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Effects of Activated Charcoal on Dewaxing Time in Microwave Hybrid Heating

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Abstract

High energy consumption, mould cracking and wax contaminations are the major problems during dewaxing process in investment casting. On the other hand, low loss factor of most mould materials and some pattern waxes make direct microwave heating them slow. In this research, activated charcoal was added to the ceramic mould in order to improve microwave absorption and reduce dewaxing time. A modified domestic microwave oven was used as a test rig. The activated charcoal was added to the back-up stucco from 0 to 30% by weight. The microwave heating tests were carried out from 5 to 20 minutes. The dielectric properties of the green mould and the wax were measured using a co-axial dielectric end probe. It was found that the loss factor of the wax is low, and the higher the percentage of activated charcoal added into the mould, the better the dielectric loss factor and the lower the dewaxing time. Adding 25% activated charcoal in the mould causes about 40% decrease in dewaxing time. This also improved energy saving and makes the process more sustainable.

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Keywords: susceptor; activated charcoal; permittivity; loss factor; hybrid heating

1. Introduction

Investment casting becomes versatile due to its flexibility to produce near net shapes when compared to other metals forming processes. One important process in investment casting is dewaxing. It is achieved through heating the ceramic Mould in order to melt the wax pattern out of the ceramic Mould. The heating should be rapid enough to minimize expansion of the wax in order to avert ceramic Mould cracking and dimensional alteration [1]. Several techniques are available for dewaxing process. One of them is autoclave dewaxing, which is carried out in a boiler clave. High pressure steam is used to melt the wax. Substantial energy and time are required to produce steam and maintain it at the required pressure. Apart from the energy consumed to produce steam, autoclave presents the following problems; it lowers the green strength of the ceramic Mould, produce scabs on the internal surface of the Mould, ceramic Mould cracking and wax contaminations [2]. It is believed that stresses of the expanding wax causes the cracks and this sometimes damage the Mould or lead to costly repairs [3, 4, 5].

Another dewaxing technique is flash fired process. This method reduces slightly the problem of cracks. In this process, wax is directly heated by jet of flame at high temperature to rapidly melt the wax out of the ceramic Mould with little or no chance to expand during melting [6]. The high cost, high energy consumption, wax burn-out and atmospheric pollution limit the popularity of this method [5]. Small foundries use hot liquid dewaxing method in order to reduce cost. Usually, hot wax at 177^{o}C is used as heating medium. Main limitation of this method is; fire hazard may develop and process time is longer than autoclave and flash fired methods [5].

Microwave can be one of the sustainable alternative sources of energy for dewaxing process. Microwave is part of the non-ionizing waves of the electromagnetic spectrum it covers frequency ranges from 0.3GHz to 300GHz with corresponding wavelengths of 1m to 0.001m [7, 8, 9]. The most commonly used frequencies for microwave heating purpose are 0.915GHz and 2.45GHz which have the corresponding wavelengths of 0.135m and 0.122m respectively [10, 11]. Microwave heating has the advantages over conventional such as, volumetric heating, selective heating, shorter processing time, complex shape

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heating uniformity and ease of automation, improve product quality [12, 13].

Direct microwave heating can only be applied effectively to materials with good microwave absorption. The effectiveness of microwave absorption of materials depends largely on their dielectric properties. Literature shows that materials with dielectric loss factor (ε") less than 0.01 are transparent to microwave. Whereas materials with dielectric loss factor between 0.01 and 5 are good microwave absorbers. Any materials with dielectric loss factor greater than 5 reflect microwave radiation.

Microwave energy was used for rapid carbothermal reduction reaction for the production of nanostructured SiC powders using rice husk as precursor [14]. It was also used to modify and transform carbon materials into microwave susceptors and catalyst in various heterogeneous reactions [15]. Molybdenum powder was sintered to 98% density within 5 minutes using microwave energy. This method saves a lot of time as compared to 10- 20 hours in conventional methods [16].

Direct microwave heating gives rise to some fundamental issues. For instance many ceramics at room temperature are difficult to heat due to their poor microwave absorption [17]. As a result, a hybrid microwave heating technique was developed. This technique can either be a combination of direct microwave heating and conventional heating or by using microwave susceptors. A microwave susceptors is any material with good microwave absorption. The most commonly used susceptors in microwave heating are silicon carbide (SiC), carbon (C) and magnetite (Fe_3O_4) [18]. The microwave susceptors do two functions during microwave heating. They heat low loss materials from room temperature to critical temperature at which the materials become microwave absorber. Secondly, they reduce energy losses at high temperature [19].

Microwave hybrid heating has been used to sinter alumina (a low microwave absorber) using a layer of SiC as a microwave susceptor [20]. It was also used for fast firing of Alumina-Zirconia nano composites to suppress grain growth. It was reported that final density was up to 99% was achieved and only required sintering time was between 30 and 35 minutes [21]. On another study, char was used as microwave susceptor to pyrolysed oil palm biomass [22].

These developments indicate that microwave technology offers huge potential for processing materials that will reduce significantly the energy consumption. However, the application of this technology in dewaxing process is hardly reported in the literature. Initial study on dewaxing using microwave was reported by Brum *et al* [23]. In their work they attempt to explore the possibilities of using microwave energy for dewaxing process where a portion of wax (500g) was placed in a domestic microwave oven (Sanyo) operating at a frequency of 2.45GHz and power input of 1100W for 20 minutes at atmospheric pressure. The wax melted and reaches the maximum temperature of 120^{o}C. No purification was carried out on the wax for a repeated 12 cycles of melting and the wax showed less significant structural changes. However, they did not consider the economical aspect and the presence of ceramic Mould [23].

The aim of this research is to evaluate the effects of varying activated charcoal content on dewaxing time in the presence of ceramic Mould.

2.0 Materials and Method

2.1 Experimental procedure

In this work, dewaxing through microwave hybrid heating was conducted. The susceptor used was activated charcoal from oil palm kernel. The activated charcoal was added to the back-up stucco at varying percentage (0, 5, 10, 15, 20, 25 and 30%). The activated charcoal particle size range used was 700 - 100μm, this is to facilitate proper mixing with the back-up stucco particles. The effects of percentage of activated charcoal added to the ceramic Mould on the mould's dielectric properties (dielectric properties, loss factor and loss tangent) were analysed. The dielectric constant and loss factor were obtained directly from a dielectric co-axial end probe. The loss tangent was calculated using the following formula [24].

$$\tan(\delta) = \varepsilon'' / \varepsilon' \qquad (1)$$

Dewaxing time and percentage wax melted (dewaxed) were analysed. The effects of percentage activated charcoal on ceramic Mould cracks were also observed.

The experimentation was conducted through the following stages; permanent Mould was designed and fabricated. Domestic microwave oven (Elba) operating at 2.45GHz and 700W was modified to serve as a test rig for the dewaxing test as show in Figure 1(a) and the internal arrangement details are shown in Figure 1(b).

Wax patterns were produced, weighted and marked. Activated charcoal was crushed using mortar and pestle, then sieved to obtain particles within the range 700-1000μm. The back-up stucco was mixed with the prepared activated charcoal at varying activated charcoal percentages by weight (i.e. 0, 5, 10, 15, 20, 25 and 30%).

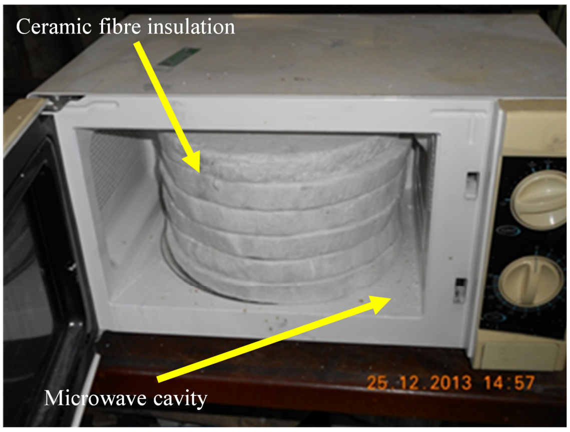

Figure 1(a) Modified microwave oven

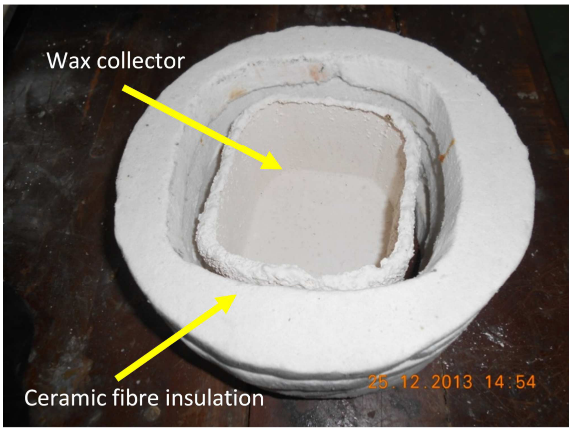

Figure 1(b) Wax collector and insulation arrangement in the modified microwave oven

In each case, the time required to melt the wax out of the ceramic moulds was recorded. The ceramic moulds were weighted before and after microwave heating. The mass of the solid wax remaining at the end of each microwave heating was immediately measured. Additional microwave heating tests were conducted to refine the actual time to completely melt wax patterns. The base time obtained from the earlier setting was reduced further until it shows the minimum time for melting for each percentage of activated charcoal. The interior and exterior surfaces of the ceramics moulds were examined for cracks. Then the moulds were fired in furnace at 800°C for 60 minutes to sinter and burnt the wax absorbed by the moulds. The moulds were also examined for cracks.

2.2 Slurry preparation

Ceramic slurry was prepared using colloidal silica as the binder and the zircon powder as the refractory. The colloidal silica was poured into a clean container. The stirrer was set and run at moderate speed of 140rpm. The zircon powder was sprinkled continuously until the viscosity was initially 22 seconds on Zahn cup number 4. This was used for the prime coat. Then the viscosity was lowered to 18 seconds on Zahn cup number 4, and was used for subsequent six layers.

2.3 Stucco preparation

The stucco used here was in two types, i.e. primary stucco and back-up stucco. Primary stucco is a fine grade with particle size range 300-700μm and this was used for the primary layer. The back-up stucco is a coarse grade with particle size range 700-1000μm. It was used to make the subsequent six layers of the ceramic moulds. The back-up stucco was prepared by mixing with activated charcoal as described above.

3.0 Results and Analysis

Figure 2 shows relationship between percentages of wax melted at different microwave heating time ranging from 5 minutes to 20 minutes for each percent activated charcoal in the back-up stucco. It can be observed here that the higher the percentage of activated charcoal (30%) in the ceramic Mould, the faster the heating rate. Therefore, more wax melt within short time.

Using the approximate time to melt 100% wax from Figure 2, further microwave heating tests were conducted to find the actual time required to completely melt wax out of the ceramic moulds. Table 1 shows the refined times to completely melts wax pattern for each percentage of activated charcoal. It also noted the observations on the interior and exterior surfaces of the ceramic moulds to identify cracks. The cracks observations show that adding activated charcoal does not significantly alter the green strength of the ceramics. Cracks were not observed up to 25% activated charcoal. Figure 3 illustrate graphically the dewaxing time reduces as the percentage of activated charcoal increased in the back-up stucco. It was noted by adding 25% activated charcoal, dewaxing time reduced about 40% as compared to ceramic moulds with no charcoal.

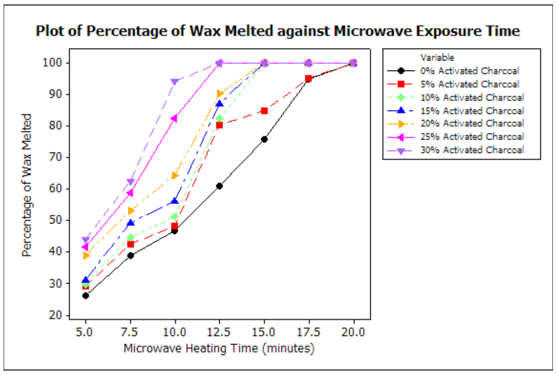

Figure 2 Percentage wax melt against dewaxing time

Table 1 Time required to completely dewax at each percentage of activated charcoal in the back-up stucco.

Percentage activated charcoal in the back-up stucco (%)	Time to completely melt the wax (minutes)	Moulds interior and exterior surface
0	20	No cracks
5	18	No cracks
10	16	No cracks
15	14.5	No cracks
20	13	No cracks
25	12.5	No cracks
30	11	Cracks(exterior surface only)

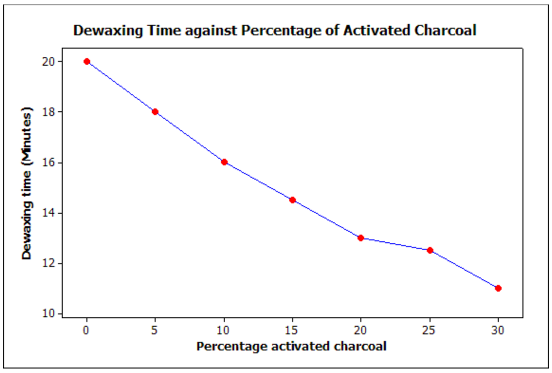

Figure 3 Dewaxing time reduces as the percentage of activated charcoal increased in the back-up stucco.

The interior surfaces of the ceramic Mould after dewaxing and firing are shown in Figure 4(a) and 4(b) respectively.

Figure 4(a) condition of ceramic Mould after dewaxing with remnant of wax.

It can be seen in Figure 5 that the crack starts from the lower open end of the ceramic moulds with 30% activated charcoal. It is believed that the expansion force during dewaxing initiated the crack at the thinnest section of the ceramic moulds.

Figure 4(b) Condition of ceramic Mould after firing with clean surface without wax.

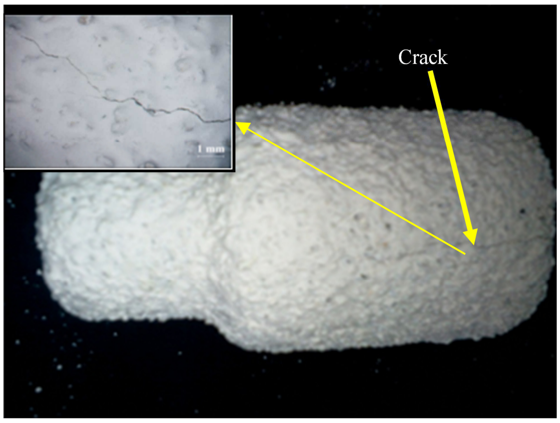

Figure 5 Crack on the fired ceramic Mould with 30% activated charcoal.

Table 2 summarizes dielectric constants, dielectric loss factor and calculated loss tangent of the ceramic Mould with a different percentage of activated charcoal.

Table 2 Dielectric properties of the ceramic Moulds (before and after adding activated charcoal) and wax

Percentage activated charcoal in the back-up stucco (%)	Dielectric constant (ε')	Dielectric loss factor (ε'')	Dielectric loss tangent (tanδ)
0	1.7995	0.0243	0.01381
5	1.9658	0.0299	0.01521
10	2.0993	0.0328	0.01562
15	2.2574	0.036	0.01595
20	2.2301	0.0368	0.0165
25	2.494	0.0381	0.01528
30	2.569	0.0394	0.01534
Wax	2.5307	0.0034	0.00134

The dielectric loss factor is responsible for the heating of materials when expose to microwave radiation. The higher the loss factor, the faster the rate of heating. The dielectric loss factor has a linear relationship with loss tangent. From the results of dielectric test, adding 25% activated charcoal to the ceramic Mould cause increase in dielectric loss factor by 56.79%. This indicated a tremendous increase in heat dissipation during microwave radiation. Earlier results exhibit that there was no crack observed under this condition compared to ceramic Mould with 30% activated charcoal. The source of heat dissipation is mainly generated from the ceramic mould since the wax has poor microwave absorption as shown by its dielectric properties in Table 2.

Figure 6(a) and 6(b) show the plots of percentage activated charcoal against dielectric constant and percentage activated charcoal against dielectric loss factor respectively. It is evident that the more activated charcoal added to the ceramic Mould, the higher the dielectric constant and loss factor. Hence heating rate increases.

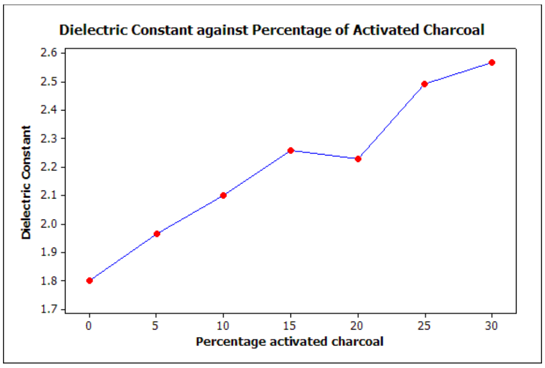

Figure 6(a) Dielectric constant against Percentage activated charcoal

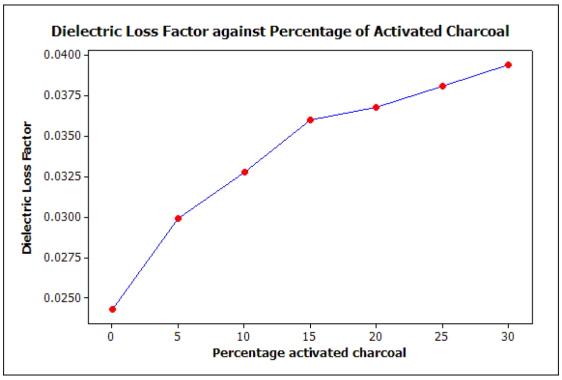

Figure 6(b) Loss factor against Percentage of activated charcoal

Conclusions

The microwave heating of the modified ceramic moulds show a significant decrease in dewaxing time as percentage of activated charcoal in the ceramic Mould increase. No cracks were observed on the ceramic Mould up to 25% activated charcoal in the back-up stucco of the ceramic Mould. At 25% activated charcoal in the ceramic Mould, the time required to completely melt wax pattern out of the ceramic moulds (dewaxing time) reduced by 40% and dielectric loss factor increased by 56.79%. This causes the rapid heating and melting of the wax at the Mould-wax interface before the wax starts expanding to cause cracks. Therefore, it reduces the chances of Mould cracking.

Dielectric properties test conducted on the green ceramic Mould shows that the loss factor increases as percentage of activated charcoal increase. This improves the microwave absorption of the ceramic Mould and hence the heating rate.

Study on the flexural strength and permeability of the green and fired ceramic Mould samples are in the process to access the effects of increase in percentage activated charcoal on Mould mechanical properties.

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