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EVALUATING THE SUITABILITY OF AVROMAN LIMESTONE, HALABJA GOVERNORATE FOR CEMENT INDUSTRY

Tola A. Mirza*[1] and Chro M. Fatah[1]

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ABSTRACT

Limestone of Avroman Formation in Halabja Governorate – Kurdistan Region, northeast Iraq were subjected to elemental and mineralogical analysis by X-ray fluorescence and X-ray diffraction, as well as petrophysical and mechanical study with the aim of accessing its extent as potential raw material for manufacturing Portland cement.

The results reflect rising the concentrations of CaO and loss on ignition, and the decrease of the concentrations of SiO_2, Al_2O_3, Fe_2O3, SO_3, Na_2O, K_2O, and insoluble residue, According to these geochemical properties, the tested samples are reliable as carbonate component for cement industry. Mineralogical study shows that calcite is the main component of limestone samples which is more than 99% of the total constituent.

The petrophysical tests reflect the increase of total density, apparent specific gravity, and the decrease of porosity and moisture content of the samples and most of the studied samples are in agreement with natural ranges for carbonate rocks used in cement industry. The mechanical tests reflect high compressive strength of the studied samples and it can be concluded that the processes of crushing and grinding need a suitable force (energy) during the extraction of samples from the quarry.

The estimated raw mixture and clinker composition are calculated and the results show that all samples are in agreement with standard specification for production of Portland cement.

دراسة جيوكيميائية وصخرية وبيتروفيزيائية لتكوين أفرمان، حلبجة، كردستان، لتقيمها كمادة أولية لصناعة السمنت

تولة أحمد ميرزا و ضرو محمد فتاح

المستخلص

أختيرت الصخور الكلسية لتكوين أفرمان فى محافظة حلبچة، للدراسة الحالية والتى تتضمن تحليل العناصر والمعدنية باستخدام جهاز الأشعة السينية الفلوريسينسية والمحايدة. تمت دراسة البيتروفيزيائية والميكانيكية لهذه الصخور من أجل تقيمها لصناعة السمنت البورتلندى.

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[1] University of Sulaimaniyah, College of Science, Department of Geology,
*e-mail: tola.merza@univsul.edu.iq

وأظهرت نتائج الدراسة نسبة عالية من أوكسيد الكالسيوم وفقدان عند الحرق، كذلك نسبة قليلة من أكاسيد السليكا والألمنيوم والحديد والكبريت والصوديوم والبوتاسيوم والفضالة غير الذائبة. واستنادا الى هذه الخواص فإن النماذج قيد الدراسة مناسبة كمكون كلسى لصناعة السمنت. كما بينت الدراسة المعدنية بأن معدن الكالسايت هو المكون الأساسى للنماذج الكلسية حيث بلغت نسبته أكثر من 99% من مجموع المكونات المعدنية.

وأظهرت الفحوصات البيتروفيزيائية للنماذج المدروسة زيادة فى الكثافة الكلية والوزن النوعى الظاهرى ونقصان فى المسامية ومحتوى الرطوبة، وهذه النتائج مطابقة وضمن الحدود المسموحة للصخور الكلسية فى صناعة السمنت. كما بينت الدراسة الميكانيكية للصخور مقاومة إنضغاطية عالية لهذه النماذج مما يترتب استخدام قوة مناسبة لكسر وطحن هذه الصخور عند استخراجها في المقلع.

لقد تم حساب وتخمين الخلطات المحضرة من المواد الأولية وتركيبة الكلينكر وبينت النتائج بأن النماذج المدروسة كلها تقع ضمن الحدود المسموحة ومطابقة مع الخواص القياسية لإنتاج السمنت البورتلندى.

INTRODUCTION

Limestone is one of the important sedimentary rocks composed mostly of calcite ($CaCO_3$). They may also contain some other carbonates and several none-carbonate impurities.

In this paper the geochemical content of major oxides of Avroman limestone Formation were studied in order to assess their suitability for use in the cement manufacturing. For this case, assessment must be done for raw materials especially limestone and clay because successful clinker production demands a defined mixture of limestone, clay and corrective additives as well as correct calculation of possible clinker mixture.

Nowadays, in Sulaimaniyah city, Sinjar Formation (Tertiary) is the main raw material for producing cement. This study tries to find new suitable resources. The Avroman Formation (Upper Triassic) is to be used as a future alternative. The reserves of limestone in this formation appear to be quite large.

GEOLOGICAL SETTING

The studied area is represented by Suren and Avroman Mountains located within Halabja Governorate, and lies between (35° 17' 02" – 35° 20' 50" N) and (46° 00' 36" – 46° 05' 56" E). Suren Mountain is bordered by the Sharazoor plain at the southwest, and it is elongated in NW – NE of Khurmal town. This mountain, represented by Avroman Formation, is located in Qulqula Khwakurk sub zone (Buday and Jassim, 1987) and Zagros Suture Zone.

The Avroman limestone Formation outcrops in the Zalam valley, Banishar and Kani Seif areas and comprises about 800 m of light grey, brownish, sometimes milky white, thick-bedded to massive, hard limestone (Jassim and Goff, 2006). The range of macrofossils and microfossils is extremely large consisting mainly of megalodones accompanied by encrusted foraminifera,algae, gastropods and brachiopods (ibid).

Megedodires indicate the Noric age of the typically light colored, massive part dolomitized limestone. The stratigraphy of the formation is obscured by intense deformation inside Iraqi and metamorphism in the Iranian territories; the deformation caused the imbrications and possible thrusting and sliding of the rock (Karim, 2007), and thus it is difficult to identify the lower, middle and upper parts of the formation.

The Avroman Formation is overlain by Qulqula Radiolaria Formation and Merga Red Beds in Iraq and Iran respectively (Fig.1), and the underlying formation is not exposed. The Avroman Limestone which is known as the Bisitoun Shoal Limestone in Iran was deposited on the Bisitoun Micro-continent (Bordenave and Hegre, 2005). It represents a big and narrow continental slab which extends over 400 Km from SW Iran (Lurestan) to the Iraqi Kurdistan region (Ibrahim, 2009).

Structurally, the studied area belongs to the imbricated and thrust zone (Buday and Jassim, 1987). The field description shows that the lithology of this formation is pure limestone, generally grey, massive, hard with joints and fractures.

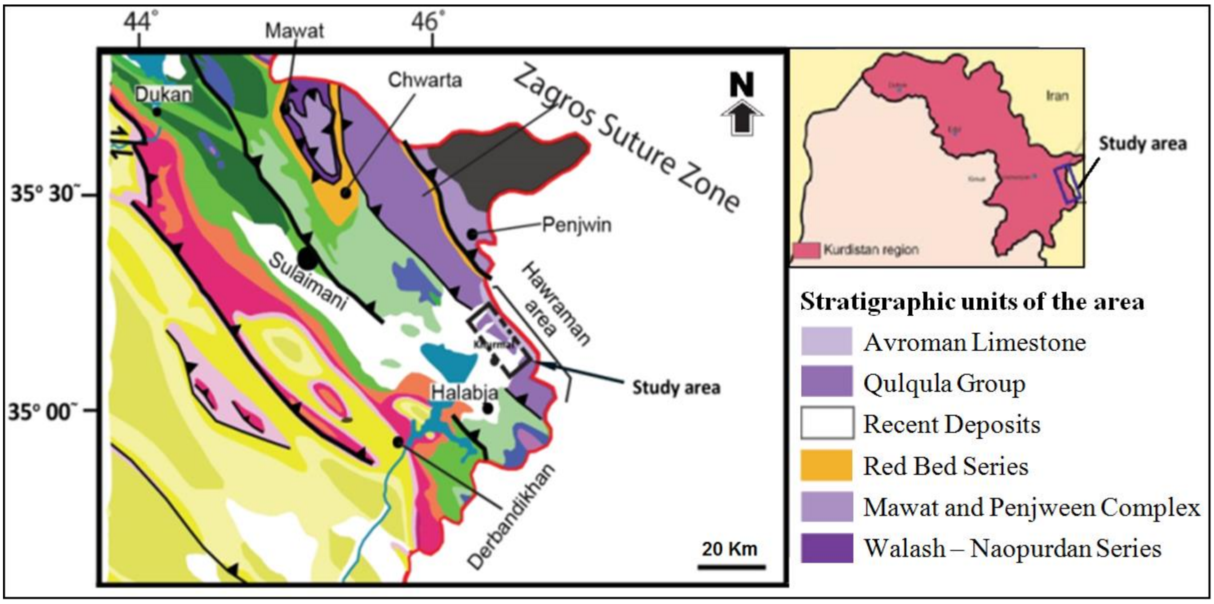

Fig.1: Geological map of northeast Iraq (Lawa *et al*., 2013)

SAMPLES AND METHODS

In this study two sections are selected: Ahmad Awa (A), and Shanaw valley (Sh) sections. The limestone and clay samples from recent valley deposits were collected along these two traverses; each collected samples weighted about 2 Kg. The first section located east of Ahmad Awa village; 16 samples were collected representing (A1 to A16) from the Avroman limestone Formation and four clay sample from recent valley deposits in the same area representing C1 to C4. The second selected section is located in Shanaw valley 13 samples are collected representing (Sh1 to Sh13) and four clay sample represented by C5 to C8. Mineralogical analyses were conducted using X-Ray diffraction (XRD) for representative limestone and clay samples from studied area in the laboratories of GEOSURV in Baghdad. For clay samples, oriented and non-oriented samples were prepared for representative clay samples C1 and C8 from each sections following Iraqi Geological Survey standard work procedures, part 2 (Al-Janabi *et al*., 1992). The XRD pattern was obtained with a Shimadzu XRD 7000 instrument operating at 45 KV and 40 mA using Cu – Kα radiation. Diffraction pattern was between 3° – 50° (2ϴ) for limestone samples while the diffraction pattern for clay samples was between 3° – 50° (2 ϴ) for non-oriented samples (Bulk sample) and between 3° – 20° (2 ϴ) for oriented specimen. Crystalline phase was identified and evaluated by XRD.

Geochemical analysis was carried by XRF type (Thermo-ARL Advant ´XP + X-ray fluorescence spectrometer) for limestone samples at Geo Analytical Laboratory, School of Earth and Environmental Science, Washington State University while the clay samples were obtained according to the ASTM C114-03 (2003) in Mass Cement Factory in Sulaimaniyah city. Insoluble residue was obtained by test method (Awad and Mashkour, 1980). The Physical and mechanical properties and of carbonate rock were established. Water absorption, moisture content and uniaxial compressive strength test was done in the department of Geology University of Sulaimaniyah, using (I.Q.S. No.31, 1981).

RESULTS AND DISCUSSION

- **Mineralogical and textural analysis**

XRD pattern of limestone samples A5 and Sh7 (Figs.2A and B) shows that the dominant mineral phase is calcite ($CaCO_3$), whereas the calcite appears to be predominant and participates in all samples which is more than 99% of the total constituent (Table 1). The quartz phase is scarce appearing as traces especially in samples (A5).

The X-ray diffraction patterns of the representative clays from the studied area (Fig.3A and B; and Fig.4A and B) reveal the presence of non-clay minerals such as (calcite, quartz and plagioclase). The percentage of non-clay minerals were calculated using peak area calculation (Table 1) which reveals that quartz is the dominant non-clay mineral in sample C1and C8 (Figs.3A and 4 A), while calcite percentage is more than in sample C1compared to sample C8. The most dominant clay minerals in sample C1 are chlorite, illite and montmorillonite while in sample C8 are chlorite and illite (Figs.3B and 4B). The grain size analysis is established for the clay samples around the study area using wet sieving and hydrometer analysis of these samples. The clay percentage in sample C1 is 49% while in sample C8 is 38%. The highest value of sand portion in C1 and C8 sample are 18% and 29% respectively. The silt portion represents an intermediate size between sand and clay. In the sections A and Sh the maximum percentage of silt is 33%. The XRD pattern for insoluble residues (I.R.) in carbonate rocks samples (A13, Sh1), (Fig.5A and B) show that the most dominant I.R. minerals in carbonate rocks are clay minerals, quartz and some of the heavy minerals hematite and pyrite which appear as trace minerals. Moreover, the percentage and weight of insoluble residue for each sample have been determined which lie between (0.26 – 2.69) %, (0.03 – 0.44) gm respectively for limestone samples; accordingly the limestone is considered as a pure limestone.

Table 1: Semi quantitative analysis for studied clayey samples and carbonate rock

Sample No.	**Semi quantitative % of mineral constituents of clayey Samples**						
	Clay Minerals %				**Non Clay Minerals %**		
	Chlorite	**Illite**	**Montmorillonite**	**Total**	**Calcite**	**Quartz**	**Total**
C1	77.3	15.2	7.6	100.1	25	75	100
C8	94.4	5.6	0	100.0	5.9	93.6	100
Carbonate Rocks	**Semi quantitative % of mineral constituents in Carbonate rock**						
	Calcite	**Dolomite**	**Quartz**	**Total**			
A5	99.8	0	0.2	100.0			
Sh7	99.8	0	0.2	100.0			

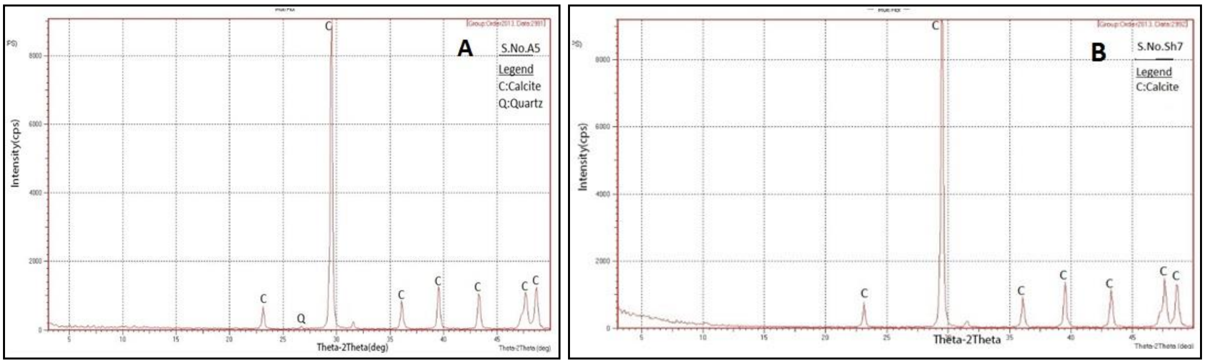

Fig.2: **A)** X-ray diffraction for limestone Ahmad Awa section (A5). **B)** X-ray diffraction for limestone Shanaw valley section (Sh7)

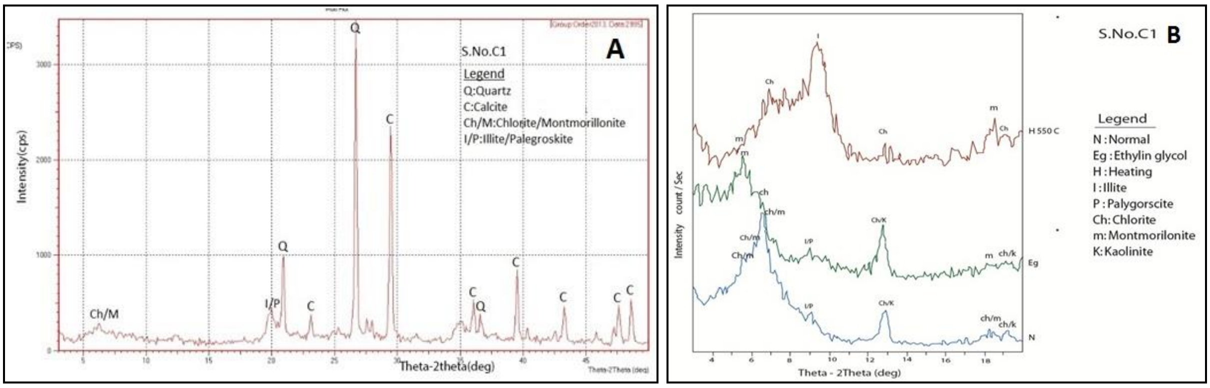

Fig.3: X-ray diffraction pattern of clayey sample from Ahmad Awa area (sample C1)
A) Bulk sample, **B)** oriented clay fraction in different treatment stages

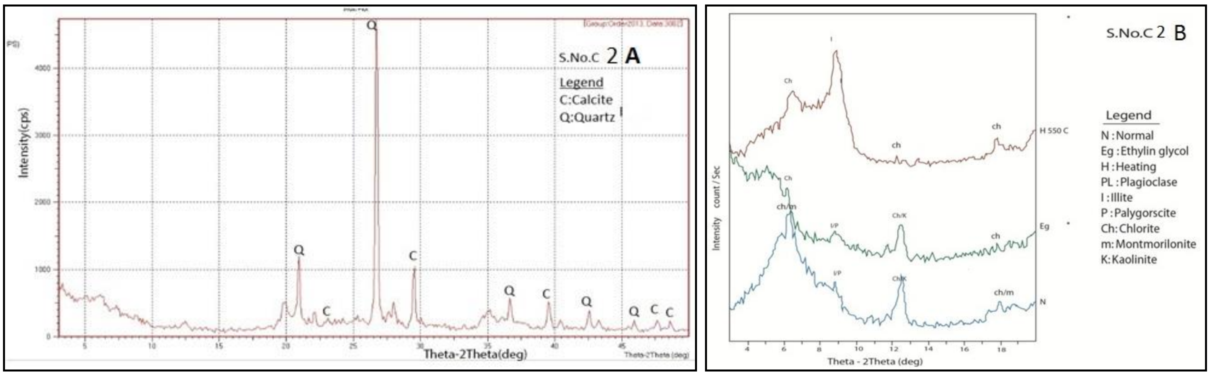

Fig.4: X-ray diffraction pattern of clayey sample from Shanaw valley (sample C2), **A)** Bulk sample, **B)** oriented clay fraction in different treatment stages.

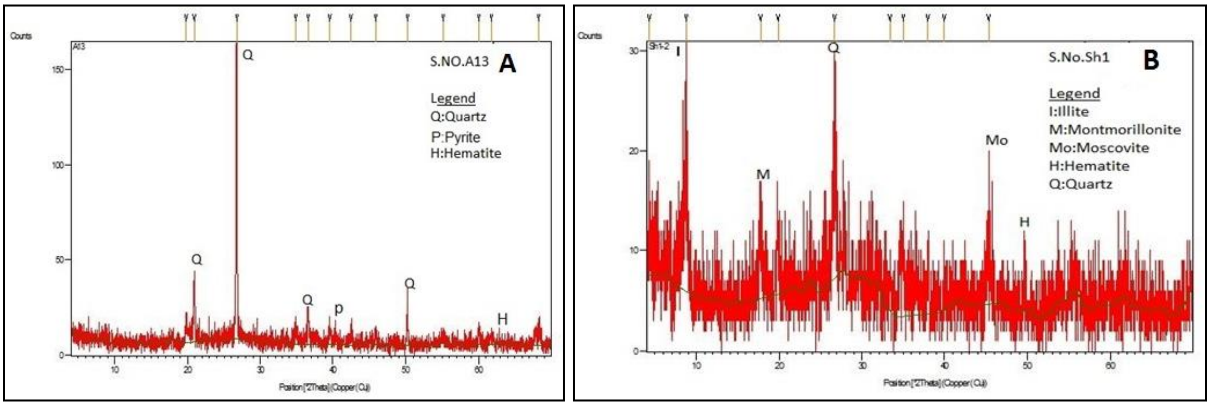

Fig.5: X-ray diffraction for (I.R) limestone **A)** Ahmad Awa section (A13),
B) Shanaw valley (Sh1)

- **Geochemistry of Raw Materials**

Table 2 displays the results of chemical analysis of the raw materials compared with results of Duda (1985) (Table 3), who determined the acceptable limits of raw materials for cement industry and with normal limestone (Clark, 1924 and Amin *et al*., 2008). Portland cement consists mainly of lime (CaO), silica (SiO_2), alumina (Al_2O_3), and ferric oxide (Fe_2O_3) compounds. The combined content of these four oxides (major constituents) is approximately 90% of the cement weight and the remaining (minor constituents) 10% consisting of magnesia (MgO), alkalis (Na_2O and K_2O), chloride (Cl), SO_3, TiO_2, P_2O_5 and MnO (Al-Dabbas *et al*., 2013).

– **Geochemistry of limestone:** The major elemental chemistry of limestone of both sections (A and Sh sections) is given in (Table 2).

1. Calcium oxide (CaO**)** is the highest constituent of limestone; the concentration of CaO in both studied sections is very high; it is more than 53.09%. These percentages are in a good agreement with certified normal limestone by Duda (1985) and others (Table 3). Lime (CaO) is a basic oxide used in cement manufacture to react with other oxides (Al_2O_3, SiO_2 and Fe_2O_3). Acceptable lime content is limited due to the lower early strength produced when lime content is too low, and unsoundness when it is high (Duda, 1985). High lime content is associated with early strength. In order to increase the strength, it is necessary to raise the lime content or finer grind or both (Al-Auweidy, 2013). But higher temperature is required to burn the high lime mixtures (Neville, 2010). The limestone loses about 45% of its weight during calcination. The lose on ignition (LOI) for the studied samples in (A and Sh) sections ranges between (42.55 – 43.73 %), (42.64 – 43.65 %), respectively (Tables 2) which are in agreement with Duda (1985) .The high content of LOI in the studied samples is contribute mostly by carbonate minerals which ($CaCO_3$) for all the samples > 97% (Table 1).
2. Silica (SiO_2) and alumina appear as impurity in limestone in the range (0.00 to 1.68 %) and (0.01 – 0.36 %) respectively in both two sections (Table 2). These are in an acceptable limit for cement industry when compared with certified limits by Duda (1985) and others, (Table 3). The limestone of Avroman Formation has variable amount of SiO_2 and Al_2O_3 which are contributed by quartz and clay mineral as insoluble residue (Figs.5A and B).

Table 2: Results of chemical analyses (wt %) of the studied limestone with LSF, SR and AR values

S.No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	SO_3	Na_2O	K_2O	P_2O5	Sum	L.O.I	Total	$CaCO_3$	I.R	LSF	SR	AR
A1	0.22	0.01	0.15	0.02	0.01	0.49	55.30	0.05	0.01	0.03	0.05	56.28	43.57	99.85	98.70	1.45	6881.03	1.29	7.50
A2	0.17	0.00	0.08	0.01	0.00	0.48	55.86	0.04	0.00	0.01	0.02	56.65	43.38	100.03	99.69	0.93	9718.24	1.89	8.00
A3	0.03	0.00	0.04	0.02	0.01	0.48	55.85	0.03	0.00	0.00	0.02	56.46	43.47	99.93	99.68	0.84	38765.52	0.50	2.00
A4	0.49	0.01	0.24	0.13	0.01	0.69	54.70	0.02	0.00	0.03	0.03	56.34	43.49	99.83	97.62	2.69	3165.23	1.32	1.85
A5	0.47	0.01	0.21	0.07	0.00	0.67	54.72	0.06	0.00	0.04	0.03	56.24	43.38	99.62	97.66	1.44	3422.53	1.68	3.00
A6	0.02	0.00	0.01	0.00	0.01	0.37	56.00	0.02	0.00	0.00	0.04	56.54	42.97	99.51	99.94	0.47	82761.03	2.00	0.00
A7	0.93	0.01	0.07	0.02	0.01	0.47	55.05	0.06	0.00	0.01	0.04	56.60	42.99	99.59	98.25	1.23	2051.18	10.33	3.50
A8	0.55	0.02	0.36	0.10	0.00	0.66	54.63	0.02	0.01	0.05	0.04	56.42	43.07	99.49	97.50	1.56	2706.19	1.20	3.60
A9	0.24	0.01	0.16	0.09	0.00	0.62	55.27	0.09	0.01	0.03	0.03	56.46	43.73	100.19	98.64	1.68	6041.73	0.96	1.78
A10	0.02	0.01	0.26	0.10	0.00	0.71	55.26	0.05	0.01	0.05	0.03	56.46	43.39	99.85	98.62	2.67	12885.10	0.06	2.60
A11	0.51	0.01	0.21	0.05	0.00	0.61	54.75	0.04	0.01	0.05	0.08	56.28	43.51	99.79	97.71	1.29	3223.80	1.96	4.20
A12	0.22	0.01	0.14	0.06	0.00	0.60	55.33	0.03	0.01	0.02	0.02	56.41	43.51	99.92	98.75	0.93	6777.64	1.10	2.33
A13	1.46	0.01	0.17	0.07	0.00	0.57	54.64	0.08	0.00	0.03	0.03	56.99	42.55	99.54	97.52	2.67	1269.57	6.08	2.43
A14	0.00	0.01	0.25	0.07	0.00	0.62	55.56	0.07	0.01	0.07	0.03	56.62	43.37	99.99	99.16	1.31	16215.63	0.00	3.57
A15	1.68	0.01	0.15	0.05	0.01	0.52	54.33	0.06	0.00	0.03	0.02	56.79	43.32	100.11	96.96	2.46	1112.99	8.40	3.00
A16	0.07	0.01	0.21	0.05	0.00	0.61	55.39	0.02	0.01	0.04	0.02	56.40	43.45	99.85	98.86	1.65	11622.79	0.27	4.20
Sh1	0.07	0.01	0.05	0.01	0.00	0.53	55.90	0.04	0.00	0.01	0.04	56.62	43.51	100.13	99.77	1.91	21446.67	1.17	5.00
Sh2	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.08	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.66	n.a	n.a	n.a
Sh3	0.25	0.07	0.14	0.04	0.01	0.50	55.48	0.03	0.00	0.04	0.09	56.54	43.26	99.80	99.02	1.01	6247.76	1.39	3.50
Sh4	0.02	0.00	0.04	0.01	0.00	0.38	55.62	0.02	0.00	0.00	0.02	56.09	43.41	99.50	99.27	0.60	50592.76	0.40	4.00
Sh5	0.63	0.00	0.04	0.07	0.01	0.34	55.25	0.07	0.00	0.01	0.13	56.48	43.01	99.49	98.61	1.63	2988.16	5.73	0.57
Sh6	0.06	0.00	0.04	0.03	0.01	0.51	55.29	0.03	0.00	0.01	0.03	55.97	43.85	99.82	98.68	0.26	23640.13	0.86	1.33
Sh7	0.00	0.00	0.02	0.01	0.00	0.23	56.00	0.06	0.00	0.00	0.02	56.68	42.64	99.32	99.94	0.53	184172.1	0.00	2.00
Sh8	0.10	0.02	0.06	0.01	0.00	0.39	55.60	0.03	0.00	0.01	0.01	56.20	43.46	99.66	99.23	1.02	15590.66	1.43	6.00
Sh9	0.03	0.02	0.13	0.09	0.00	0.45	55.07	0.03	0.00	0.03	0.01	55.83	43.80	99.63	98.28	1.05	18561.98	0.14	1.44
Sh10	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.05	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.59	n.a	n.a	n.a
Sh11	0.03	0.01	0.04	0.01	0.00	0.39	55.92	0.04	0.00	0.00	0.02	56.43	43.74	100.17	99.80	0.76	40586.64	0.60	4.00
Sh12	0.14	0.01	0.16	0.15	0.00	0.43	55.74	0.02	0.00	0.02	0.03	56.68	42.73	99.41	99.48	2.77	8226.34	0.45	1.07
Sh13	0.00	0.00	0.00	0.00	0.00	0.47	55.98	0.03	0.00	0.00	0.01	56.46	42.99	99.45	99.91	0.20	0.00	0.00	0.00

Not: n.a = not analyzed

Table 3: The comparison between the average composition of the studied limestone from Ahmed Awa and Shanaw valley sections with that of normal limestone (Duda, 1985)

Oxides	Ahmed Awa Section			Shanaw valley Section			Normal limestone	Duda 1985
	Min %	Max %	AV %	Min %	Max %	AV %		
SiO?	0.00	1.68	0.44	0.00	0.63	0.12	5.19	<6.75
TiO?	0.001	0.021	0.01	0.00	0.07	0.012		
Al?O?	0.01	0.36	0.17	0.00	0.16	0.06	0.81	<2.0
Fe?O?	0.00	0.13	0.06	0.00	0.15	0.04	0.54	<0.66
MnO	0.002	0.013	0.004	0.001	0.009	0.003		
MgO	0.37	0.71	0.57	0.23	0.53	0.42	7.9	< 2
CaO	54.33	55.56	55.17	55.07	56.00	55.62	42.61	> 45
SO?	0.015	0.09	0.04	0.02	0.075	0.04		<1.5
Na?O	0.00	0.01	0.005	0.00	0.00	0.00		<0.28
K?O	0.00	0.07	0.03	0.00	0.04	0.012		<0.2
Na O+K?O	0.00	0.08	0.035	0.00	0.04	0.012	0.38	
P?O5	0.019	0.081	0.03	0.009	0.132	0.04		
L.O.I	42.55	43.73	43.32	42.64	43.85	43.31		> 38
CaCO?	96.96	99.94	98.47	98.28	99.94	99.27		
I.R	0.47	2.69	1.58	0.20	2.77	1.08		
LSF	112.99	82908	13047	0.00	184172	37205		
SR	0.00	10.33	2.44	0.00	5.727	1.11		
AR	1.78	7.50	3.35	0.00	4.20	2.63		

3. The iron (Fe_2O_3) in the form of oxides and sulphides occurs as impurity in the limestone, which if present in high amount, can cause deterioration in the building construction (Amin *et al.*, 2008). Iron compound present in limestone influences its color and according to Royak and Royak (1985) it provides green to blue colour. There is a strong correlation between Fe_2O_3 and whiteness-degree. The whiteness-degree value increases with decreasing of Fe_2O_3 concentration if the concentration is less than 0.5%, the material is very white (Ertek and Öner, 2008). All the studied limestone samples have low concentration of Fe_2O_3 which is less than 0.34% (Table 2). On the other hand, an amount of Fe_2O_3 was found in the specified range of normal limestone (Table 3).

4. Magnesium oxide in the limestone is a function of both magnesium content of skeletal debris and also other dolomitization processes due to post depositional events, because increasing of MgO cause increasing the dolomitic component of limestone. Dolomite cannot be used in the manufacture of Portland cement because of its high magnesium. MgO is only present in small quantities in Portland cement ranging typically (1 – 5) % (Al-Auweidy, 2013). Too high MgO content leads to expansion cement and consequently loss strength of the concrete, but this can be avoided by sufficiently quick quench of the clinker (Peray, 1986). The quench will affect the degree of crystallization and amorphous material present known as glass. In all studied samples the concentration of MgO is low ranging between (0.37 to 0.71%) and (0.34 to 0.53%) in both sections A and Sh respectively. This shows that all the samples are suited with the national specification for production of (ordinary Portland cement), and I.Q.S., No.5, 1984, (Tables 3 and 4).

5. The concentration of Na_2O and K_2O are very low in all studied samples (less than 0.1%), (Table 2) with average percentage $Na_2O + K_2O$ that reaches (0.035, 0.012 %) in A, and Sh, sections respectively (Table 3). The materials have low alkali content especially sodium. High sodium concentration is more harmful to cement quality than increased potassium concentration (Thanoon, 1999).

The alkali content in raw materials used for cement industry must be less than < 1%. The low alkali content qualifies the materials for use even in low alkali cement predictor which requires the Na-equivalent to be < 0.6% according to the equation (Na-equivalent = $Na_2O + 0.658\ K_2O$) (Schafer, 1987). In all studied samples, the Na-equivalent is within this limit, (Table 5).

Table 4: Comparison of the results of chemical analysis for the studied samples with I.Q.S., No.5 (1984) for the production of ordinary Portland cement

sample No.	**MgO max.5%**	**(Na_2O+K_2O) Max.0.6%**	**SO_3 max.2.5%**	**SR (1.5-4.0)**	**AR (1.4- 3.5)**
A1	0.49	0.04	0.048	1.29	7.5
A2	0.48	0.01	0.0412	1.89	8
A3	0.48	0	0.031	0.5	2
A4	0.69	0.03	0.021	1.32	1.85
A5	0.67	0.04	0.061	1.68	3
A6	0.37	0	0.017	2	o
A7	0.47	0.01	0.058	10.33	3.5
A8	0.66	0.06	0.015	1.2	3.6
A9	0.62	0.04	0.09	0.96	1.78
A10	0.71	0.06	0.051	0.06	2.6
A11	0.61	0.06	0.038	1.96	4.2
A12	0.6	0.03	0.031	1.1	2.33
A13	0.57	0.03	0.078	6.08	2.43
A14	0.62	0.08	0.07	0	3.57
A15	0.52	0.03	0.058	8.4	3
A16	0.61	0.05	0.021	0.27	4.2
Sh1	0.53	0.01	0.038	1.17	5
Sh2	n.a	n.a	0.075	n.a	n.a
Sh3	0.5	0.04	0.03	1.39	3.5
Sh4	0.38	0	0.02	0.4	4
Sh5	0.34	0.01	0.07	5.73	0.57
Sh6	0.51	0.01	0.03	0.86	1.33
Sh7	0.23	0	0.06	0	2
Sh8	0.39	0.01	0.031	1.43	6
Sh9	0.45	0.03	0.034	0.14	1.44
Sh10	n.a	n.a	0.048	n.a	n.a
Sh11	0.39	0	0.035	0.6	4
Sh12	0.43	0.02	0.021	0.45	1.07
Sh13	0.47	0	0.034	0	0

Table 5: Sodium equivalent values for the studied samples using the equation derived from Schafer (1987)

Sample No.	**Na-equivalent %**	**Sample No.**	**Na-equivalent %**
A1	0.03	Sh1	0.01
A2	0.01	Sh2	n.a
A3	0.00	Sh3	0.03
A4	0.02	Sh4	0.00
A5	0.03	Sh5	0.01
A6	0.00	Sh6	0.01
A7	0.01	Sh7	0.00
A8	0.04	Sh8	0.01
A9	0.03	Sh9	0.02
A10	0.04	Sh10	n.a
A11	0.04	Sh11	0.00
A12	0.02	Sh12	0.01
A13	0.02	Sh13	0.00
A14	0.06		
A15	0.02		
A16	0.04		

6. Sulfur (SO_3) and Phosphorous (P_2O_5) are regarded as the most undesirable impurities. The presence of P_2O_5 slows down the setting time of Portland cement. The SO_3 content for all studied samples is less than 0.1% (Table 2) and this coincides with data from Duda (1985) (Table 3), and I.Q.S., No.5 (1984), (Table 4). Chatterjee (2004) indicates that the allowable value of P_2O_5 content is less than 0.06% in OPC and thus all studied samples are in agreement with this range (Table 2).
7. The TiO_2 and MnO are present in traces in the studied limestone samples (Table 3). Rao *et al*. (2011) believe that the existence TiO_2 and MnO could be due to the presence of clay materials in the limestone samples. TiO_2 generally improves the grindability of the clinkers; this element has favorable effect on the porous structure, on the shape, size and colour etc. of the clinkers. MnO is known as a coloring element and if concentration is less than 0.5% the material is very white.
8. The average insoluble residue (IR) in A and Sh sections is (1.58 and 1.08) % respectively (Table 2). The IR is non-cementing materials which eventually exist in Portland cement. This residue affects the properties of cement, especially its compressive strength (Kiattikomol *et al*., 2000 and Hani, 2011). To control the non-cementing materials in Portland cement, British Standard (B.S. 12, 1996) allows the IR content to maximum limit of 1.5%; accordingly both two sections are in agreements with B.S. 12, 1996.
9. Limestone saturation factor (LSF) is the ratio of the actual amount of lime to the theoretical lime required by other major oxides in the raw mix or clinker; when LSF > 100% the ordinary clinker always contains some free lime. This free lime changes to hydroxide with time then to carbonate, and enlarges the volume, thus leads to the expansion of the concrete and fracturing. For the present samples the LSF ranges from (2988 to 184172) (Table 2) which is highly erratic and needs to be in uniform range for cement making; therefore for calculation of LSF of raw mixture and clinker are fixed on 90.
10. The silica ratio SR = (SiO_2/ Al_2O_3 + Fe_2O_3) and aluminum ratio AR = (Al_2O_3/ Fe_2O_3) were calculated and compared with I.Q.S., No.5 (1984), (Table 2). The SR of the studied samples is less than 4% except a few samples in two sections which reached (10.33, 6.08, 8.4 and 5.72) % in (A7, A13, A15 and Sh5) respectively. This is due to the very low percentage of SiO_2, Al_2O_3 and Fe_2O_3. The range of AR is less than 4% in the two studied sections except a few samples; these samples include (A1 and A2) in which it reached (7.5 and 8) %. Some data of the studied samples the SR and AR shown in (Table 3) do not agree with I.Q.S., No.5 (1984), (Table 4) and therefore, the clay materials were used to make the mixture and repair both SR and AR to be in agreement with the standard specification.

– **Geochemistry of clay:** The clay is used as raw material for production of ordinary Portland cement and it is considered as the main source for providing SiO_2, Al_2O_3 and Fe_2O_3.

Eight samples of clay from the studied area were analyzed for major elemental components, (Table 6). The results show that SiO_2 varies from (70.7 to 31.1 wt.%). The composition of the studied clay is also compared with that normal clay (Table 6) by Shah *et al*. (2007). SiO_2 content of all samples is more or less in agreement with normal clay. Fe_2O_3 is quite similar to that of normal clay. Other constituents are generally low except CaO. This is due to weathering from surrounding rocks which are mostly carbonate.

Table 6: The results of chemical analysis (wt.%) for the studied clay samples with comparison with normal clay by Shah *et al*. (2007)

S. No.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I	Total	I.R
C1	42.20	11.17	6.28	14.86	2.67	0.03	0.14	0.98	21.25	99.44	68.40
C2	59.35	10.85	6.20	4.72	2.56	0.02	0.16	1.09	13.92	98.87	81.80
C3	39.94	12.27	10.80	14.09	3.45	0.03	0.17	0.93	17.54	99.22	65.60
C4	70.27	10.15	5.96	1.01	1.78	0.03	0.18	0.85	8.91	99.14	89.80
C5	42.67	13.21	8.60	10.61	2.90	0.04	0.13	0.95	20.32	99.43	81.70
C6	33.80	9.83	8.26	20.66	1.72	0.06	0.13	0.79	24.94	100.19	54.80
C7	31.10	7.88	5.82	29.30	2.27	0.07	0.30	0.74	22.30	99.78	35.20
C8	53.17	11.46	7.88	5.88	2.76	0.05	0.37	1.20	16.73	99.50	85.50
Normal clay	50.33	19.17	6.50	1.43	3.77		0.81	2.32			

RAW MIXTURE COMPOSITION

If an essential component needed in cement raw mixture is not present in the required amount, corrective ingredients are used as additives. Thus example for the completion of silica content sand and high silica clay are used as additives ingredients (Duda, 1985). The purpose of calculating the composition of raw mixture is to determine the quantitative proportions of the raw component in order to give the desired chemical and mineralogical composition for the clinker. The studied limestone samples have widely differing LSF values ranging from 82761.03 to 1112.99 (Table 2). Most samples have values above the limits required for high quality cement; therefore the clay sample from the some area have been added to limestone to set pointing clinker. In Kurdistan most cement factories depend on the LSF value which is between 90 – 100. For the present samples the proportion of raw mix composition are calculated using LSF = 90 and depending on the final equation, limestone saturation factor (LSF) used previously, (Alao, 1979). The expected mixing ratio of clay samples (C1 and C8) with some limestone of (A and Sh) section are shown in (Table 7).

▪ Calculation Clinker Parameters (Ratio)

The silica ratio (SiO_2 wt.%/ Al_2O_3 wt.% + Fe_2O_3 wt.%), the aluminum ratio (Al_2O_3 wt.%/ Fe_2O_3 wt.%) and the lime saturation factor LSF {CaO wt.%/ (2.8 SiO_2 wt.% + 1.2 Al_2O_3 wt.% + 0.65 Fe_2O_3 wt.%)} are considered as important factors for control of cement. The LSF is often referred to as a percentage and therefore multiplied by 100 and this is mostly applied to clinkers.

– **The limestone saturation factor (LSF):** Form the chemical composition of limestone of the studied area (Table 2) it is evident that for manufacturing cement some quantity of clay must be added to compensate for the percentage of silica alumina and iron oxides for the suitable limestone. In order to ensure the clinker quality, the following composition parameters (moduli) (LSF, SR and AR) must be controlled.

The LSF controls the ratio of alite to belite in the clinker; a clinker with a higher LSF will have higher proportion of alite C_3S to belite C_2S than clinker with low LSF. Rao *et al*. (2011) believed that if the LSF values are above 100%, it will indicate that free lime is likely to be present in the clinker. This is because, in principle, at LSF = 100 all the free lime should have combined with belite to form alite. Moreover, the normal range of LSF is 90 – 98 %, but if it is 80% it does not create any problem in cement manufacturing process and cement strength but should not go below this range. The LSF in the studied samples ranges between

(89.95 – 91.22), (Table 7) and this indicate that all the studied samples are in an acceptable range.

– **Silica ratio (SR):** It is sometimes called silica modulus and has especially great influence on burning process and on some cement features (Rao *et al.*, 2011).

When SR is increased the amount of liquid phase is decreased and vice versa. So SR has a major influence on the formation of liquid phase. The SR also affects the grindability of clinker, when there is more liquid phase which means that SR is low and this it causes the lower grindability of the clinker (Tokyay, 1999).

$$\text{Liquid phase} = 71/\ 0.53 + \text{SR}$$

When the SR increases the formation of nodules and the chemical reactions may become too slow making it difficult to operate and it is harder to burn. This causes slow setting and hardening of the cement and high strength of cement is obtained. According to Aldieb and Ibrahim (2010), SR ranges between 1.9 – 3.2. Large variation of SR in the clinker can be an indication of poor uniformity in the kiln feed. The SR in the studied limestone samples ranges between (0.0 to 10.33), (Table 2) while when these samples are mixed with clay materials C1 and C8 theoretically the SR are changed to (1.86 – 2.41) (Table 7), and this indicates that the studied raw mixture samples are in agreement with acceptable range and this due to the effect of silica, alumina and iron content in clay.

Table 7: Chemical composition of mixture and cement clinker with produced some properties. When LSF = 90

	Requirments	**A1+C1**	**A2+C1**	**A3+C1**	**A1+C8**	**A2+C8**	**A3+C8**	**Sh1+C1**	**Sh3+C1**	**Sh4C1**	**Sh1+C8**	**Sh3+C8**	**Sh4+C8**
Raw mix	X	0.34	0.35	0.35	0.41	0.42	0.42	0.35	0.34	0.35	0.42	0.41	0.42
	Y	0.66	0.66	0.65	0.59	0.59	0.58	0.65	0.66	0.66	0.58	0.60	0.59
	SiO_2	14.66	14.75	14.70	14.03	14.10	14.09	14.73	14.68	14.65	14.11	14.05	14.01
	Al_2O_3	3.94	3.93	3.91	4.13	4.12	4.11	3.92	3.93	3.90	4.12	4.13	4.10
	Fe_2O_3	2.17	2.19	2.20	3.41	3.43	3.45	2.19	2.19	2.19	3.44	3.42	3.43
	CaO	41.56	41.74	41.70	41.07	41.24	41.16	41.73	41.62	41.59	41.19	41.67	41.10
	MgO	1.24	1.24	1.24	1.00	0.99	1.00	1.28	1.25	1.18	1.02	1.01	0.93
	SO_3	0.04	0.04	0.03	0.05	0.05	0.04	0.04	0.03	0.02	0.05	0.04	0.04
	Na_2O	0.05	0.05	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	K2O	0.36	0.35	0.34	0.34	0.33	0.33	0.35	0.36	0.34	0.33	0.35	0.33
	L.O.I	36.02	35.79	35.82	35.92	35.71	35.72	35.85	35.77	35.81	35.75	36.13	35.73
	ToTal	100.05	100.07	100.00	100.00	100.02	99.95	100.13	99.88	99.72	100.07	100.84	99.71
Clinker	SiO_2	22.90	22.95	22.91	21.89	21.92	21.93	22.92	22.90	22.93	21.93	21.71	21.90
	Al_2O_3	6.15	6.11	6.10	6.45	6.40	6.41	6.10	6.14	6.10	6.41	6.38	6.40
	Fe_2O_3	3.39	3.40	3.43	5.32	5.33	5.37	3.41	3.41	3.42	5.35	5.29	5.36
	CaO	64.91	64.94	64.97	64.08	64.12	64.08	64.92	64.92	65.07	64.03	64.39	64.23
	MgO	1.94	1.93	1.94	1.55	1.54	1.55	1.98	1.95	1.84	1.59	1.55	1.46
	SO_3	0.07	0.06	0.05	0.08	0.08	0.07	0.05	0.05	0.04	0.07	0.07	0.06
	Na_2O	0.09	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	K2O	0.56	0.54	0.53	0.53	0.52	0.51	0.54	0.57	0.53	0.52	0.54	0.51
	L.O.I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	ToTal	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ratio	LSF*	90.05	89.95	90.14	90.01	89.99	89.89	90.11	90.08	90.10	89.87	91.22	90.13
	LSF**	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00	90.00
	SR	2.40	2.41	2.41	1.86	1.87	1.86	2.41	2.40	2.41	1.87	1.86	1.86
	AR	1.81	1.80	1.78	1.21	1.20	1.19	1.79	1.80	1.79	1.20	1.21	1.19
clinker phases	C_3S%	43.86	43.87	44.39	43.36	43.54	43.30	44.14	44.03	44.63	43.08	46.58	44.22
	C_2S%	32.56	32.70	32.20	30.05	30.01	30.20	32.40	32.43	32.06	30.38	27.09	29.43
	C_3A%	10.57	10.44	10.36	8.08	7.95	7.89	10.39	10.49	10.39	7.92	7.95	7.90
	C_4AF%	10.33	10.34	10.42	16.19	16.22	16.34	10.38	10.38	10.40	16.29	16.08	16.30
clinker properties	H.M.	2.00	2.00	2.00	1.90	1.91	1.90	2.00	2.00	2.01	1.90	1.93	1.91
	M.B.T	1359.77	1360.10	1361.72	1292.88	1293.77	1291.33	1361.10	1360.22	1362.94	1290.89	1309.17	1295.96
	B.I	2.16	2.17	2.19	1.83	1.84	1.83	2.18	2.17	2.20	1.82	1.98	1.87
	L.Ph.	28.75	28.58	28.59	33.57	33.43	33.52	28.62	28.72	28.49	33.54	33.26	33.37

– **Alumina ratio AR or Alumina modulus (AM):** The AR determines the potential relative proportions of aluminate and ferrite phase in the clinker, an increase in clinker AR means there will be proportionally more aluminate and less ferrite in the clinker (Rao *et al.*, 2011).

The AR only has a significant effect on clinker formation at low temperature and affects the colour of clinker and cement. In general the AR in ordinary Portland cement clinker is usually between 1.0 and 4.0 (Rao *et al*., 2011). The AR in the studied raw mixture samples ranges between (1.19 – 1.81), (Table 7); this indicates that all the studied samples are in agreement with acceptable ranges. While in studied limestone samples the AR ranges between (0.0 to 8.0) and this is due to high purity of limestone samples.

- **Clinker Phases**

The properties of Portland cement are determined mainly by the proportion of its four principal clinker phases which are the impure forms of Ca_3SiO_5 (alite), Ca_2SiO_4 (belite), $Ca_3Al_2O_6$ (tricalcium aluminate) and C_4AF (tetracalcium aluminate ferrite). Other phases such as periclase (MgO), quartz (SiO_2), free lime (CaO), etc. may also be present in minor quantities, usually less than 1%w (Dutta, 2011). The clinker phases C_3S, C_2S, C_3A and C_4AF in the studied samples range between (43.08 – 46.58) %, (27.0 – 32.56), (10.33 – 16.34) and (7.9 – 10.57) % respectively (Table 7). Comparing these results with typical constituents of C_3S, C_2S, C_3A and C_4AF in normal Portland cement by Newman and Choo (2003), (Table 8) it becomes clear that all studied samples are within the range.

Table 8: Mineralogical composition percent Portland cement,
(after Newman and Choo, 2003)

Cement notation	Mineral name	Typical level (Mass %)	Typical range (Mass %)	Chemical composition
C_3S	Alite	57	38 – 60	$3CaO. SiO_2$
C_2S	Belite	16	15 – 38	$2CaO. SiO_2$
C_3A	Aluminate	9	7 – 15	$3CaO. Al_2O_3$
C_4AF	Ferrite	10	6 – 18	$4CaO. Al_2O_3. Fe_2O_3$

- **Clinker Properties**

Some important properties of clinker were calculated. These properties include:

– **Hydraulic modulus (HM):** It is generally limited by the values 1.7 – 2.3 (Aldieb and Ibrahim, 2010), and it has the following form:

$$HM = CaO/ SiO_2 + Al_2O_3 + Fe_2O_3$$

It was found that with an increasing HM, more heat is required for clinker burning, the strength, especially the initial strength set up, and also the heat hydration rises, and simultaneously the resistance to chemical attack decreases (Rao *et al*., 2011). Generally cement with HM lesser than 1.7 shows mostly insufficient strength; cement with HM greater than 2.3 has poor stability of volume; hence, the HM of the clinker of the studied samples ranges between (1. 9 – 2.0), (Table 7). This means that all the studied samples have acceptable range of HM.

– **Minimum burning temperature (MBT):** The MBT represents the degree in which the liquid phase begins to appear in the furnace, and depends on the ratio of (Al_2O_3, Fe_2O_3) in the raw mix, but (Fe_2O_3) has greater effect. The proportion of lime and silica causes augmentation in value which is better not to be less than (1250 °C), since only after this temperature (C_3S) is begins to appear (Chatterjee, 1979). The MBT is calculated using this equation:

$$MBT°C = 1330 + 4.51 * C_3S – 3.74 * C_3A – 12.64 * C_4AF$$

The MBT of clinker in the studied samples ranges between (1290.89° – 1362.94°), (Table 7) and this means that all the studied samples have acceptable range of MBT.

– **Burnability index (BI):** It is expressed as the percentage between the phase (C_3S) to total phases ($C_3A + C_4AF$) as follows:

$$BI = C_3S/ C_3A + C_4AF$$

Susceptibility depends on the chemical composition of the burning mixture of raw mix, since any change in the composition leads to a change in susceptibility burning, the rate of BI in cement ranging between 2.6 to 4.5 (Al-Ali, 2004). This ratio has good susceptibility burning. The B.I of clinker of the studied samples ranges from 1.83 to 2.2 and this indicates that most of samples have BI lower than the acceptable ranges.

– **Liquid phase at the burning zone (L.Ph.):** The liquid phase of the studied samples was calculated as follows:

$$L.Ph.\ \% = 3.0\ Al_2O_3 + 2.25\ Fe_2O_3 + MgO + K_2O + Na_2O + SO_3\ (1450\ °C)$$

The acceptable ranges of L.ph in cement clinker at temperature 1450 °C ranging between 23% to 27%. The L.Ph. of the studied samples ranges between (28.49 to 28.75), (Table 7). Accordingly, most the studied samples have not acceptable values. To reduce the liquid phase, SR must be increased by adding higher amount of sand to the mixture because sand is the main source for SiO_2.

▪ Petrophysical Properties of Limestone

Quarry management is an art; most quarries will probably have good material from which cement can easily be made. They may also have some material that is not as good. This might be harder to grind, or be of less convenient composition. Therefore the petrophysical characterization of limestone from Avroman Formation must be studied.

The procedure described by IQS No.31 (1981) were used and the results as in (Table 9). Physical properties of rock were influenced by internal geometry of the rock such as grain size, pore size, grain shape, pore connectivity, fracture geometry, orientation structure and texture.

– **The porosity (P):** The porosity of the studied samples ranges between (2.57 – 2.77 %), (Table 9). The low porosity of studied sample produce a high compressive strength and this cause difficulties in crushing and grinding of materials.

– **The bulk density (ρ):** The bulk density of studied samples range between (2.41 – 2.68), (Table 9), and the high bulk density of studied samples is related to low porosity of samples.

– **Moisture (water) content:** ASTM. D2216-10 (2010) is used to determine the moisture content at standard temperature of 110 ± 5 °C.

$$\text{Moisture content} = \{Mw/ Ms\} *100$$

Where Mw: mass of water in gm and Ms: mass oven dry spacemen in gm.

The moisture content of studied samples ranges between (0.004 – 0.089), (Table 9). The low moisture content cause low energy consumption during drying of raw mixture before burning.

– **Apparent specific gravity (T):** The apparent specific gravity value of the studied samples ranges between (2.60 – 2.77) gm/cm^3 (Table 9). The low difference between the bulk density and specific gravity values indicate very low pores in the studied samples.

Table 9: Petrophysical properties of the studied limestone

Sample No.	Apparent Porosity %	Bulk Density gm/cm^3	Apparent SPG gm/cm^3	Natural Moisture Content %
A1	2.35	2.6	2.66	0.0055
A3	2.13	2.64	2.69	0.004
A4	3	2.61	2.69	0.0092
A5	3.51	2.62	2.71	0.0182
A6	4.56	2.61	2.73	0.0181
A7	4.14	2.65	2.77	0.0135
A8	3.27	2.6	2.69	0.0131
A9	3.1	2.6	2.69	0.011
A10	2.52	2.65	2.72	0.0132
A11	2.63	2.63	2.7	0.0206
A12	1.82	2.65	2.7	0.0063
A13	3.27	2.64	2.73	0.0113
A14	1.87	2.68	2.73	0.0124
A15	3.09	2.66	2.75	0.016
A16	3.49	2.58	2.68	0.0157
Sh1	5.16	2.47	2.6	0.0353
Sh2	3.68	2.53	2.62	0.025
Sh4	3.86	2.55	2.66	0.0003
Sh5	6.19	2.41	2.57	0.0895
Sh6	3.12	2.55	2.63	0.0407
Sh7	4.57	2.52	2.64	0.0051
Sh8	3.22	2.56	2.65	0.0554
Sh9	3.47	2.55	2.65	0.0028
Sh10	1.91	2.6	2.65	0.0057
Sh11	2.52	2.59	2.66	0.019
Sh12	4.52	2.51	2.63	0.011

MECHANICAL PROPERTIES (UNIAXIAL COMPRESSIVE STRENGTH UCS) OF LIMESTONE

Compressive strength measures the failure point and it is defined as many forces including internal cohesion between grains and crystal with external force that is perpendicular on the sample. It is used to define the failure point at rock sample during size reduction where the sample is loaded.

The UCS test was determined for 29 samples of limestone using point load apparatus (ELE-model) in the University of Sulaimaniyah. This test is used in samples of different diameter and the results are shown in (Table 10). Anon (1972) classified the rock sample into very strong if the value of UCS range between 100 – 200 MN/m^2 and strong if the UCS range between 50 – 100 MN/m^2. Accordingly the studied limestone samples are classified as strong to very strong. The compressive strength of limestone for cement industry must be less than (950 – 1000) Kg/cm^3, but according to standard world the range of compressive strength of limestone ranges between (458.81 – 1414.0) Kg/cm^3 (Chatterjee, 2004). The results of UCS value for studied samples in A and Sh-sections range between (742 – 1405) Kg/cm^2 and (674 – 1484) Kg/cm^2 respectively. Comparing these results with standard world for compressive strength of limestone by Chatterjee (2004) indicate all studied samples are in agreement with standard range of international world range of limestone. The increasing and decreasing of compressive strength are related to the porosity that is present in the samples; the strength increases, with porosity decrease. Moreover, joints and fractures affect the compressive strength of this rock. From the above results, it can be conclude that the processes of crushing and grinding need a suitable force (energy) during the extraction of a sample in the quarry.

Table 10: The results of uniaxial compressive strength (UCS) of limestone samples for each studied section

Sample No.	**P (KN)**	**De (mm)**	**Is = p/De^2 (MN/m^2)**	**Is50 = F * Is (Mn/m^2) F = (De/50)^0.45**	**UNS (Mpa) UNS = 22.5*Is50**	**UNS (Kg/cm^2)**	**Classification (after Anon, 1972)**
A1	8.50	39.00	5.59	5.00	112	1147	Very strong
A2	13.00	45.00	6.42	6.12	138	1405	Very strong
A3	8.50	39.00	5.59	5.00	112	1147	Very strong
A4	6.50	39.00	4.27	3.82	86	877	Strong
A5	16.00	52.00	5.92	6.02	136	1382	Very strong
A6	6.00	39.00	3.94	3.53	79	809	Strong
A7	6.50	39.00	4.27	3.82	86	877	Strong
A8	7.50	33.00	6.89	5.71	129	1311	Very strong
A9	11.50	38.00	7.96	7.04	158	1615	Very strong
A10	5.50	39.00	3.62	3.23	73	742	Strong
A11	6.00	39.00	3.94	3.53	79	809	Strong
A12	13.50	47.00	6.11	5.94	134	1364	Very strong
A13	6.50	41.00	3.87	3.54	80	811	Strong
A14	7.00	39.00	4.60	4.12	93	944	Strong
A15	6.50	41.00	3.87	3.54	80	811	Strong
A16	3.00	13.00	17.75	9.68	218	2221	Extremely strong
Sh1	8.50	35.00	6.94	5.91	133	1356	Very strong
Sh2	5.00	23.00	9.45	6.66	150	1529	Very strong
Sh3	7.50	39.00	4.93	4.41	99	1012	strong
Sh4	8.00	39.00	5.26	4.70	106	1079	Very strong
Sh5	6.50	23.00	12.29	8.66	195	1988	Very strong
Sh6	10.00	43.00	5.41	5.05	114	1159	Very strong
Sh7	8.50	39.00	5.59	5.00	112	1147	Very strong
Sh8	5.00	39.00	3.29	2.94	66	674	strong
Sh9	5.00	39.00	3.29	2.94	66	674	strong
Sh10	11.00	39.00	7.23	6.47	146	1484	Very strong
Sh11	7.50	35.00	6.12	5.21	117	1196	Very strong
Sh12	6.50	39.00	4.27	3.82	86	877	strong
Sh13	7.50	39.00	4.93	4.41	99	1012	strong

CONCLUSIONS

- The chemical analyses of 29 samples of limestone and 8 samples of clays indicate that the limestone contain a qualified raw material appropriate for the cement industry.
- The LSF value ranges between (91. 22 to 89.87) in a raw mixture composition which indicate good agreement with standard specification for manufacturing Portland cement.

- Comparing the composition of raw materials and raw mixture with the required standards for normal Portland cement it has been proved that all the materials meet the specification required for clinker production and have a composition close to that of normal Portland Cement.
- Petrophysical test of the studied samples revealed that all samples have high specific gravity, bulk density, and generally with low porosity, very low water absorption and moisture content and are in agreement with standard ranges for cement industry.
- The mechanical property of the Avroman Limestone Formation indicates that the limestone is very strong to strong hence it needs a suitable force during the extraction and crushing.

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About the author

Dr. Tola Ahmed Mirza is assistant professor of the University of Sulaimaniyah, School of Science, Geology. She obtained the BSc. in Geology, the MSc. in industrial rocks and minerals, and Ph.D in ore geology. She has more than 15 researches in her field and in nonmetallic ore deposits. She is an associate editor of the (International journal of applied industrial science). She is at present supervising five MSc students in the field of ore geology and industrial rocks and minerals. She participated in translating the book (Science for All), (Class Nine Primary School, 2009). She is a member of the Scientific Committee of the School of Science since 2014.

e-mail: tola.merza@univsul.edu.iq