A study on microwave susceptor material for hybrid heating

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Abstract. Efficient use of available resources at controlled and potential manner required a systematic approach for the technological advancement and creating product solutions. The proper choice of susceptor material for the desired heating rate is a prime concern for the effective utilization of microwave radiation and lower down the energy requirement. The present paper presents a comparative analysis of three different susceptor materials namely graphite boat, charcoal, and silicon carbide for the use in microwave hybrid heating (MHH). These susceptor materials are tested experimentally with 900W and 2.45GHz electromagnetic frequency to highlight the key role of a hybrid mode during microwave processing. The results claimed that the maximum temperature achieved in case of graphite boat is 350°C with 70 minutes of exposure. However, in the case of charcoal and silicon carbide, the maximum achieved temperature is 410°C and 255°C respectively at duration of 10 minutes.

Keywords: MHH, susceptor materials, insulating material, heating rate, exposure time

1. Introduction:
The interaction of microwave energy with different material depends on the type of material exposed to the radiation. The interaction of microwave energy with the material can be categorized based on the interaction of molecule and electromagnetic energy. They can be stated under the group of opaque, transparent, absorbing and magnetic material. For insulating purpose microwave transparent is well suited as it absorbs the negligible amount of microwave energy [1-3]. Generally, ceramic, glass, teflon, mullite tube, porous alumina fibre board, silicon nitride, boron nitride, yttria stabilized zirconia and air considered as transparent to microwave radiation at normal operating frequency range [4]. However, the transparent material gets heated after the critical temperature of the material is reached. For example, ceramic material starts coupling with microwave energy at a temperature range of 900 to 950°C [5]. Stating the different advantageous such as selective heating and rapid heating, shorter processing time, environmentally friendly process the microwave energy is widely accepted in different manufacturing operation like cladding, joining, casting and sintering process [6,7]. The molecular vibration generated by the microwave energy absorption produces the heat in the material. In microwave heating, the material is getting heated from core to the surface of the material. However, after a certain point, the heating rate is very slow as it requires larger time for the effective coupling with the material [2]. The heating rate is dependent upon the penetration depth or skin depth of the material. The skin depth for any material is defined as the surface distance from which the current density is fall to 0.3679 of its...
The value of skin depth can be given by the empirical relation \( \delta = \frac{1}{\sqrt{\pi f \sigma \mu}} \); where, \( \delta \) is the skin depth of material, \( f \) is the applied frequency (Hz), \( \sigma \) is the magnetic permeability (H/m) and \( \mu \) is the electrical conductivity (S/m).

For the efficient use of microwave energy, the microwave absorbing material is essential for the different heating process. The microwave absorbing material comes under the materials which absorb the electromagnetic energy and convert it into heat and is commonly termed as susceptor material [2]. The simple way of using microwave susceptor is the make use of susceptor crucible or coating of susceptor material in the different crucible which is used for the different operation. However, in the case of suspecting crucible, the heating rate is slower comparatively susceptor material applied on the crucible periphery. For the use as susceptor following different type of material is generally employed for heating application. Table 1 shows the different susceptor material and their penetration depth along with loss tangent value.

**Table 1:** Different kinds of susceptor material and their penetration depth value (data taken from Bhattacharya and Basak, 2016)

| Susceptor material                     | Loss tangent factor | Penetration depth (cm) |
|----------------------------------------|---------------------|------------------------|
| SiC                                    | 0.37                | 1.43                   |
| Graphite powder (20-80 micron)         | 0.37                | 1.34-2.09              |
| Graphitized Carbon Powder (60-80 mesh) | 0.4-1               | 0.5-0.9                |
| Charcoal powder                        | 0.14-0.38           | 6-11                   |
| Carbon black                           | 0.23                | 5.75                   |
| Water                                  | 0.15                | 3                      |
| Activated carbon                       | 0.31-0.9            | 0.7-3.43               |
| Carbon fiber                           | 0.45-0.5            | 0.5-0.7                |
| Carbon nano-tube                       | 1.11                | 0.2                    |

The proper design of susceptor assisted microwave heating is insignificant without the use of insulating material. The microwave insulating material is the material which is having excellent microwave transparency during the entire working region at a high temperature. The insulating material prevents heat loss to the microwave cavity and protect the functional unit of the microwave [7,8]. For microwave insulation different material such as alumina board, fibre wool, alumina glass wool, porous alumina blanket and fiber board etc. are employed. The insulating material is having very high thermal and wear resistance over an extensive range of temperature. Three different modes of microwave susceptor material is suggested in the time span by various researchers which comprise the use of the rod, powder material and tubular kind of susceptor. For the rod kind of microwave susceptor SiC, MoSi_2 and BN rod are effectively employed [7,9].

The present aim of the study involves the make the comparative assessment of three different kinds of susceptor material *i.e.* charcoal and silicon carbide for a fixed interval of time and microwave susceptor crucible graphite is used. The present study helps in the selection of the amount of susceptor material for different manufacturing operation like cladding, joining, sintering and casting. The study implicates the heating rate for the selected susceptor material for a fixed interval of time.
2. Experimental Details:

2.1 Materials:
For the comparative assessment three different material charcoal and silicon carbide were used without any further purification. The charcoal powder material is purchased from the local merchant while the silicon carbide powder material is purchased from Alpha Chemika Pvt. Ltd. Mumbai India. The average size of the graphite and silicon carbide ranges in between 50 to 100 micron. The microwave susceptor assisted crucible i.e. graphite crucible, purchased from HiTech Ceramics Pvt. Ltd. Chennai India.

2.2 Experimental Procedures:
The experimental trails were carried out in the conventional domestic LG charcoal oven microwave the different experimental trials. The test was carried out at 900W with 2.45 GHz microwave frequency level at normal atmospheric conditions and at room temperature. Figure 1 represents the schematic representation of the tested experimental setup for the study of heating rate in the microwave. For the protection of the inner wall of microwave and to prevent heat loss alumina board is used as insulating material [7]. The temperature measurement was carried out by the setting up the infra-red thermometer in the test arrangements. During experiment non-contact Fluke 572 infrared thermometer was used. The thermometer is capable of measuring temperature range of 30 to 900 °C with advanced extra-bright three-dot laser sighting having resolution of 0.1 °C. For the experimental trails with charcoal and silicon carbide similar arrangements were made and covered with alumina board as an insulating medium.

![Figure 1: Experimental setup used for hybrid microwave heating process](image)

3. Results and Discussion:

3.1 Microwavesuscepting graphite crucible:
Microwave suscepting graphite boat of thickness 25mm is employed for hybrid microwave heating process. The test trail is run for 70 minutes to know the heating rate of the curable under 2.45 GHz frequency with 900 W. The heating profile of the suscepting crucible is presented in Fig. 2 (a) and Fig. 2 (b) represents the actual experimental setup by the use of microwave suscepting crucible. Form the graphical representation it is evident that the heating rate is very slow and the maximum attainable temperature is 350 °C with the time duration of 70 minutes. The slow heating rate of the graphite crucible can be attributed due to following reasons: (a) higher wall thickness of the graphite plate (b) lower microwave power and (c) use of solid block of graphite in the heating process. It is evident from the literature that the solid form (plates or rod) of susceptor tends to generate slower heating rate compare to powder form. It may be possible that the use of microwave power is not enough for the generation
of higher temperature in the crucible. For the higher temperature with the use of microwave, crucible may require longer processing time and higher energy for the effective utilization of electromagnetic energy [3,10].

![Graphite Crucible Heating Profile](image)

**Figure 2**: (a) Heating profile of graphite susceptor crucible; (b) Actual experimental setup in microwave

### 3.2 Charcoal and Silicon carbide as susceptor material:
Charcoal is considered as a good absorber of electromagnetic energy having loss factor in the range of 0.14 to 0.38 with penetration depth 6 to 11 cm. Charcoal is widely employed for joining and cladding purpose for different work material as the melting point of charcoal is considerably high and transfer the heat from microwave radiation [11,12]. The various investigators reported the charcoal as susceptor material during joining and cladding operation however, the heating profile with the amount is not mentioned properly [11-14]. Fig. 3(a-b) represents the heating profile of charcoal and silicon carbide as susceptor material for 10 minutes. In the present case amount of 15-gram and 30-gram charcoal and silicon carbide is placed inside the oven for proper scale-up consideration in future for different material processing applications. Initially, the coupling of electro-magnetic energy with charcoal is poor due to which the rise in temperature is slower. Once the molecules of charcoal get couples with electromagnetic energy the temperature advances rapidly [13,14]. Fig. 4 represents the schematic presentation of the charcoal at higher temperature zone. The red burning of the charcoal is observed at higher temperature. The coupling of electromagnetic energy with the material can be understood by the penetration depth of the material at a microwave frequency of 2.45GHz. The size of the material plays a vital role in the enhancement of temperature (i.e. reduced particles size increases the heating rate) [15]. For the effective coupling of the microwave energy, the particles size must be less than or equal to the penetration depth of the material at the operated frequency [16]. Sometimes, the moisture content, the presence of an oxide layer in the susceptor material enhances the heating rate for the material. Similar observation can be made in the case of silicon carbide (SiC) powder material for heating in the microwave. The temperature increment is initially very poor but once the critical point of the material is reached the temperature rises in a faster manner [8]. The use of hybrid heating is dependent on the size and amount of material to be used. This phenomenon is well demonstrated by the temperature profile obtained during heating of two different amount of powder susceptor material under similar operating conditions and environment.
4. Conclusions
A comparative assessment of the heating profile of three different susceptor material (i.e. susceptor assisted crucible, charcoal and silicon carbide) is presented in brief. During the experimental procedure, it is found that the selection of susceptor assisted crucible is easier to use and handling purpose. However, the heating rate achieved is very poor compare to powder form of susceptor material. The following concluding remark can be given as per the experimental observation made in the study:

- For slow heating rate and low-temperature application susceptor assisted crucible is well found for the easy use and supervision.
- Heating of charcoal is very good and dependent upon the amount used in the study. Beyond 550 °C the charcoal becomes red hot and starts burning in the exposure of microwave radiation. The charcoal heating is well suited for the application where the temperature is in the range of 500 to 600 °C. Also, the investment cost is very less in case of charcoal and is readily available.
- The heating pattern of silicon carbide is similar to charcoal and totally dependent upon the amount of susceptor used. Due to the very high melting point of silicon carbide, it is found to be in order for high temperature application such as cladding, sintering and material melting applications.
The presented paper gives an overview of the heating profile of different susceptor material under the exposure of microwave radiation. This will help the researcher to find out an optimum amount of susceptor for different material processing application.

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