Improved Drying Efficiency using Microwave in Lost Wax Molds and Reduced Drying Time in Plaster Molds Using Microwave

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1. Introduction

Wax to be used in the investment casting molds has a drawback that size is likely to change because of the repeated expansion and contraction due to changes in the temperature of the room. Thus, when drying the mold, it is generally carried out in natural air-drying over a long time under the environment maintained at a constant temperature and humidity. For this reason, the molding process of the lost wax mold, usually takes about one week to dry. The author has developed the technologies to dry each layers more efficiently applying microwave to this process. [1), 2), 3)].

In this paper, we report how the microwave will affect the temperature of the wax model and the mold, the moisture content of the mold, and also report how the drying efficiency will improve when forced circulation air blown into the microwave drying chamber, and combining the local air nozzles[4),5)].

In addition, we report the impact of shorter delivery times, yield improvement, and further, how microwave will affect to shorter the drying time and electrical energy efficiency on plaster mold and ceramics [6), 7)].

2. Experiment Method

2.1. Test Equipment

Figure 1 and 2 show our Microwave Shell Drying System used for this experiment, and figure 3 shows wax pattern. With the figure 1 microwave chamber, microwave was irradiated from the microwave generator (2.5kw x 2 units) installed in the back of chamber outside. With the figure 2 microwave chamber, microwave was irradiated from the microwave generators (1.5kw x 3 units) installed in the sides and bottom of chamber outside.

Figure 1. Microwave mold drying camber
(Inside dimension: 900mm×1,200mm×900mm)

Figure 2. Microwave mold drying camber
(Inside dimension: 1,350mm×1,350mm×1,500mm)

2.2. Test Tree

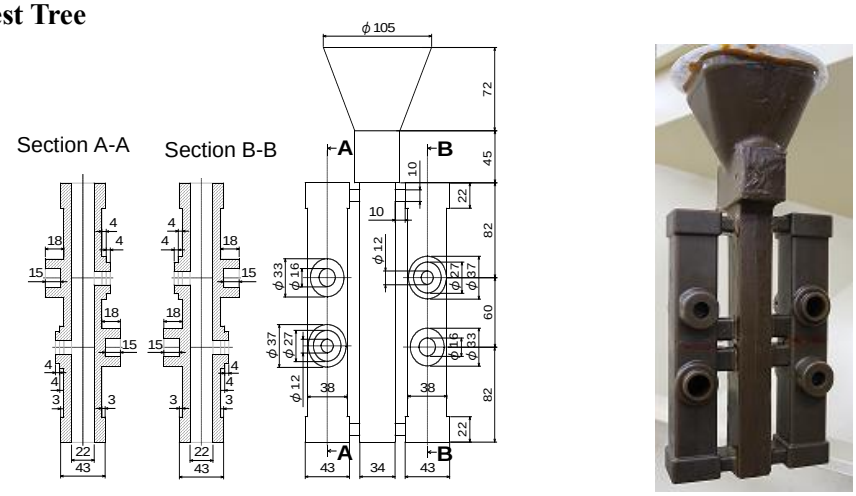

Figure 3. Test Tree Wax pattern

2.3. Mold material

Materials used are slurry consisting of colloidal silica and fused silica, stucco consisting of 0.3 – 0.7 mm sized coarse particle alumina.

2.4. Experiment Procedure

The wax patterns were dipped into slurry, covered with alumina sand, and hung onto the hook inside of the chamber. Then microwave was irradiated to the wax tree 4 cycle times. One cycle is 5 minutes; 10 seconds with microwave irradiation and 4 minutes and 50 seconds without microwave irradiation. Then the temperature transition and moisture contents of the test tree were measured. Fiber-Optic thermometer was used for temperature measurement, and a hygrometer for moisture content measurement.

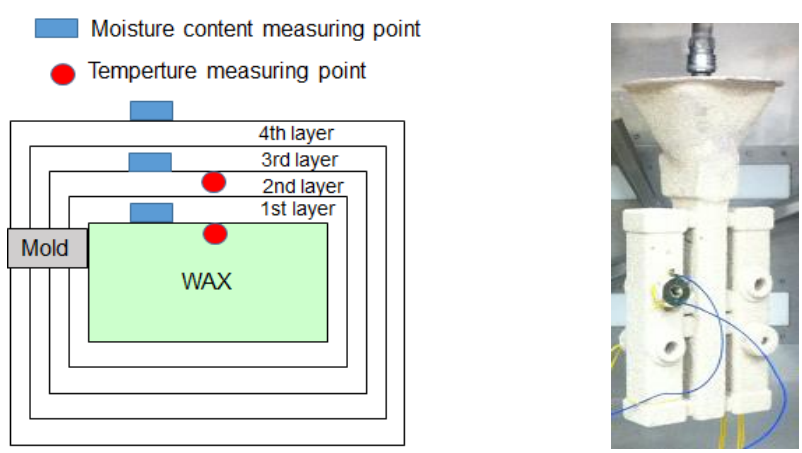

Figure 4. Measuring points of moisture content and temperature in test tree

Figure 4 shows measuring points of moisture content and temperature. In general hygrometer was used for relative comparison under the certain conditions. Therefore the weight transition of mold after being covered with stucco both in natural drying and microwave drying was measured.

3. Experiment Result and Observation

3.1. Mold and wax temperature transition in microwave drying

Figure 5 shows the temperature transition of second coat surface area and inside of the wax pattern. The surface temperature of second coat increased approximately 2.5 C from 20.0 C in 10 seconds of microwave irradiation, and it gradually decreased after microwave was turned off. The temperature of wax pattern inside remained the same during the 10 seconds microwave irradiation, and during the remaining cycle time of 4 minutes and 50 seconds, it showed slight increase of 0.5 C. This temperature increase is considered to be caused by the heat conduction from mold to wax pattern. Therefore it must be addressed to maintain the consistency of the mold temperature.

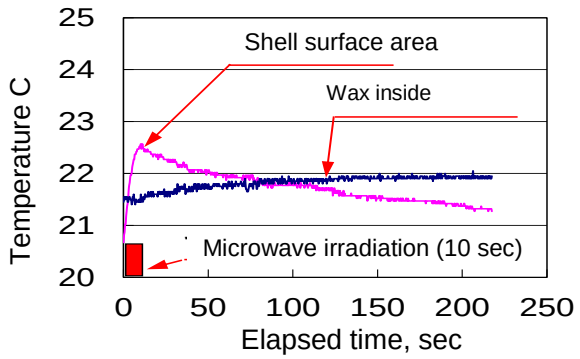

Figure 5. Temperature transit of mold and wax during 10 seconds-microwave irradiation

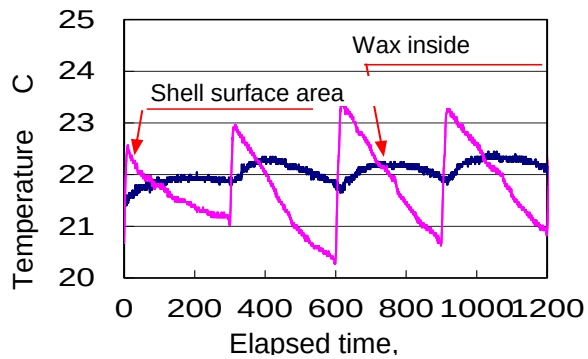

Figure 6. Temperature transition of mold and wax: 10 seconds microwave irradiation by manual operation, air circulation, 5 minutes / cycle x 4 times.

In order to prevent the mold surface temperature from increasing, fresh air from the shell room was supplied into the microwave chamber. Furthermore, air circulation system using circulating fan for inside of the chamber was installed. Figure 6 shows the experiment result of microwave drying with manual operation. The surface temperature variations during these 4 cycles (5 min. in each cycle)were kept within the same range. This clearly proves that microwave drying system enables to control the temperature of the mold and the wax inside. This indicates, when automatic temperature control is applied, mold surface temperature can be maintained to constant levels.

Figure 7 shows the temperature transition of mold surface of another tree; its temperature was controlled to stay within certain temperature range. The tree was dipped into slurry, covered with stucco, and dried in the microwave mold drying chamber shown in figure 2. The mold surface was controlled within ± 1 to1.5 C temperature range. Based on the above experiment results, mold surface temperature that prevents the mold from cracking is considered as follows; At actual production process, molds are dipped after certain numbers of previous coats are dried. When trees are dipped into slurry under the shell room temperate at 24C, mold tree surface temperature after dipping rapidly decreases 4 to 5C, down to 19 to 20 C by heat of vaporization.

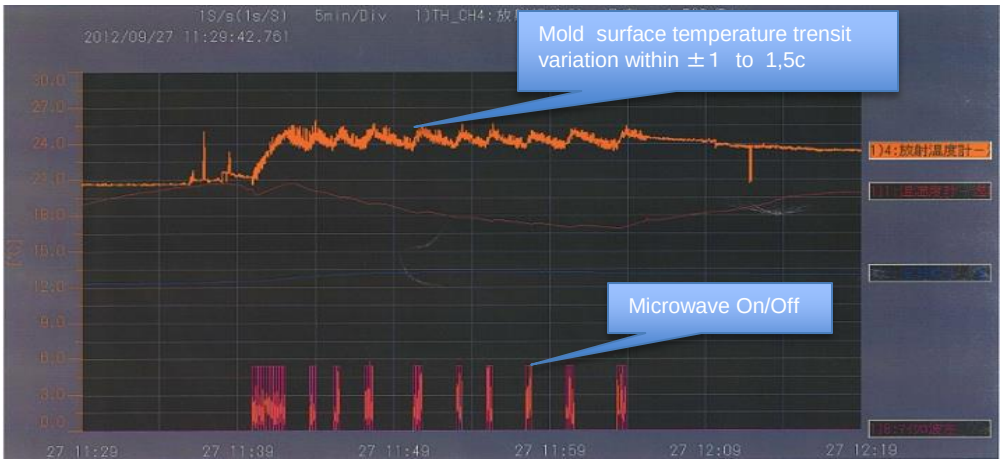

Figure 7. Temperature transition of mold surface under temperature control was in place. (The chart shown above is a result obtained from another tree.)

In backup layer coating process, mold temperature near the wax right after slurry dipping is maintained at approximately 24C for few minutes, and thus temperature variation is assumed to be within 4 to 5C in thickness direction. Under such temperature variation on normal operations at any given foundries, no cracking should be observed in the molds. It is therefore we assumed that molds would not crack when mold surface temperature is controlled within ±1.5 to ±2 C range with microwave. It is also confirmed under this experiment that molds do not crack with microwave irradiation. Also, microwave would not have an impact on quality such as product dimensional defects as mold surface temperature is kept as long as the normal room temperature of 21 to 25 C range.

3.2. Experiment result of moisture content change during microwave irradiation

Test tree was dipped into slurry and coated with stucco, put into a microwave chamber, and microwave was irradiated for certain period. During microwave drying process, microwave irradiation was stopped to measure moisture content of 3rd to 6th layer (Figure A3 to A6). This process was repeated, and figure 8 shows the measurement result. Drying time was 70 minutes, and moisture content was quite stable.

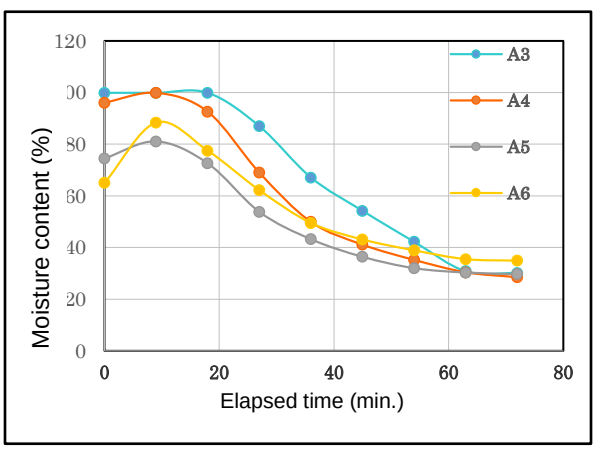

Figure 8. Moisture content of 3rd to 6th layer with microwave drying in microwave chamber

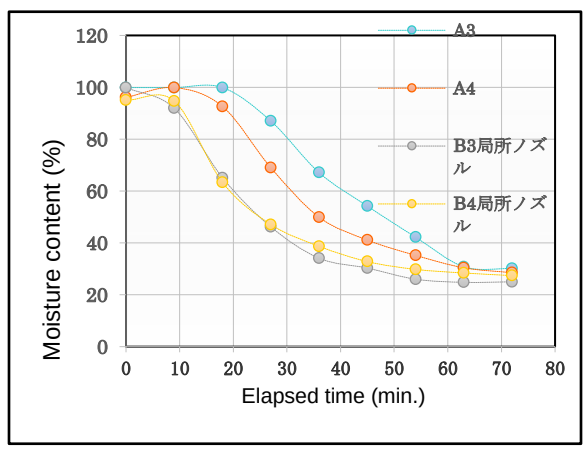

Figure 9. Moisture content change comparison: with and without using

Figure 9 shows the moisture content change of 3rd and 4th layer during microwave dry with and without using local nozzle. It indicates using local nozzle is effective to facilitate mold drying.

Figure 10 shows weight change in natural drying and microwave drying. This indicates microwave would facilitate faster mold drying. Also usually microwave can dry various type of mold approximately in 15 to 45 minutes depending on the mold size, weight, and cavities. Molds after seal coating prior to dewaxing need longer drying time recommended.

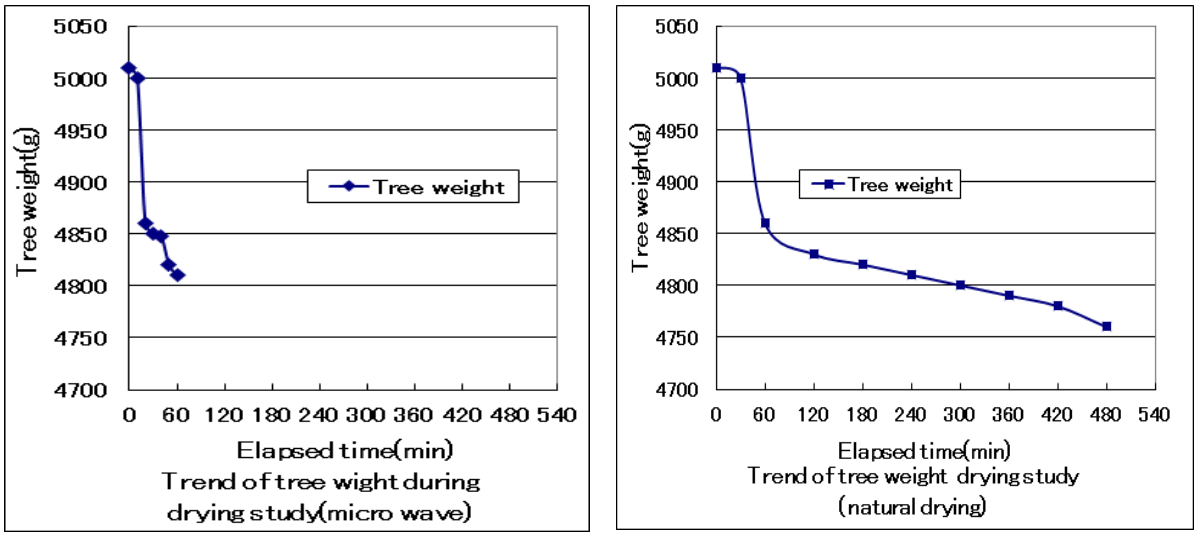

Figure 10. weight change in natural drying and microwave drying

3.3. Drying of mold with cavities

When molds have cavities, its drying time would be usually longer. Although microwave can't fully eliminate high humidity air remained inside the holes and complex cavities. To resolve this issue, fresh air was sent into the holes to exhaust the humid air stayed inside to the outside using local air nozzles, yellow color pipes shown in figure 11. As a result of this combined use of microwave, local air nozzle, and controlled air circulation, the expected drying time normally taking 6 to 8 hours can be reduced to as short as one hour.

Figure 11. Local air nozzle used for mold tree with cavities

3.4. Actual example of temperature control in microwave

When microwave chamber is used for an actual operation at a customer site, two or four trees or mixed loading of different tree types are processed at the same time.

4. Drying time of lost wax mold and the surface temperature

4.1. Drying time (Working Example)

The following illustrates the drying time when drying large size four trees with complex cavities at the weight of 180Kg in the microwave drying system. It normally takes 5 to 8hrs to dry, and microwave dried them in 2.2 to 2.5hrs accordingly.

Table 1. Comparison of the mold drying time (hr)

	4th layer	5th layer	6th layer	7th layer	8th layer
Natural dry	5	6	7	8	8
Microwave dry	2.2	2.1	2.5	2.5	2.5

4.2. Mold surface temperature

Fig. 12. shows the progress of surface temperature and the transition of the microwave output when dried four trees at the same time. The surface temperature of all four trees are maintained within the target temperature range of ± 1.5 ° C.

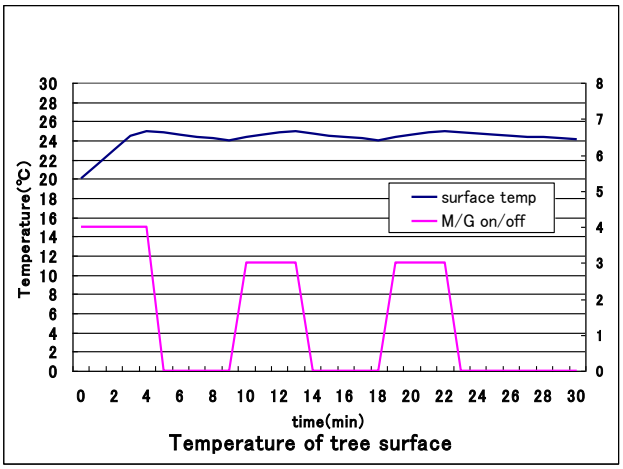

Figure 12. 4 trees/batch, 8 coats, 45 kg / tree, 2.5Kw magnetron x 8 units

5. Drying plaster mold by microwave

Usually it will take 18-40hrs to dry at 280 C in electric furnace. The following will examine the case of drying by microwave.

5.1. Test procedure

Fig. 13 shows the plaster mold at 18kg used in this test. The microwave drying system shown on Fig 1 was used for this test. Placed the plaster mold into the system and conducted continuous microwave irradiation using two magnetrons of 2.5kw. Meanwhile, microwave irradiation was interrupted in every 15 minutes in order to measure the mold weight, core temperature and humidity.

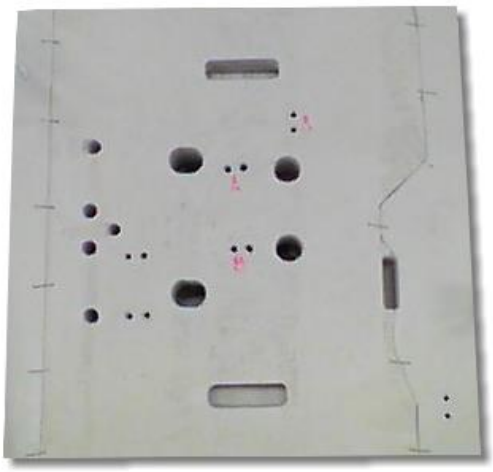

Figure 13. The appearance of the plaster mold used in the test .

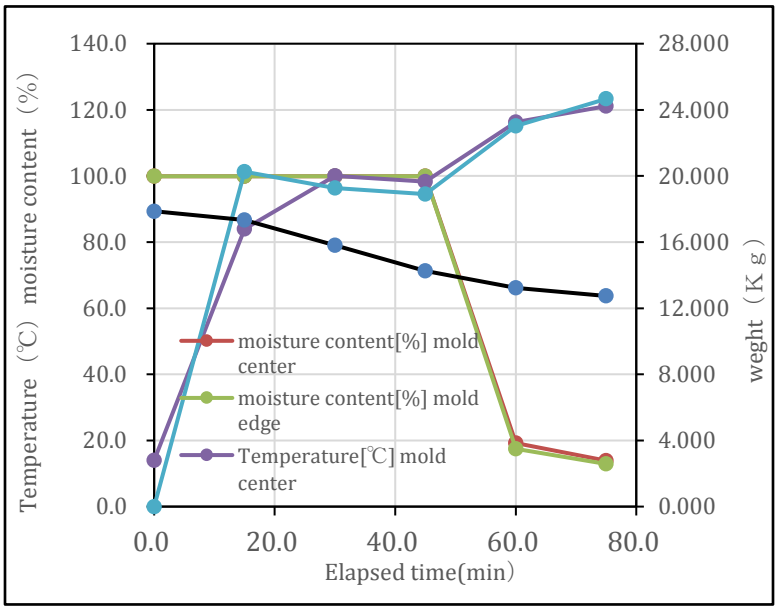

Figure 14. Transitions of the weight changes, internal temperature, and moisture content in microwave drying

5.2. Test results and observation

The transition of the weight, core temperature and humidity of the plaster mold from the start of drying to its completion is shown in Fig. 14. In this case microwave dried the 18kg plaster mold for only 1.25 to 1.5hr while electric furnace took 18hrs to dry the same sample. In addition, the moisture content of the plaster mold may vary depending on the product type, however it was 22% in this test case. Significant difference in drying time between microwave drying and electric furnace was reported.

Microwave is absorbed only in the plaster mold and heating the moisture of the internal mold and its surface at the same time, while the electric furnace heats the surface of the plaster mold with radiant and convective heat transfer. This is why it takes time because the heat transmitted to the interior from the surface by heat conduction. With respect to electricity consumption, electric furnace does not heat the plaster mold only, but further shelves and the inner wall of the furnace is to be heated including heat-insulating material of the furnace wall as well thus electrical energy consumption will be the total of the followings.

(1) Energy for heating the plaster mold
(2) Energy to raise the temperature of each part of the furnace enclosure
(3) Energy dissipation from the outer wall of the furnace into the room

Since (2) & (3) are considered loss of energy, energy efficiency is inferior to the microwave. As described above, even in the case of plaster mold, microwave drying system can achieve significant reduction of drying time and saving electrical energy consumption.

6. Drying the honeycomb core (the base material of the ceramic deodorizing materials)

In the case of drying ceramics microwave can improve its drying process. Fig. 15.1, Fig. 15.2 shows the photo images after the different shaped honeycomb core were immersed in

deodorizing solution that comprised a ceramic material, and drained. Fig. 15.3, Fig.15.4 describes the weight change when dried by microwave. In both cases the microwave achieved shorter drying time. By the way the ceramics industry already applies so-called hybrid system in practical use, that combined microwave and hot air in continuous operating furnace.

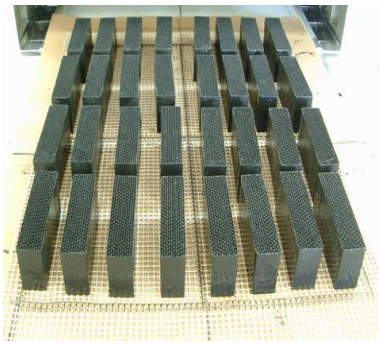

Fig. 15.1 Filter A

Fig. 15.2 Filter B

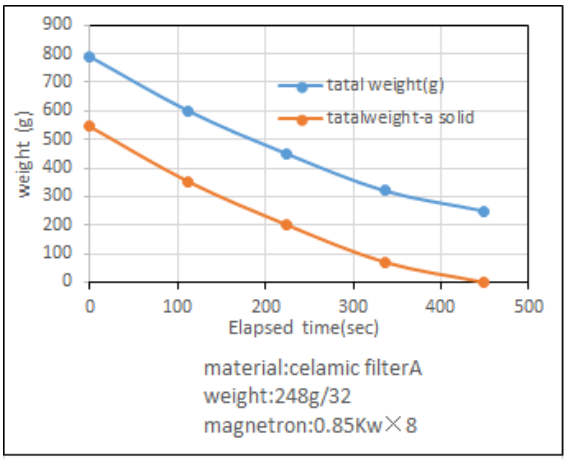

Fig. 15.3 Filter A weight change

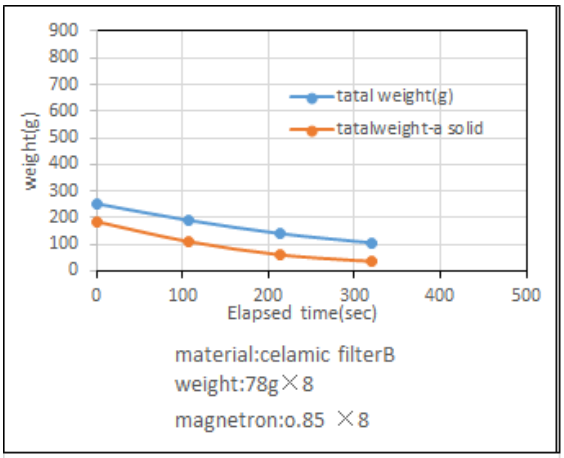

Fig. 15.4 Filter B weight change

7. Summary

We examined how microwave affects the temperature of the wax model, the lost wax molds and the changes in internal moisture content. Further, it was confirmed the effect on drying using the local air nozzles for the molds with complex cavities having holes. Based on these experimental results, we have developed microwave mold drying system with combination of each effective function and succeeded for practical application. Compared to conventional natural drying method microwave drying can cut the drying time in half to 1/3 or even less, and drying efficiency of the lost wax mold was improved.

In addition we have custom shell room solutions using microwave mold drying system are available combining the slurry tank, the rainfall sander, our proprietary designed hanger conveyor and the robots. They are being used by named foundries in Japan, Taiwan and North America.

Further, microwave can be also applicable in drying and sintering plaster mold and ceramics and it can reduce drying time and electric energy cost. We will continue to advance our

technology research and development in the future to promote the production efficiency, and will contribute to the investment casting industry.

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