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ScienceDirect

Ceramics International 40 (2014) 4351–4358

CERAMICS INTERNATIONAL

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Evaluation of potential applications of recycled moulding and core sands to production of ceramic building materials

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Received 28 May 2013; received in revised form 26 August 2013; accepted 26 August 2013
Available online 16 September 2013

Abstract

This study summarises the properties of ceramic materials containing used moulding sand, from processed and recycled mould and core mixes. The sand preparation procedure involves crushing and separation of metallic parts. Thus obtained substance acts as a substitute for natural quartz sand, commonly used as a leaning agent in ceramic plastic bodies to be formed into ceramic-based construction materials. The study summarises the basic functional parameters, structure and microstructure of ceramic materials made from plastic bodies containing variable qualitative proportions of used sand. The issues addressed in the paper include the potential threats associated with manufacturing and disposal of these types of materials. Potential hazards include atmospheric emissions of hazardous gaseous substances in the form of polycyclic aromatic hydrocarbons (PAHs) as derivatives of organic binders used for manufacturing of moulding and core sand mixes. These substances are formed in the process of combustion of ceramic products or can be produced when heavy metals are released from the ceramic matrix. This process can occur throughout the entire service life of ceramic products under the specific conditions. Applicability of used sand in this disposal scheme is well proved by good parameters of thus obtained ceramic materials and positive test results evidencing the absence of atmospheric emissions of hazardous substances and low-level leaching of heavy metals.

Keywords: Ceramic building materials; Leaning agent; Recycling mould and core sands; Polycyclic aromatic hydrocarbons (PAHs) emission; Heavy metal leaching

1. Introduction

The Polish foundry engineering sector typically uses about 1 million tons of good-quality natural silica sands. Silica sand acts as the quartz matrix and when mixed with other substances (binders, hardening agents and organic admixtures), the sand is used for preparing the moulding mix to obtain moulds and cores required for casting operations [1]. However, in typical processes, moulding sand and core sand can be used only once. In practice that means that when the casting process is over, the sand is treated as waste and dumped on open dumping sites, practically with no potential for their re-use in the production cycle [2,3]. This method of disposing of the used moulding sand has become a major environmental problem which might become even worse unless some action is taken promptly. On the other hand, used sand mix contains significant amounts of silica components, mostly β-quartz, so it seems reasonable to attempt to re-use it outside the foundry engineering sector. A good example here is the manufacturing of construction materials, particularly the technologies that require huge amounts of natural quartz sand. Depending on the type of construction materials, quartz sand can play a different role; in most cases it acts as the source of crystalline quartz [4]. Accordingly, duly processed used moulding sand might become an alternative for natural quartz sand [5,6] In order to be able to effectively recycle the used moulding and core mix to ensure their effective disposal and re-use, it is required that the original properties of natural quartz sand be brought back to the largest extent. The process must involve the crushing of aggregated portions of sand mix formed in the course of knock-out operations, without making the grains finer. Besides, metallic and non-metallic substances, the remnants of the casting operations, have to be removed. However, this method of sand mix processing does not remove the remainders of the binder agents, used for preparing

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http://dx.doi.org/10.1016/j.ceramint.2013.08.104

green mix, from the surface of the quartz matrix grains. Hence on the grain surface there is still a thin, adhesive and water-insoluble layer of the binder agent. That is why silica materials obtained from the moulding mix recycled in the manner described before can be used only in those manufacturing technologies that involve their heat treatment [7–13], At high temperatures the remainders of binder agents, particularly of organic origin, are oxidised and thus formed gaseous products shall be released to the atmosphere, together with the flue gas. The main products of the oxidation reaction are CO_2 and H_2O which are not particularly noxious, however there is also a possibility of atmospheric emission of dioxins and furanes, posing a threat to all living organisms. In the case considered here these substances come in the form of polycyclic aromatic hydrocarbons (PAHs) [14–18]. If the emission levels of potentially harmful products of oxidation of organic binders, mostly polycyclic aromatic hydrocarbons (PAHs), dioxins and furanes, do not exceed the admissible values, those sands might be well used in indicated applications [19,20]. Oxidation of such binders is accompanied by release of a specified amount of thermal energy, becoming and additional source of heat, which should reduce the fuel consumption required to heat a vast mass of feed materials to the specified process temperature. An example of such technology is manufacturing of ceramic construction materials, involving the use of silty minerals, mostly illite and montmorillonite [21]. On account of their mineralogical composition, these materials exhibit good plastic properties and demand huge amounts of process water to achieve the required consistence, adequate to the widely applied plastic forming methods. The presence of large amounts of process water prolongs the drying time, increases the unit costs of production, and what is more, leads to excessive shrinking during the drying, causing deformations and cracks to appear on semi-finished products being dried. All these are consequences of a negative feature of silty minerals, referred to as excessive sensitivity to drying. For that very reason, silty minerals displaying this property should not become the single components of plastic bodies used for manufacturing of ceramic construction materials. It is necessary, therefore, to use leaning additives. As their grains are much coarser than those of silty minerals, such materials lead to reduction of their plasticity and hence of the demand for process water. In the consequence, that reduces the shrinking and helps limit the tendency to defects during the drying process, which adversely affect the quality of finished products. A typical leaning agent, that has been used for that purpose, is natural quartz sand. However, according to the author's hypothesis, the potential leaning materials that can be added are the used moulding and core mix from the foundry processes, in which the amounts of crystalline silica exceeds 95% of their mass [1]. It is reasonable to recommend this group of waste products as the substitute of natural quartz sand in plastic bodies intended for production of ceramic construction materials. However, the re-use of waste moulding and core mix in manufacturing of this type of ceramic materials is possible only when the following requirements are met:

- in accordance with principles of sustainable development, manufacturing and use of ceramic construction materials made from recycled moulding mix should not negatively impact on the environment or the impacts produced must not be more serious than when traditional manufacturing technologies are chosen, and
- there is no deterioration of quality of ceramic materials obtained using the recycled materials when compared to materials manufactured from traditional components.

Except above mentioned also leachability of heavy metal ions is important feature if foundry wastes are used as raw material. Literature gives some data dealing with this subject [22–28] which points that leachability test should be performed for waste bearing materials.

2. Experimental

2.1. Design of the test procedure

The main objective of this study is to determine the characteristics of ceramic materials made from recycled moulding and core sand. The design of the research programme is based on the assumption that silica products from recycled moulding and core sand should act as substitutes for natural quartz sand, which typically plays the role of a leaning agent in manufacturing of ceramic construction materials [5]. The effectiveness of this approach is evaluated on the basis of a comparative analysis of key functional parameters and microstructure analyses of the two types of ceramic products: the reference material and experimental products differing in quality of the recycled materials. Further evaluation of reused moulding and core mix as alternatives for natural quartz sand involves the analysis of potential environmental impacts associated with manufacturing and use of ceramic building materials containing used sands. That is why a qualitative EGA-evaluated gas analysis is performed of the gaseous phase emitted to the atmosphere during the burning of ceramic materials. Besides, the authors tested the leaching of selected heavy metals, which might potentially get released from the ceramic matrix during the entire service life of ceramic components.

2.2. Materials

The main components of ceramic products, both the reference and experimental material mixes, is silty mineral in the form of Tertriary Krakowiec clay (IKK). The conventional leaning agent in component mix to prepare the reference material is the natural quartz sand (PK-GL). This sand is used to obtain the moulding and core sand in the foundry plants which later provided the used moulding and core sand for the purpose of the research programme. In the case of experimental products, natural sand is replaced by an equivalent amount of silica material from the processing of used mould mix from different foundry plants, using different production technologies and different binders to prepare the fresh sand mix.

Particular batches of ceramic products used in the experimental programme contain four types of recycled materials