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Improvements in Shell Moulding For Investment Casting

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Abstract: Metal casting to produce solid objects is a manufacturing process that has been carried out for over 5000 years, with investment casting being one of the oldest known methods of metal shaping. The investment casting has its own advantages over the other method of casting. The investment casting process has been increasingly used to manufacture components for the different industry and has been especially successful in the manufacture of single turbine blades. The method itself has considerable advantages in the manufacture of components of consistency and the main advantages of precision, flexibility and honesty. The process is therefore one of the most cost-effective methods of forming a wide range of metal components. Nevertheless, environmental and economic stresses have contributed to the industry's need to improve current casting efficiency, reduce production costs and explore new process markets. This paper aims at summarizing current ceramic developments and exploring possible methods for improving shell performance.

Keywords: Investment casting, Colloidal, Polymer, Organic fiber, Green strength, Autoclave.

INTRODUCTION

The investment design process involves the manufacture of castings using an expendable template. Although Early Man used the process to manufacture primitive devices, the ideas can be traced back to 5000 BC. This had been followed by centuries in the use of jewelry and artistic items prior to the advent of the Second World War when aerospace and subsequently engineering components were created. The investment casting comes from the typical use of mobile ceramic slurry to form a mould with an extremely smooth surface. These are replicated from exact patterns and sent to the casting in turn. Investment casting makes it possible to produce dimensional accurate components and is a cheaper alternative to forging or machining as waste material is kept to a minimum. Production of ceramic shell mould investment casting is a crucial part of the entire process. The basic steps of producing an investment cast part using a ceramic shell mould are shown in Fig. 1. First, composed of a fine mesh refractory filler system and a colloidal binder system, multi component slurries are prepared. Then a pattern wax is immersed in the slurry, sprinkled and dried with coarse refractory stucco [1].

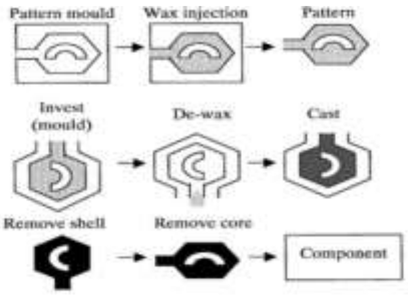


Figure 1: Basic Principles of the Investment Casting Process

The aim of stucco is to mitigate drying stress in the coatings by presenting a number of stress concentration centers that distribute and thus lessen the severity of local drying stress. The stucco's second main purpose is to present a rough surface, thus facilitating a mechanical bond between both the primary coating and the secondary or back-up investment. Whenever the primary coat has been set (air-dried until the binder gels), the assembly will be manually plunged into secondary slurry and stucco until the appropriate shell thickness is defined. The particle size of both the stucco is increased by adding more coats to maintain the maximum permeability of the mould and to provide the mould with bulk. Each coating between the dipping is thoroughly hardened [2].

Thus, an investment casting mould is made up of individual layers of fine refractory material and granular refractory material held together by a binder set to a rigid gel. There is versatility in modifying each layer's composition. The wax pattern can be removed using different methods, usually steam autoclave, leaving a hollow shell. Shells have been fired and full with molten metal inside the shell that solidifies. After casting, mechanical or chemical methods to obtain the parts remove the ceramic shell [3].

METHODOLOGY

Development of ceramic shells:

Investment casting is indeed a time-consuming, labor-intensive process that produces complicated, high-value added components in a range of alloys for a number of specialized industries. The moulds currently take between 24 and 72 hours to produce due to the need to use controlled removal of moisture for water-based colloidal gellation on each coat. Unless sufficient moisture has been removed, the preceding coat will have negligible mechanical strength to allow the application of another coat. Drying and strength development are the industry's most significant rate limiting factors in reducing lead times and manufacturing costs.

Dimensionally stable components can indeed be produced in large or small volumes— a much affordable alternative to forging or turning metal since the waste products is kept to a minimum. Through rises in labor and machining costs associated through traditional metal manufacturing methods, the economic incentive has increased to use the investment casting technique to manufacture progressively larger components. Since the technique produces monolithic components in a variety of regulated grain sizes, investment casting is extended to generate large turbine blades, wheels and nuclear reactor components. Reduced creep, dimensional stability and reproducibility for all of these applications are main requirements. Investment cast components show all these properties, so the process is adopted as the preferred production path. Ironically, the production of larger moulds using traditional silica bonded ceramics resulted in unacceptable failure rates of up to 40%. Two main causes were due to failure: the casting of bulge and metal–the presence of the mould. Casting bulge requires large areas of convex exterior casting surface instead of flat and is assumed to arise from moulding wall movement after metal pouring but before solidification of metal [4] [5].

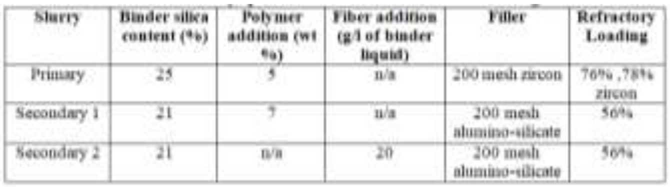
Therefore, the need to reduce production times, improve shell performance to reduce casting scrap level and reduce metal mold reaction to improve as cast part surfaces is fuelled by scientific development within the industry.

Experiment details:

• Ceramic shell specification

In this study, the ceramic shell was designed to repres ent a standard shell used for casting aluminum alloy. In Table 1, shell building specifications; in Table 2, s ample details; in Table 3, the slurry specifications are contained.

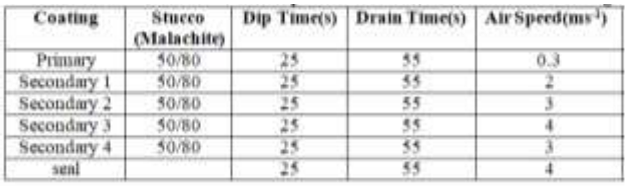
Table 1: Slurry Specification for Aluminum Shell Coating



Slurry	Binder silica content (%)	Polymer addition (wt %)	Fiber addition (g/l of binder liquid)	Filler	Refractory Loading
Primary	25	5	n/a	200 mesh zircon	76% ,78% zircon
Secondary 1	21	7	n/a	200 mesh alumino-silicate	56%
Secondary 2	21	n/a	20	200 mesh alumino-silicate	56%

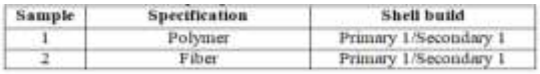
Table 2: Shell Build Specification for Aluminum

Shell Coating



Coating	Stucco (Malachite)	Dip Time(s)	Drain Time(s)	Air Speed(ms^{-1})
Primary	50/80	25	55	0.3
Secondary 1	50/80	25	55	2
Secondary 2	50/80	25	55	3
Secondary 3	50/80	25	55	4
Secondary 4	50/80	25	55	3
seal		25	55	4

Table 3: Sample Specification for Aluminum Shell



Sample	Specification	Shell build
1	Polymer	Primary 1/Secondary 1
2	Fiber	Primary 1/Secondary 1

• Microscopy

To view the structure of ceramic mould sections and fiber morphology, scanning electron microscopy was used. The instruments used were an electron microscope for scanning JEOL 840A and an electron microscope for scanning ISI-100A.

• Strength measurement

Injected wax bars according to requirements were used as formers for ceramic shells. De-waxed at 7 bar for 5 min after dipping the shells, followed by a controlled de-pressurization process at 1 bar / min. Test pieces were cut using a grinding wheel, about 18 mm 85 mm. Testing was conducted as per BS 1902. In the 3-point bend mode, sample testing was performed on a 5 kN load cell Instron test facility. With an outer span of 70 mm, the load rate used was 1 mm / min cross head speed.

• Permeability test

10 mm impervious mullite rods, on which table tennis balls of 40 mm in diameter were attached, were used as ceramic shell formers in accordance with the specifications in Fig. 2. The plastic balls are burned out at a heating rate of no more than 40C / min at 7500C for 5 min after drying. Shell samples are then fired at a heating rate of 100 C / min at 10000C for 80 minutes.

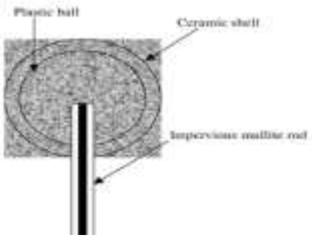


Figure 2: Schematic Section through Permeability Test Piece Coated with Ceramic Shell

RESULTS AND DISCUSSION

Addition of the organic fiber

Fig. 3 displays the organic fiber additions structure and morphology. The replacements are acrylic, of about a fiber diameter. 20 mm and 1 mm in length, with an aspect ratio of 45. Fig. 4 shows a higher fiber surface magnification micrograph. Of note is the nylon surface's relatively smooth design, which will impact the relative ease of fiber pull-out during mechanical force application [6].

Figure 3: Secondary Electron SEM Image of Nylon Fiber Additions

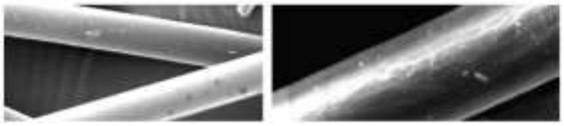


Figure 4: Higher Magnification Secondary Electron SEM Image of Nylon Fiber Additions

Strength comparison:

However in practice, fiber-additive moulds are less vulnerable to autoclave cracking, indicating a higher green power. The modified fracture load (AFL) can be used to further evaluate the load capacity. AFL is described as the load required to break a standard 10 mm wide test piece across a span of 70 mm. It could be said that the polymer system's load-bearing capacity is still slightly higher when unfired moulds. The improved fiber system has a higher load bearing capacity when fired, although at these temperatures both polymer and organic fiber would have burned off. The AFL claims that from the polymer-modified system, the fiber system would yield a ceramic shell with very little difference in 3-point bend power, making it a viable alternative [7].

Fired permeability comparisons:

During casting, liquid metal is poured into the ceramic mould at a high temperature and allowed to cool. The mold as a whole is full of air and the incoming liquid metal displaces this. It is critical that this air exits the cavity quickly and completely to avoid trapping and resulting porosity, bubbles and more seriously misrun or" non-fill" areas of components where trapped air has created positive backpressure and stopped liquid metal from flowing. Air is extracted through several mechanisms: direct displacement through the pouring cup; absorption into the alloy and through the permeation of air through the ceramic shell's open porosity network. The shell permeability is the most important factor, with most investment shells in the structure having at least 30 percent open porosity [8].

At temperature, the permeability remains unchanged by time and consistent throughout the test. It greatly benefits the casting process, allowing additional air transport from the mould cavity and reliable data input for the casting cycle computer simulations. These findings suggest that when compared to the polymer-modified system, the fiber system will produce a ceramic shell with significantly increased fired permeability, making it an excellent alternative [9].

Green and fired fracture surfaces:

Unfired as well as fired fracture surfaces of fiber-modified shell samples were analyzed using SEM to determine fiber alignment during fracture. Fig. 5 displays the green fiber fracture surface that appears to have been removed from the ceramic network. This is as expected with this kind of composite device, where the energy required extracting fibers in this way increases the strength needed to break the sample and eventually the weight [10].

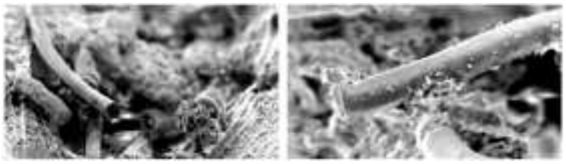


Figure 5: Secondary Electron SEM Image of Green Fracture Surface of Fiber-Modified

CONCLUSION

Investment casting industry is becoming imperative to improve current casting quality, reduce production costs and explore new markets to remain competitive. To achieve these goals, it will be necessary to optimize the mechanical and physical properties of the ceramic shell. Mold processing is time consuming, taking at present between 24 and 72 h depending on the item, due to the need to use controlled removal of moisture. Drying and strength development are the industry's most significant rate-limiting factors in reducing lead times and manufacturing costs.

Using a latex modified binder has increased the shell thickness by a factor of 15 % over that add a comparable system. It means that amount of coats added to wax can be decreased which has important production time and material cost.

Further work will also be needed to quantify the full benefit of this shell technology development, but all initial results suggest that the use of organic fiber reinforcement will have a huge impact on the conventional casting foundry.

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