Journal of Materials Processing Technology 220 (2015) 107–112

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Ceramic cores for turbine blades via injection moulding

Magdalena Gromada[a,*], Adam Świeca[a], Marek Kostecki[b], Andrzej Olszyna[b], Rafał Cygan[c]

[a] Institute of Power Engineering Ceramic Department CEREL, Research Institute, 1 Techniczna St., 36-040 Boguchwała, Poland
[b] Warsaw University of Technology, Faculty of Materials Science and Engineering, 141 Wołoska St., 02-507 Warsaw, Poland
[c] WSK "PZL – Rzeszów" S.A., 120 Hetmańska St., 35-078 Rzeszów, Poland

ARTICLE INFO

Article history:
Received 26 August 2014
Received in revised form 9 January 2015
Accepted 14 January 2015
Available online 22 January 2015

Keywords:
Ceramic core
Injection moulding method
Gas turbine
Turbocompressor

ABSTRACT

The proposed injection moulding method to produce ceramic cores of turbine blades required the selection of raw materials and the thermoplasticiser as well as the determination of the optimal processing conditions. The selected material enabled the formation of cores with a small cross-section area and was characterised by low shrinkage as well as a relatively low coefficient of thermal expansion. The high mechanical strength of the material allowed for the cores to be formed in a wax model and their assembly in a foundry mould; in addition, the appropriate porosity of the cores ensured their easy etching by means of a water solution of bases. The cores were characterised by high dimensional precision and negligibly small shape deformation. The usability of the cores was positively verified in the process of turbine blades casting in production conditions.

1. Introduction

Ceramic cores are utilised for shaping internal cooling canals in the process of turbine blade casting, which positively influences the turbine engine efficiency. The aim of the hollow spaces inside of the blades is to provide cooling during turbine engine operation, allowing for the temperature increase of the working gases; in addition, the hollow spaces decrease the weight of the blades, which reduces the load of the drive shaft. Obtaining such precise shapes inside the blades during the casting process is only possible by using special 'near net shape' ceramic cores. To satisfy these requirements, the material for the cores should be characterised by the following properties: possibility of the complex shape forming, low shrinkage during forming and sintering, small surface roughness (enabling good mapping of internal blades canal after their casting), and low coefficient of thermal expansion (ensuring resistance to thermal shocks and dimension stability of the cores at the temperature of their casting in liquid alloys). Moreover, the developed material must often satisfy contrasting requirements, for example, a high mechanical strength (that allows the cores to form in the wax model and their assembly in foundry moulds) with the apparent porosity of the cores reaching 35% (allowing for their relatively easy etching by means of a basic water solution). To satisfy these requirements, in this paper, the high pressure injection moulding method was applied, which enables the formation of cores of very complicated shapes and high dimensional precision.

Soykan and Karakas (2001) stressed that the ceramic powder injection moulding method is used to form complicated elements with shapes that are very close to actual products in mass production at a competitive cost. As was stated by Karatas et al. (2004), this technique is mostly utilised for producing fine shaped pieces with a relatively small cross-section. Park et al. (2001) consider this method as competitive in comparison with casting and mechanical machining. However, according to Zauner (2006), this technique is quite demanding because it generates a wide range of defects, beginning from cavity filling to binder removal and sintering. Krug et al. (2001) confirmed that the wider industrial implementation of the injection moulding method requires high quality standards and low rejection rates.

Thomas and Marple (1998) indicated that the process of ceramic powder injection moulding that has been developed from the injection moulding approach used for the shaping of plastics is quite complicated because of the presence of additional steps after forming. They confirmed that to remove the thermoplasticiser and to densify and strengthen the shaped pieces, the process of heat treatment is applied alone or in combination with other processes.

Wang and Hon (1995) described the process of the fabrication of ceramic cores for single crystal casting. They emphasised that the application of thin and delicate ceramic cores has an influence on the efficiency of turbine engines. The properties of ceramic cores must be finely balanced to produce acceptable dimensions in the blade cast. Wang and Hon (1995) reduced the list of possible

* Corresponding author. Tel.: +48 17 87 20 226; fax: +48 17 87 11 277.
E-mail address: gromada@cerel.pl (M. Gromada).

http://dx.doi.org/10.1016/j.jmatprotec.2015.01.010
0924-0136/

ceramic materials to only a few candidates (fused silica, zirconia, and alumina) due to the required chemical solubility.

Recently, a few papers were published regarding the material composition for ceramic cores fabrication. Kazemi et al. (2014) investigated the effect of the zircon content on the mechanical and chemical behaviours of injection moulded silica-based ceramic cores. Kazemi et al. (2013) presented the results of the crystallisation of fused silica and its effects on the most important properties of injection moulded silica-based ceramic cores, including the flexural strength and leachability. Qin and Pan (2009) prepared a series of alumina-based ceramic core nanocomposites by adding silica-sol to an alumina matrix and using the in situ synthesis method. The microstructure and the effect of silica sol on the properties of alumina-based duplex ceramic cores were discussed.

Also new technologies were applied for the fabrication of ceramic cores used in the casting of blades. Kim et al. (2013) presented a new process that consists of the development of a mixture of an inorganic precursor composed of silicate and metal alkoxide; the prepared ceramic core was found to exhibit reasonable strength without shrinkage and shape deformation. Wu et al. (2009) developed a rapid prototyping process to fabricate complex-shaped alumina-based ceramic cores by combining stereolithography with gelcasting. To decrease the drying shrinkage, the conventional air drying process was substituted by the freeze drying one. In addition, the mineraliser in the form of magnesium oxide power was added, which minimised the sintering shrinkage of the cores to below 0.5%.

The aim of this paper was to develop a manufacturing technology for the entire process of the fabrication of ceramic cores that satisfies all of the above-mentioned requirements to be applied in high precision blades. The developed technology, because of its efficiency, can be applied at industrial scale.

2. Materials and methods

In this paper, for the precise fabrication of cores, the injection moulding method was applied, which consists of four basic stages: preparation of feedstock, element formation, binder removal, and sintering. The powder composition and its particle size distribution were developed to ensure the appropriate density of material after sintering. The particle size distribution of raw materials and input powders were determined using Mastersize 2000 from the Melvern Company. Table 1 presents the composition of eleven materials fabricated for the injection process. The fused silica or quartz glass are the basic raw materials for cores, which are characterised by a low coefficient of thermal expansion, sufficient refractoriness, resistance on thermal shock, very good chemical inertness and very high softening temperature. The difference between the quartz glass and the fused silica (SiO_2) is in the phase composition. The quartz glass has a relatively small content of an amorphous phase in relation with the crystal one, while the fused silica contains almost entirely the amorphous phase. The boron glass serves as an agent allowing for the better sintering of cores. At the sintering temperature, the boron glass passes in liquid phase and attracts grains of other raw materials, which causes the increase of sintering stage of material and in turn increases the mechanical strength. The quartz and boron glasses are added as powders. The particle size distributions of these powders are presented in Fig. 2; the average particle sizes (d_{50}) are equal to 31.1 μm and 27.0 μm for the quartz and boron glasses, respectively. The modifying compounds $ZrSiO_4$ and Al_2O_3 were chosen to decrease the value of sintering shrinkage of ceramic cores and improve the dimension stability during cores casting with liquid alloys. The application of water soluble thermoplasticiser Siliplast HS enables the mould powder elimination in the process of binder removal from cores, which has a positively influence on quality of external surface of cores.

Fig. 1. The two types of ceramic cores for the turbine blade.

The feedstocks were prepared in a GC-MIX-12/13 heated mixer, where the powder and the thermoplasticiser were kneaded at 160 °C to the moment of reaching the homogenous consistence. Next, for the sake of the worm geometry of the injection moulding machine, the obtained material was crushed to the granule size in the range of 1.5–4 mm.

In the stage of the formation of elements, two moulds were designed and executed. The first mould with two cavities enabled the formation of beams of a diameter of 6 mm and length of 60 mm. After sintering, these beams served to determine the materials shrinkage, the density, the bending strength, the coefficient of thermal expansion, and the roughness of the surface; the beams were also used in tests of material etching in a basic water solution. The second mould with two cavities for two types of experimental core shapes enabled the examination of small cross-section formation. The experimental cores had a length of over 30 mm and a minimal cross-sectional area of only 5 mm^2. Fig. 1 presents a photo of the two types of ceramic cores for the turbine blade.

The selection of injection parameters contained many variables, including temperature, pressure, velocity, volume and time. The improper setting of even one parameter brought the appearance of defects in elements. The mould temperature and dwell time of semi-products were found to have a significant influence on the deformation of the shaped pieces. The forming process was performed on a BOY XS injection moulding machine with a closing force equal to 100 kN, a maximal volume of injection of 6.1 cm^3 and a maximal pressure of injection of 230 MPa.

The last two stages of the injection moulding process include the thermoplasticiser removal from the shaped pieces and their

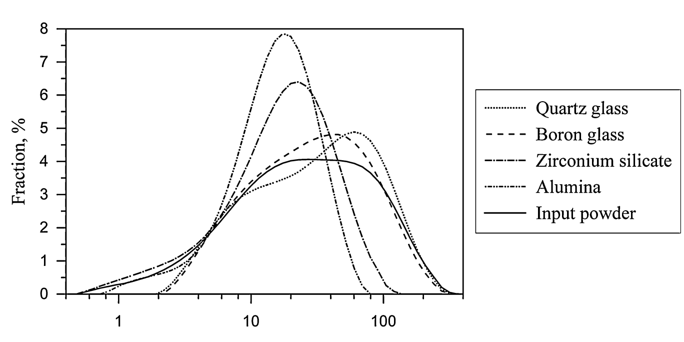

Fig. 2. The particle size distribution of the input powder and the applied raw materials.