EFFECT OF GROUND GLASS FINENESS ON PHYSICAL AND MECHANICAL PROPERTIES OF CONCRETE

Aleksandrs Korjakins', Genadij Shakhmenko, Diana Bajare, and Girts Bumanis

Riga Technical University, Institute of Materials and Constructions,
Azenes str. 16, LV-1658 Riga, Latvia

Abstract

This research is focused on the development of concrete mix by using borosilicate glass micro-filler obtained from the waste of outworn fluorescent lamps. The task of the research is to find the optimal fineness of glass particles, which can improve packing of microparticles in cement matrix to increase the strength properties of concrete. Previous research as well as chemical composition of glass proved that ground glass can be used as an effective concrete component.

Borosilicatc glass micro-fillers with different grinding degree were used in experiments. Particle grading was determined by using the laser diffraction method. The morphology of microparticles was investigated. The effect of glass powder on cement setting time was checked. It was determined that fine glass particles powder produces a long-term hardening effect.

I Experimental work includes preparation of samples from standard concrete and concrete with borosilicate glass micro-filler (with particles of different sizes and mixed in different proportions) and testing after the ageing period of 7 and 28 days. The long-term hardened samples were also tested. The compressive strength of concrete samples is decreasing when rough glass powder is used as cement replacement. At the same time fine glass filler with particle size up to 0.1-10 ^m allows improvement in mechanical properties of concrete and makes it possible to replace up to 25% of the cement without impairing the strength characteristics of concrete. As a result, concrete with improved water resistance and durability was obtained.

Keywords: borosilicate glass, concrete, strength

1 INTRODUCTION

Borosilicate glass from outworn fluorescent lamps is a waste, which is not possible to recycle bv traditional methods due to specific chemical composition. It constitutes a problem for glass disposal because glass is not biodegradable and landfill is not the best environment-friendly solution.

On the other hand, there arc a lot of investigations in the area of utilization of glass waste in concrete industry as replacement of the aggregates or cement. Similar to other Baltic countries, Latvia is poor with natural pozzolanic materials and only local artificial pozzolans are able to satisfy all demands of the construction industry. Many pozzolans that are available for use in construction today were previously looked at as waste products, which were landfilled. It is well known that use of pozzolans can allow for a 40% decrease from the requested amount of Portland cement in concrete production. It is a significant effect from the point of view of cost-saving. Utilization of pozzolans in concrete is possible without significant impairment of the final compressive strength or other performance characteristics on the provision that the concrete mix is properly designed.

""Correspondence to: aleks@latnet.lv

Broekmans, MATM (editor)
Proceedings, 1<y^h International Congress for Applied Mineralogy (ICAM)
1-5 August 2011, TRONDHEIM, Norway
ISBN-13: 978-82-7385-139-0

Pozzolan is a siliceous or aluminosiliceous material with high vitreous qualities. 1'his material has no cementitious properties of its own but in the presence of a lime-rich medium like calcium hydroxide shows better cementitious properties towards the later day strength (>28 days). The mechanism for this display of strength is the reaction of silicates with lime to form secondary cementitious phases (calcium silicate hydrates with a lower C/S ratio), which display gradual strengthening properties usually after 7 days. Therefore, pozzolans are commonly used as an addition to Portland cement concrete mixtures to increase the long-term strength and other material properties of concrete and in many cases reduce the cost of the material. The pozzolanic reaction can be slower than the rest of the reactions that occur during cement hydration; thus, the short-term strength of concrete produced by adding pozzolans may not be as high as in concrete made from purely cementitious materials. The degree of strength development depends on the chemical composition of the pozzolan: the higher the composition of alumina and silica along with the vitreous phase in the material, the better the pozzolanic reaction and strength display.

Since glass consists mainly of highly vitreous siliceous material, many investigations are focused on the efforts to use waste glass as partial replacement of coarse or fine aggregates in concrete manufacturing industry. Owing to a strong reaction between the alkali in the pore solution of concrete and the silica-rich glass particles (alkali-silica reaction), the results of the studies related to the use of glass in concrete are not always satisfactory. The explanation of these failures is connected to the fact that at the basis of pozzolanic reaction stands acid—base reaction between calcium hydroxide (known as portlandite Ca(OI I)2) and silicic acid (H4Si04 or Si(OH),i). The product formed during this reaction is a calcium silicate hydrate (CaJ [2Si04*2 H2O) labeled as CSH. Measurements showed that the Ca/Si ratio and the number of water molecules in CSII varied as well as differences in the stoichiomctry were stated. As the density of CSI I is lower than that of portlandite and pure silica, the effect achieved by this reaction is swelling of the reaction products. This reaction may also occur with time in concrete between alkaline pore water and poorly crystalline silica aggregates. Such delayed process is also known as alkali silica reaction (ASR) and can seriously damage concrete structures because the resulting volumetric expansion is also responsible for spalling and decrease of concrete strength |1|. Therefore, in many cases strength reduction and excessive expansion of concrete were observed in the course of research.

It is important to recognize that the reactivity of glass depends on its type, chemical composition, and physical features such as presence of pores and separate solid phases in glass. Glass particle size and alkali content of the mortar or cement are the other two important factors influencing the reactivity of glass as an aggregate [2, 3].

Recent studies have shown that glass particle size is a crucial factor for ASR to occur. In particular, glass aggregate fineness factor and surface area directly relate to the phenomenon called alkali-silica reaction in concrete |4]. It seems that there exist certain boundaries for glass particle size where the maximum expansion of concrete occurs and where the particles act as pozzolan. It was discovered that glass particle size of around 1.5 mm may cause excessive expansion whereas particles <0.25 mm caused comparatively smaller expansion [4]. Other research shows that glass particles of around 1.2 mm caused the largest mortar bar expansion in the particle size range of 0.15-4.75 mm [5|. It has also been concluded that the largest ASR expansion is caused by the particles in the size range of 1.18-2.36 mm [3]. Larger ASR expansion of concrete made by using glass aggregates can also be explained by the experiments during which hydration temperature was determined. Significantly, higher temperatures were observed during hydration of concrete made with glass aggregates compared to those produced from natural aggregates |6|. Thus, it is possible to conclude that finer glass aggregates are more effective in reducing the ASR in the concrete and mortars.

Waste glass can be used in concrete not only as a coarse or fine aggregate but also in the powder form. The coarse and fine aggregates can trigger ASR in concrete whereas glass powder can suppress tendency to ASR and produce the effect similar to that of supplementary cementitious materials such as pozzolan |4|.

Glass is an amorphous material with a high silica content, which is the primary requirement for pozzolanic materials. It was reported that particle size of powdered glass should be 75 (am or less to be favorable for pozzolanic reactions |7, 8|. Some other researchers demonstrated that glass aggregates with particle size less than 300 |am cause pozzolanic activity, and this implies that the fine glass powder behaves like cement in the mix [9, 10|.

Chemical reaction between the alkali in Portland cement and the silica in glass aggregates leads to formation of silica gel, which not only causes cracks upon expansion but also weakens concrete and shortens its life. It was proved by the research that waste glass of the size 4-16 mm used as aggregate in concrete reduced the compressive strength of concrete [11]. Besides, more than 30% of waste glass with particle size of 0-5 mm added to concrete decreased the compressive strength of concrete |12,13|. Previous researches proved that addition of waste glass in crushed form to concrete decreased its flexural strength |11, 12, 14}. Opposite results were produced by the study dedicated to the effect of glass as an aggregate replacement on concrete strength. Small increase in the compressive strength indicator was observed at the replacement of the aggregate with 0-10 mm waste glass [15|.

On the other hand, powdered waste glass seemed to have a positive effect on the micro-structural properties of the concrete resulting in the obvious improvement of its mechanical performance |8|. Some investigations demonstrated that both fine glass powder and crashed glass aggregates could be used in concrete together without adverse effect on concrete durability [2, 3, 14|.

It has been proved that 30% of glass powder could be incorporated as cement or aggregate replacement in concrete without any long-term detrimental effect. Up to 50% of both fine and coarse aggregates could be also replaced in concrete of 30 MPa or higher strength grade with acceptable strength development properties |4, 3, 14].

2 RAW MATERIALS AND METHODS

2.1 Studying the recycled glass powder

Fluorescent lamp recycling process includes lamp classification, glass separation, cleaning from harmful components, and grinding. Rough ground glass powder (GP) obtained from utilization of lamps was used as the mineral raw material for concrete mixtures. I Examination of chemical composition indicates the presence of the following oxides: $SiOz$ – 74.3%, PbO – 0%, B_20, – 16.63%, $A1_20_3$ – 1.7%, Fe_20, – 0.16%, CaO – 2.1%, MgO – 0%, Na_20 – 3.8 %, and K_20 – 0.93%. Given its chemical composition, this material is classified as borosilicate glass.

The product of lamp recycling (GP) represents roughly ground powder with the grain size smaller than 0.4 mm. In order to increase chemical activity of glass material, glass powder was additionally ground with the help of the laboratory planetary mill Retsch PM 400. The applied grinding periods were 15, 30, 45, and 60 min. The particle size distribution in powder material was determined with the help of laser diffraction method. Grading analysis results show that rough ground material contains a wide range of particle sizes: from 8 |am up to 50 |am with the average grain size of 26.3 (am. Glass material grading curves indicate a considerable increase in the fine particle content after additional grinding of the powder. .After additional grinding (60 minutes), the average grain size was reduced to 4.0 |am, and particle dimensions ranged from 0.1 (am up to 10 (am. The results of grading analysis are summarized in Figure 1.

Particle morphology was investigated by using the static technique Morphology G3S, which is capable of analyzing the shape characteristics of material particles. Figure 2 shows typical shape distribution of glass powder. Obtained results of morphology investigations show the following shape characteristics of glass particles: circularity coefficient 0.920, convexity coefficient 0.987, and elongation coefficient 0.256. It should be stressed that ground glass particles have quite smooth and rounded surface compared to traditional micro-fillers used in concrete industry. To compare the results, quartz micro-filler was tested. The following results were obtained: circularity coefficient 0.868, convexity coefficient 0.978, and elongation coefficient 0.335.

2.2 Concrete mix compositions

Laboratory mixes were designed close to the concrete mix commonly used in the industry. Normal moderate hardening Portland cement CEM I 42.5 N was applied as a binding agent. Natural local dolomite-based aggregate (gravel) was used as the coarse aggregate and natural sand was applied as a fine concrete aggregate. Proportions between the aggregates were calculated in order to obtain the best grading curve of the aggregate in accordance with the standard DIN 1045. Modern advanced concretes such as self-compacting, high strength, and high performance concretes arc highly susceptible to the content of micro-filler admixture, which is necessary to provide satisfactory mix workability. For obtaining the pumpable concrete, the recommended fine particle content (<0.125 mm) is 375 ... 450 kg/m^3. In the case of laboratory mixes, the optimal fine component content is provided by cement and glass micro-filler.

The experimental program provides for the use of borosilicate glass micro-filler with different grinding time (from 0 to 60 min). Concrete mix compositions are summarized in Table 1. Concrete mixes were prepared in the laboratory drum mixer. Aggregates used were in dry conditions. The dry ingredients were weighed and mixed for 1 min, 80% from designed water content was added during the next 1 min. The remaining water was added to the mix during the process of mixing. Mixes were tested for workability by using slump test for conventional concrete. Water dosage was selected to provide the cone slump in the range between 95 and 105 mm.

Standard testing sample cubes of dimension 100 x 100 x 100 mm were produced for studying the mechanical characteristics of the material. Concrete mixtures were cast into the oiled steel moulds and installed on the vibrating table. .After 2 days, the samples were dismantled. Sample measurements and testing were performed after ageing period under standard conditions (temperature +20 °C, Rl I >95%). The samples were tested for compressive strength in conformity with the IA'S FEN 12390-3. The compressive strength was tested with the help of the testing machine with an accuracy of ±1%; the rate of loading was 0.7 MPa/s.

Water permeability was tested in conformity with the standard L\'S I EN 12390-8. The samples were cured in water for 72 h under a pressure of 0.5 MPa; after that the degree of splitting and depth of water penetration were determined. Frost resistance test was carried out by using the CDF method. The samples were partially immersed in 3% sodium chloride solution and subject to freeze—thaw cycles (amplitude +20 ... —20 °C, one cycle duration—12 h). Scaling from concrete surface was determined after 14 freeze—thaw cycles.

3 COMPRESSIVE STRENGTH RESULTS

Concrete samples were tested after 7 and 28 days and 1 year hardening period. Compressive strength results are summarized in Figure 3.

Concrete water permeability and frost resistance testing were carried out after 28 days ageing period under normal hardening conditions. Water permeability results are shown in Figure 4. Results of scaling from surface after 14 freeze-thaw cycles in 3% sodium chloride solution are summarized in Figure 5.

4 DISCUSSION

Glass powder improves the mix workability, makes the mix more homogeneous, and prevents segregation. It was observed that the consistency of concrete mixes containing ground glass is tackier in comparison to the conventional concrete mix. It should be stressed that concrete mixes containing glass powder lose workability during the first hour.

The required water content decreases a little with the increasing glass powder grinding time. This effect can be explained by improvement of the fine particle packing quality. Cement particles have grain dimensions in the range between 2 and 50 (am. In addition, ground glass particles (0.1 ... 20 (am) effectively fill in the voids between cement grains, thus improving the grading curve of micro-aggregate and increasing the packing density of the cement matrix. As result, better strength and durability characteristics were obtained for the mixes with added ground glass powder. The best strength, water permeability, and frost resistance results were demonstrated by the composition containing the glass ground for 60 min.

After 7 days, the compressive strength is about 30 MPa for all samples. At the same time, after 28 days and 1-year hardening periods the strength results for extra ground glass composition arc higher by 20% than for rough ground glass composition. This effect can be explained by activation of pozzolanic reactions caused by additional glass grinding and increase in specific surface and also because of the lower water/cement ratios of the tested concretes. 1 Experimental results show high long-term compressive strength indicators after a 1-ycar hardening process. Samples containing additionally ground glass and having the lower water/cement ratios demonstrate about 50% gain in strength compared to 28 days strength.

Nowadays, the civil construction industry is looking for alternatives to satisfy the increasing demand for pozzolan in cement and concrete production, and glass-based pozzolan could be one of the solutions. Therefore, many authors studied the possibilities to utilize glass waste in the form of glass powder as the cement replacement material in concrete. The use of glass powder as pozzolan would have increased monetary and environmental value than the use of waste glass as an aggregate. Glass powder will always be cheaper than cement and, in particular, it could be used as a value-added product since it is capable of replacing a proportion of expensive concrete ingredients such as cement itself or supplementary, cementitious materials such as fume and fly ash |3).

Production of concrete by using pozzolans from glass waste should be a cost-effective and environmentally friendly process thanks to the possibility to decrease the amount of required cement in the building sector and following decrease in CO2 emission in the cement industry; moreover, it offers the possibility to utilize glass waste in a useful product. The effect of glass particle sizes on the mechanical and physical properties of concrete have been researched in these studies.

5 CONCLUSIONS

- The properties of fresh concrete mix and those of hardened concrete considerably depend on the fineness of lamp borosilicate glass powder. Borosilicate glass powder improves the concrete mix workability and increases compressive strength, water resistance, and durability of the material.
- In addition (for 60 min), ground glass powder as well as glass dust demonstrates properties of the active micro-filler, which produces a long-term hardening effect. Samples containing additionally ground glass after 1-year hardening process provide a considerable gain (about 50%) in strength compared to 28 days strength.
- By using additionally ground glass powder it is possible to obtain a denser cement matrix, which is characterized by lower water penetration (15 mm) compared to the samples with rough ground glass

(19 mm) and improved resistance against freeze-thaw cycles in 3% sodium chloride solution (scaling from the surface was minimized from 1.70 to 1.02 kg/m^2 after 14 cycles).

- Careful evaluation of hygienic and ecological aspects of using lamp glass recycling products as concrete micro-filler must also be carried out.

6 ACKNOWLEDGEMENTS

The financial support of the Ministry of [Education and Science of the Republic of Latvia and Riga Technical University is acknowledged.

7 REFERENCES

[1| Swamy, RN (1992): The alkali-silica reaction in concrete, Blackie and Son Ltd.

[2| Shayan, A and Xu, A (2004): Value-added utilization of glass in concrete. Cement and Concrete Research (34): 81-89.

[3| Shayan, A and Xu, A: Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs. Cement and Concrete Research (36): 457-468.

|4| Karambcry, A and Moutsatsou, A (2005): Participation of colored glass cullet in cementitious materials, Cement and Concrete Composites (27/2): 391-327.

[5| Jin, W, Meyer, C, and Baxter, S (2000): "Glascreat"- concrete with glass aggregate. ATI Materials Journal (97): 208-213.

|6| Poutos, KM, Alani, AM, Waldcn, I'J, and Sangha, CM (2008): Relative temperature changes within concrete made with recycled glass aggregates. Construction and Building Materials (22): 557-565.

[7| Shao, Y, I,efort, T, Moras, S, and Rodriguez, D (2000): Studies on concrete containing ground waste glass. Cement and Concrete Research (30/1): 91-100.

[8| Corinaldesi, V, Gnappi, G, Moriconi, G, and Montenero, A (2005): Reuse of ground waste glass as aggregate for mortars. Waste Management (25): 195-201.

|9| F.wan, AB, Morales-Hernades, B, and Zhy, ITY (2004): Waste glass as concrete aggregate and pozzolan. Concrete, 41

1101 Kozlova, S, Millraht, K, Meyer, C, and Shimanovich, S (2004): A suggested screening test for ASR in concrete-bound composites containing glass aggregates based on autoclaving. Cement and Concrete Composites (26/7): 827-835.

|11| Topacu, IB and Cabaz, M (2004): Properties of concrete containing waste glass. Cement and Concrete Research (34): 267-274.

[12] Park, SB, Lee, BC, and Kim, [II (2004): Studies on mechanical properties of concrete containing waste glass aggregate. Cement and Concrete Research (34): 2181-2189.

[13| Limbachiya, MCE (2009): Bulk engineering and durability properties of washed glass concrete. Construction and Building Materials (23): 1078-1083.

|14| Turgus, 1' and Yahlizade, FES (2009): Research into concrete block with waste glass. International |ournal of Civil and I Environmental [Engineering (1/ 4): 203-209.

[15| Sangha, CM, Alani, AM, Walden, PJ (2004): Relative strength of green glass cullet concrete. Magazine of Concrete Research (56): 293-297.

TABLF. 1: Concrete mix compositions, water/cement ratio, and results of cone slump .

Grinding time (min)	0	15	30	45	60
Portland cement CRM I 42.5 N	330	.330	330	330	3.30
Gravel 2/12 mm	1000	1000	1000	1000	1000
Sand 0.3/2.5 mm	650	650	650	650	650
Sand 0/0.5 mm	120	120	120	120	120
Glass powder	80	80	80	80	80
Water	219	211.3	210	205	202
Water/cement ratio	0.66	0.64	0.64	0.62	0.61
Cone slump (mm)	95	100	105	100	100

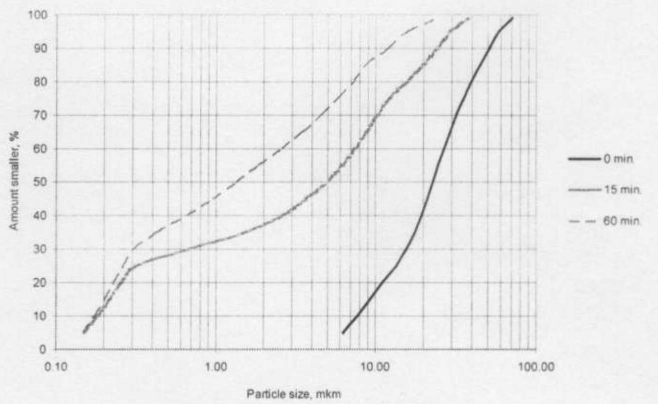

Figure 1: Grading curves of ground glass materials.

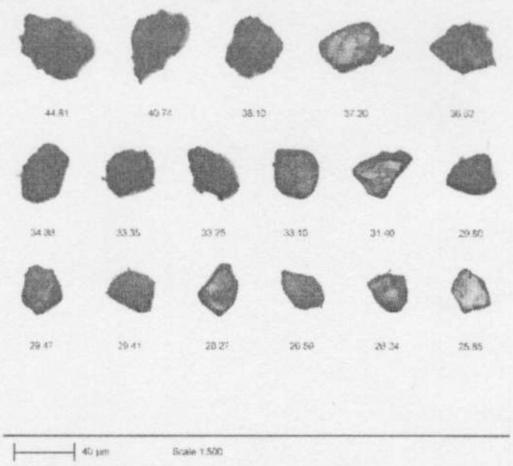

Figure 2: Typical shapes and dimensions of glass powder particles.

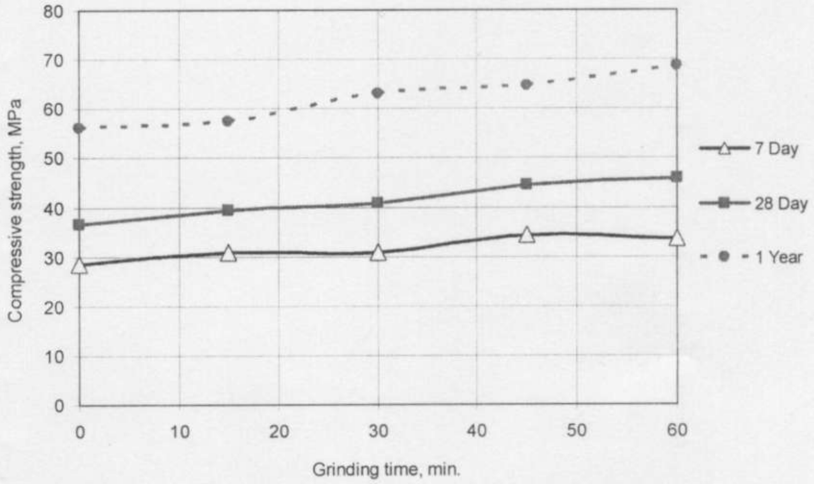

Figure 3: Compressive strength results for concrete samples after 7 and 28 days and 1-year ageing.

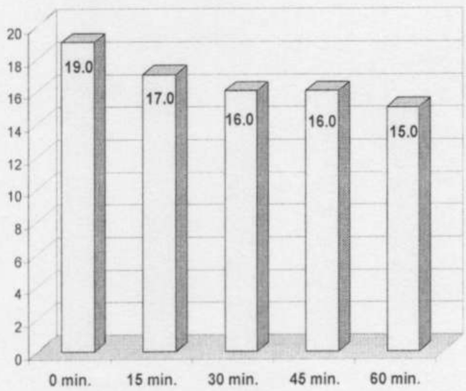

Figure 4: Water penetration results for concrete samples after 28 days ageing (mm).

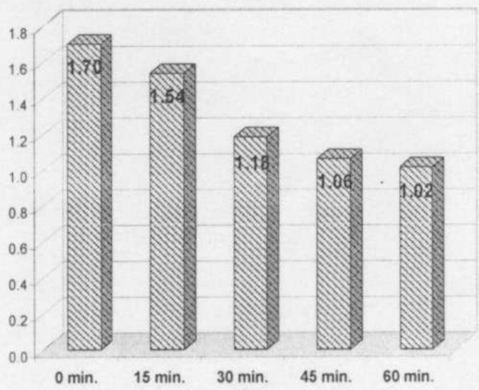

Figure 5: Scaling from surface after 14 cycles in 3% NaCl solution (kg/m^2).

ASSESSMENT OF QUARTZITE CRYSTALLINITY INDEX BY FT-IR

Michael V. Korovkin, Lyudmila (i. Ananieva, Anastasia A. Antsiferova

Institute of Natural Resources, Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk 634050, Russia

Abstract

Quartzite from Antonovsk group of fields, located in Western Siberia, Russian Federation were studied as a source of high-purity quartz by FT-IR method. Quartzites arc scdimcntary-mctamorphic rocks, the products of lithification in the early metagenesis condition of quartz-hydromica-sericite fades. Due to the metamorphism of siliceous-biogenetic stratum, initially amorphous silica was crystallized. The cleanest quartzite can be displayed for their genetic trait by the determination of crystallinity index. The increasing quartzitc crystallinity indices are caused bv metamorphic overprint.

Crystalline phase of a-quartz was determined by the presence of double peak 797-778 cm^{-1} of IR-sorption, which can wiggle Si-O-Si bonds in quartz. All in all, it was determined that the cleanest quartzite diversities have the lowest crystallinity index.

Keywords: ultrapure quartz, natural quartz resources, degree of crystallinity, FT-IR, metamorphic purification

1 INTRODUCTION

The demand for a high-grade quartz source increased during the last few years, which is the result of the productive growth of new materials and goods from quartz (fiber optic communication systems, special types of glass, crystalline silica for electronic industry, and silica of "solar" quality for photoelectric converters). That is why there is an actual problem of quality and perspective usage of pervasive quartz rock (quartzitc and quartz arenitc), as a cheap source of high-purity quartz.

Studied quartzites as a source of high-puritv quartz related to Antonovsk cluster of fields, located in Western Siberia, Russian Federation |4, 5|.

Quartzite has a sedimentär)' metamorphic origin and is a lithification product in early metagenesis of the quartz-hydromica-sericite facics. Due to the metamorphism of siliceous-biogenetic strata, initially amorphous silica was crystallized. As a result of this process the crystalline a-quartz phase appeared, as identified by both infrared spectroscopy (PT-R) and X-rav structure analysis (X-ray diffraction, XRD). The conditions led to self-purification of quartz grains.

We suggested that it is possible to determinate cherty strata degree of conversion and identify' the purest quartzitc phase, measuring the crystallinity index by infrared spectrometric method and X-ray method. Methods for determination of crystallinity index were initially described by Murata and Norman (XRD) |1|, by Plyusnina (1R) f2|, Deutsch et al. (DTA) |3], and Shoval et al. (FT-IR) |4|.

""Correspondence to: aaants@mail.ru

Brockmans, MATM (editor)
Proceedings, 10th International Congress for Applied Mineralogy (ICAM)
1-5 August 2011, TRONDHKIM, Norway
ISBN-13: 978-82-7.385-1.39-0