials showed appreciable amounts of MgO, K<sub>2</sub>O, Na<sub>2</sub>O, TiO<sub>2</sub>, and MnO. The five oxides (Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, K<sub>2</sub>O, and Na<sub>2</sub>O) are considered as fluxing materials in ceramic industries. Loss on ignition is calculated during firing at 1000°C and is ranging between 17.44 and 18.89 %. The causes of this loss is attributed to the molecular and adsorbed water presents in and on the crystal structure of clay minerals, in addition to decomposition of carbonate minerals and liberation of CO<sub>2</sub> gas and other volatiles.

Table-4: Chemical analysis of the studied raw materials.

Oxides %	BB	SB	NB
SiO <sub>2</sub>	44.67	45.59	48.06
Fe <sub>2</sub> O <sub>3</sub>	3.50	3.17	3.32
Al <sub>2</sub> O <sub>3</sub>	14.79	15.67	15.04
TiO <sub>2</sub>	0.59	0.54	0.46
CaO	12.56	11.16	10.84
MgO	1.14	1.25	1.41
Na <sub>2</sub> O	0.42	0.33	0.38
K <sub>2</sub> O	2.42	2.76	2.11
MnO	0.81	0.89	0.76
P <sub>2</sub> O <sub>5</sub>	0.12	0.11	0.10
SO <sub>3</sub>	0.08	0.12	0.08
L.O.I.	18.89	18.41	17.44
Total	99.99	100	100

***Evaluation tests of pellets:***

According to results of the chemical analysis for raw materials (Table 4), and depending on the Riley’s diagram (1951) the proportion of refractory and flux materials are recalculated to determine the position of the studied samples on this diagram (Table 5). The plot shows that Sararu and Nazdur samples fell inside the optimum field whereas the Beduhe sample fell slightly outside the bloating area (Fig. 6).

Table-5: The proportions of refractory and flux materials of the Beduh deposits.

Oxides %	BB	SB	NB
SiO <sub>2</sub>	56.19	57.04	59.22
Al <sub>2</sub> O <sub>3</sub>	18.60	19.60	18.53
Fluxes (CaO + MgO + Fe <sub>2</sub> O <sub>3</sub> + Na <sub>2</sub> O + K <sub>2</sub> O)	25.21	23.36	22.25

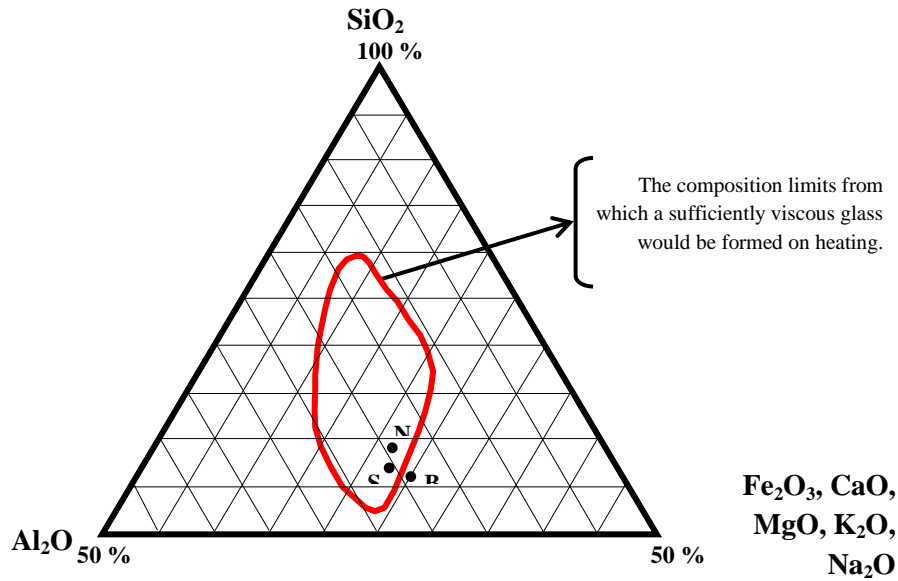


Figure-6: The position of studied shale samples with respect to bloating area (after Riley, 1951).

Preliminary firing tests on pellets showed that the pellets start melting at about 1140°C and completely melted at about 1160°C (Fig. 7). Therefore, the firing temperatures used for lightweight aggregate during later operations are less than 1140°C. The formed pellets are fired at 1040°C, 1060°C, 1080°C, 1100, and 1120 °C with soaking times 10, 30, and 60 minutes for each temperature. The results shows that with flash (rapid) firing of the studied pellets (fine and coarse grained) at 1040°C, 1060°C, 1080°C, 1100, and 1120 °C with soaking times 10, 30, and 60 minutes for each temperature (after drying at 105 °C for 24 hours) tend to explode. The explosion of the pellets is attributed to sudden escape of gases and molecular water (Fig. 8) without the formation of melt. Accordingly the gas escaped before forming closed pore spaces.

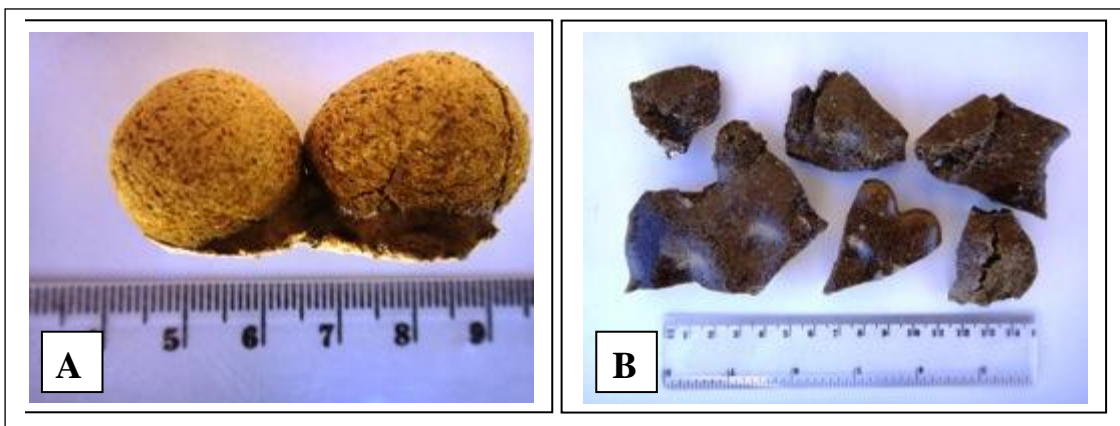


Figure-7: (A) beginning of melting and (B) complete melting of studied pellets.



Figure-8: Explosion of studied pellets due to flash firing without pre-heating.

A gradual firing of pellets, at same firing temperatures, did not give the required specifications as lightweight aggregate, in term of bloating ability, weight loss, true porosity, water absorption and bulk density (Fig. 9-A). Most probably because the escape of gases is slow and did not synchronize with melting. Vitrification process have taken place at firing temperature 1120°C, in all soaking times and for both fine- and coarse-grained samples (Fig. 9-B).

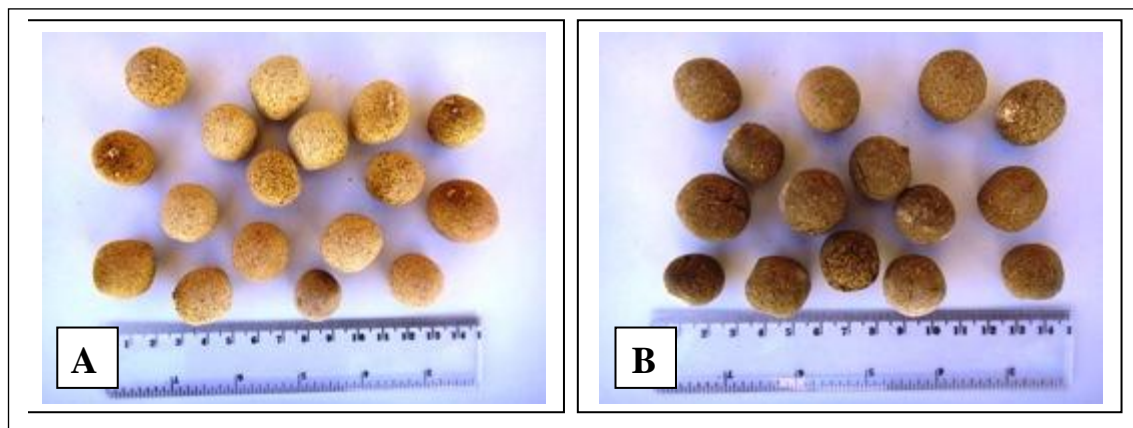


Figure-9: (A) non- bloating pellets without vitrification, (B) non-bloating pellets with vitrification.

In order to avoid the explosion and to obtain the best bloating, the studied pellets are pre-heated to 300 to 350°C for 10 to 15 minutes, and then fired at 1040°C, 1060°C, 1080°C, 1100, and 1120 °C with soaking times 10, 30, and 60 minutes for each firing temperature. The results of this method show that flash firing of pellets (at 1040°C, 1060°C, 1080°C, and 1100°C with soaking times 10 and 30 minutes for each temperature followed by rapid cooling gives relatively a low true porosity and water absorption values with a high bulk density values. These results are attributed again to lack of synchronization between escaping of gases and melting and therefore no bloating took place (Table 6). At firing temperature 1100°C and soaking time 60 minutes the vitrification began due to sufficient time but after escaping the gases (Table 6), i.e. lack of synchronization between the two processes.

The flash firing for the pellets of all studied samples at temperature 1120°C with soaking time 30 minutes for both fine and coarse grains pellets, gave the best results in term of bloating ability, weight loss, true porosity, water absorption and bulk density (Tables 7, 8 and 9). This is attributed to synchronization of gas generation with the melting process (Fig. 10). The rapid cooling (by opening the kiln door immediately after soaking time is over) has been carried out in this operation, because the gradual cooling (leaving the samples inside the kiln after shutting down) gives more time for melting and closing the pores. It is also noted that the pore size decreased towards the wall of pellets (Fig. 11). The reason of this may be attributed to that the outer surface of pellets is affected by firing temperature more than the inside. This tend to be less viscous than the inner parts and consequently suffering more gas escape than the inner parts which allow more bloating and growing of gas (Al-Awjar, 2008). The results obtained show that the grain size of raw materials has an important effect on the lightweight aggregate products. Pellets formed from coarse grain sizes (< 1.0 mm) give the best properties than that formed from fine grain sizes (< 0.075 mm) (Tables 7, 8 and 9). The reason of this may be that the primary porosity is higher due to its coarseness (Fig. 12).

Table-6: Lightweight aggregate tests of pellets fired with flash firing at different temperatures and soaking times (P = true porosity, A = water absorption, BD = bulk density, f = fine-grained raw material, c = coarse-grained raw material).

Section	Properties	Sample no.	Firing temperatures with soaking times											
			1040°C			1060°C			1080°C			1100°C		
			10 min.	30 min.	60 min.	10 min.	30 min.	60 min.	10 min.	30 min.	60 min.	10 min.	30 min.	60 min.
Beduh	P%	c	22.32	22.86	21.22	21.54	20.82	19.86	20.42	21.51	18.11	18.44	17.53	15.01
		f	17.53	18.11	17.97	17.01	17.25	16.15	18.55	17.01	16.23	15.50	16.32	13.15
	A%	c	15.55	15.36	17.20	16.63	18.14	18.01	17.62	16.33	14.03	15.55	14.43	12.26
		f	11.09	10.73	12.33	12.23	12.33	11.09	14.50	13.11	10.09	12.33	12.52	11.40
	BD g/cm <sup>3</sup>	c	1.52	1.50	1.50	1.63	1.52	1.45	1.47	1.41	1.52	1.41	1.45	1.60
		f	1.61	1.66	1.66	1.71	1.82	1.82	1.66	1.71	1.82	1.66	1.71	1.88
Sararu	P%	c	20.00	20.23	20.05	21.64	21.21	22.14	20.85	22.12	19.44	18.88	18.03	16.64
		f	18.82	18.22	17.06	16.91	16.45	17.17	16.89	16.45	15.21	16.92	15.56	12.00
	A%	c	14.45	13.25	16.61	18.91	17.56	17.70	19.00	18.55	16.33	16.20	14.44	13.02
		f	12.20	12.50	13.37	14.02	12.56	13.20	13.89	12.64	11.01	13.29	13.77	11.82
	BD g/cm <sup>3</sup>	c	1.47	1.497	1.63	1.71	1.70	1.64	1.59	1.67	1.70	1.55	1.50	1.61
		f	1.66	1.61	1.81	1.86	1.72	1.64	1.78	1.81	1.90	1.77	1.76	1.88
Nazdur	P%	c	23.15	21.44	21.20	22.01	22.79	21.11	21.25	19.89	17.56	17.66	16.21	15.01
		f	16.66	17.42	17.90	18.02	17.56	17.66	18.81	17.23	16.51	17.01	15.01	12.22
	A%	c	19.51	19.10	17.66	18.28	16.55	17.11	16.33	16.25	14.00	15.55	15.00	13.31
		f	12.27	12.67	11.34	13.90	13.55	12.41	15.25	13.60	11.99	12.83	11.44	10.98
	BD g/cm <sup>3</sup>	c	1.55	1.59	1.63	1.62	1.62	1.68	1.50	1.62	1.71	1.44	1.50	1.60
		f	1.77	1.69	1.66	1.80	1.76	1.74	1.73	1.71	1.82	1.69	1.76	1.83

Table-7: Lightweight aggregate tests with flash firing at 1120°C and soaking time 30 minutes, for channel sample collected form Beduhe section.

Sample no.	Weight loss %	Volume increase %	True porosity %	Water absorption %	Bulk density g/cm <sup>3</sup>
<b>Coarse grain raw material (&lt; 1.00 mm)</b>					
1	23.99	29.15	23.34	18.04	1.29
2	23.98	31.23	22.79	17.94	1.27
3	21.69	27.70	24.98	18.46	1.35
4	21.72	31.84	27.94	21.62	1.29
5	20.78	31.57	23.89	17.90	1.33
6	26.95	30.56	24.14	19.50	1.24
<b>Fine grain raw material (&lt; 0.075 mm)</b>					
1	17.62	14.20	15.38	10.06	1.53
2	14.94	11.37	15.85	10.16	1.56
3	12.08	13.56	16.66	10.31	1.62
4	18.05	13.04	18.26	12.34	1.48
5	17.68	14.09	19.84	13.15	1.51
6	19.95	13.82	19.91	12.70	1.57

Table-8: Lightweight aggregate tests with flash firing at 1120°C and soaking time 30 minutes, for channel sample collected form Sararu section.

Sample no.	Weight loss %	Volume increase %	True porosity %	Water absorption %	Bulk density g/cm <sup>3</sup>
<b>Coarse grain raw material (&lt; 1.00 mm)</b>					
1	20.73	31.27	24.37	18.23	1.34
2	20.39	29.65	24.45	19.10	1.28
3	25.08	30.47	25.50	20.51	1.24
4	22.52	29.52	25.01	19.07	1.31
5	23.83	29.94	24.27	18.17	1.34
6	27.61	26.86	27.08	21.71	1.25
<b>Fine grain raw material (&lt; 0.075 mm)</b>					
1	17.24	15.57	18.62	12.31	1.51
2	16.23	13.93	14.88	9.21	1.62
3	14.44	12.45	19.31	12.11	1.60
4	18.72	12.64	19.70	13.27	1.48
5	19.02	13.03	16.12	10.57	1.53
6	11.69	12.97	15.45	9.65	1.60

Table-9: Lightweight aggregate tests with flash firing at 1120°C and soaking time 30 minutes, for channel sample collected form Nazdur section.

Sample no.	Weight loss %	Volume increase %	True porosity %	Water absorption %	Bulk density g/cm <sup>3</sup>
<b>Coarse grain raw material (&lt; 1.00 mm)</b>					
1	20.09	31.10	24.07	18.41	1.31
2	19.58	29.09	25.54	19.40	1.32
3	19.59	31.90	24.42	18.50	1.32
4	21.34	32.25	24.10	18.82	1.28
5	20.45	31.35	24.72	18.60	1.33
6	19.48	29.34	23.69	18.47	1.28
<b>Fine grain raw material (&lt; 0.075 mm)</b>					
1	17.45	13.20	16.22	10.34	1.57
2	18.98	12.82	16.02	10.60	1.51
3	17.53	11.09	17.62	10.97	1.61
4	16.16	10.83	15.74	9.73	1.62
5	16.44	13.02	19.07	12.84	1.49
6	14.48	14.59	16.37	10.09	1.62

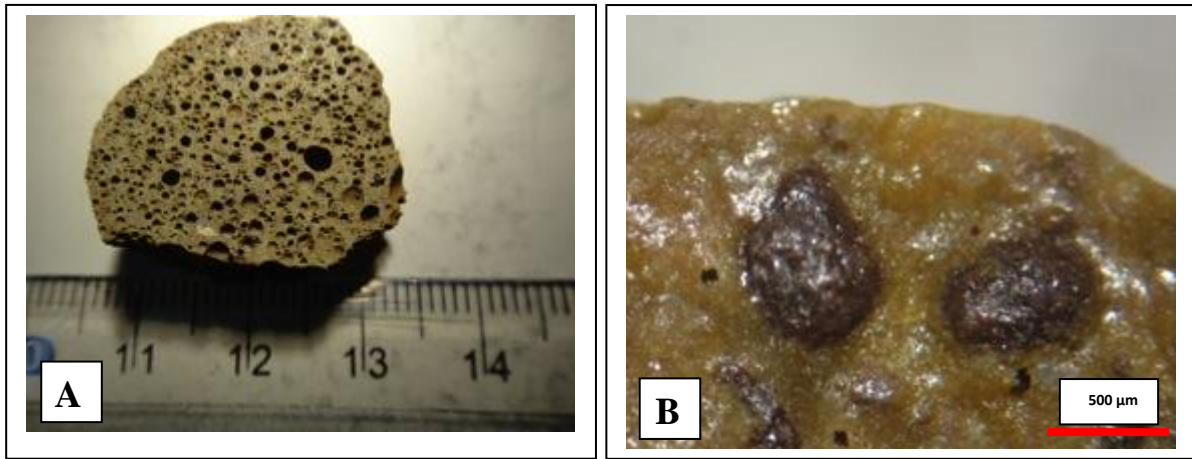


Figure-10: (A) internal view and (B) external surface, after bloating.

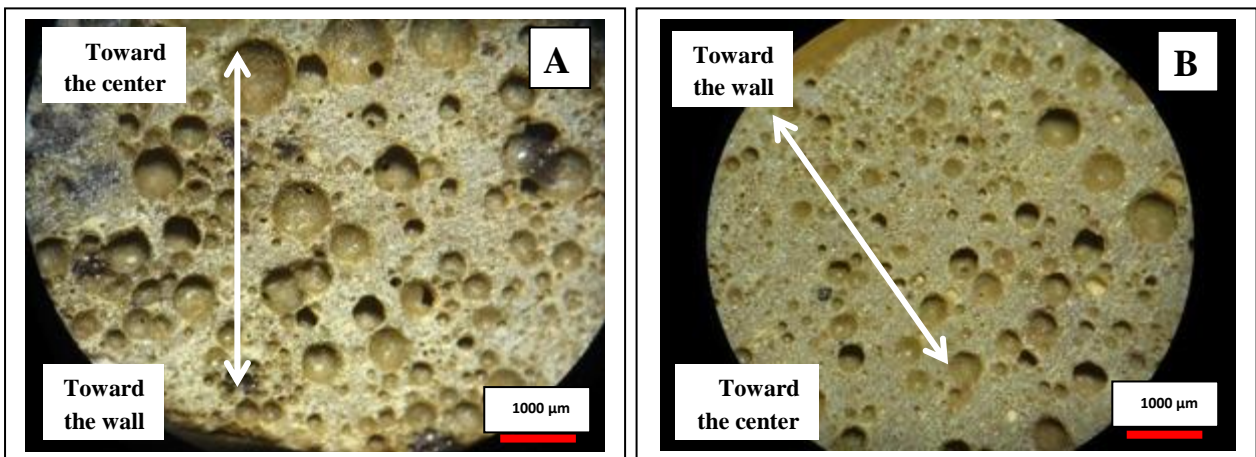


Figure-11: Decrease of pore size towards the periphery of pellet; (A) from coarse grain and (B) from fine grain raw materials, after bloating.

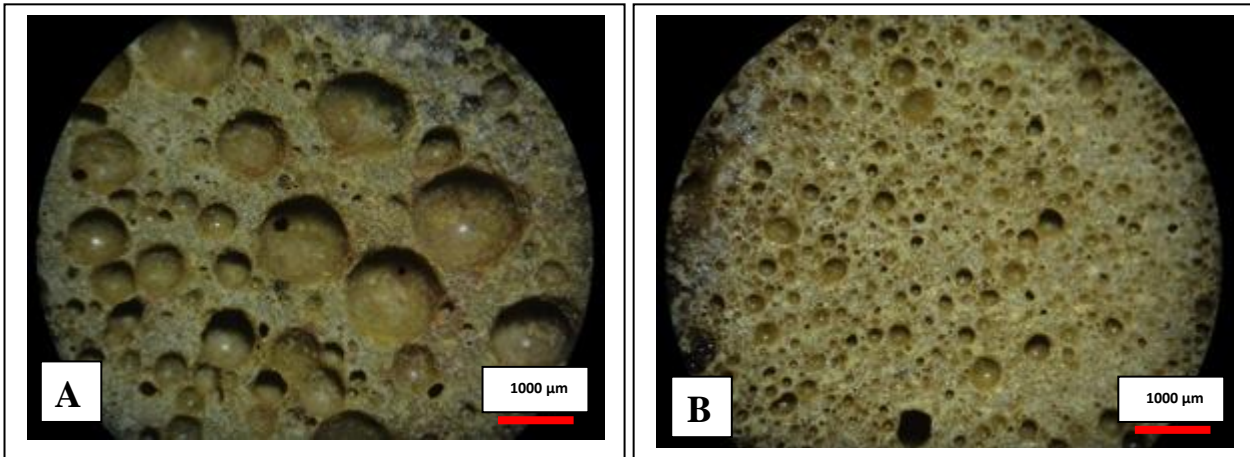


Figure-12: Difference in pore size between (A) coarse grain and (B) fine grain raw materials.



Figure-13: The open pores produced by bloating of the raw materials mixed with motors waste oil.

Table-10: Lightweight aggregate tests with flash firing at 1120°C and soaking time 30 minutes, for mixed all studied samples with motors waste oil.

Sample no.	Weight loss %	Volume increase %	True porosity %	Water absorption %	Bulk density g/cm <sup>3</sup>
<b>Coarse grain raw material (&lt; 1.00 mm)</b>					
1	20.01	29.05	49.66	37.30	1.33
2	19.41	27.36	51.88	38.75	1.34
3	23.30	29.12	50.85	38.02	1.34
4	20.20	32.80	51.92	39.51	1.31
5	19.94	32.91	49.46	38.37	1.29
6	20.43	29.88	50.78	38.41	1.32
<b>Fine grain raw material (&lt; 0.075 mm)</b>					
1	10.33	33.94	35.56	24.29	1.46
2	9.20	31.68	31.87	22.42	1.42
3	11.90	34.08	36.56	25.92	1.41
4	13.45	32.28	40.58	28.32	1.43
5	6.08	35.78	29.17	19.45	1.50
6	9.24	29.35	34.26	23.09	1.48

The firing results of pellets prepared by mixing the raw materials with motors waste oil show that the produced pellets gave better properties in terms of true porosity and bulk density at firing temperatures 1080°C and vitrified for 60 minutes (Fig. 13 and Table 10). Water absorption values of these products are very high due to connected pores of product during gases escaping, and this is unsuitable property for lightweight aggregate, especially when used in concrete industry because it will absorb the cement liquid material, and then lose its properties.

### **Conclusions:**

Evaluation tests of pellets prepared from the shales of Beduh Formation and fired rapidly (flash firing) and gradually at 1040°C, 1060°C, 1080°C, 1100, and 1120 °C with soaking times 10, 30, and 60 minutes for each temperature have failed in the preparation of lightweight aggregate. Pellets fired rapidly at 1040°C, 1060°C, 1080°C and 1100°C after pre-heating to about 300 to 350°C for 10 to 15 minutes with same mentioned soaking times, have failed too. By contrast the pellets fired rapidly (flash firing) at 1120°C with soaking time 30 minutes and rapid cooling, after pre-heating to about 300 to 350°C for 10 to 15 minutes, are suitable for preparation of lightweight aggregate when compared with Bates (1969), Cheeseman *et al.*, (2005) and Cheeseman (2011). The pellets prepared from coarse-grains size (< 1.00 mm) show the best lightweight aggregate properties than that prepared from fine-grains size (< 0.075 mm). These pellets gave good properties in term of bloating ability (volume increase) (26.86 – 32.25% and 11.09 – 15.57% for coarse and fine grain pellets respectively), loss in weight (19.48 – 27.61% and 11.96 – 19.95% for coarse and fine grain pellets respectively), true porosity (22.97 – 27.94% and 14.88 – 19.91% for coarse and fine grain pellets respectively), water absorption (17.90 – 21.71% and 9.21 – 13.27% for coarse and fine grain pellets respectively) and bulk density (1.24 – 1.35g/cm<sup>3</sup> and 1.48 – 1.62 g/cm<sup>3</sup> for coarse and fine grain pellets respectively). In respect to the firing results of the raw materials mixed with motors waste oil, the test results showed it is unsuitable as lightweight aggregate uses, due to high water absorption values.

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