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OPTIMIZED CERAMIC SHELL FOR MANUFACTURING OF ALUMINIUM CASTINGS USING LOST WAX TECHNOLOGY

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Abstract: The presented paper is focused on the optimization of the ceramic shell for pouring thin walled aluminium castings by investment casting technology. The main objective is firstly to find the optimal binding system (ceramic slurry) and stucco materials for the shell and secondly its optimal structure and heat treatment (drying of each coat and final shell firing) prior to metal pouring. The paper deals with a complete technological process focusing on production and quality control of the ceramic shell and slurries. The main goal of this research is the implementation of the achieved results into practice and thus to increase the foundry chances to address customers from aircraft, aerospace, defense and similar hi-tech industries.
Keywords: Lost - wax technology, investment casting, ceramic shell, ceramic slurry, refractory material

1. INTRODUCTION

Investment casting technology ("lost wax") is among the advanced foundry technologies enabling to achieve both very narrow dimensional casting tolerances (so called "net shape technology") and also very complex casting shapes. This allows using materials which cannot be produced by other economically advantageous technologies or their production is impossible. Nowadays the range of castings is growing rapidly and also demands on dimensional tolerance, surface quality and materials are increasing. All this leads to the development of new technologies, materials and direct, efficient and economical manufacture. Applications for castings made by lost wax technology are enormous, however also competitive technologies to lost wax are evolving, therefore only foundries using the latest technology of lost wax process have chance to be successful in producing high quality castings, complex shapes and very high dimensional accuracy [1].

The whole concept of the research join project of Fimes, a.s. (aluminium investment casting foundry in Uherske Hradiste) and Brno University of Technology is focused on development of ceramic shell for large, thin-walled, high quality aluminium castings for aircraft, aerospace and hi-tech industries. Production of high quality aluminium castings brings high demands on the technology of the process where the ceramic shell is very important. When appropriate materials are not used and the correct procedure of production is not followed, a quality shell or cast cannot be achieved.

2. PRINCIPLE OF LOST WAX TECHNOLOGY

The process of investment casting includes wax pattern production on injection machine where wax is injected into a die and finished wax patterns are assembled. Ceramic shells are made by dipping the wax pattern assemblies into ceramic slurry, applying granular stucco materials and drying. Then the shells are ready for de-waxing and firing. Subsequently, metal is poured into these fired shells. After all these operations, the ceramic shell is removed, the castings are separated from a gating system by cutting, surface cleaning such as blasting, grinding and polishing and heat

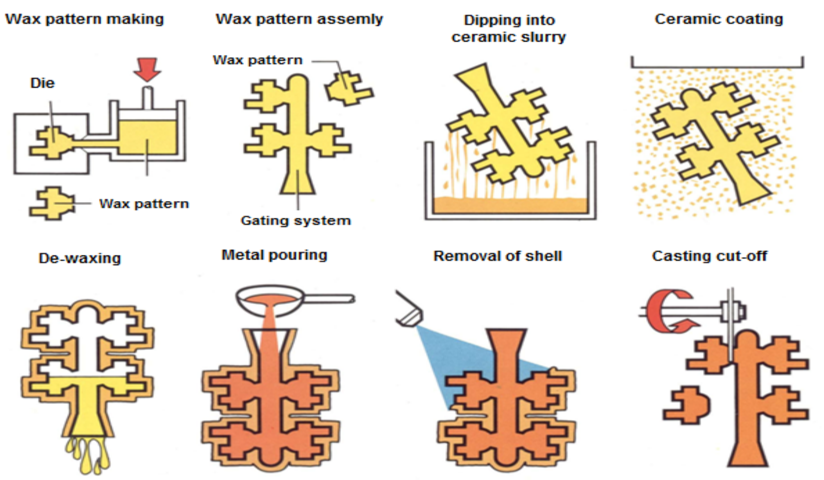

Figure 1: Principle of lost wax technology [3]

treatment. A quality inspection of castings include a chemical composition and structure, internal and surface quality, dimensional accuracy and mechanical properties like hardness, tensile strength, ductility, etc. [2]. The process of lost wax technology is shown in Figure 1. The phases of ceramic shell manufacture are further elaborated in the following sections.

3. CERAMIC SHELL MANUFACTURE

A ceramic shell is built up around a wax pattern assembly. This procedure involves the application of a number of separate layers, usually between five and fifteen, according to the required strength of the shell, refractory material and alloy. Each layer is produced by immersing the pattern assembly into ceramic slurry. Before the coating has dried, the surface is sprinkled with a coarse ceramic refractory grid. The assembly is manipulated to ensure that all surfaces are covered as evenly as possible. The grid adheres to the wet ceramic coating, which is then hardened before repeating the operations and thus building up the shell thickness layer by layer [2], [3].

3.1. Dipping into ceramic slurry

A ceramic slurry determines the basic properties of ceramic shells; it consists of filler of suitable size suspended in a liquid binder and other liquid components such as water, wetting agent and antifoam [3]. The first step how to prepare the ceramic slurry is to select a formula. An important parameter is the kind of cast metal and if the slurry is used for primary or back-up coats. The proper formula with improper preparation gives poor results. Slurry is mixed when each refractory particle is completely wet with binder solution (no air between refractory particles and binder) [4].

3.2. Stucco applied with the ceramic grit

Dipping the wax assembly in ceramic slurry and draining is followed by sprinkle with stucco (refractory material) of appropriate granularity. The first two coats, which determine the surface quality, refractory materials are used with a grain size 0.175-0.25 mm and the other coats with a grain size 0.25-0.5 mm because of better permeability [3].

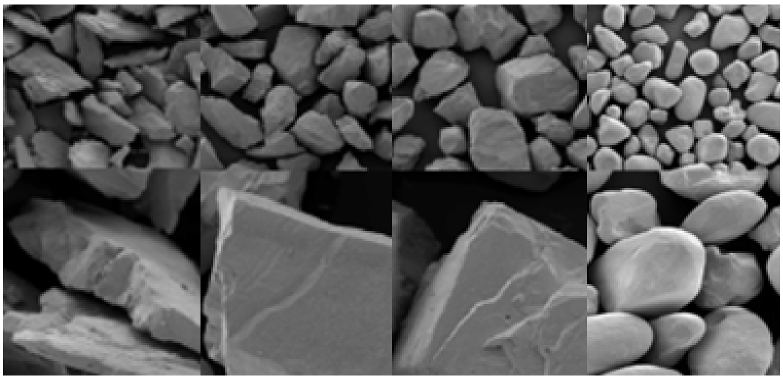

Figure 2: Particle shape analysis of refractory materials [6]

Refractory materials (Figure 2) are inorganic non-metallic materials used as flour in the ceramic slurries and stucco. Refractories are able to resist the high temperatures, abrasion, corrosion, pressure and thermal shock. A large temperature difference will develop across the thickness of the shell during de-waxing, shell burnout and casting. The ability of the shell to withstand this temperature difference without cracking is known as thermal shock resistance. This resistance is a combination of material properties; thermal expansion, thermal conductivity, and elastic modulus. To select a suitable refractory material, the important properties are e.g. high heat resistance, low thermal expansion and resistance to molten alloy. Only material contained in the primary coat has to comply with the minimal reaction with molten alloy [5], [6], [7].

3.3. Ceramic shell dryig

Dipping and applying the stucco is followed by drying. Solidification of individual coats of which the shells are composed is done by evaporation of water from the ceramic slurry (transformation of the sol into a gel) or by treatment with a chemical agent. Alcohol-based slurries offer rapid hardening via exposure to ammonia whilst water-based slurries require longer drying periods between coats [2].

3.4. Ceramic shell de-waxing

De-waxing is used to remove the wax pattern assembly from the completed ceramic shell mould without the risk of damage [2].

3.5. Ceramic shell firing

The ceramic shell has to be fired before casting. There are three reasons for firing the green shell before casting: sinter the structure of the ceramic, remove residual pattern material and present the ceramic shell for casting at a predetermined and consistent temperature. To ensure the required mechanical properties, temperature has to reach more than 800°C, generally from 900 to 1100°C, depending on the nature and characteristics of the furnace and ceramic shell. The nature of refractory material allows casting into moulds preheated to temperatures as high as 1550°C. Because of this, the ceramic moulds can be used for a very wide range of alloys and casting techniques [2], [3].

The fired temperature of ceramic shells for aluminium alloys are often below the minimum of the required temperature, which ensures adequate mechanical properties. At such low temperatures, all reactions have not been finished. The consequence is a low strength of ceramic shell which is usually lower than before firing. Therefore it is necessary to select a material which is able to provide sufficient strength for de-waxing and pouring.

4. ANALYSIS OF THE CERAMIC SHELL

The aim of the experiments was to suggest an optimal ceramic shell and technology of the process for large, thin-walled aluminium castings for the foundry Fimes, a.s. In the first step, a detailed laboratory analysis was proposal of ceramic shell made in the Fimes, a.s. including a proposal to optimize the technological process and material recommendations. According to these results, a combinations of viscosity of ceramic slurry and refractory materials as a flour and stucco were tested. All analyses have been done in laboratory C.A.R.R.D. of IMERYS. The selected formula of ceramic shell was subsequently tested in pilot conditions in the foundry. On the basis of these measurements, an optimal variant of ceramic shell mould which was established into operation was chosen.

4.1. Slurry control

Control of these processes affects shell thickness, cover properties of ceramic slurries, destabilization of binders and ensures optimum properties of ceramic shell.

A series of individual tests was performed on several types of slurries, from which three primary slurries were selected containing binder Primecoat and flours Molochite 325#, Mulgrain 60 325# and two sizes of Molochite 120# and 200# in a ratio 50/50. These were mixed in closed barrels all the time. Following the Fimes procedure, viscosity was used as a leading parameter. For better evaluation of behaviour of ceramic slurries, several tests were executed such as viscosity test, plate weight, pH, density. The most interesting is a plate weight test which serves as a main indicator of surface coverage and adhesion to the wax pattern. Despite using the same binder and setting the slurries to the same viscosity, Molochite and Mulgrain gave very different slurry parameters (Figure 3). Based on these tests, four Mulgrain was selected for primary slurry.

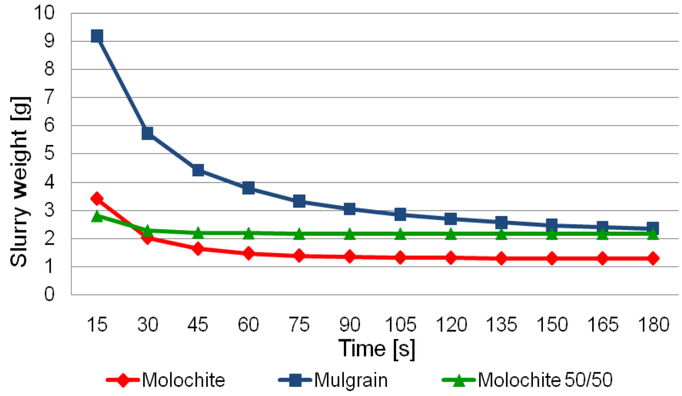

Figure 3: Plate weight curves of primary ceramic slurries

4.2. Shell testing

Tests used to characterize shell properties show the behaviour of shells at ambient and higher temperature using different types of refractory materials.

Ceramic shells were tested to obtain various properties such as strength, permeability, thermal expansion, etc. The structures of ceramic shells were assessed using a scanning electron microscope. Micro-structural analyses of shells show an overall appearance of the shell, compactness, the amount of porosity, thickness of the layers and the ability of slurry to penetrate into grains. Any changes in the technology of this process are immediately reflected in the structure. Laboratory tests showed that the shells based on Molochite material had a very good strength, permeability, structure and low thermal expansion, which provides dimensional stability of the mould.

4.3. Evaluation of laboratory tests

Based on the results of laboratory tests and pilot tests in foundry Fimes, a.s., an optimal ceramic shell and technology of the process was suggested for large, thin-walled, high quality aluminium castings. A newly developed ceramic shell (Figure 4, Figure 5), compared to the previous shell, and has a significantly better properties (Figure 6, Figure 7). Porosity was reduced in the intermediate layers of the shell. Along the whole length of the shell, equal thickness of the second and third layers is maintained, even in the corner (Figure 8). Low porosity in this case is helpful to better conduct the gases away during de-waxing and pouring. At higher magnification (Figure 9) no stucco impingement occurs and the stucco grains are not too far from the surface. Mulgrain 60 leads to a denser face coat than Molochite (Figure 7). A much higher filler load and more compact/round shaped particles may be responsible for that.

Material composition of the newly developed shell:

» Primary coat
  Binder: Primcote
  Flour: Mulgrain 60 325#
  Stucco: Molochite 50-80 DD
» Backup coats
  Binder: Remasol SP Ultra
  Flour: Molochite 200#
  Stucco: Molochite 30-80 DD, 16-30 DD

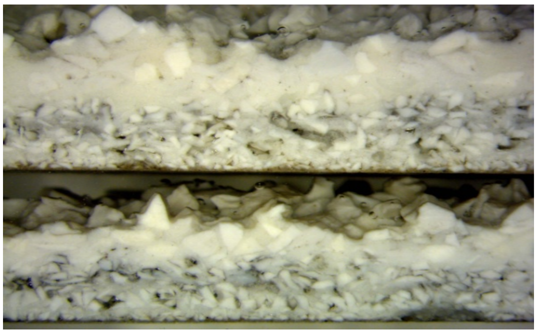

Figure 4: The real view of a ceramic shell sample (Courtesy of C.A.R.R.D., Austria)

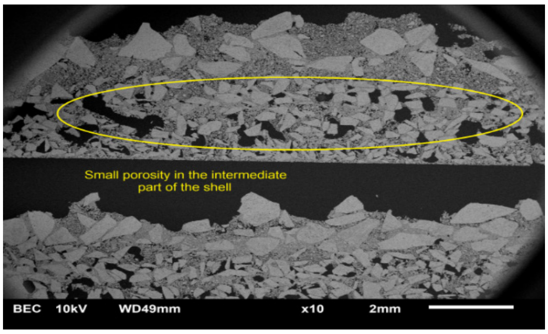

Figure 5: SEM picture of newly developed ceramic shell (Courtesy of C.A.R.R.D., Austria)

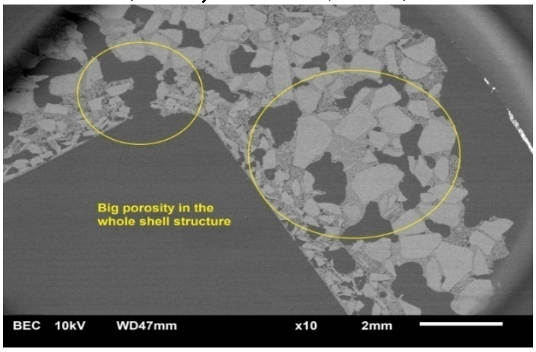

Figure 6: SEM picture of a full Molochite ceramic shell (Courtesy of C.A.R.R.D., Austria)

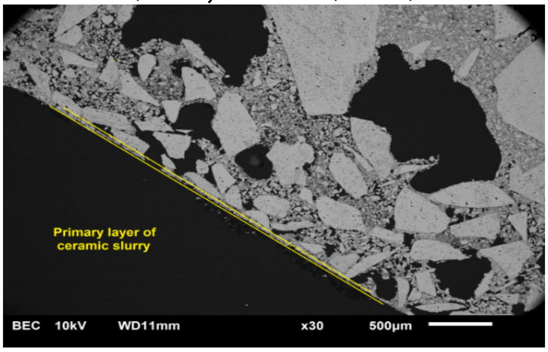

Figure 7: Detail of the full Molochite ceramic shell (Courtesy of C.A.R.R.D., Austria)

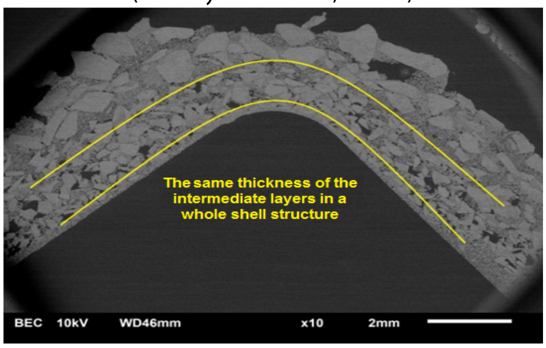

Figure 8: SEM picture of corner of newly developed ceramic shell (Courtesy of C.A.R.R.D., Austria)

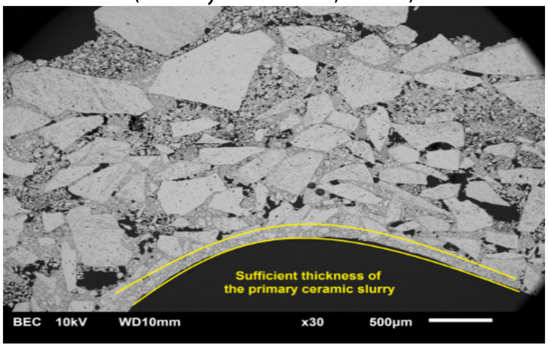

Figure 9: Detail of the corner (Courtesy of C.A.R.R.D., Austria)

5. CONCLUSION

The main goal of this research was to find an optimal solution for manufacturing and a material composition of the ceramic shells for large, thin-walled, high quality aluminium casting and the implementation of the achieved results into daily foundry practice. During the three-year project Alfa TA ČR, the laboratory and pilot plant tests were compared and several types of refractory materials were tested and on the base of these tests a new ceramic shell was selected.

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References

[1.] COLECTIVE OF AUTHORS. Research and Development of Technology for Large – Thin Wall – High Quality Aluminium Castings for Aircraft Industry (ALFA-TA 01010766): Report of results, Uherské Hradiště, 2012.
[2.] BEELEY, P. R. a R. F. SMART. Investment Casting. 1st ed. Cambridge, UK: The University Press, 1995. ISBN 0-901716-66-9.
[3.] HORÁČEK, Milan. Výroba přesných odlitků: Výroba přesných odlitků technologií vytavitelného modelu. In: Odbor slévárenství [online]. ÚST, FSI VUT Brno, 2009 [cit. 2014-03-03]. Available from: http://ust.fme.vutbr.cz/slevarenstvi/opory.html
[4.] IMERYS FOUNDRY MINERALS EUROPE (IFME). Slurry Make Up and Control. EU: corporate document, 2005, 89 s.
[5.] IMERYS FOUNDRY MINERALS EUROPE (IFME). Refractories. EU: corporate document 2005, 88 s.
[6.] FRULLI, CRISTINA DI DAVIDE a SCHMIDT-KLUGE.Alumina and Silico-Aluminate Refractories: and their roleinceramic mould properties. IMERYS, 2006, 39 s.
[7.] BIJVOET, Mark. Refractories for the Investment Casting Industry and Ceramic Shell Strength: Recent Trends in Investment Casting [International Seminar]. Ransom & Randolph, 2007, 42 s.