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Chert Deposit Used in Cement Production as a Quartz-Sand Alternative in the Iraqi Kurdistan Region: An Assessment Study

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Abstract Silica-sand is one of the main additives in cement production. Cement plants in the Iraqi Kurdistan Region had been using silica sand which is 98% quartz that was quarried from the Iraqi Western Desert. However, during the last decade, it was not possible to supply these cement plants with material from this location; therefore, the silica sand was imported from Iran. Recently, radiolarian chert of the Qulqula Group was quarried from the Sharbazhar Quarry in Kurdistan and used in some cement plants in the Kurdistan Region. This research was performed to study the specifications of the chert which is interbedded with claystone of the Qulqula Group that can be used as an alternative to silica-sand from other regions outside of Kurdistan. Five samples were collected from the Sharbazhar Quarry and subjected to XRF testing. The acquired results were encouraging; therefore, 20 additional samples were collected from the quarry, but also from other outcrops of the Qulqula Group along the road towards Sulaimaniyah city. The collected samples were subjected to XRF testing and the results showed that the weighted average of the SiO_2 in the quarried chert–claystone deposit is 83.71%., when the plants used claystone:chert ratio is 3:2; as it is used with mix-raw material in some cement plants in the Bazian district. This deficiency in the weighted average of the SiO_2 is overcome by adding more chert from the chert–claystone deposit to the raw-mix.

Keywords Silica-sand · Chert · Claystone · Cement plants · Qulqula Group · Iraq

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1 Introduction

Almost all buildings in the world use concrete as a building material. Concrete is a strong, durable and resists weathering. Concrete consists of cement and various aggregate materials which constitutes fragmented or weathered rock from a variety of sources

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including alluvial fans, glacial moraines, volcanic ash, and tuffs. Cement is a binding agent or glue that holds these loose or aggregate materials together (Duggal 1998; Mamlouk and Zaniewski 2006). The composition of cement has changed over the millenniums. Clay was the first cementing material used by the Assyrians and Babylonians over 6000 years ago. The Egyptians used lime and gypsum cement to build the Great Pyramids. The Romans were the first to understand the chemistry of cement and they used this knowledge to build many large structures including the Pantheon, a 2000 years old building that still exists today (Duggal 1998). Modern-day cements were developed over the last two centuries. Portland cement was introduced and patented by Joseph Aspdin in 1824. It was formed by heating a mixture of limestone and fine clay. Today the most common cement is referred to as basic Portland cement which is made from lime, silica, alumina, and other lesser constituents (Duggal 1998; Mamlouk and Zaniewski 2006).

The Iraqi Kurdistan Region has been witnessing large constructional development over the last two decades. Currently, six cement plants already exist in the region; five of them are in Sulaimaniyah Governorate in the Bazain district and one is in Erbil Governorate at Qara Chough Mountain. Moreover, three plants have been granted licenses by the Ministry of Natural Resources, but are not constructed, yet. All the existing plants use silica sand as a required additive beside other additives which are used depending on the type of the produced cement and type of the used limestone and claystone as the two main raw materials in cement production (Portland Cement Association 1969).

Previously, silica-sand which is rich in quartz (up to 98%) was supplied from the Iraqi Western Desert from a quarry called Erdhuma which is located 12 km west of town of Rutba town. After 2003, it was not possible for the cement plants of the Kurdistan Region to obtain silica-sand from Erdhuma quarry; therefore, the sand was imported from Iran.

Recently, some of the cement plants in the Kurdistan Region started using radiolarian chert which is utilized from a quarry located along the road between towns of Chwarta and Penjween (Fig. 1) which is called the Sharbazhar Quarry, the distance from the quarry to the cement plants complex at Bazian town is about 100 km. The quarried beds belong to the Qulqula Group consist of radiolarian chert alternating with reddish brown claystone with occasional clayey limestone beds.

The aim of this study is to evaluate the quality of the chert deposit which is quarried from Sharbazhar quarry and used as an alternative to silica-sand. Silica sand is used in cement production in three cement plants at Sulaimani Governorate in the Iraqi Kurdistan Region. Moreover, this study was carried out to confirm that the cement and associated concrete produced at these cement plants meets international standards. The Sharbazhar quarry is about 100 km NE from the cement plants (Fig. 1). An attempt was carried out to check the quality of the exposed rocks within the Qulqula Group (from which the deposit is quarried) along the road to Chwarta town (Fig. 1). It was found that the rocks in many locations have the same chemical composition of those quarried from Sharbazhar quarry with almost the same quarrying conditions. Therefore, these other locations may also be quarried.

1.1 Previous Studies

In the Iraqi Kurdistan Region, as well as, other parts of the Iraqi territory, chert was not used previously in the cement production since very, high quality, quartz-sand occurs in the Iraqi Western Desert (Muradian 1985; Al-Bassam 2013). However, due to difficulties in transporting quartz-sand from the Erdhuma quarry to the Kurdistan Region and security concerns, chert of the Qulqula Group has recently been used as an alternative for the quartz-sand in cement production in the Bazian district of the Sulaimaniyah Governorate. Concerning this deposit, no previous studies have been conducted. Many other studies were reviewed including the works of Koting et al. (2014), Sharmaa et al. (2014), Hemalatha et al (2018), Magistri and Lo Presiti (2019), Penkala et al. (2019) and Tiwari et al. (2019), but none addressed the use of chert as an alternative.

1.2 Materials and Methods

To perform the current research, we have used the following data:

- Geological maps and satellite images of the quarry area and surroundings.

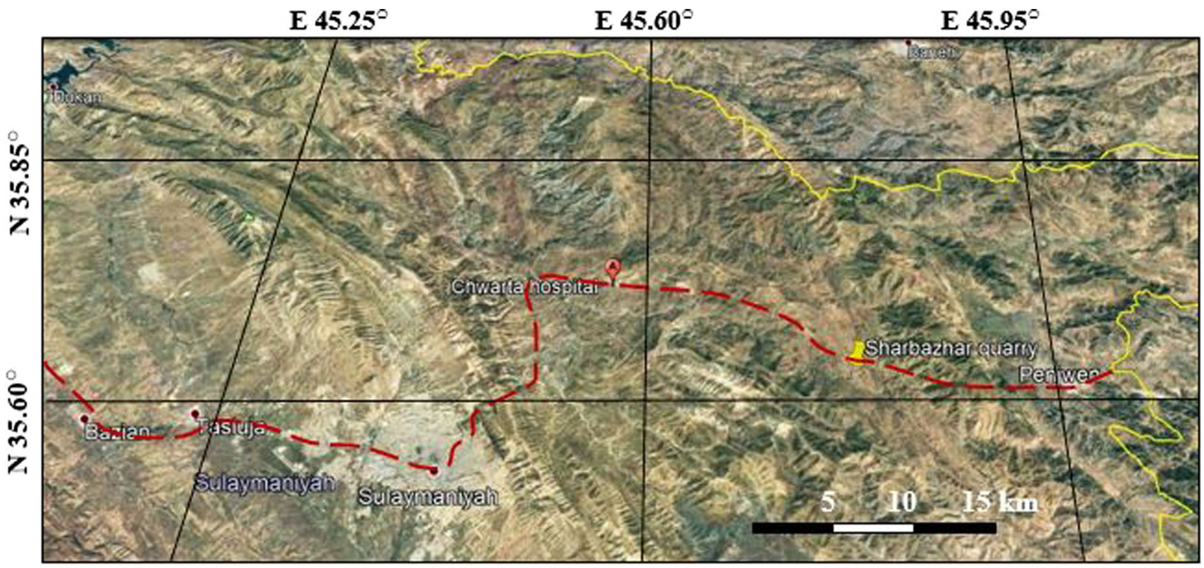

Fig. 1 Satellite image showing the location of Sharbazhar Quarry and the cement plants complex near Bazian town

- Relevant publications which are concerned in using of the quartz-sand in cement production.
- Geochemical data acquired from XRF testing of the 20 collected samples.
- Comparing the acquired geochemical data with international standards for cement production.

The exposed rocks in Sharbazhar quarry (Fig. 2) were sampled twice. In the first round of sampling, five samples were collected and subjected to XRF testing. Upon receiving relevant results, the second round of sampling was performed by collecting 20 additional samples. Samples were described and the thicknesses of the beds were measured and recorded as presented in Table 1. Samples from the second investigation were collected at equally spaced intervals across the quarry from southwest to northeast. Sampling began from the oldest exposed beds in the southwest to the youngest ones in the northeast. The Sharbazhar Quarry was divided into three parts: Lower, Middle and Upper parts as present in Fig. 2. Each part was delineated based on topography and the thickness of the rock formations. The sampling was performed along the entire width of the quarry. In addition, samples were collected outside of Sharbazhar quarry along the road toward the town of Chwartah (Figs. 1 and 3) and from another abandoned small quarry.

1.3 Geological Setting

The geological setting of the Sharbazhar Quarry and nearby surroundings is briefly described hereinafter. Descriptions of the geomorphology, tectonic and structural geology, and stratigraphy (Fig. 4) are included based on the work of Buday and Suk (1978) and Sissakian and Fouad (2014).

Stratigraphically, the Qulqula Group consists mainly of radiolarian chert, claystone, and limestone beds (Figs. 3 and 5) (Bolton 1954). The upper part is described by Buday and Suk (1978) as a dominant, thick sequence of dark red ferruginous-siliceous shaly, rubbly mudstone, with occasional beds of oolitic and detrital limestone. The lithology of the sequence does not vary for long distances. The same succession of rocks was observed and followed along the road from the Sharbazhar Quarry towards the town of Chwartah for a distance approximately 10 km (Fig. 4).

Geomorphologically, the quarry site is an undulatory plain with an average elevation of 1110 m (a.s.l.), surrounded by gentle cliffs which represent the hard chert beds as shown in Fig. 5. The existing drainage is parallel to and follows the main ridges, usually in a wide U-shape; having gentle banks and wide floors (Fig. 5).

Tectonically, Sharbazhar Quarry is located within the Zagros Suture Zone, Qulqula-Khwakurk Subzone, which belongs to the Outer Platform of the

Fig. 2 General view of the Sharbazhar Quarry looking north eastwards and showing three parts

Table 1 Field description of the collected samples

S. no.	Thick. (m)	Part of the quarry	Description	Location
1	8	Lower	Reddish brown claystone, soft, slope forming	N 35° 38.029′
2	10		Yellowish brown chert, hard, ridge forming	E 45° 46.028′
3	5		Reddish brown claystone, soft, slope forming	
4	5		Yellowish brown chert, hard, ridge forming	N 35° 38.008′
5	8		Reddish brown claystone, soft, slope forming	E 45° 46.331′
6	3		Yellowish brown chert, hard, ridge forming	
7	12	Middle	Reddish brown claystone, soft, slope forming	N 35° 38.013′
8	8		Reddish brown claystone, soft, slope forming	E 45° 46.365′
9	2		Olive green claystone, soft, slope forming	
10	4		Yellowish brown chert, hard, ridge forming	N 35° 38.081′
11	7		Reddish brown claystone, soft, slope forming	E 45° 46.329′
12	5	Upper	Reddish brown claystone, soft, slope forming	N 35° 38.027′
13	7		Reddish brown claystone, soft, slope forming	E 45° 46.409′
14	14		Reddish brown claystone, soft, slope forming	
15	3		Yellowish brown chert, hard, ridge forming	N 35° 37.899′
16	4		Yellowish brown clayey limestone	E 45° 45.867′
17	12	Along the road	Reddish brown claystone, soft, slope forming	N 35° 38.165′
18	5		Yellowish brown chert, hard, ridge forming	E 45° 45.154′
19	4	Abandoned quarry	Yellowish brown chert, hard, ridge forming	N 35° 38.270′
20	9		Reddish brown claystone, soft, slope forming	E 45° 44.945′

Arabian Plate. Moreover, the whole platform belongs to the Zagros Fold-Thrust Belt (Fouad 2012). The beds of the Qulqula Group are highly deformed and crushed due to the exerted tectonic forces during the collision of the Arabian and Eurasian (Iranian) plates, and the presence of competent (chert beds) and incompetent rocks (claystone) alternated together in rhythmic style has increased the deformational style of the beds.

2 SIlica-Sand as Additive in Cement Production

Silica-sand is one of the most common varieties of sand found in the world. It is used for a wide range of applications, among them is cement production. In industry, it has different terms: Commercial Silica Sand, Ground Silica Sand, Quartz-sand (Bates and Jackson 1984). For industrial and manufacturing applications, deposits of silica consist of at least

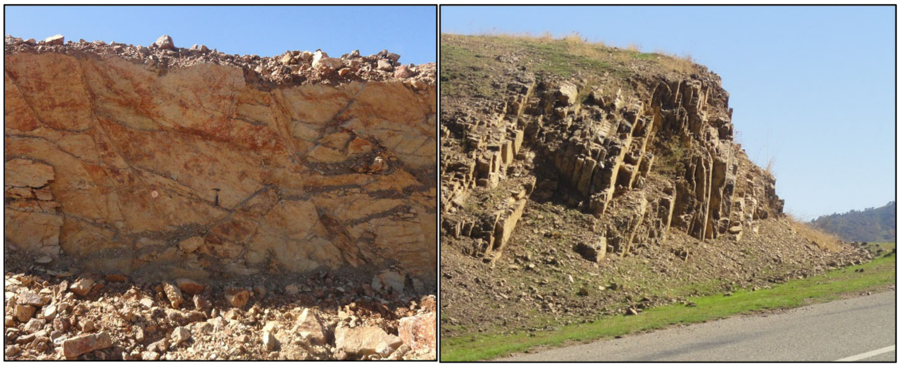

Fig. 3 (Left) The sampled abandoned quarry, (Right) A sampled location along the road

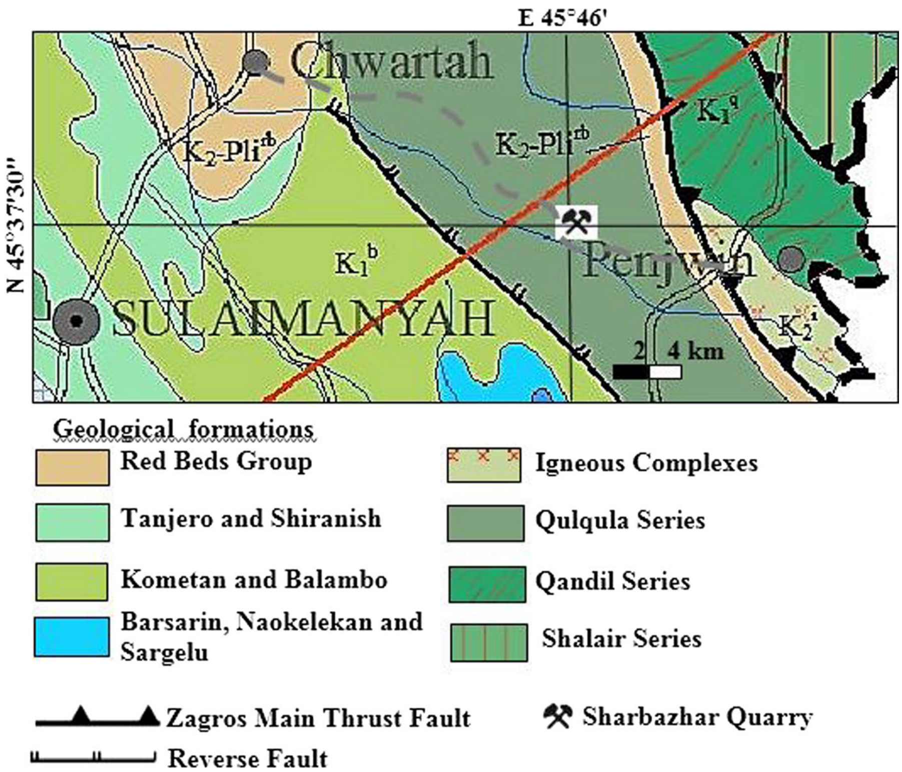

Fig. 4 Geological map of the Sharbazhar Quarry and surroundings (Sissakian and Fouad 2012)

95% SiO_2. Silica is hard and chemically inert and has a high melting point, attributable to the strength of the bonds between the atoms; therefore, it is used as an additive in cement production. Silica is one of three main constituents in Portland cement besides lime and alumina (Table 2). In addition, other components consist of iron oxide, magnesia, sulfur trioxide, and alkalis. Silica is a primary component of Portland cement without which it cannot be made (Duggal 1998).

The amount of the silica-sand used in cement production of some cement plants (ISO Certified) in Sulaimaniyah Governorate, Iraqi Kurdistan Region, ranges between 2.5 and 3.3 kg/ton for Resistant Cement. This ratio depends on the type of the limestone and claystone needed since these

Fig. 5 (Left) The undulatory plain of the quarry, (right) ridges and U-shaped valleys

constituents are the two, main, raw materials in cement production.

2.1 Commercial Silica Sand

Commercial Silica Sand, Industrial Sand and Ground Sand are terms normally applied to high purity silica sand products with closely controlled sizing. Ground silica performs as a functional extender to add strength durability, anti-corrosion, and weathering properties in epoxy-based compounds, sealants, and caulks (Duggal 1998).

2.2 Chert and Radiolarian Chert

Chert is a rock resembling flint and consisting essentially of a large amount of fibrous chalcedony with smaller amounts of cryptocrystalline quartz and amorphous silica. Chert is a hard, fine-grained sedimentary rock composed of crystals of quartz (silica) that are very small (i.e., microcrystalline or cryptocrystalline) (Knauth 1979). Quartz (silica) is the mineral form of silicon dioxide (SiO_2). Chert is often of biological origin (Radiolarian, organic) but may also occur inorganically as a chemical precipitate or a diagenetic replacement (e.g. petrified wood) (Bates and Jackson 1984). Geologists use chert as a generic name for any type of microcrystalline or cryptocrystalline quartz. However, the radiolarian chert which is the present type in the Qulqula Group is a siliceous, comparatively hard, fine-grained, chert-like, and homogeneous sedimentary rock that is composed predominantly of the microscopic organisms of radiolarians. This term is also used for indurated radiolarian oozes and sometimes as a synonym of radiolarian earth. A radiolarian chert is well-bedded, microcrystalline radiolarite that has a well-developed siliceous cement or groundmass (Neuendorf et al. 2006).

Table 2 Basic chemical composition of portland cement (After Duggal 1998)

Chemical constituent	Amount (%)	Attribute
CaO (limestone)	60–65	Control strength and soundness
SiO_2 (silica-sand)	17–25	Give strength
Al_2O_3 (clay)	3–8	Responsible for quick setting
Fe_2O_3 (hematite)	0.5–6	Give color and helps fusion
MgO (limestone)	0.5–4	Imparts color and hardness
$Na_2O + K_2O$ (limestone)	0.5–1.3	Minor constituent
TiO_2	0.1–0.4	Minor constituent
P_2O_5	0.1–0.2	Minor constituent
SO_3	1–2	Make cement sound

3 Sharbazhar Quarry

Sharbazhar Quarry is an open pit one-bench quarry (Fig. 2) located along the main road between towns of Penjween and Chwartah (Figs. 1 and 4). The chert and claystone beds are quarried by ripping using bulldozers (i.e., strip quarrying method) (Figs. 2 and 5Left).

3.1 Specifications of the Deposit in Sharbazhar Quarry

The twenty collected samples were dried, crushed and ground; then subjected to XRF testing. The results are presented in Table 3 as samples Nos. 1–20. Beside testing each sample alone, all claystone samples of the Sharbazhar Quarry were mixed in a uniform amount and subjected to XRF testing. The result of this testing is presented in Table 3 as sample No. 21. The same was done for all chert samples and the result is presented in Table 3 as sample No. 22. Moreover, samples No. 21 and 22 were mixed in a 2:3 ratios (claystone: chert), and the acquired result from XRF test is presented in Table 3 as sample No. 23. All concerned cement plants in the Sulaimaniyah Governorate use a 2:3 ratio of claystone to chert as supplied from the Sharbazhar Quarry.

Besides, the oxides mentioned in Table 3, Na_2O, MgO and Cl^{-1} were also analyzed by the XRF device (Rigaku, Model: NEX QC Quant). In some cases, the results were below the detection limits of the device in which case the results were recorded as non-detected.

3.2 Quarrying Conditions

3.2.1 Advantages of the Sharbazhar Quarry

The Sharbazhar Quarry has the following advantages:

- There is neither overburden nor inner burden in the deposit, apart from a thin residual and/ or colluvial soil, which is not more than one meter in thickness; it is easily removed from the Sharbazhar quarry and in surrounding areas (Figs. 2, 3 and 5).
- The chert is very hard (7 according to Mohs Hardness scale), but because it is very thinly bedded (3–10 cm), highly jointed and deformed (Fig. 6, Left), it is easily quarried by ripping using bulldozer (Fig. 6, Right). The chert and claystone are crushed in the quarry using portable crushing machine (Fig. 7, Left) and screened using metallic mesh (Fig. 7, Right).
- The ground water depth ranges from 40 to 60 m (Al-Jiburi and Al-Basrawi 2015); therefore, no hydrogeological problem may arise when quarrying below the present-day quarrying level which is ground level.
- The deposit in the Sharbazhar quarry and near surroundings extends in three dimensions for several hundred meters. The thickness of the Qulqula Group is about 3000 m (Bolton 1954) and the surface area is extremely large. The width of the exposures in the quarry area is about 12 km and the length is more than several hundred kilometers (Fig. 4).
- The quarrying can be extended along the strike of the exposed rocks. Existing villages and/or agricultural lands should not be impacted (Figs. 1 and 5). Quarrying can be performed by the multi bench method without facing any hydrogeological problems down to a depth of between 40–60 m.
- The quality of the deposit is very homogeneous, not only in the quarry, but outside of the quarry as indicated from the chemical composition of the collected samples (Table 3).

3.2.2 Disadvantages of the Sharbazhar Quarry

The Sharbazhar Quarry has the following disadvantages:

- The total thickness of the chert beds in the quarry is less than that of the claystone beds. Even though the thickness of the individual bed is lower, the maximum recorded thickness of the chert is 8 m, whereas that of the claystone bed is 18 m (Table 1). This means that the quarried amounts of the claystone should be higher than the chert which is to offset the difference in the content of silica between them. This is the main reason the claystone and chert are mixing to achieve a ratio of 3:2 by volume as shown in Table 3.
- Although many claystone quarries occur near cement plants in the Bazian district, claystone from Sharbazhar Quarry is still needed due to its chemical composition which includes more Fe_2O_3 and Al_2O_3 than the normal claystone beds which are available near the cement plants in the region. Moreover, claystone from the Sharbazhar Quarry

Table 3 Chemical composition of the studied samples

Sample No.	Thickness (m)	Rock name	Location at the quarry	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	L.O.I.	S
1	10	Claystone	Lower part	67.3	4.5	4.1	0.72	0.99	23.0	0.060
2	8	Chert		95.2	2.09	1.85	0.35	0.37	ND	0.089
3	5	Claystone		65.5	6.62	3.15	0.72	0.99	23.0	0.060
4	5	Chert		98.0	1.82	ND	ND	ND	0.012	0.138
5	8	Claystone		84.0	5.58	2.48	0.80	1.30	5.77	0.073
6	3	Chert		86.2	4.85	3.49	0.91	1.55	2.96	0.082
7	18	Claystone	Middle part	78.3	7.91	4.47	0.93	1.37	6.92	0.077
8	8	Claystone		79.1	8.64	5.51	0.98	1.74	3.92	0.074
9	2	Claystone		91.7	4.89	2.00	0.55	0.78	ND	0.097
10	4	Chert		99.1	0	0.43	0.14	0.16	ND	0.147
11	7	Claystone		76.1	7.49	4.83	0.86	1.47	9.15	0.055
12	5	Claystone	Upper part	79.1	6.44	4.13	0.80	1.07	8.41	0.062
13	7	Claystone		88.9	4.25	3.54	0.62	0.90	1.71	0.061
14	14	Claystone		77.0	7.23	5.24	0.86	1.31	8.31	0.064
15	3	Chert		99.0	0	0.45	0.14	0.19	ND	0.215
16	4	Clayey limestone		20.0	2.34	1.64	39.3	ND	36.6	0.14
21	109	Sum of Claystone beds		72.8	6.16	4.26	7.33	1.26	8.1	0.094
22	34	Sum of Chert beds		96.7	3.08	0.03	ND	ND	ND	0.216
23	Ratio of 3:2 (Claystone: Chert)			83.8	4.15	3.25	4.65	1.05	2.97	0.115
17	5	Chert	Out of Sharbazhar Quarry	97.2	2.66	ND	ND	ND	0.012	0.102
18	12	Claystone		66.1	3.22	1.62	12.7	ND	16.2	0.102
19	4	Chert		93.9	4.36	3.43	0.65	1.15	6.48	0.082
20	9	Claystone		85.4	4.41	3.48	0.69	1.11	4.88	0.082

Weighted Average of SiO_2 (%) out of Sharbazhar Quarry with 3:2 ratio	Sample No.	Along the road	17	78.54
			18	
		Abandoned Quarry	19	88.80
			20	

N.D. = Not detected

L.O.I. = Lost on Ignition

should be used because it occurs in very large quantities and it is not easy to dump them nearby the quarry site or elsewhere. Therefore, the cost of the used raw materials is increased.

Fig. 6 (Left) The thinly well bedded and jointed chert beds, (right) easily quarried deposit (ripping) by means of a Bulldozer

Fig. 7 (Left) Portable crushing machine, (right) metallic mesh for manual screening

- The distance of the Sharbazhar Quarry to the Bazian district where the cement plants are located is about 85 km. The road to these cement plants is a single lane type with a lot of dangerous curves which makes the driving of trailer type trucks which can carry about 30 tons of material very arduous. Therefore, the road is likely to be damage within a few years and will require additional maintenance.

4 Results

The XRF test results of the collected samples (Table 3) showed high silica (SiO_2) content in the chert samples. The silica content ranges from 83.9 to 99.1%, whereas the silica content in the collective chert samples (Sample No. 22 in Table 3) is 96.7%. However, the claystone samples also showed high silica content; it ranges from 65.5 to 88.9%, and in the collective claystone samples (Sample No. 21 in Table 3) the silica content is 72.8%.

The weighted average of SiO_2 content in the chert and claystone samples are presented in Table 4. The weighted averages of the SiO_2 in the chert and claystone samples are 95.81% and 75.08%, respectively. Cement plants are also using the claystone in the raw-mix of the main raw materials such as limestone and claystone, since the SiO_2 content in claystone beds at Chamchamal district ($\sim$ 40 km SW of Bazian district) which are used by the cement plants in the Bazian district range from 37.57 to 39. 87% (Hafidh et al. 2011).

5 Discussion

The quarried chert and claystone deposit from Sharbazhar Quarry are successfully used in many cement

Table 4 Percentage of SiO_2 and weighted averages in the collected and analyzed samples within Sharbazhar Quarry

Sample no.	Thick (m)	Rock type	SiO_2 (%)	Weighted average (%)	Quarry part	Remarks
1	10	Claystone	67.3	673.0	Lower	Includes the thickest chert beds and forms high areas.
2	8	Chert	95.2	761.6		Thickness of chert is 16 m, W. A. of SiO_2 is 94.39%
3	5	Claystone	65.5	327.5		Thickness of claystone is 23 m, W. A. of SiO_2 is 72.72%, and 3:2 ratio is 81.39%
4	5	Chert	98.0	490.0		
5	8	Claystone	84.0	672.0		
6	3	Chert	86.2	258.6		
7	18	Claystone	78.3	1409.4	Middle	Includes thick
8	8	Claystone	79.1	632.8		claystone beds.
9	2	Claystone	91.7	183.4		Thickness of chert is 4 m, WA of SiO_2 is 99.1%
10	4	Chert	99.1	396.4		Thickness of claystone is 29 m, W. A. of SiO_2 is 78.91%, and 3:2 ratio is 86.99%
11	7	Claystone	76.1	532.7		
12	5	Claystone	79.1	395.5	Upper	Includes thick
13	7	Claystone	88.9	622.3		claystone beds.
14	14	Claystone	77.0	1078.0		Thickness of chert is 3 m, WA of SiO2 is 99.0%
15	3	Chert	99.0	297.0		Thickness of claystone is 30 m, W. A. of SiO_2 is 72.53%, and 3:2 ratio is 83.12%
16	4	Clayey limestone	20.0	80.0		
Total	23	Chert	Weighted average	95.81		W. A. = weighted average
	88	Claystone		75.08		

plants (ISO Certified) in Bazian district, southwest of Sulaimaniyah city. This is attributed to the quality of the chert and claystone beds of the Qulqula Group.

The previously used silica-sand in cement production was supplied by Iraq Geological Survey from Erdhuma quarry which is located 12 km west of Rutbah town in Anbar Governorate, Iraqi Western Desert. The SiO_2 content in the previously used silica-sand ranges from 95 to 99% quartz and generally less than 1% Fe2O3 (Al-Bassam 2007). The silica (SiO_2) content in the quarried chert beds of the Qulqula Group in Sharbazhar Quarry ranges from 86.2 to 99.1%, whereas the weighted average of the SiO_2 in chert beds is 95.81%. Moreover, the used claystone includes high percentages of SiO_2 which range from 20.0 to 91.7% (Table 3), whereas the weighted average of the SiO_2 in the claystone beds is 75.08%.

The used chert and claystone are mixed in a ratio of 3:2 (claystone:chert). This means that the used weighted amount of SiO_2 in the raw mix of cement production is calculated as follows:

$$\begin{aligned} & 3 \text{ shares of claystone } \times 75.08\% \\ & \quad + 2 \text{ shares of chert } \times 95.81\% \\ & \quad = 225.24 + 191.62 = 416.86\%. \end{aligned}$$

Therefore, the weighted average for the used SiO_2 will be: 416.86% $\div$ 5 shares (3 claystone + 2 chert) = 83.37%. Accordingly, the used chert–claystone deposit as an alternative for the usually used silica-sand in cement production of some cement plants at Bazian district is not within the international standards, as the SiO_2% in the used commercial-sand or silica-sand should be not less than 95% (Duggal 1998; Select Sand 2019). It is worth mentioning that the SiO_2% in the previously used sand from the Iraqi Western Desert, Erdhuma quarry ranges from 96 to 99.9%.

Normally, the used amount of the silica-sand in cement production ranges from 17 to 25% (Table 2 in Duggal 1998). In some of cement plants at Bazian district, the used chert–claystone deposit ranges from 2.5 to 3.3 ton/ 10 tons of raw mix (limestone and claystone). The used amount depends on the type of

Table 5 Weighted averages of Al_2O_3 and Fe_2O_3 in the claystone samples of Sharbazhar Quarry

Sample no.	Thick. (m)	Rock type	Al_2O_3		Fe_2O_3	
			Concen. (%)	W. A. (%)	Concen. (%)	W. A. (%)
1	10	Claystone	4.5	45.00	4.1	41.00
2	8	Chert	2.09	16.72	1.85	14.80
3	5	Claystone	6.62	33.10	3.15	15.75
4	5	Chert	1.82	9.10	ND	0.00
5	8	Claystone	5.58	44.64	2.48	19.84
6	3	Chert	4.85	14.55	3.49	10.47
7	18	Claystone	7.91	142.38	4.47	80.46
8	8	Claystone	8.64	69.12	5.51	44.08
9	2	Claystone	4.89	9.78	2.00	4.00
10	4	Chert	0	0.00	0.43	1.72
11	7	Claystone	7.49	52.43	4.83	33.81
12	5	Claystone	6.44	32.20	4.13	20.65
13	7	Claystone	4.25	29.75	3.54	24.78
14	14	Claystone	7.23	101.22	5.24	73.36
15	3	Chert	0	0.00	0.45	1.35
16	4	Clayey limestone	2.34	9.36	1.64	6.56
Total	23	Chert	Weighted average (%)	1.75		1.23
	88	Claystone		6.92		4.14
Weighted average (%) according to 3:2 ratio				4.85		2.98

Table 6 Chemical composition of four cement samples collected from a cement plant

Production date	Sample number	L.O.I.	SiO_2	AL_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	CL^{-1}	Total
06/03/2019	SS-012719 -3	3.78	20.32	4.25	2.05	66.58	0.61	0.00	0.15	0.10	0.011	99.85
22/06/2019	SS-061719 -1	3.00	20.90	3.87	2.06	66.51	2.73	0.15	0.40	0.15	0.016	99.79
01/07/2019	SS-061919 -2	3.73	22.78	6.31	2.67	61.37	1.67	0.18	0.43	0.14	0.015	99.50
10/07/2019	SS-070419 -1	3.84	20.80	5.32	3.12	62.65	2.85	0.20	0.50	0.20	0.022	99.50

the used raw mix. This means the used silica amount by those cement plants ranges from 25 to 33%, which is higher than the normal used amounts (Table 2). This is attributed to the low SiO_2 content (83.37%) in the Sharbazhar deposit (Table 4) as compared to the normal silica-sand in which the SiO_2 content ranges from 96 to 99%. Which means the low SiO_2 percentage in the used chert–claystone deposit is substituted by adding more chert and claystone deposit to the raw mix. However, this will increase the Fe_2O_3 percentage in the raw mix which is calculated as follows:

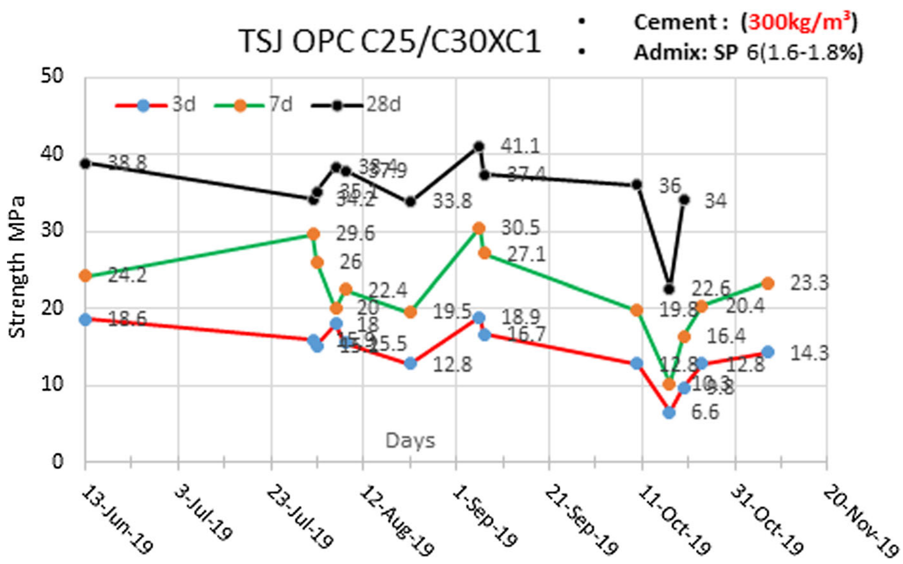

Fig. 8 Compressive strength test results of concrete tests from a cement plant at Bazian district, Sulaimaniyah, Kurdistan Region

$$3\text{shares of claystone} \times 4.14\% + 2\text{shares of chert} \times 1.23\% = 12.42 + 2.46 = 14.88\%.$$

Therefore, the weighted average for the used Fe_2O_3 (Table 5) will be: 14.88% ÷ 5 shares (3 claystone + 2 chert) = 2.98%, which will be not suitable for Portland cement production.

The used Al_2O_3 percentage (Table 5) in the raw mix is calculated as follows:

$$3\text{ shares of claystone} \times 6.92\% + 2\text{ shares of chert} \times 1.75\% = 20.76 + 3.50 = 24.26\%.$$

Therefore, the weighted average for the used Al_2O_3 will be: 24.26% ÷ 5 shares (3 of claystone + 2 of chert) = 4.85%, which will be suitable for cement production (Table 2).

The weighted averages of the used chert–claystone deposit in the three parts of the Sharbazhar quarry (Fig. 2) are different (Table 4). The best weighted average of SiO_2 is in the Middle part; therefore, the middle part is more quarried, and the deposit is almost exhausted (Fig. 2).

Although the used chert–claystone deposit of the Qulqula Group includes less SiO_2 and more Fe_2O_3 than those specified standards (Table 2), some of the cement plants at Bazian district are still using the deposit; successfully. This is attributed to the suspension of the supply of silica-sand from the Erdhuma quarry in the Iraqi Western Desert after 2003 and the low price of the chert–claystone deposit from the Sharbazhar Quarry. The price of the chert–claystone deposit supplied to the cement plants in the Bazian district is about $13 USD/ton, whereas, the price of the silica-sand of Erdhuma quarry was $22 USD/ton supplied at the quarry (loaded on trucks).

To confirm the results of this research, an analysis was performed on four (4) samples collected from Portland cement produced at one of the cement plants in Sulaimaniyah, Bazian District, Iraqi Kurdistan Region to verify the quality of the cement produced. This plant is ISO certified. These samples were chemically analyzed (XRF). The results are shown in Table 6 and coincide with the chemical composition of the Portland Cement as shown in Table 2 (Duggal 1998) and with the chemical composition mentioned by Civil Engineering Home (2019).

Moreover, the results of concrete tests (cubic samples) were acquired from a cement plants which use the same deposit of Sharbazhar Quarry in producing Portland Cement (Fig. 8). At each test, three samples were used with three different curing times (3, 7 and 28 days).

Referring to Fig. 8, samples cured for 28 days had the highest compressive strength, which is a normal case. However, some defects have occurred in some time intervals, especially on the tests performed on

16th of October, where the compressive strength decreased instead of increasing. According to the manufacturer, these ambiguous results are most probably due to the different materials used in the concrete and not the Portland cement produced (i.e., the aggregate).

6 Conclusions and Recommendations

From the current study, the following can be concluded. Cement plants in the Bazian district (ISO Certified) of the Sulaimaniyah Governorate in the Iraqi Kurdistan Region are using the chert–claystone from the Sharbazhar Quarry as an alternative to silica-sand which was previously supplied from the Iraqi Western Desert. The SiO_2 weighted average in chert beds is 95.81%, whereas in claystone beds is only 75.08%. If the chert–claystone deposit is used and mixed in a 3:2 (claystone:chert) ratio, the weighted average is 83.37%, which is less than the normal standards for cement production. Some of cement plants in the Bazian district are using additional amounts (2.5–3.3 ton/10 ton) of material (e.g., limestone and claystone) in the raw-mix to offset the SiO_2 deficiency. Unfortunately, this increases the amount of Fe_2O_3 in the cement which will be inconsistent with industrial standards for Portland cement production.

Since the lithology of the Qulqula Group is almost similar along its exposures; therefore, it is recommended that the location of the quarry be changed to a place which is closer to the exposures of the Qulqula Group along the road east of town of Chwarta ($\sim$ 50 km east of Bazian district). This will also decrease the transportation cost and potential damage to the road which may be caused by heavy trucks.

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