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Introducing Mesozoic siliciclastic-rich refractory sand levels based on geochemical and physical properties in Iran

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Abstract

This research work introduces the Early Triassic, Late Triassic-Early Jurassic, and Early Cretaceous silica-rich sand levels at east and central Alborz, Kopeh-Dagh, and Central Iran, and compares them with the Permian silica-rich sand level in the Chirouk mine at east Iran. Ghoznavi and Gheshlaq loose sand in Alborz (Early Triassic-Early Jurassic), Soh quartzite in Central Iran (Early Triassic-Early Jurassic), Firuzeh sands with mud levels in Kopeh-Dagh (Early Cretaceous), and Sarnaza in Central Alborz (Late Triassic-Early Jurassic) silica-rich levels are studied in this work. Geochemical analysis and physical factors of the studied silica levels are checked regarding grain size, heat resistance, and steel molding. The laboratory and industrial methods used for washing, sieving, heating, molding, and controlling the purity of refractory sand levels show that the main difficulty of these levels within the molding process is intra-grain cracks, which spoils the alloy's final product. The Early Triassic level in the Ghoznavi area has a high purity but the average grain size is below the steel molding standard. The Late Triassic to Early Jurassic levels in Alborz and Central Iran are oversize with grain cracks but can be fixed by the industrial refinery methods. The size of Early Cretaceous refractory sands of Firuzeh (Kopeh-Dagh) is below the standard molding process; it can be fixed by the washing and refinery methods. The systematic exploration methods show that all the studied silica-rich sand levels have an intra-grain collapse within the molding process. Final test shows that the Chirouk silica-rich levels can be used as refractory sand for cast and molding in the steel industry.

Keywords: *Mesozoic Refractory Sand, Heat Resistance, Grain Size, Iran.*

1. Introduction

The human population is highly increasing and requires mechanical and industrial tools. The demand for building materials and steel accessories has led to use more refractory sands such as silica, olivine, garnet, zircon, and alumina in foundry industry for making molds since the last century. The term "sand" is applied to loose granular materials falling within a specified particle size range. Silica or quartz sand, also known as industrial sand, is natural or processed sand for several applications [1]. Natural silica sands refer to granular materials composed primarily of quartz with minor amounts of other minerals or organic constituents such as feldspar, iron oxides, micas, clay minerals, and coal [2]. Silica sand is an essential raw material in many industries, and is used in glass-making, ceramic, metal casting, water filtration, sand-blaster, grinding and polishing, millstone and mortar, high voltage electricity, pavement, and railroad ballast [2, 3]. The quality of the products depends upon the physical and chemical characteristics like size, shape, density, chemical composition, fusion temperature, and reactivity nature of molding sand particles. The first points that should be under consideration regarding the refractory sand exploration are purity and grain resistance. Another point is the low grade of heat-shock during the alloy molding process [4]. The last point is the percentage of grain size (315 μ in diameter of total package) that should be more than 70%. In fact, this average can lead to a better product after the molding process [5]. Heat shock is the main point in the molding process, while sand grains have a low resistance rate due to the sedimentation condition; the porosity rate increases as a result of crushing down during the molding time. Blowholes are a technical point that spoils alloy production after molding. In order to decrease the blowhole or have a better product, there should be a better porosity and low ratio of inter-grain collapse during the molding process [5, 6].

Silica sand levels can be traced in continental and near shore deposits in different ages such as Michigan (North America), India, and Saudi Arabia sand deposits [7]. Silica sand resources in America are classified into inland dunes, old beach, glacial, and friable sandstone deposits [2], while grain size, optical characteristics, and impurities such as Fe and Cr are used for classification of silica sands in Saudi Arabia [7]. Conducting the manufacturing material assessment requires the geological data. This research work deals with the exploration and technical properties of excavated anomalies (silica sand levels) in the Mesozoic time interval of Iran (Figure 1).

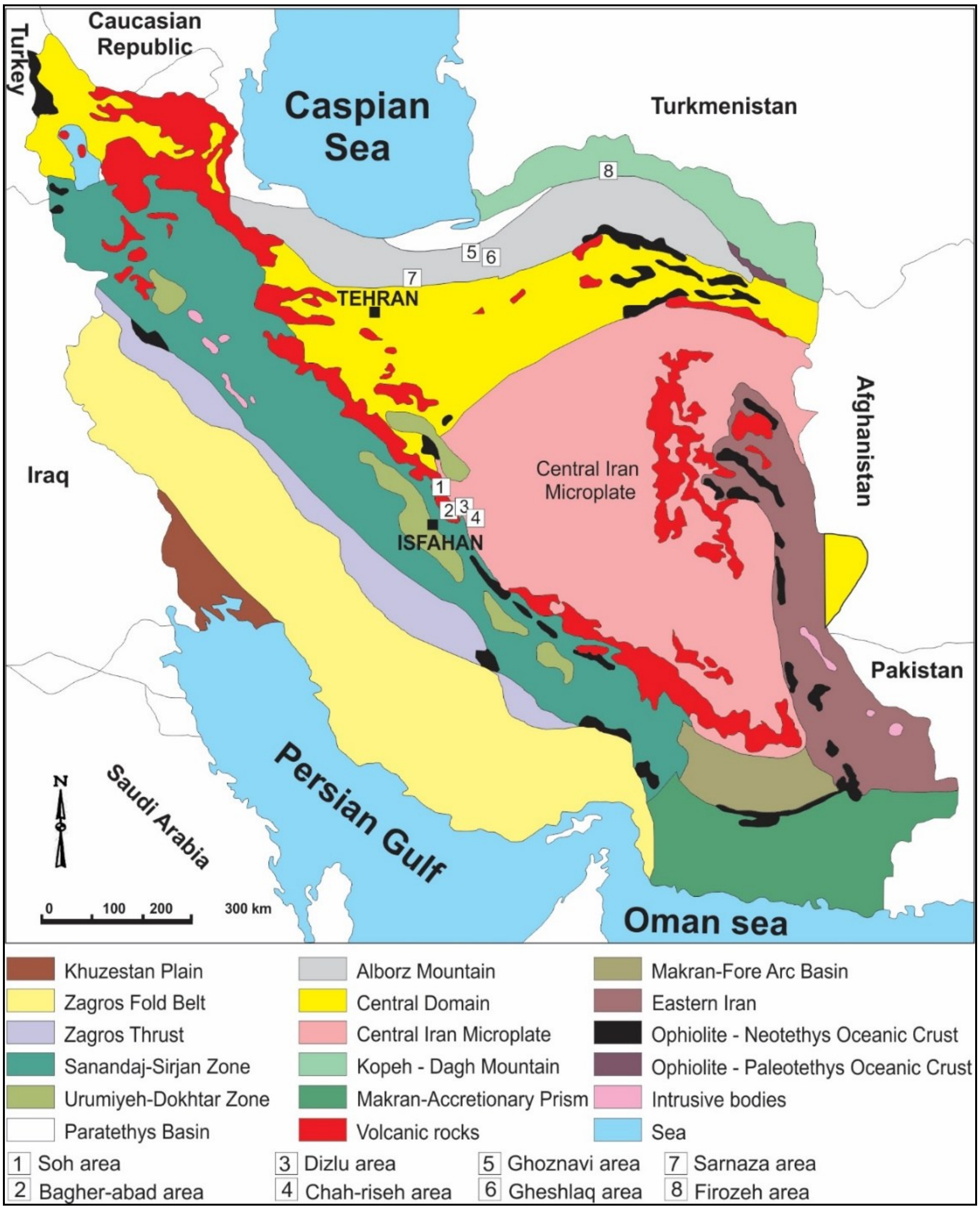

Figure 1. Structural units of Iran [8] and the studied localities (positions 1 to 8).

2. Methods and materials

This investigation utilized the same samples from a National Iranian Steel Company project that were studied by [9, 10]. Some parts of the final results' sampling and controlling have been done recently at the University of Isfahan. Size fraction and sieving were done before and after washing (Figure 4). As a whole, more than 200 thin sections and handy samples were prepared and studied for determination of grain size, texture, and composition of sand levels. In 50 samples, the major elements and L.O.I were measured by the XRF method in National Iranian Steel Company (Table 1). 20 tons of sandy materials were collected from each sand level for measuring the heat resistant, porosity, and molding purpose, and semi-industrial tests were done on them in the Isfahan Steel Company (Melting and Molding Factory). Final industrial tests were done on 100 tons of samples that were collected from two levels (Firuzeh, Early Cretaceous) and Chirouk area (base of Permian System, not described in details in this research work). Systematic exploration was also completed on the Early Permian silica-rich levels in several localities of Iran [9]. Early Permian transgressive silica-rich levels in Chirouk Mine were checked by three tests: first, geological systematic tests regarding purity and grain resistance under pressure and heat; a semi-industrial test was carried out by 10 tons of this level average; and an industrial test was done by the total average of the levels (100 tons) in Isfahan Steel Company, located in Zarrin Shahr (Table 1).

3. Geological setting

Siliciclastic and continental deposits during the Mesozoic (Early Triassic, Late Triassic-Early Jurassic, and Early Cretaceous) are scattered along the north and central part of Iran. Their most distinctive lithological components are silica sand and silica grained levels together with coal deposits or quartz-rich grained sequences that were considered in this research work.

The Elika Formation was described as an Early Triassic unit, dominantly composed of red-colored marginal marine succession in Alborz Mountains; it can be correlated with the Sorkh Shale Formation in the East Central Iran. The Elika Formation consists mainly of carbonates, sandstones, and evaporates, with shale as a minor constituent. These levels are believed to be deposited in a low energy, storm-dominated inner-ramp setting [11].

Outcrops of Late Triassic–Early Jurassic siliciclastic, up to 4,000 m thickness, are widespread across the Iranian plate, especially in the northern and Central Iran. This unit is termed as the "Shemshak Formation" on the geologic maps. During the Late Aalenian–Early Bajocian, the basin was infilled by a large delta system. Rough estimations of subsidence rates give an average value of 126 m/Ma; the subsidence rate increases toward the Early Bajocian. These high subsidence rates suggest that the Shemshak Formation deposits in the Alborz Basin were formed in a rift basin [12].

The Shurijeh Formation is cropped out in the Kopeh-Dagh basin is Early Cretaceous in age, and mainly consists of sandstone deposits. This unit is originally deposited in the craton interior and recycled orogenic belt. The geochemical investigations suggest that the composition of probable source rocks mostly has been acidic-intermediate with minor mafic igneous rocks. Remnants of Paleo-Tethys and collisional orogeny (e.g. Mashhad granite and its equivalents in the south and west of Mashhad area) may have been the source-area for these rocks [13, 14].

4. Outcrops of Mesozoic siliciclastic rocks in North and Central Iran

4.1. Early Triassic

Triassic sequences are the first silica sand-bearing levels that were served as examples. Geology of the Eastern Alborz was first published by [15]. [16 and 17] reported Asteroids fossil (Ophiuridae) or *Palaeocoma iranica* from the base of the Ghoznavi section (Figure 2i). Stratigraphy of Triassic in Iran was published by [18 and 8]. Silica-bearing loose layers of the Elika Formation (first measured by [19] from the Ghoznavi section, Figures 2b and 2c) with the Early Triassic age were collected for geochemical and technical factors by [9]. He systematically explored and sampled this bed.

The geochemical and physical results of this sampling (4 samples, each sample about 10 Kg) are provided in Table 1. Similar to this Early Triassic level in the north of Iran (the Ghoznavi section) can be traced in the Central Iran such as the Bagher Abad, Chahriseh, and Dizlu areas at the northern Isfahan and the Soh area at the NE Isfahan, although Early Triassic silica sand level in these localities was not loose and changed into consolidated quartzite. The geology of these areas was reported by several researchers [e.g. 20-29]. In the Soh area (Figures 2e and 2f), a quartzite level (almost 5 m in thickness) can be traced in the Permian/Triassic Boundary (almost 20 m above the bauxite level) [28]. Thin sections of this level are similar to the Ghoznavi section (north of Iran) regarding the grain size and purity. The geochemical analysis of this level (a selective sample through thickness) is reported in Table 1.

This quartzite level in the Soh area (Nachaft Valley) shows approximately the same geochemical analysis regardless of Al_2O_3 and SO_3 of the Early Triassic silica sand in the Ghoznavi section (see Table 1). The purity of raw materials (for example, high silica content) is essential with the least possible Al_2O_3. The presence of Al_2O_3 lowers the refractoriness of silica [30]. Regarding the molding usage of these levels, both Ghoznavi loose sand and Soh quartzite levels cannot be used for iron molding due to very fine-grained components and high content of Al_2O_3. They are very good for colored alloy molding, ceramic, grinding stone, and cement industries. Intra-grain collapse within the molding process is due to grain cracks.

Table 1. Geochemical analysis of silica sand (average of several samples) in studied areas. Contents are given in percent. All samples are from Mesozoic except for Chirouk Mine, which is Early Permian in age.

Oxides / Locality	SiO_2	Fe_2O_3	TiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.O.I
North of Iran										
Ghoznavi-188	96.18	0.13	0.07	0.44	1.35	0.02	-	-	0.01	1.30
Ghoznavi-189	97.90	0.07	0.04	0.42	0.43	0.02	-	-	0.01	0.61
Ghoznavi-191	98.00	0.05		0.27	0.78	0.03	-	-	-	0.69
Ghoznavi-100	98.84	0.13	0.09	0.29	0.18	0.13	0.02	0.08	-	0.19
Gheshlagh-166	93.04	0.21	-	0.17	0.11	0.03	-	-	-	1.34
Gheshlagh-167	92.90	1.12	-	0.17	0.02	0.11	-	-	-	1.17
Sarnaza Mine	91.85	0.48	0.33		1.80		-	-	-	3.62
Firuzeh-101	95.98	0.40	0.19	1.40	0.07	0.15	0.03	0.31	-	0.35
Firuzeh-102	94.60	0.44	0.22	1.91	0.55	0.05	-	-	0.06	1.11
Central Iran										
Soh area	91.84	0.69	0.15	3.74	0.15	0.12	0.19	0.71	1.30	0.84
Chirouk Mine	96.7	0.40	0.20	0.7	1.00	0.10	0.04	0.10	0.08	0.80

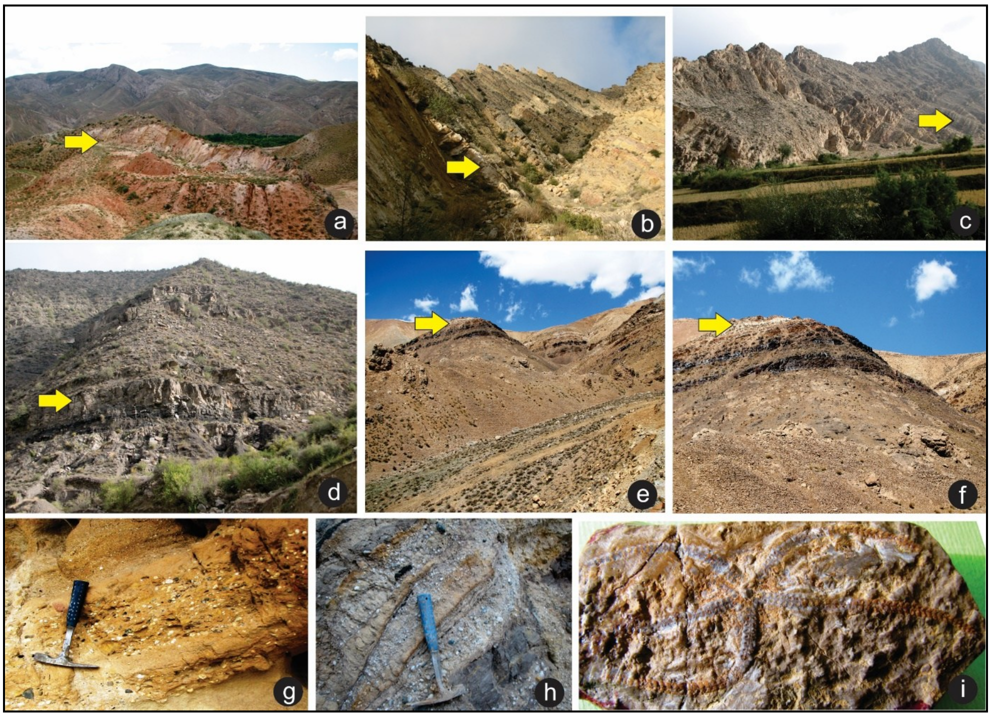

Figure 2. Field photos of studied localities: (a, g) Early Cretaceous Shorijeh Formation (Firuzeh area-Southern Bojnourd, Kopeh-dagh); (b, c, i) Early Triassic silica-rich level, Ghoznavi area, Eastern Alborz (b, c) and Asteroids fossil (Ophiuridae), *Palaeocoma iranica* (7×4 cm) from base of the Elika Formation, Ghoznavi area (i); (d, h) Late Triassic to early Jurassic silica-rich levels, Vatan Bridge, Gheshlagh area (d), base of Jurassic silica-rich level, Farsiayan (Gheshlagh) area (h); (e, f) Early Triassic quartzite level equal to Ghoznavi level (Soh area, Nachaft Valley, NE Isfahan).

4.2. Late Triassic-Early Jurassic

Late Triassic-Early Jurassic time interval (the Shemshak Formation) in Iran has some silica-rich levels. These levels as continental sediments are associated with coal-bearing levels. [31] reported Jurassic silica-rich continental deposits (the Shemshak Formation) in Central Alborz. [32] reported the general geology of Eastern Alborz (Gonbad-e-Qabus). [33] studied the Shemshak Formation in Alborz range. [34] studied coal deposits of this time interval in Iran regarding the stratigraphy and paleogeography of silica-rich levels. The Shemshak Formation was studied by [35] in the northern part of Iran. The silica-rich levels in Alborz and Central Iran can be traced in the Gheshlagh (Figures 2d and 2h) (Eastern Alborz), Zirab and Firouz-kuh (Central Alborz), Sangrud (Western Alborz), and Soh (Central Iran) areas. In Sarnaza Mine (Firouz-Kuh), these silica-rich levels were excavated for molding sand; the mined levels in this area were processed by silica refractory sand factory, near Garmsar. The grain size of these levels varies to centimeters. The geochemical and physical results of the total average of this level are from [36]. The technical points related to this area will be discussed in the technical part regarding grain resistance. The Silica-rich levels can be seen in the Soh area as well. Late Triassic to Early Jurassic silica levels are suitable for refractory sand molding.

4.3. Early Cretaceous

Early Cretaceous transgressive sequences are the last levels that were studied in this research work regarding the silica-rich levels. Early Cretaceous sandstone of the Shurijeh Formation is exposed in the NE of Iran, close to Firuzeh Village (south Bujnurd, Figures 2a and 2g). This Formation was firstly reported by [37]. [9] performed a systematic exploration on the silica-rich levels in Firuzeh Village. The purity of this area is good but the technical point is that the average of total sand grain diameters is fewer than the standard size (315 μ) for molding purposes. In other words, the grain with an average size of 315 μ is fewer than 5% (Figure 2). This average should be more than 75% for a standard molding sand. Another point of this area is the percentage of calcium carbonate that in some levels is up to 3% (in the shape of nodules), which needs more acid consumption. More details are declared in the technical part. Our studies show that the Early Cretaceous sand levels are suitable for colored alloy molding, ceramic industry, sand blasting, and cement industry.

5. Discussion and technical points

For high technology purposes, silica sand known as refractory or molding sand should have a high heat and pressure resistance related to grains, high purity (more than 95% SiO_2), well-rounded grains and average grain (it is better to be more than 70% in the diameter, of 315 μ in total) ([2] and several internal technical reports, National Iranian Steel Company). The geochemical analysis, grain size, and physical properties of the studied samples are in Table 1 and Figure 4.

5.1. Sand size distribution

Size fractionation is done before and after washing (Figure 4). The washing process can involve three to four cycles to ensure that the sand has an exceptionally low turbidity and is free from clay and fine particles and unwanted salts with an acceptable pH value. Here, we used metric sized sieves (μ) to determine the sand size distribution. The intended size sieves are assembled and placed in a vibratory jig. The sand sediments that are retained on each sieve is weighed and tabulated, and the weight percent of each size is calculated (Figure 4). Most of the studied samples show two pics in 180 and 300 μ before and after washing. Washing causes increasing the frequency (%) of size fractions in 180 μ except in the Ghoznavi area. In all samples, increase in frequency (%) occurs as a result of washing at about 300 μ, except for the Chirouk mine samples. The most increase in frequency (30%) as a result of washing occurs in the Firuzeh samples at around 180 μ.

5.2. Chemical and thermo-physical properties

Silica sand is used predominantly due to its chemical purity and advantageous thermal properties. It is resistant to molten steel and iron, and its hardness is high. Silica has a high melting point (above 1690 ˚C), although this dramatically decreases by fluxing some agents such as calcium, sodium, potassium, and iron. These elements can intensively lower the sintering point of silica from 1700 ˚C to less than 1200 ˚C. Deleterious agents such as lime not only raise the pH of the sand but also increase the acid demand values.

The molding process should lead to no blowholes in the final product. This point can be achieved by highly controlled processes from mining to the molding process (factory). Studying the grain shape and size, purity, and physical properties of the studied silica-rich sand-bearing formations in

Iran, it can be concluded that the Shemshak Formation silica-rich levels are suitable for molding industry. However, there are some technical points that should be considered in the molding process. Since the grains of silica-rich levels of the Shemshak Formation were cracked after the depositional process (Figures 3b and 3f), this technical point cause intra-grain collapse within the molding process. This collapse leads to decrease intra-space, and consequently, less gas losing within the molding process. Finally, the grain-crack leads to more blowholes and more spoiled alloys in the final steel products.

Figure 3. Silica pebbles, (a) Early Cretaceous Shurijeh Formation in Firuzeh area (7×4 cm); (b, f) Silica rich sandstone, Late Triassic-Early Jurassic (9×5 cm) with grain cracks (Gheshlagh area, Eastern Alborz), (c) Late Triassic-Early Jurassic (9×5 cm) with grain cracks (Sarnaza area, Central Alborz); (d) A part of Early Triassic Ghoznavi silica-rich level (2.5×2 cm), (e) Microscopic photo of sand grains of Ghoznavi area (2×2 mm); (g) microscopic photo (thin section) of Early Triassic quartzite, Soh area, Nachaft section (×40, XPL); (h) microscopic photo (thin section) of Early Triassic loose sand, Ghoznavi area (×100, XPL); (i) microscopic photo (thin section, PPL) of Early Triassic loose sand, Ghoznavi area (×100, PPL).

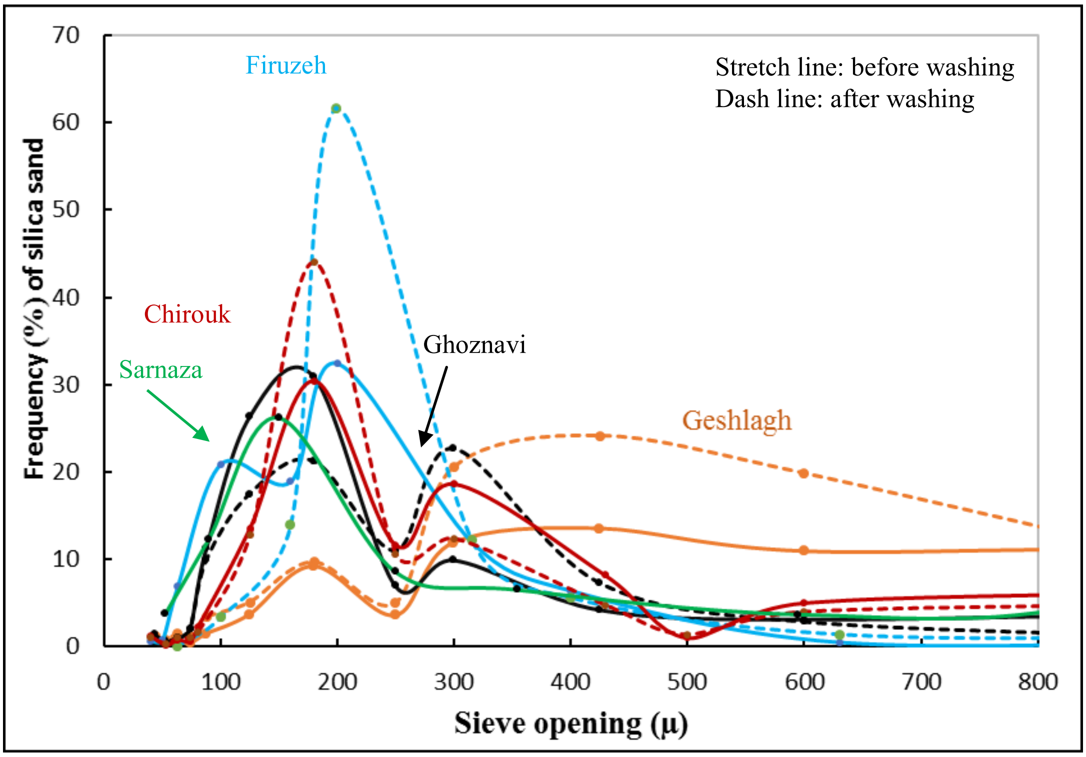

Figure 4. Grain size (fineness) specifications of silica sand from studied areas.

6. Conclusions

Geochemical and physical laboratory analysis of the Mesozoic silica sand-rich levels of Iran revealed that the Elika Formation of Early Triassic has a rich, pure, and fine grain silica sand in the Ghoznavi and Soh areas. This level has a more loose content in north Iran (Ghoznavi area), and changes into quartzitic sandstone in Central Iran (Soh area). They are useful for colored alloy molding, ceramic, grinding stone, and cement industries. Intra-grain collapse within molding process is due to grain cracks.

Late Triassic to Early Jurassic Shemshak Formation has silica sand-bearing levels both in the Alborz (Gheshlaq and Sarnaza) and Central Iran (Soh) areas. Sand grains of this time interval were cracked, which led to the production of more blowholes and final spoiling alloys in the molding process (collapsing within heat process).

The Cretaceous silica levels of the Shurijeh Formation in Kopeh-Dagh (Firuzeh area) are not suitable for use in the molding process as a result of the small size of grain and high content of Al_2O_3 and CaO. Intra-grain collapse within the molding process due to grain cracks in Triassic, Late Triassic to Early Jurassic, and Cretaceous silica-rich levels decrease them beneficially in the molding processes.

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معرفی افق‌های قاره‌ای ماسه نسوز غنی از سیلیس ایران بر اساس ویژگی‌های زمین‌شیمیایی و فیزیکی

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چکیده:

این کار پژوهشی، افق‌های ماسه‌ی سیلیسی تریاس زیرین، تریاس بالایی- ژوراسیک زیرین و کرتاسه زیرین را در البرز مرکزی و شرقی، کپه داغ و ایران مرکزی معرفی و آن‌ها را با افق ماسه‌ی سیلیسی پرمین در معدن چیروک طبس در شرق ایران مقایسه می‌کند. ماسه سست قشلاق و غزنوی در البرز (تریاس زیرین- ژوراسیک زیرین)، کوارتزیت سه در ایران مرکزی (تریاس زیرین- ژوراسیک زیرین)، ماسه‌های فیروزه با افق‌های گلی در کپه داغ (کرتاسه زیرین) و افق‌های سیلیسی البرز مرکزی در سرنزا (تریاس بالایی- ژوراسیک زیرین) در این پژوهش مطالعه شده است. تجزیه‌های زمین‌شیمیایی و فاکتورهای فیزیکی در افق‌های سیلیکای مطالعه شده، در ارتباط با اندازه دانه، مقاومت گرمایی و قالب‌گیری فولاد بررسی شده است. روش‌های آزمایشگاهی و صنعتی استفاده شده برای شستشو، الک، گرما، قالب‌گیری و کنترل خلوص افق‌های ماسه نسوز حاکی از آن است که مشکل اصلی این افق‌ها درون مراحل قالب‌گیری، شکاف‌های بین دانه‌ای است که محصول نهایی آلیاژ را از بین می‌برد. افق تریاس زیرین در ناحیه غزنوی خلوص بالایی دارد اما میانگین اندازه دانه آن کمتر از اندازه استاندارد مورد نیاز برای قالب‌گیری فولاد است. افق‌های تریاس بالایی تا ژوراسیک زیرین در البرز و ایران مرکزی بزرگ‌تر از شکاف‌های دانه هست اما می‌تواند توسط روش‌های پالایشی صنعتی اصلاح شود. اندازه ماسه‌های نسوز کرتاسه زیرین فیروزه (کپه داغ) کمتر از مراحل قالب‌گیری فولاد است که می‌تواند توسط روش‌های شستشو و پالایشی درست شود. روش‌های اکتشاف سیستماتیک نشان می‌دهد که همه افق‌های ماسه پر سیلیس مطالعه شده یک متلاشی شدن درون دانه‌ای درون قالب ریخته‌گری دارند. آزمایش نهایی نشان می‌دهد که افق‌های پر سیلیس چیروک به خاطر هزینه و قالب‌گیری، به عنوان ماسه نسوز می‌توانند در صنعت فولاد استفاده شوند.

کلمات کلیدی: ماسه نسوز مزوزوئیک، مقاومت گرمایی، اندازه دانه، ایران.