Cement & Concrete Composites 26 (2004) 639–643

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

Production of expanded-clay aggregate for lightweight concrete from non-selfbloating clays

L.S. Pioro [a], I.L. Pioro [b,*]

[a] Institute of Gas, Ukrainian Academy of Sciences, 39 Degtyarovskaya Str., Kyiv 03113, Ukraine

[b] Institute of Engineering Thermal Physics, Ukrainian Academy of Sciences, 2A Zhelyabov Str., Kyiv 03057, Ukraine

Received 2 September 2002; accepted 17 June 2003

Abstract

A technology of processing non-selfbloating clays into expanded-clay aggregate (fillers) for lightweight concrete in a melting-converter with submerged combustion was developed, tested and implemented in the building industry. The technology involves melting tuf-claystone with sandstone and/or other charging materials in a melting-converter, draining the melt into a water pool with water-jet granulation inside a draining chute, drying granules inside a drying drum, granule grinding, mixing the resultant powder with a foaming agent (coal powder) and binder (clay), and granulation of the mixture with subsequent roasting inside a rotary kiln. This technology allows production of expanded-clay aggregate for lightweight concrete from non-selfbloating clays with predetermined properties: bulk weight within the range 160–850 kg/m^3 and cylinder compressive strength within the range 0.78–14.4 MPa. Concrete with azerit as a filler is at least twice lighter than regular concrete and has thermal conductivity at least in two times less than regular concrete.

Specific to the melting process is the use of a gas–air–oxygen mixture (O_2 up to 75%) with direct combustion inside a melt (submerged combustion). The submerged combustion provides melt bubbling and helps achieve: maximum heat transfer from combustion products to the melt; an increased rate of the chemical reactions; improved mixing and, thus, a highly homogenized melt. The annual plant capacity is about 120,000–150,000 m^3 of "azerit", i.e., expanded-clay aggregate for lightweight concrete.

Keywords: Melting-converter; Expanded-clay aggregate; Non-selfbloating clay; Concrete; Submerged combustion

1. Introduction

Development of the northern regions of Russia, Canada and USA—rich with various mineral resources (oil, gas and ore mineral resources)—cannot be successful without development of a local building material industry. (The same statement applies to other regions, for example, Arabian Gulf [1].) To supply expanded-clay aggregate for lightweight concrete for the building industry from other regions is very expensive due to the remote location of these areas and/or the high transportation costs that significantly increase building expenses.

Usually, there is a lack of selfbloating clays in many industrial areas around the world; however, non-selfbloating clays can be found in these regions. Therefore, development of a technological process for production of expanded-clay aggregate for lightweight concrete from non-selfbloating clays is a very important task.

2. Design features of the technological process for production of expanded-clay aggregate for lightweight concrete from non-selfbloating clays

2.1. Technology of processing non-selfbloating clays into lightweight concrete fillers

The technology of processing non-selfbloating clays into lightweight concrete fillers was developed at the НИИСМ (NIISM) (Scientific Research Institute of Building Materials) by the name of Dadashev (Baku, Azerbaijan). These fillers are new artificial porous fillers, called "azerit" (Fig. 1). Azerit is an expanded-clay aggregate with bulk weight two times lighter and with

* Corresponding author. Present address: Chalk River Laboratories, Stn 87, Chalk River, ON K0J 1J0 Canada.

E-mail address: pioroi@aecl.ca (I.L. Pioro).

0958-9465/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0958-9465(03)00103-3

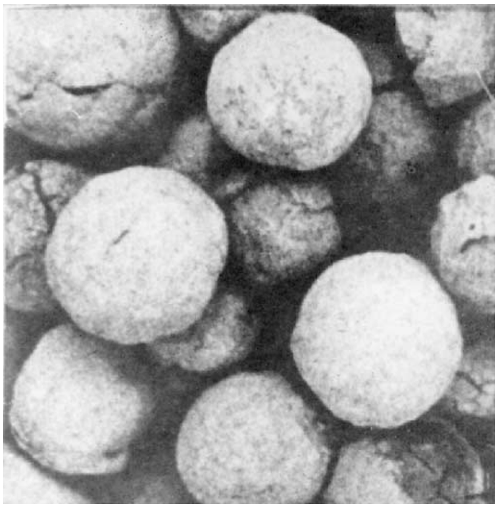

Fig. 1. Azerit granules (actual diameter 10–20 mm).

2–2.5 times higher crushing strength than high-quality fillers.

This technology allows production of azerit fillers from readily available materials, including non-selfbloating clays, which vary widely in chemical, mineralogical and granulation content. The technology also allows production of azerit from various materials with predetermined properties in a wide range of bulk weight from 160 to 850 kg/m^3 (regular lightweight aggregate has bulk weight of 530–1630 kg/m^3 [2]) and cylinder compressive strength from 0.78 to 14.4 MPa; and production of high-quality porous fillers in any economical zone worldwide. Concrete with azerit as a filler is at least twice lighter than regular concrete and has thermal conductivity at least two times less than regular concrete.

Specific to the technology is the transferring of the initial raw materials into a glassy (amorphous) phase by means of melting and consecutive fast cooling by means of water granulation.

The physical properties of the final product—azerit fillers—depend on the nature of the obtained molten glass. This is explained by the fact that glass in the amorphous phase has a softening temperature 50–70 °C lower than crystallized glass. Besides that, amorphous glass has a wider temperature range between its softening temperature and fluid state, i.e., the viscosity range is more favorable for granule bloating during roasting.

A melting-converter (Fig. 2) is used for the glass production. Its main advantage related to this technology is the possibility of obtaining high-quality and well-melted homogeneous glass. The melting-converter is a mobile apparatus that can be easily used with any type of raw materials, and can have a high degree of heat utilization due to its usage in steam and hot water production. The higher the specific melting capacity—the better the technical characteristics of the converter.

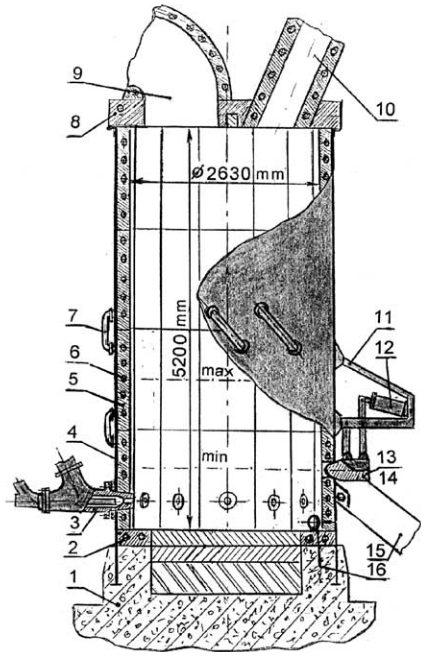

Fig. 2. Melting-converter for processing non-selfbloating clays into fillers for lightweight concrete: (1) concrete foundation, (2) bottom water jackets, (3) gas–air–oxygen burner, (4) converter case, (5) wall water jackets, (6) metal water jackets with cast inside water-cooling tubes, (7) joint branch pipes, (8) vault water jacket with cast inside chamotte bricks, (9) exhaust pipe, (10) loading opening, (11) bracket, (12) pneumatic actuator, (13) operational tap hole, (14) locking cylinder, (15) hydraulic monitor with draining chute, (16) emergency tap hole.

2.2. Basic azerit plant design

An azerit production plant was built in Noril'sk (Russia) in 1986 (Fig. 3). The azerit plant design, construction and initial operation were performed by the Норильскпроект (Noril'sk Design Institute), СибцветметНИИпроект (Siberia non-ferrous metals Scientific-Research Design Institute), Сибцветметавтоматика (Siberia non-ferrous metals automation Institute), In-

Fig. 3. Photograph of the azerit plant.

stitute of Gas Ukrainian Academy of Sciences and НИИСМ (Scientific Research Institute of Building Materials) by the name of Dadashev. Annual plant production capacity is 120,000–150,000 m^3 of azerit.

The principal technological scheme of the azerit plant consists of the following operations:

- melting of tuf-claystone and sandstone inside the melting-converter;
- melt granulation, drying and milling;
- mixing milling material with foaming agent (coal powder) and binder (clay) [1];
- three-component mixture granulation and granulate powdering with fine milling clay;
- granulate roasting (range of temperatures from 700 to 1000 °C) and storage.

2.3. Design of the melting-converter and its components

2.3.1. General layout of the converter

The melting-converter design [3] is shown in Fig. 2. The melting-converter intended for melting charging materials consisting of a tuf-claystone and sandstone.

Gray tuf-claystone from the Kayerkan deposit (Noril'sk, Russia) used in azerit production consists of SiO_2 (57.8%), Al_2O_3 (18.4%) with the remainder being Fe_2O_3, CaO, MgO, SO_3 etc. Red tuf-claystone from the Kayerkan deposit, also used in azerit production, consists of SiO_2 (55.0%), Al_2O_3 (19.4%) with the remainder being Fe_2O_3, CaO, MgO, SO_3 etc. It is important to keep the moisture content of the charging materials low.

The hearth of the converter is made of refractory bricks of various kinds on a concrete base. The smelting shaft of the converter is cylindrical with a diameter over the metal water jackets of 2630 mm. The converter case is rigid and made from double metal sheets. Metal water jackets (14 over the shaft perimeter and four rows high) have been installed on the case inside the shaft. The metal water jackets, which withstand the shaft weight, have been installed on the converter hearth. These water jackets prevent the hearth from exposure to intensive melt bubbling.

On the first row of the water jackets is a lancing belt where lances and tap holes are located. Two tap holes were used: one for periodic melt draining (operational tap hole) and another for emergency melt draining.

The dimensions of all water jackets are: height 1300 mm, width 600 mm and thickness 115 mm.

The converter vault is flat and made from refractory bricks mounted on water jackets. A loading opening and an exhaust pipe for combustion products are made in the vault.

[1] Percentage of foaming agent and binder depend significantly on the properties of charging materials. On average, content of foaming agent is within 3–5% and binder is about 10%.

A solid metal cylinder with a conical end was used for opening and closing the operational tap. This locking device is operated by a pneumatic mechanism.

A draining chute with a granulator was installed underneath the operational tap. The granulator consists of a hydromonitor, which ejects high-speed water. The jets burst the melt flow moving inside the chute. The water jets are also used for transporting granules into a large water pool for final cooling. To prevent steam explosion and excessive steam generation inside the pool, the melt has to be drained slowly. For example: 8–14 t of the melt with a temperature of 1500 °C should be drained into the pool over 10–15 min. Also, the pool size should correspond to the converter melting capacity. For the example given above, the pool volume is several hundred cubic meters.

Granulate from the pool is transported to an azerit production line.

2.3.2. Submerged burners

The submerged burners are intended for combustion of a mixture of natural gas–air–oxygen directly inside the melt and within a wide range of oxygen content (from 40% to 75% by volume).

The burner design allows cleaning of its nozzle in case of plugging by the melt lining.

The gas combustion is carried out with an excessive content of the oxidizer. The outflow speed of the gas–air–oxygen mixture is several hundred meters per second. At such a flow the mixture possesses high kinetic energy that prevents the nozzles from plugging with melt lining.

At the same time all burners can be used as sight ports to control the melting process.

Natural gas (calculated density of 0.7466 kg/nm^3, combustion heat of 35,378 kJ/nm^3) was supplied from a pipeline with a primary pressure of 0.6 MPa, which is subsequently reduced to 0.145–0.2 MPa.

Total natural gas consumption was 5100 nm^3/h including: 3000 nm^3/h for the converter, 1100 nm^3/h for drying the aggregate and 1000 nm^3/h for the roasting rotary kiln.

Technological oxygen for the converter was supplied at a pressure of 0.23 MPa. The oxygen consumption was 6350 nm^3/h.

Air was supplied at a primary pressure of 0.6 MPa. The maximum air consumption was 6300 nm^3/h. Subsequently, air pressure was reduced to 0.13 MPa and air was directed to the mixer in which the air–oxygen mixture was prepared.

2.4. Technical characteristics of the converter

The melting-converter of a melting capacity of 8 t/h operated in the following regime (melting occurs due to the combustion of the gas–air–oxygen mixture in the submerged burners): loading for 15 min, 5 min for melting, followed by melt draining. To support this operational regime nine submerged burners operated at a gas consumption of 1500 nm^3/h, oxygen consumption of 3000 nm^3/h and air consumption of 1900 nm^3/h. Thus, the air–oxygen mixture consumption was 4900 nm^3/h with O_2 content of about 67%. Working pressures for the air–oxygen mixture and natural gas were 0.14 MPa.

The charging materials were tuf-claystone and limestone.

The inlet cooling water temperature was about 26 °C and the outlet temperature was about 37 °C. Cooling water consumption was 300 m^3/h.

Dusty combustion products from the converter were directed to the dust precipitation chamber in which they cooled to a temperature of 400 °C. In the chamber dust and the small discrete particles entrained from the converter were precipitated. The precipitated conglomerate was transported back for remelting and the combustion products were directed to wet cleaning. Pulp (i.e., dust and water) from the wet cleaning system was transported into the pool and after that to the azerit production line.

The melting-converter was fully equipped with measuring and control devices for safe and reliable operation.

Further improvements in the melting-converter design can be attained by changing from water-cooling to evaporative-cooling, including the use of two-phase thermosyphons in the most heat-loaded places (burners, etc.) [4,5]. Also, the heat from the evaporative-cooling system can be recovered later.

The design of the melting-converter for azerit production is based not only on the results of these tests, but also on experience gained during development and operation of various types of the melting-converters with submerged combustion [6–14] including an experimental-industrial melting-converter for a one-stage vitrification process for high-level radioactive wastes [15]. Industrial melting-converters for mineral materials have been operating now for more than 10 years at building-materials plants producing mineral fiber: at a melting material capacity of 3 t/h in Kyiv (Ukraine) and Bereza (Belarus') [16].

3. Advantages of submerged combustion

As mentioned above, nine submerged burners were installed in the bottom of the melting bath. The combustion products from these burners are injected directly under the melt in the form of high-speed jets. This feature provides melt bubbling, resulting in partial "pseudo-boiling." Submerged burners help to achieve maximum heat transfer from combustion products to the melt, to improve mixing and to increase the rate of chemical reactions [17].

Under conditions of intensive bubbling of the melt from combustion products, the charging materials create a homogeneous melt with predetermined chemical content.

4. Summary

An innovative technology of processing non-selfbloating clays into expanded-clay aggregate (fillers) for lightweight concrete in a melting-converter with submerged combustion was developed, tested and implemented in the building industry. This technology allows production of expanded-clay aggregate for lightweight concrete from non-selfbloating clays with predetermined properties (bulk weight within the range 160–850 kg/m^3 and cylinder compressive strength within the range 0.78–14.4 MPa). Concrete with azerit as a filler is at least twice lighter than regular concrete and has thermal conductivity at least two times less than regular concrete.

Specific to the melting process is the use of a gas–air–oxygen mixture (O_2 up to 75%) with direct combustion inside a melt (submerged combustion). The submerged combustion provides melt bubbling and helps achieve maximum heat transfer from the combustion products to the melt, increases the rate of chemical reactions, improves mixing and, thus, produces a highly homogenized melt.

The plant in Noril'sk has an annual capacity of 120,000–150,000 m^3 of "azerit".

References

[1] Alduaij J, Alshaleh Kh, Haque M, Ellaithy Kh. Lightweight concrete in hot coastal areas. Cement Concrete Compos 1999;21:453–8.

[2] Chen HJ, Yen T, Lia TP, Huang YL. Determination of the dividing strength and its relation to the concrete strength in lightweight aggregate concrete. Cement Concrete Compos 1999;21:29–37.

[3] Knyazev MV, Filatov AV, Chentemirov MG, Pioro LS, et al. Melting furnace, Patent of the USSR No. 1260650, September 30, 1986, Bulletin #36.

[4] Pioro LS, Pioro IL. Industrial two-phase thermosyphons. New York, NY, USA: Begell House; 1987. 288 p.

[5] Pioro IL. Investigation of closed two-phase thermosyphons used for cooling of melting converters (in Russian) In: Applied problems of heat transfer and hydrodynamics. Kiev, Ukraine: Naukova Dumka Publ. House; 1982. p. 76–9.

[6] Pioro LS, Osnach AM, Olabin VM, Mikhaylenko VI, Rusin VI. Converter melting of silicate materials (in Russian) Stroitel'nye Materialy (Building Materials) 1966;(8):18–9.

[7] Pioro LS, Bondarev KT, Rusin VI, Mikhaylenko VI, Minin VI, Zabkov FE. Producing melts in slag ladles with preset physico-chemical properties (in Russian) Stroitel'nye Materialy (Building Materials) 1967;(2):35–6.

[8] Bondarev KT, Pioro LS, Mikhaylenko VI, Olabin VM. Mixing and melting hot slag and charging materials in continuously operating converters (in Russian). In: From domestic and foreign experience in glass industry, Issue III. Kyiv: Ministry of Building Materials of Ukraine; 1968. p. 5–9.
[9] Pioro LS, Bondarev KT, Mikhaylenko VI, Olabin VM, Rusin VI. Melting slag together with additives in the continuously operating converter (in Russian) Stroitel'nye Materialy (Building Materials) 1968;(8):20.
[10] Pioro L. Betriebsintensivierung der Bestehenden und Entwicklung von prinzipiell neuen Schmelzaggregaten (in German). In: International Congress on Glass, Praha, ČSSR, 1977. p. 408–17.
[11] Pioro LS. Leistungssteigerung existierender und entwicklung neuer schmelzaggregate. Energieanwendung 1978;27(2):61–6.
[12] Pioro LS, Osnach AM, Olabin VM. Converter type furnace for melting glass melts (in Russian). In: Proceedings of the Conf, Ministry of Light Industry, Institute of Glass and Fine Ceramic, Sofia, Bulgaria, 1981. p. 142–6.
[13] Pioro LS, Pioro IL. Wasteless combined aggregate—coal-fired steam-generator/melting-converter. Waste Manag 2003;23(4):333–7.
[14] Pioro LS, Pioro IL. Reprocessing of metallurgical slag into materials for the building industry. Int J Waste Manag 2003; in press.
[15] Pioro LS, Sadovskiy BF, Pioro IL. Research and development of a high-efficiency one-stage melting converter-burial method for vitrification of high-level radioactive wastes. Nucl Eng Des 2001;205:133–44.
[16] Sheppard LM. Progress continues in glass melting technologies. Ceram Indus 1996;146(1):18–20.
[17] Pioro LS. Fuel economy in glass making (in Russian) Kyiv, Ukraine: Naukova Dumka Publ, House; 1981. 140p.