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Effects of activated charcoal on physical and mechanical properties of microwave dewaxed investment casting moulds

B. Yahaya, S. Izman [*], M.H. Idris, M.S. Dambatta

Faulty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

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ABSTRACT

Dewaxing processes are crucial to investment casting. But the processes currently in use required series of steps that consume a lot of time (e.g. steam production in an autoclave and preheating in furnace systems). Ceramic moulds should meet required strength, porosity, collapsibility and reliability. The aim of the research is to study the effects of increasing activated charcoal content on dewaxing time and moulds properties. Ceramic moulds were prepared using modified coarse back-up stucco that was applied to the layers 3–6 only. The modified stucco was prepared by mixing with 0–30% activated charcoal. The moulds were dewaxed in microwave dewaxing test rig and then fired. During dewaxing, it was found that moulds with 30% activated charcoal usually crack on their edges. The green and fired moulds were tested for density, porosity and strength. Weibull analysis was conducted on the strength data for moulds with 0% and 25% activated the charcoal content. The dewaxing time reduced by about 37.5%, density and flexural strength of the both green and fired samples decreased for 25% increase in activated charcoal content. Whereas the porosity increase in both samples for the corresponding increase in activated charcoal content. The Weibull analysis shows a narrower strength distribution at 25% activated charcoal content. Lastly, the findings of this research show that increasing activated charcoal content in the moulds improves microwave absorption and decrease dewaxing time with no preheating required. Furthermore, porosity and collapsibility of the mould improve, while moulds strength and density decreased.

Introduction

The purpose of investment casting process is high-quality casting with excellence dimensional accuracy [1]. Investment casting finds prominent applications in biomedical (dental and orthopedic implants) and aerospace (turbine components) industries. The investment casting process involves pattern making, slurry preparation, mold making, dewaxing, firing (preheating) and metal casting [2]. For quality casting, ceramic mold should fulfill the following requirements; low thermal expansion, sufficient green mold strength, sufficient fired mold strength, good gas permeability and cracks free mold. Several investigations have been conducted in order to improve ceramic mold quality. These studies investigate mold strength, permeability and dewaxing methods using conventional and unconventional heating techniques. The strength and permeability of the investment casting molds depend on its thickness and porosity. Thicker molds are stronger but less permeable, but thinner molds show less strength with high permeability. The mold's thickness is influence but the stucco particle size and slurry viscosity. The permeability of ceramic mold can be improved by increasing the porosity of the mold through the addition of ceramic fiber to the mold [3].A study conducted to investigate the strength of ceramic moulds revealed that bending strength is directly proportional to the amount of filler in the slurry [4]. The addition of high polymer during the preparation of the ZrO_2 investment casting ceramic molds was found to improve the collapsibility and green strength but lower its fired strength [5].

As stated earlier, ceramic mold should have enough green and fired strength to withstand dewaxing and metal pouring stresses respectively. The strength is usually tested using four or three points bending test. However, statistical analysis is required to evaluate the distribution of the strength data for the ceramic mold. This is because identical components tested under similar conditions failed at different strength values [6]. Various studies utilized Weibull statistical distribution tool to analyze the distribution and magnitude of the ceramics mold strength data [7]. The most important parameter in Weibull distribution analysis

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[*] Corresponding author. Tel.: +60 197147400.
E-mail address: izman@mail.fkm.utm.my (S. Izman).

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is Weibull modulus. Large values of Weibull modulus indicate small scatter in stress distribution [8].

One of the crucial processes of investment casting is dewaxing. This involves melting out the wax pattern from a ceramic mold without cracks and change in dimensional accuracy. Dewaxing is achieved by heating the ceramic mold at appropriate rate to minimize the expansion of the wax pattern. This wax pattern expansion subjects the ceramic mold to stresses that result in mold crack, which may lead to mold damage or costly repairs [9–12]. Several conventional heating methods have been used for dewaxing process. One of the methods is autoclave dewaxing which uses high-pressure steam to melt the wax out of the ceramic mold. The dewaxing process is usually conducted within 15 min. However, sufficient time and energy is required to produce steam at 550 to 620 kPa. In addition, cracks and scabs are the major drawbacks of autoclave method [12]. Study found that autoclave usually lower the green strength of the ceramic mold [13].

Another method is flash fired dewaxing technique. It uses heat to rapidly melt-out wax from the mold giving wax little or no chance to expand during melting [14]. High energy consumption and wax burn-out are the major drawbacks of this process. The Hot liquid method is prominent in dewaxing. It uses hot wax at 177 °C as a heating medium, the method presents the risk of fire hazard with longer processing time compared to autoclave and flash fired methods. A reverse of solidification path dewaxing (RSPD) is another dewaxing method used. In this technique, dilation gap is formed and the ceramic mold is rapidly heated from inside through the gap at around 1000 °C. Even though this method reduces the problems associated with autoclave, but it is associated with high energy consumption and environmental hazards due to burning of wax at high temperature [15].

In general, all the above mentioned conventional heating methods involve the use of large amount of energy, environmental pollution, sometimes longer processing time, ceramic mold cracks and wax contamination. To reduce these problems, the use of microwave energy in dewaxing was investigated. This is due to its advantages over conventional heating methods. Microwave heating involves direct deposition of electromagnetic energy into materials, which is converted into heat within the material. This result in rapid and volumetric heating that reduces thermal gradients. This gives microwave heating wide acceptance in industrial processing of dielectric materials [16]. Most of the microwave ovens and furnaces operate at 0.915 GHz and 2.45 GHz of the electromagnetic spectrum [17–19].

Materials can be classified according to their interaction with microwave into either following classes. Microwave transparent materials are those that have low interaction with microwave energy. They allow the microwave to pass through them with little or no absorption. Microwave reflectors are opaque to microwave. They do not allow the microwave to pass through them, neither do they absorbed it. While microwave absorbers are materials that absorbed microwave energy and convert it to heat [20].

In an attempt to explore the possibilities of using microwave for dewaxing process, Brum et al utilizes domestic microwave oven equipped with mineral oil bath to melt wax blend (mineral wax, vegetable wax, resin, low molecular weight polymer and anti-oxidant). After several trials the purity, structural and chemical integrity of the wax blends were better than those from autoclave dewaxing [21]. But the research did not consider the economic aspects and presence of ceramic molds. Similar study was also performed by Rani et al. [22] but focused no the pattern shrinkages and hardness. They reported that percentage of linear shrinkage is less as compared to the gradual change in volumetric shrinkage. Change in hardness shows no defined pattern [22]. In addition, microwave dewaxing was found to be viable method since no dirt or water is incorporated in the wax. This research investigated the effect of activated charcoal on dewaxing time, mold porosity, density and flexural strength. Weibull analysis was employed to verify the reliability of unmodified and modified mold samples.

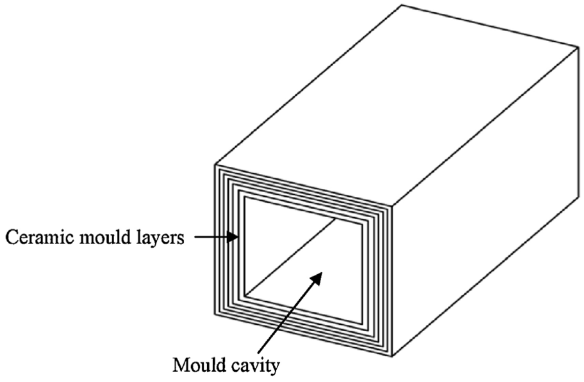

Fig. 1. Schematic diagram of wax pattern.

Materials and methods

Samples preparation

Fig. 1 shows the schematic diagram of ceramic wax pattern indicating the prepared layers. The first layer is the primary layer without stucco. The second layer is sprinkled with fine stucco (0.3 to 0.7 mm particle size). Then the subsequent four layers are sprinkled with the standard and modified coarse stucco. The final layer was made without stucco. The modified backup stucco was prepared by mixing with activated charcoal from oil palm shell. The charcoal was crushed to particles size of range 0.7 mm to 1 mm and added to the backup stucco at 5%, 10%, 15%, 20%, 25% and 30%, then mixed thoroughly.

Dewaxing was conducted on the molds by microwave heating for 5 to 20 min using the developed test rig shown in Fig. 2. The ceramics molds were fired in resistance furnace at 800 °C for 1 h to burn absorbed waxes and sinter them. The dewaxed and fired samples are shown in Fig. 3.

Porosity and density test

The apparent porosity and bulk density tests were conducted according ASTM standard designated C20-00. The tests were carried out on both green and fired molds. The samples were weighed and recorded as W_a (g). All samples were suspended in water and boiled for 2 h. The samples were then allowed to cool for 12 h inside water bath before reweighing. The samples suspended and saturated weights were recorded as W_b (g) and W_c (g)

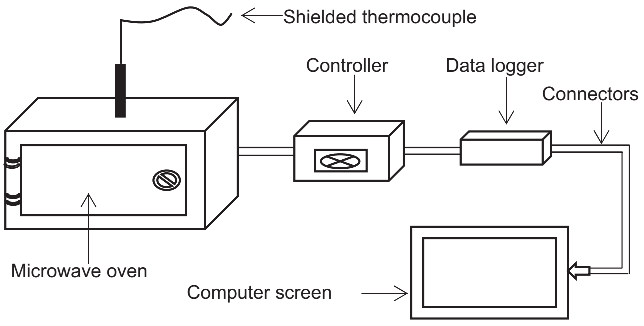

Fig. 2. Schematic diagram of microwave dewaxing test rig.