RHEOLOGICAL PROPERTIES OF ALUMINA CERAMIC SLURRIES FOR CERAMIC SHELL-MOULD FABRICATION

Joanna Szymańska, Pawel Wiśniewski, Marcin Malek, Jaroslaw Mizera
Warsaw University of Technology, Faculty of Materials Science and Engineering, Wołoska Street 141, 02-507 Warsaw, Poland
joanna.szymanska.pl@gmail.com

This research is about the properties of ceramic slurries prepared from hydrous nano-alumina-based binder and a corundum matrix used for fabricating the prime coat of ceramic shell moulds. Solid-state alumina powders with different granulations were used. The modification of the technological properties of the prepared slurries was based on additions of a polyacrylic binder with different amounts of polymer with respect to the alumina for different powder ratios. The slurries were prepared and tested in a mechanical mixer. During the slurry preparation (within 96 h), the plate weight, Zahn cup 4# viscosity and dynamic viscosity were controlled. The morphology and chemical properties of corundum powders and polymer were characterized with SEM and powder-grain-size distribution. The obtained results of the corundum-based ceramic slurries indicate that the application of a polymeric binder with various concentrations based on nano-alumina oxides causes different properties in comparison to the other commonly used binders.

Keywords: ceramic slurries, investment casting, shell moulds, alumina powder

1 INTRODUCTION

The investment-casting process is commonly applied in the manufacturing of the materials for the aviation, energy and military industries. The limiting components (flight safety parts) such as aircraft turbine blades characterized by complicated shapes are cast with the Bridgman method. A commonly applied technique is the lost-wax processing including the use of ceramic shells. It determines the precise shape, dimensional accuracy, appropriate structure and metallurgical purity of designed parts. So far, ceramic shell moulds were fabricated on the basis of colloidal silica. However, the presence of SiO₂ in the prime coat during the Ni- or Co-superalloy casting causes a reaction with the liquid metal at a high temperature, inducing an oxidation of the reactive metal such as Hf. Such an adverse phenomenon reduces the quality of the properties of cast parts, affecting its exploitation time.

The basic components for a ceramic slurry are binders and fillers in the form of ceramic powders and supportive materials. A commonly used binder is hydrolyzed tetraethylorthosilicate together with organic compounds of silicon. However, pure ethyl silicate does not have the binding capacity. Water-based binders dry more slowly than alcohol-based ones. Consequently, there is a time elongation enabling the control of the surface smoothness, permeability, strength and dimensional stability of the model.

A proper selection of powder for ceramic shell moulds and their parameters such as the kind, shape and size of particles affect the final characteristics of the cast elements. Ceramic powders present a thermal resistance, a slight thermal expansion and a lack of polymorphic transitions.

Deflocculants, softeners and surfactants mainly determine the rheological properties of ceramic slurries.

It was found that a nano-Al₂O₃-based binder does not react with Ni-alloy components. Moreover, such a binder demonstrates a higher melting point and a larger surface area than other inorganic solvents. It is also characterized by an improved dispersion of the particles in water, thus allowing the control of rheological properties by preventing the sedimentation of heavy particles in a ceramic slurry. This is why such a binder can be applied instead of the colloidal silica-based binder.
The main aim of the following research was to examine and define the properties of a nano-aluminum-oxide-based binder and a corundum matrix using a polymeric binder with various concentrations.

2 MATERIALS AND EXPERIMENTAL METHODS

The subject of this research was a powder of Al$_2$O$_3$ with granulation of 0–30 and 200 mesh (Treibacher) characterized by the average size of 11.79 and 45.00 μm, respectively. Solvent, binder and a hydrous polymer were dispersed in colloidal Al$_2$O$_3$ with a particle size of 16 nm (Imerys, Evonik). The additive material applied to modify the rheological properties of the slurry was a poly acrylic polymer (Imerys, Evonik).

Ceramic slurries with a solid phase content of 72.5 % by weight and polymer amounts of (6, 10, 15) % mass fractions with respect to the alumina for different powder ratios of 35:65 and 65:35 (200:030 mesh) were prepared in a mechanical mixer within 96 h with a speed of 160 min$^{-1}$. During the slurry preparation, the pH (with the use of a pH meter), plate weight and Zahn cup 4# viscosity were checked every 24 h. These measurements are fundamental for the investment-casting industry. After 96 h of mixing, rheological properties such as dynamic viscosity were also defined with a Brookfield DV-II rheometer with the spindle rotating in a speed range of 1–200–1 min$^{-1}$. All the measurements were taken in an air-conditioned lab at 21 °C.

To characterize the morphology of the corundum powders and the polymer, SEM images were taken with a Hitachi SU70 scanning electron microscope and a BSE detector at a voltage of 5 kV. A particle-size test was done using a Horiba LA-950 laser diffraction device (Hitachi, Japan).

The plate test was based on immersing the plate (7.5x7.5 cm) in the moulding mass and estimating its weight after 120 s.

3 RESULTS AND DISCUSSION

The morphology of the powder based on the SEM analysis of #200 and #0–30 indicated typical structures of molten powders with angular-shaped particles.

The obtained results shown on Figure 1 prove that the lowest plate values correspond to 6 % of mass fractions of the polymer content for a powder ratio of 35:65. The largest ones were noticed for the slurries with 6 and 15 % of mass fractions of the polymer content at a proportion of 65:35. The highest plate stability was obtained for the slurries with 15 % of mass fractions of polymer addition (65:35) and 10 % of mass fractions of polymer content (35:65). The values of the plate weight controlled on the last days of the measurements were in a range of 1.7–2.4 g. The measurements of the plate weight revealed a correlation with the polymer content: a 6 % of mass fraction of the polymer addition resulted in the highest weight value, equal to 2.40 g; this value was slightly lower in the case of a 15 % of mass fraction of the polymer content and the lowest for a 10 % of mass fraction of the polymer amount.

Zahn Cup 4# measurements showed (Figure 2) the lowest values (13–15 s) for the slurry with the 6 % of mass fraction of the polymer at the 35:65 ratio. The highest viscosity was noticed for the slurry with the 15 % of mass fraction at a powder ratio of 65:32. In this case, there was also a rapid viscosity change from 32 s (noticed on the first day) to 21 s after 96 h. The viscosity was stable during the whole ceramic-slurry preparation process for 6 (at 65:35) and 10 % of of mass fractions (at 35:65).

The obtained results shown on Figure 3 indicate stability of all the measured slurries within the measurement time. The lowest values were noticed for the slurries with 10 % of mass fractions of the polymer content at the 65:35 ratio and for 6 of % of mass fractions of the polymer addition at the 35:65 powder proportion. The thickness values estimated after 96 h oscillated from 0.12 to 16 mm. Moreover, the slurries...
with 6 and 10 % of mass fractions of the polymer content were characterized as similar according to the viscosity level.

The measurements of the ceramic-slurry dynamic viscosity are shown on Figures 4 to 6 where the relationship between the shear rate and viscosity is presented. As seen on the diagrams, additions of different concentrations of polymers to the ceramic slurries of Al₂O₃, with two powder ratios, determine their viscosity. The obtained results indicate that the application of 10 % of mass fractions of polymer at the 35:65 powder ratio causes the largest increase in the dynamic viscosity where the maximum value is 763 MPa s. The most effective was the addition of 6 % of mass fraction of polymer at the 35:65 powder ratio resulting in the lowest dynamic-viscosity value of 321.12 MPa s.

4 CONCLUSION

The Al₂O₃ powder characterized by irregularly shaped particles with sharp edges demonstrates the ability to agglomerate, resulting in a non-uniform particle-size distribution. The Zahn cup viscosity (7.35 s) is slightly larger in comparison to water viscosity (5.83 s), thus the Al₂O₃ particle dispersion in the binder is facilitated.

In addition, a relatively large content of the solid phase in a slurry reduces the coat shrinkage during the drying process and enhances its strength. The properties of the coating surface may be improved by increasing the plate weight. An addition of a poly acrylic polymer at the lowest content to the alumina powders with various granulation values allows a regulation of the rheological properties of the ceramic slurry towards more effective ceramic shell-mould fabrication.

The investigated slurries show standard features in the investment-casting process on an industrial scale. They are prospective for future shell-mould fabrication.

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