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Suitability of quartz sands for different industrial applications

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Abstract

Quartz is found in the nature in varying purity and is traded in varying quality for different industrial applications. It can be used either for high added value applications such as silicon-metal wafers , optical glass or PV panels or for more ordinary applications such as foundry sand for metal castings or as a filler for adhesives and grouts. Extended exploration work in area of central Macedonia , resulted in the identification of medium purity quartz river deposits. Preliminary laboratory tests verified the suitability of these quartz sands to be used as filler materials for making adhesives and grouts.

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***Kewwords*:** quartz sand , silica sand, ortical glass, foundry sand, filler for adhesives

1. Introduction

Sand is used in a great variety of products and the term “quartz sand is used for the essential raw material for the glass and foundry casting industries, as well as in other industries such as ceramics and chemical manufacture and for water filtration purposes” according to BGS Mineral Planning Factsheet (September 2009). The significance of the end use rather than the nature of the sand in the ground is recognized by the British Geological Survey (BGS) which has defined quartz sand as “sand used for applications other than construction aggregates and which are valued for their physical and chemical properties”.

According to N.R. Shaffer (2006) quartz sand is the final product of rock weathering *which* is an important part of the rock cycle. The weathering of any quartz-bearing rock creates sand: igneous, sedimentary, or metamorphic. It is involved in a continuous cycle of rock formation and erosion that started with the Earth’s formation and continues today. Weathered grains become separated from inter-grown or cemented minerals that make up hard rocks. Grains are transported mainly by water and as they travel, weaker minerals are removed and resistant grains become smaller in size, become more rounded in shape, and their surfaces are

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modified by constant abrasion or chemical attack. The longer times that grains travel the more mature they become. Many sand grains are very well rounded indicating several cycles of deposition and transport. Scientists study mineral compositions, grain size distribution, measures of grain roundness, statistics of particle sorting and other details to unfold a sediment's history . Very mature sands make the most chemically pure, most ideally round, and best sorted sand deposits. Silica sand deposits are usually mature or super-mature. Super mature sands often are more than 95% quartz with some natural deposits containing 98% quartz. These high-purity sands have numerous economic applications and are required for glass manufacture.

The suitability of quartz sand for different industrial applications is determined by the quality of the sand in terms of :

- Grain size distribution. Normally unprocessed sand may be suitable for a limited range of applications. Washing and sizing increases considerably the possible product range.
- Chemical analysis. The grade is determined by the impurities content of the quartz sand in the ground.
- Color. Very low iron content results in naturally white quartz sands which are preferred for some industrial applications.

A research initiative was undertaken in 2013 by the Institute of Technology of West Macedonia with the following aims :

- To establish the chemical and physical properties that are required for the different industrial applications of quartz sand.
- To determine whether sands in the area of Central Macedonia traditionally worked as building sands display these properties.

2. Specifications

There is a number of requirements which quartz sand deposits must meet to be considered as potential sources for different industrial applications. The most stringer chemical specifications are for the chemical and glass industries. The initial iron content of the quartz sand must be approximately 0,13% Fe_2O_3. At the next step the sand is washed, sized and the iron content is further reduced by magnetic separation or froth flotation. On the other hand , quartz sand for water filtration, aerated concrete and the foundry industries have higher minimum specifications for iron. Grouts, paints and fillers require a white sand to give a consistent color and high brightness.

2.1 Specifications of quartz sand for optical glass

The optical glass is used in cameras, optical instruments, microscopes, and in optical fibres for telecommunications . In general, the specifications of the raw materials depend on the glass produced and the purity level of quartz sands is dominated by the iron content. The British Standard BS2975 includes recommended limits for the composition and of quartz sand for seven different grades of glass (Table 1). Aluminum , magnesium, calcium and potassium levels affect the melting properties and have to be kept at low levels. Additionally titanium and chromium minerals may melt if fine enough and will color the glass.

Grade	Product	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	Cr_2O_3 %
A	Optical glass	99,7	0,013	0,2	0,00015
B	Tableware glass	99,6	0,01	0,2	0,0002
C	Borosilicate glass	99,6	0,01	0,2	0,0002
D	Colourless container	98,8	0,03	0,1	0,0005
E	Flat glass	99,0	0,1	0,5	-
F	Coloured container	97,0	0,25	0,1	-
G	Insulating fibres	94,5	0,3	3,0	-

Table 1 : The seven specified grades of glass according to BS2975 for optical glass

Grain size and grading is another very important requirement by the glass manufacturers. Finer grains are more likely to carry iron oxide and refractory mineral grains, while larger grains will melt slower than smaller grains and will remain un-melted causing inclusions in the final product. A typical grading of quartz sands for optical glass is shown in Figure 1.

2.2 Specifications of quartz sand for metal castings

Large tonnages of quartz sand are used to make moulds and cores for metal castings in iron and steel foundries. The heat resistant nature of quartz (melting point = 1.710 ^{0} C) makes quartz sand an excellent refractory substance for a number of industrial processes. The ideal molding sand has been described as “a sand consisting of uniform-sized rounded grains of quartz, each grain evenly coated with the thinnest necessary layer of the most refractory and fattest clay” (Moldenke, 1930).

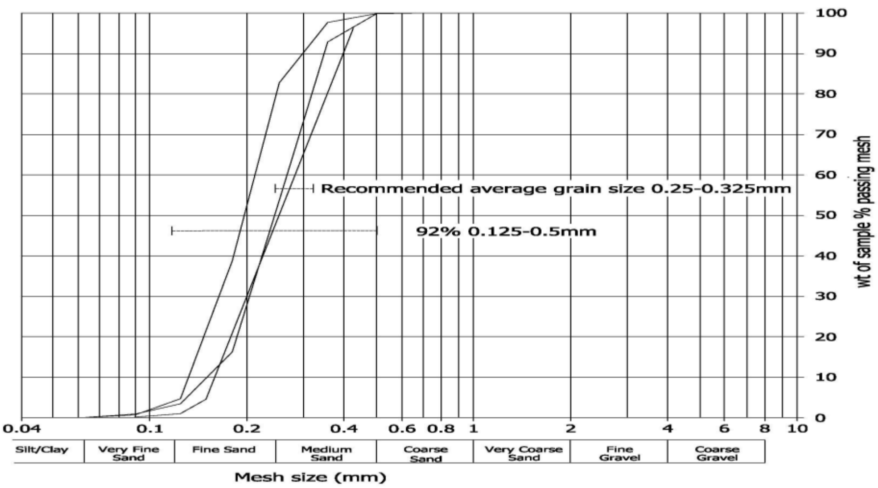

Figure1. : *Typical grading curves for processed glass quartz sand*

The quality of castings produced depends largely upon the properties of the quartz sand utilized. A foundry mold must have the ability to withstand the high temperature of molten metal without damaging the contact surface between metal and sand. To ensure high quality castings the quartz sand must satisfy specifications such as permeability, grain fineness, moisture, bond strength and refractoriness.

2.3 Specifications of quartz sand for adhesives, grouts, fillers and extenders

Quartz sand in its finest forms , as micro-silica, flour or precipitated finds application in reinforcement filler and extender applications. Here the particle size and surface area of the quartz sand are two of its most important attributes. The quartz sand has to conform to a closely specified granulometry and to be free from particles of clay or schist, furthermore not more than 30% of the sand can be of limestone particles.

As a filler and extender in paint formulations quartz sand in the form of flour or tripoli serves to render the paint more resistant to chemicals because of its acid resistance and because of its hardness, scrubbing and wear resistance of surface films are also enhanced. The addition of quartz improves also durability and flow ability of the paint.

Additionally, quartz sand in these ultra fine particle sizes finds extensive applications in both silicone and industrial rubber where they are incorporated for their reinforcement qualities. In tire linings quartz sand offers superior adhesion, tear resistance and heat aging properties.

3. Results and discussion

Regional scale exploration was carried out in the rivers of central Macedonia in order to find quartz sand occurrences to cover most of the geologically favorable areas. Six major rivers drain central Macedonia: river Nestos which springs in Bulgarian territory and extends 143 km length in Greek territory, river Strymonas which also originates in Bulgaria and extends 120 km length in Greek territory, Gallikos river which springs from Fyrom and has a length of 73 Km , Axios river which springs in Yugoslavia and extends to 82 km and Loudias and Aliakmonas rivers both springing from Grammos mountain range and extending to 314 km. Shorter rivers like Aggitis, also drain among these six main rivers. All the rivers carry large amounts of bed load sediments and have gravelly braided beds. The principal geological features of the rivers consist of the Quaternary and Neogene sediments. The Quaternary sediments are divided into Holocene and Pleistocene aged sediments. The Holocene sediments consist of fine-grained sands, clays and conglomerate sands. The Pleistocene sediments have a thickness of approximately 100 meters and consist of limestone breccias, red clays and cones of trench deposits (Veranis, N. 2011)

Because quality of the quartz deposit is more significant at first approach than the size of the deposit, the first step in each case was bench scale quality testing. Representative sampling and quality characterization of quartz resulted to prospect evaluation and discovery of new deposits. Sixteen representative samples of quartz samples were collected from the area of central Macedonia mainly from the basins of the rivers. After splitting into fractions, each sample was analyzed by means of X-ray diffractometry (XRD), scanning electron microscopy (SEM) and inductively coupled plasma spectroscopy (ICPS). The mineralogical analysis was carried out by using a Siemens D-5005 X-ray powder diffractometer, with copper radiation and graphite mono chromatographer . The mineralogical phases were determined by computer using THERMOCALC software. Microprobe analysis, grain size distribution and the mineral chemistry of the quartz sample were determined by SEM using a JEOL JSM-7600.

The Nestos river

Nestos river springs from Rila Mountains in central Bulgaria, crosses the terrain of Bulgaria and Greece, and discharges into the Thracian Sea. The river basin is 5,479 km^2 in total, while its length is 243 km. The upper part of the basin between the border and Paschalia consists of metamorphic rocks (gneisses, schists e.t.c.), while the lower area between Paschalia and Toxotes consists mainly of karstified marbles. Only the eastern part of the valley, between Stavroupoli and Pascalia , consists of metamorphic rocks. The chemical analysis of the samples is given in the following Table 2 :

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.
Ne -1	62,38	3,81	6,37	9,67	2,95	7,81	0,08	5,96
Ne-2	61,43	3,42	5,92	10,23	3,41	5,62	0,07	6,31

Table 2: Chemical analyses of the Nestos river

The chemical analysis of the Nestos river has a moderate SiO_2 content and a low CaO content.

The Gallikos river

Gallikos river starts from Kroussia mountains (Disoro mountain) and flowing south falls into Thermaikos gulf close to Kalochori village. It is one of the largest rivers in Central Macedonia. The area according to Ramsar Treaty is one of the 11 Greek wetlands of worldwide importance. The chemical analysis of the fine grain size (0-4 mm) of the samples is given in the following Table 3 :

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.
Gal-1	87,45	3,32	1,69	1,87	0,33	0,67	0,87	2,61
Gal-2	88,34	3,37	0,92	1,65	0,28	0,57	0,45	2,33
Gal-3	87,62	3,17	1,55	1,91	0,38	0,52	0,84	2,58
Gal-4	88,22	3,49	1,02	1,53	0,29	0,51	0,52	2,42
Gal-5	88,26	3,45	0,97	1,68	0,24	0,66	0,57	2,48

Table 3: Chemical analyses of the Gallikos river

These chemical analyses show that Gallikos river has a high SiO_2 content and low K_2O and Na_2O content.

The Srtymonas river

The Srtymonas river has a total length of 360 km about 240 of which are in Bulgarian territory. The basin covers an area of 17.300 Km^2 . The geological layers are divided into two large groups : rocks of Quaternary (alluvial deposits, diluvia, gneiss and granite) and rocks of Paleozoic (mainly metamorphic rocks of schist, gneiss and marble). The chemical analysis of the samples is given in the following Table 4 :

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.
Stry-1	66,49	3,39	1,08	20,57	0,35	0,73	0,88	5,41
Stry-2	66,23	3,37	1,85	21,55	0,71	0,77	0,94	5,74
Stry-3	67,35	3,26	1,42	21,24	0,93	0,66	0,78	5,67

Table 4: Chemical analyses of the Strymonas river

The chemical analysis of the Strymonas river resulted to low SiO_2 content (<75%) and high CaO content (>15%).

The Loudias river

The Loudias river collects water that comes mainly from mountain Paiko and its main sources are close to Aravissos village. Part of the river has been converted into an artificial channel, through which was achieved the draining of Giannitsa Lake. The Loudias river flows through the regional units of Pella and Thessaloniki.

The chemical analysis of the samples from Loudias river is given in the following Table 5:

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	L.O.I.
Lou-1	42,37	3,37	1,12	43,21	0,32	0,73	10,42
Lou-2	45,19	3,17	1,27	44,13	0,21	0,45	12,74

Table 5: Chemical analyses of the Loudias river

The chemical analysis of the Loudias river resulted to the lowest SiO_2 content (<46%) and the highest CaO content (>43%).

The Aliakmon river

The Aliakmon river rises in the Gramos mountains in northern Greece, near the border with Albania. In its upper course it flows generally towards the east, and turns southeast near Kastoria. It describes a wide curve around the ophiolithic complex of Vourinos mountains, and turns northeast near the village Paliouria. It feeds the large valley of Veria and has a total length of 314 km.

The chemical analysis of the sand from the Aliakmon river is given in the following Table 6 :

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	L.O.I.
Hal-1	58,71	2,34	3,85	31,07	0,02	4,47	8,65
Hal-2	51,15	1,19	2,21	36,15	0,01	1,23	9,71

Table 6: Chemical analyses of the Aliakmon river

A comprehensive research work was carried out concerning the physical and chemical properties of the river sands. Six samples were collected from the river's basin and were tested for their suitability to be used as raw materials for the production of adhesives, grouts, fillers and extenders. It was proved that the samples from Gallikos, Srymonas and Nestos gave initial promising results, even though further research work is needed. The high SiO_2 improved considerably the tensile strength and the impact resistance when added to adhesives specimens.

4. Economic Evaluation

The price of the above mentioned river sands varies significantly according to their chemical and physical properties. The river sand is mined by the open pit method and the degree of processing is a function of the needs and specifications of various consumers. Normally after the sand is mined and stockpiled , may be processed by screening, washing, drying and beneficiation. The purchasing price for a ton of river sand varies between 3 to 7 € , depending on the chemical analysis and the grain size distribution. This price is competitive if it is compared with other filler materials such as calcium carbonate which has an average purchasing price from 8 to 22 €/ton. Due to confidentiality issue among the sand producers further economic analysis was not available.

5. Conclusions

● The known industry specifications for adhesives, grouts, fillers and extenders cover a wide range of values and the samples collected from Gallikos, Srymonas and Nestos have grain size distribution and surface area which fall within the range and would appear to be suitable for the above mentioned applications.
● Quartz sand when added to adhesives for tiles improves considerably its tensile strength and impact resistance.
● None of the river sands collected meet the specifications for high quality glass and other high added value uses.
● The purchasing price for the river sand to be used as filler material is competitive compared with other filler materials.
● The sand from the Gallikos river due to its high SiO_2 content , appears to be suitable to be used as foundry sand and as raw material for aerated concrete.

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7. Disclaimer

For reasons of commercial confidentiality producers of industrial sand have not supplied a detailed breakdown of production by product type and in some cases have asked that details of markets and customers remained confidential.

8. References

B.G.S. 2007. Silica Sand : Geology and Mineral Planning Fact Sheets for Scotland, pp. 11-25
BS2975:1988 Methods of sampling and analysis of glass-making sands.
BS EN 12904:2005 Products used for treatment of water intented for human consumption. Silica sand and silica gravel.
BS 7533-3:2005 Pavements constructed with clay, natural stone or concrete pavers.
Bolen, W. P. (1996). Sand and gravel, industrial. In *1995 Minerals yearbook* (pp. 715-730). Reston, VA: U.S. Geological Survey.
California State Board of Equalization, (1997). The appraisal process. In *Assessment of mining properties, assessors' handbook* (Sec. 560, pp. 6-14 - 6-15). Sacramento, CA: California State Board of Equalization.
Carr, D. D. (1971*). Specialty sand resources of Indiana* (Bulletin 42-F). Bloomington, IN: Department of Natural Resources Geological Survey.
Davis, L. L., & Te p o rdei, V. V. (1985). Sand and gravel. In *Mineral facts and problems*. Washington: U.S. Bureau of Mines.
Dolley, T. P. (2002). Silica. In *2002 Minerals yearbook* (Vol.1). Washington: U.S. Geological Survey.
Dolley, T. P. (2004a). Silica. In *2004 Minerals yearbook* (Vol.1). Washington: U.S. Geological Survey.
Dolley, T. P. (2004b). Sand and gravel (industrial). In *Mineral commodity summaries (*pp. 142-143). Washington: U.S. Geological Survey.
Heinrich, E. W. (1981). Geologic types of glass-sand deposits and some North American representatives. *Geological Society of America Bulletin* 92 (9), 611-613.
Holeman, J. N. (1968). The sediment yield of major rivers of the world. *Water Resources Research* 4(4), 737-747.
Ingram, R.l. (1970) : Sieve Analysis. – In : Carver, R (ed.) Procedures in Sedimentary Petrology, Wiley-Interscience, New York 48-68.
Ketner, K. B. (1973). Silica sand. In D.A. Brobst & W.P. Pratt (Eds.) *United States Mineral Resources Professional Paper 820 (*pp. 577-580). Washington, DC: U.S. Geological Survey.
Kondolf, G. M. (1997). Hungry water: Effects of dams and gravel mining on river channels. *Environmental Management* 21(4), 533-551.
Langer, W. H. (2003). A general overview of the technology of in-stream mining of sand and gravel resources, associated potential environmental impacts, and methods to control potential impacts. In *U.S. Geological Survey Open File Report OF-02-153* (version 1.0).
Meade, R. H, Yuzyk, T. R., & Day, T. J. (1990), Movement and storage of sediment in rivers of the United States and Canada. In *The Geology of North America* (Vol. O-1, Surface Water Hydrology) (pp. 255-280). Boulder, CO: The Geological Society of America.
Moldenke, R (1930) The Principles of Iron Founding, 2nd edition New York, McGraw-Hill, 654 p.
Sandecki, M. (1989). Aggregate mining in river systems. *California Geology* 42(4), 88-94.
Shaffer, N.R. (2006) The Time of Sands : quartz-rich sand deposits as a Renewable Resource. University of Idaho 1-22.
Siever, R. (1988). *Sand*. New York: Scientific American Library.
The Mineral Gallery. (2004). *The Tectosilicate subclass*. Retrieved November 5, 2005 from http://mineral.galleries.com/minerals/silicate/tectosil.htm
Tsoar, H., Blumberg, D. G., & Stoler, Y. (2004). Elongation and migration of sand dunes. *Geomorphology* 57
Veranis N. et oth.(2011) Hydrological conditions of the lower reaches of Aliakmonas and Loudias rivers aquifer system, Region of Central Macedonia , Advances in the Research of Aquatic Environment pp. 357-364