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Metal-Casting by using Integration of Microwave Energy

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Abstract : Metal casting processes traditionally rely on conventional heating methods such as induction furnaces or gas-fired furnaces. its key drawbacks are poor mechanical and metallurgical qualities, accuracy issues, porosity, surface polish, inappropriate solidification, and process control. Because of the more even heating and self-limiting characteristics of the microwave heating in metal casting presents a promising alternative due to its potential for rapid and localized heating. Microwave heating offers several distinct advantages over conventional methods, including enhanced energy efficiency, shorter processing times, and precise control over heating gradients. These benefits stem from the ability of microwaves to directly couple with metal particles, generating heat internally through molecular friction. This localized heating mechanism reduces overall energy consumption and minimizes heat loss to the surroundings. In this work, a multimode home microwave applicator operating at 900 W and 2.45 GHz is used to evaluate the feasibility of microwave casting bulk Al, Pb and Cu. The many susceptor components or additives, such as charcoal powder, graphite powder and plates were utilized to heat bulk metals hybridly. We use fire bricks to support the metal and give it height. When the bulk metals were exposed to heat for melting and casting, the heating conditions of the susceptor and the metals were monitored.

***IndexTerms* - Microwave energy, bulk metal casting, localized heating, Additive or susceptor**

[I]INTRODUCTION

The oldest primary manufacturing process, metal casting, has gained acceptance in industries because it can produce intricate shapes with flexibility, cast both ferrous and non-ferrous metals, is a cost-effective way to create extremely complex geometry near net shape components, and has no restrictions on product size or weight. Researchers now have the chance to create sophisticated casting techniques for higher-quality casts because of the restricted dimensional accuracy and surface polish of the items produced by casting processes. However, because of their inherent processing challenges, the current need of the industries is focused on casting processes that can cater to near net shape manufacturing, energy efficient, eco-friendly, and less processing time for the most suitable metals (like Mg, Ti, and so on) for structural, light-weight, and medical applications.

Recent research has demonstrated successful applications of microwave energy in various metal casting processes, including investment casting and sand casting. These studies highlight improvements in casting efficiency, material utilization, and mechanical properties of cast products compared to conventional methods. An alternative to the high energy consumption casting procedures that are widely employed in industry is microwave metal processing. As opposed to conventional heating, which transfers heat from the outside to the inside of the material, microwave processing creates energy inside the material through the interaction of electromagnetic waves with molecules [1]. Metals such as tin, zirconium, uranium, copper, brass, bronze, and aluminum with masses ranging from a few kg to 350 kg were reported to have undergone microwave melting and heat treatment [2].

There have been reports of bulk metals melting, including copper, stainless steel, and aluminum, without any metal heating properties [3]. By adjusting the loads and microwave power levels, an experimental study and lumped parameter model for hybrid microwave melting of Iron, lead, tin, aluminum, and copper were presented. The investigation showed that temperature has a significant influence on heat absorption [4]The functioning of a reduced-scale empirical model was examined using the Comsol Multiphysics simulation program, and temperature profit was validated [5]. Additional reports included the drilling of metallic sheets [6], the cladding of different materials on bulk metal substrates [7–16], and the joining of similar [17–23] and dissimilar [24] metallic bulk materials.

The potential of microwaves to metal metallic materials with the right tooling and the possibilities of microwave casting process have been demonstrated in published literature on microwave processing of metallic materials; however, the experimental procedure, results, and characteristics of casted materials are not reported so for. This study presents the initial findings from a research project on in-situ microwave casting and bulk lead and copper characterization employing microwave radiation in a multimode applicator

[II] PROCEDURE

This section has covered the materials and procedure utilized to develop the microwave cast during the experimental experiments.

2.1 Material details

In the current work, a home microwave oven with 900 W of power and a frequency of 2.45 GHz was employed to create microwave casts utilizing commercially available copper scrap wire, aluminum 6061 plate, and lead ingots as casting materials. Fire brick was utilized to make a sizable split mold. For this reason, a pouring configuration, a mold cavity, and sprue were created. As a separator layer, a 99% pure alumina plate with a thickness of one millimeter was employed. The separator prevents the powder from the susceptor from possibly contaminating the molten metal. The Table 1 present the chemical compositions of all the metals used for microwave casting.

Table 1. Chemical Compositions of Metals

Metal/ Alloy	Constituents (Weights %)																			
	Cu	Bi	Sb	As	Fe	Ni	Pb	Sn	S	O	Zn	P	Ag	Cd	Al	Mg	Si	Mn	Ti	Cr
Cu	99.965	0.002	0.002	0.001	0.006	0.002	0.006	0.001	0.006	0.001	0.006	0.002	-	-	-	-	-	-	-	-
Al	0.13-0.45	-	-	-	0.65	-	-	-	-	-	0.25	-	-	-	94.96-98.56	0.15	0.4-0.8	0.08-o.12	0.13	0.04-0.35
Pb	0.001	0.13	-	0.001	0.0010	0.0002	98.985	0.004	-	-	0.002	-	0.0025	0.002	-	-	-	-	-	-

2.2 Development of Cast

When it comes to microwave casting, the mold design is crucial. Since graphite is a good microwave heat-absorbing substance that minimizes temperature gradients during casting solidification and ensures primary hybrid heating of bulk metal with susceptor, it is selected as the mold material. Additionally, this gives the ejected materials and mold interface a firm lubricant. The graphite blocks were machined to create the pouring basin, sprue, and mold cavity that were needed. The mold system was placed in the microwave applicator, and the bulk metal was poured into the base as shown in Fig. 1. All the steps are shown in Fig.2

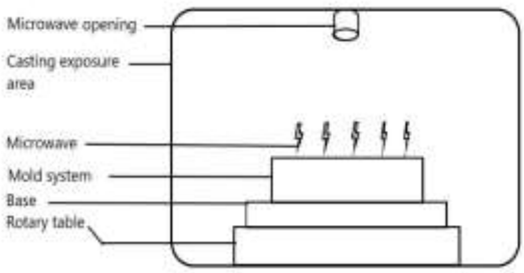

Fig 1 Schematic of experimental setup

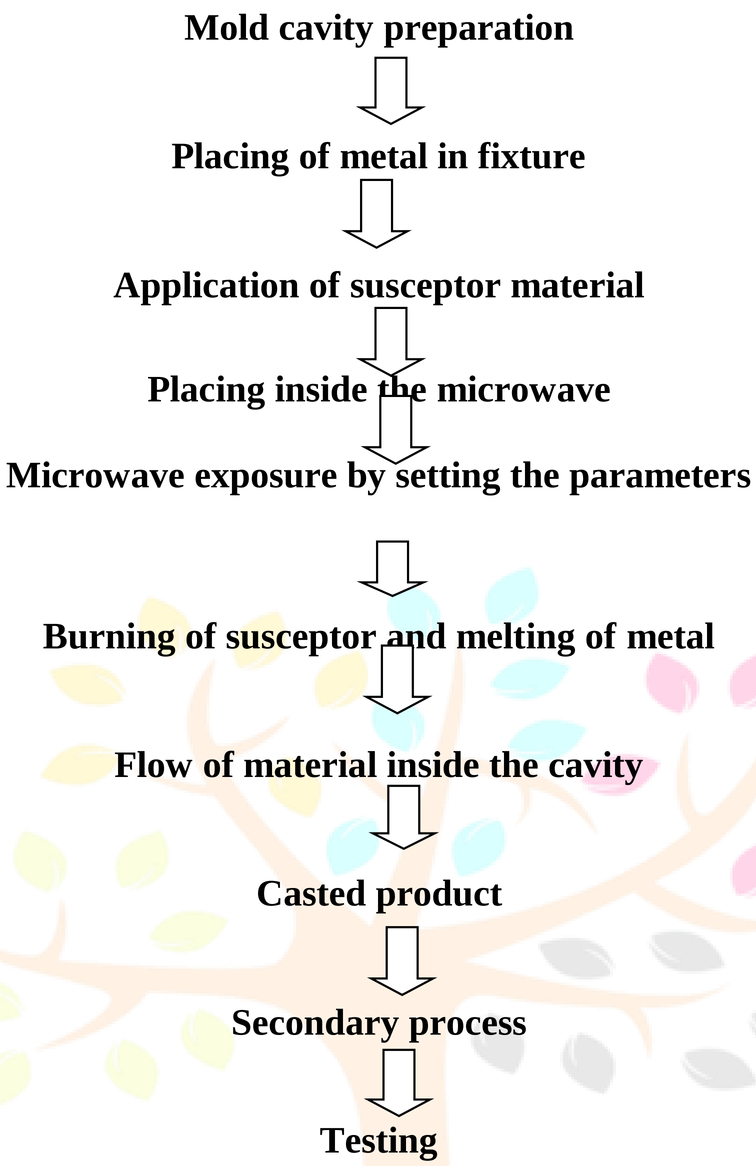

Fig. 2 Steps involved in Metal Casting by microwave energy

[III] RESULTS/ OBSERVATIONS

The development of microwave casting of the target metals was carried out using a home multimode microwave applicator. Throughout the investigation, the microwave power of 900 W and frequency of 2.45 GHz remained constant. Graphite molds were used to test various combinations of susceptor materials (charcoal and graphite) and metals (lead, copper, and aluminum). With varying microwave exposure times to the mold system, the impact of the microwave on metals and susceptor materials was studied. Many experimental experiments were conducted with various variations of the aforementioned conditions to achieve total melting of metals.

The observations of experimental trials have revealed encouraging results which are tabulated in Table 2 and a few castings are shown in fig 3.

Table 2. Observations of experimental trials

S.No	Susceptors /Additives	Metals	Time of exposure (in minute)	Observations of heating status	
				Additive	Metal
1	Graphite Powder	Al	12	Burn	Fusion
2		Cu	9	Burn	Melting
3		Pb	5	Burn	Melting
4	Graphite Plate	Al	32	Heat	Min. Heating
5		Cu	18	Heat	Heating
6		Pb	7	Heat	Heating
7	Charcoal powder	Al	22	Burn	Moderate Heating
8		Cu	13	Burn	Fusion
9		Pb	8	Burn	Melting

(a) Microwave applicator (b) Molding System in fire bricks (c) Fused part of Cu and Al (d) Cast part of Pb

Fig3 Images of a few microwave cast parts

[IV] CONCLUSION

Because microwaves reflect at ambient temperature, it is very difficult to cast metallic materials in bulk using microwave radiation. In the current work, a multimode microwave system was used to cast lead, copper, and aluminum. The creation of appropriate metal castings and their characterization is ongoing. Seldom has the use of microwave energy for metal casting been documented in other sources. The following key findings can be used to summarize the observations made during microwave casting in experimental trials:

1. Using a multimode household microwave applicator operating at 2.45GHz, bulk metals and alloys can be cast using microwave hybrid heating.
2. Pure aluminum metal casting is challenging and heavily influenced by the oxide layer that forms after heating. Conventional heating by the susceptor is impacted by the presence of Al2O.
3. By selecting the right settings, lead and copper can be cast with microwave energy with ease.
4. Microwave casting is primarily influenced by the duration of the material's microwave exposure. An excessive amount of exposure time could lead to energy loss and separator cracking, while a short exposure period could result in incorrect metal melting.
5. The microwave casting process is also impacted by the choice of susceptor material that has the appropriate thickness to be placed on the separator layer.
6. High dielectric loss factor susceptors are able to absorb microwaves faster and heat materials to the point of melting.
7. Like with traditional casting, pouring metal from a poring basin into a mold cavity during microwave casting depends on the design of the mold sections according to part configuration.
8. Height and location of mold assembly may matter during microwave exposure.

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