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Possible use of waste olivine powders from a foundry process into the ceramic industry: Sintering behaviour of olivine, kaolin and their blends

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Abstract

The present basic research aims to evaluate the possible recycling of olivine, a by-product of a foundry process, into the ceramic industry. With this goal in mind, olivine powders (*O*) were milled alone or blended with 20, 40, 60 and 80 wt% of a high grade kaolin (*K*) by attrition milling to obtain powders of different composition. Samples made with *K* alone were also prepared as blank composition. All mixtures were dried, sieved, uniaxially pressed into specimens and air sintered for 1 h at temperatures ranging from 1100 to 1400 °C. The resulting materials were characterized by water absorption, shrinkage and phase composition in order to test their sintering behaviour. It was observed that all compositions, sintered below 1100 °C display high open porosity, but enter into the final sintering stages between 1150 and 1200 °C as a function of their compositions, when their water absorption lowers below 5%.

Keywords: Olivine; Kaolin; Sintering; Traditional ceramics

1. Introduction

Foundry sand is a natural raw material used by foundries to create molds or cores particularly for casting iron based alloys. The criteria for foundry sand selection vary with the type of casting process employed by a given foundry (i.e., type of alloys produced) and include refractoriness, permeability, bond strength, grain fineness and chemical reactivity which are determined by grain shape, grain size, clay and moisture content and others.

Ideal foundry sands are generally subangular in shape which allows individual grains to interlock and form good molds while providing necessary pore spaces for superheated gases to escape without breaking the mold during the casting process. Grain size affect mold permeability and the finish of the casted part. A suitable grain size distribution for foundry sand is centred on U.S. Standard Sieve 70 (212 μm), with very little sand being retained on sieve sizes lower than 30 (590 μm) or greater than 140 (105 μm). It follows that any commercial sand supplied to a foundry and there stored, must be de-pulverized before its use for molds preparation in order to cut off its finest fraction. This fine sand part turns into a by product, although not a real waste, and needs to be used as raw material in any other production process rather than an eventual landfill disposal.

Foundries generally use high quality quartz sands for their molding preparations which are of a higher quality with respect to the typical bank run or natural sands used in fill construction sites; their finest fraction, cut off by the de-pulverization process, is presently used for the production of special cements [1–3], additional component for concretes [4,5] or starting material for glass or other ceramics preparation [6,7] and others [8–10].

On the other hand, for the production of manganese containing steels parts, it has been demonstrated that quartz sand needs to be replaced by *O* sand in order to reduce the reaction between quartz particles and the metal

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under casting [11]; also *O* sands must display a restricted grain size distribution because particles must fall into a range of acceptable values and therefore must be de-pulverized before its use in molds preparation. *O* fine powder is therefore a non ordinary by product which would require a possible valuable application as component raw material of another production process.

Concerning quartz sands, many papers document their use as component for the production of some ceramic wares [12,13], conversely, the use of Mg containing silicates such as forsterite or cordierite is widely documented [14–17], but that of olivine or olivine containing powders is presently confined to the production of some special refractory bricks [18,19] or particular glazes for tiles [20].

The aim of present research is to study the sintering behaviour of *O* fine powders alone or mixed, in different proportions, with a high grade *K* in order to evaluate its possible recycling into the production of ceramic materials. With this goal in mind, powders of each composition, pressed into several specimens, were fired at different temperatures for 1 h, then shrinkage and water absorption were measured in order to build up their sintering curves; crystal phases were investigated as a function of the sintering cycle.

2. Materials and methods

The *O* powder used in the present work is a by product of a foundry process devoted to the production of a high manganese steel. Before molds preparation, *O* sand needs to be de-pulverized in order to cut off particles with size below 20 μm. The resulting *O* powder was used, in the present research, alone or blended with 20, 40, 60 and 80 wt% of a high grade *K*. Samples made with *K* alone were also prepared as reference composition. Symbols used for samples identification are, respectively *O*, OK20, OK40, OK60, OK80 and *K*.

The particle size distribution (PSD) of the as received *O* and *K* powders are reported in Fig. 1 which also displays that of a blend after the attrition milling process.

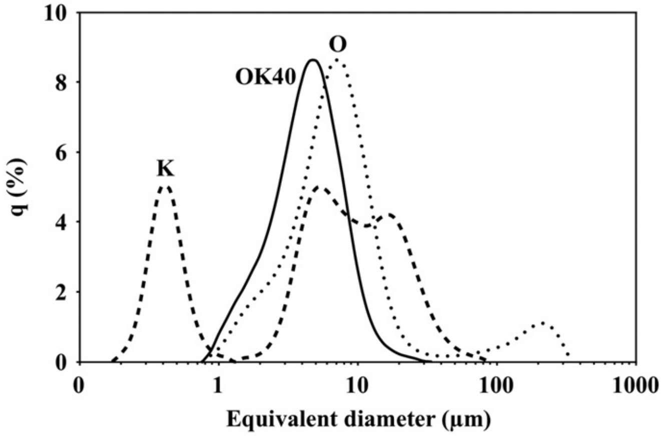

Fig. 1. Particle size distribution of the as received olivine (*O*) and kaolin (*K*) powders and that of the blend OK40 after the attrition milling process. Curves are represented with logarithmic abscissa.

The chemical composition of the above raw materials, obtained by a Spectro Mass 2000 induced coupled plasma (ICP) mass spectrometer, is reported in Table 1 which also displays lost on ignition (LOI) after a thermal treatment at 1000 °C for 2 h.

Table 1
Composition (wt%) and LOI (%) of kaolin (*K*) and olivine (*O*) used as starting materials in the present study.

Component	Kaolin	Olivine
SiO_2	47.20	41.35
Al_2O_3	36.84	0.96
CaO	0.05	1.08
MgO	0.09	45.65
Na_2O	0.08	< 0.01
K_2O	1.10	< 0.01
Fe_2O_3	0.34	–
FeO	–	6.61
Cr_2O_3	< 0.01	0.19
TiO_2	0.31	< 0.01
NiO	< 0.01	0.27
MnO	< 0.01	0.06
P_2O_5	0.28	< 0.01
$SO_4^=$	0.08	< 0.01
Cl^-	0.14	< 0.01
Undetermined	1.19	0.73
LOI	12.30	3.10

O alone, *K* alone and all the blends (70 g of powder for each preparation) were homogenized by attrition milling for 1 h in a home made instrument. Milling parameters are as follows: high-density nylon container (volume = 750 ml); 500 g of 99 wt% alumina balls (diameter = 6–8 mm); 150 ml of distilled water; 300 cycles min^{-1}. At the end of the milling process, slurries were oven dried for 24 h at 80 °C. After milling, PSD was evaluated using a Horiba LA950 laser scattering PSD analyzer: analyses were made in water after a 3 min sonication time. For clarity of comprehension PSD curves are represented with logarithmic abscissa, as it is commonly done for the presentation of this type of results. Dried powders were sieved (200 μm–70 mesh) and uniaxially pressed at 100 MPa into cylindrical specimens ($\Phi = 27$ mm, $h = 4.5$ mm). Density of green samples was determined by the ratio between weight and volume which was evaluated by a caliper. Reported data are averaged over three measurements. Sintering experiments were performed in air, by an electric muffle, at several temperatures ranging from 1100 to 1350 °C with intervals of 50 °C using heating and cooling rates of 10 °C min^{-1} and a dwell time of 1 h.

Shrinkage on firing was evaluated, by a caliper, along the diameter (27 mm on green specimens) using the ratio $(\Phi_0 - \Phi_1)/\Phi_0$ (subscripts 0 and 1 refer to the sample dimensions before and after the sintering), whereas water absorption was determined following the norm EN99; in line with this norm, fired samples were first weighed in air (W_1), then placed in a covered beaker and boiled in