ORIGINAL RESEARCH PAPER

Engineering

MICROWAVE WELDING OF THERMOPLAST

KEY WORDS:

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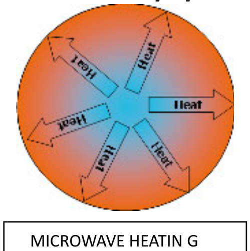
ABSTRACT

Microwave heating has a number of advantages over conventional heating due to the ability to heat specimens directly through specific interaction of electromagnetic radiation with the material. Thus it is possible to consider highly localised, rapid melting of thermoplastics using microwave radiation as a means of forming and Welding. The potential benefits of this technique over conventional methods are shorter weld times and non-contact processing. It should be emphasized that microwave welding is still under development and is not currently a commercially available process. Therefore, the feasibility of each potential application must be investigated thoroughly at the present time. The microwave processing of materials provides improved mechanical, physical and electrical properties with much reduced processing time.

INTRODUCTION

Say there's a leak in a sewer pipe—and that pipe happens to be under the Buckingham Palace. How do you fix it? You're not going to tear up the palace to access it, that's for sure.Repairing leaking pipes in out-of-the-way locations has long been a vexing problem.
One option for fixing a leaking plastic pipe is repairing it with a patch or a weld: but how do you patch or weld when you can't get someone to the site?

The solution to the problem lies in two words **MICROWAVE WELDING**.Microwave welding is a form of electromagnetic welding, similar to radio frequency, laser, induction and IR welding, but using a radiation frequency of typically 2.45 GHz. Since most thermoplastics do not experience an immediate temperature rise when irradiated with this frequency of radiation, this technique normally works by placing a microwave energy absorbing material, in the form of a gasket, at the joint interface. The heat generated in this implant then melts the surrounding thermoplastic, producing a weld upon cooling. However, some thermoplastics, that is, those containing polar groups as part of their molecular structure, such as ABS, PVC, nylon, and PVDF, will heat in a microwave field and can be welded directly. Microwave heating has a number of advantages over conventional heating due to the ability to heat specimens directly through specific interaction of electromagnetic radiation with the material. Thus it is possible to consider highly localised, rapid melting of thermoplastics using microwave radiation as a means of forming and welding. However, most polymers exhibit very low dielectric losses in the GHz regionwhichmeans that it is difficult to heat them efficiently by this means.



MICROWAVE HEATIN G

Basic principles

Rapid and contact-free heating with microwaves

As a result of their long wavelength, microwaves can penetrate deeply into many polymers. This enables contact-free heating deep in the material. Heating occurs volumetrically and is relatively independent of the thermal conductivity. We offer heating devices ranging from simple multimode ovens and continuous ovens to tailored solutions optimized according to field distribution, time scale and energy consumption.

The **microwave implant welding** process consists of **five steps:**

(1) Application of Implant: A consumable, microwave susceptible implant is applied at the joint interface. The implant is a INTRINSICALLY CONDUCTING POLYMER.

(2) Clamping: The parts to be joined are clamped together to ensure that the surfaces to be welded are in intimate contact throughout the welding cycle.

(3) Heat Generation: Heat is generated in the implant by absorption of the microwave radiation.

(4) Heat Conduction and Melting: The heat is conducted from the gasket to the thermoplastic parts, resulting in melting in the joint area. Material starts to fl ow and a weld is formed due to intermolecular diffusion and chain entanglement as the parts come into intimate contact.

(5) Cooling: The microwave power is terminated and the weld interface and bulk material are allowed to cool and solidify.

LITERATURE REVIEW

Microwave Welding has enormous potential in welding technology. If utilized properly, it can save a large amount of welding time and skilled labour required. In the words of **Mr. R.J. Wise** and **Mr. I.D. Froment**, in their **JOURNAL OF MATERIAL SCIENCE** in **2001**, a new and versatile method for welding thermoplastic material is Microwave energy. For this they developed a multimode cavity applicator to deliver an even energy density and to apply weld pressure. These two things are the most desirable properties required for the welding using microwaves.

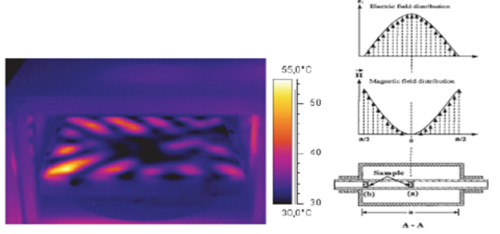
Mr. E.T. Thostenson, in his research paper on **MICROWAVE PROCESSING** in **1999**, explained the significance of microwave energy as a potential method of heating and welding materials apart from food. He concluded that the energy is supplied by an electromagnetic field directly to the material. He pointed out certain properties of microwaves which are utilized by us in welding the thermoplastic sheet of Polymethyl Metha-acrylate.

In the journal of **JOINING OF THERMOPLASTICS** in 2003 by **Mr. L.A. Stoynov** and **Prasad K.D.V. Yarlagadda,** various methods of joining of thermoplasts were studied. Today most manufacturing technologies and facilities are being developed for efficient and environmentally friendly production.

MICROWAVE HEATING

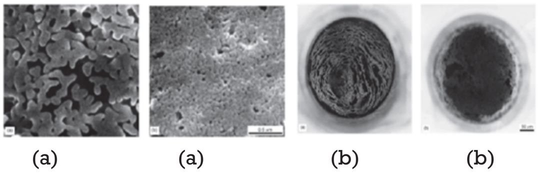
Microwave versus conventional heating

Conventional heating usually involves the use of a furnace or oil bath which heats the walls of the reactors by convection or conduction. The core of the sample takes much longer to achieve the target temperature. On the other hand Microwave penetrates inside the material and heat is generated through direct microwave-material interaction. Moreover volumetric heating, reaction rate acceleration, higher chemical yield, lower energy usage and different reaction selectivity the advantages microwave heating has over conventional methods. Combustion synthesis has been one of the methods used to obtain powder with compositional uniformity. Figure 3 illustrates merit of microwave heating over conventional method during the synthesis of $LaCrO_3$ powder as homogeneous fine particles (Park et al.1998). The mixer solution of the parent constituents was equally divided and kept for combustion separately on a hot plate and in a microwave oven. Combustion products thus obtained were treated in a similar way and morphology was examined by scanning electron microscopy (SEM). The product obtained by hot plate combustion is found to be consisting of hard agglomerates formed by the two dimensional interconnection of spherical particles. On the other hand product of microwave induced combustion appears to be smaller in size and with reduced agglomeration.



(a) (b)

FIG 6 (a) INFRA RED THERMAL IMAGING INSIDE MICROWAVE OVEN (b) THE SCHEMATIC OF THE MICROWAVE FIELD DISTRIBUTION (E & M) IN THE MICROWAVE cavity.



(a) (a) (b) (b)

FIG 7 MORPHOLOGY WITH SEM MICROGRAPH OF THE COMBUSTION PROCESS (a) HOT PLATE (b) MICROWAVE RADIATION

A few reactions which were carried out using microwave heating and compared with conventional heating indicating time and energy efficiency of the technique is compiled in Table 1.

Table 1 Comparison Of Microwave And Conventional Heating

Compound synthesized	Reaction time - microwave	Reaction time - conventional	references
Esterification (benzoic acid with methanol)	5 min.	8h	Gedye et al (1988)
4-nitrobenzyl ester	2 min	1.5 h	Gedye et al (1988)
$CuBi_2O_4$	5 min	18h	Jones & Akridge (1995)
Bi_2Pd(Intermetallic)	4 min.	12 h	Lekse et al. (2007)
Ag_3In(intermetallic)	2 min.	48 h	Lee & So. (2000),
Layered Al and Zn double hydroxide with Na-dodecyl sulfate	1-2 h	2-3 days	Hussein et al. (2000)
Bronzes (Na_xWO_3)	13-15 min.	-	Guo et al. (2005)
Ti N	30 min	-	Vaidhyanathan & Rao (1997)
Cubanite $CuFe_2S_3$	3min	3 days	Chandra et al. 2010
$La_{2-x}Sr_x Mn_2O_4$	30 s	-	Mingos & Baghurst. 1991
High Tc superconductors YBCO	12 h	72 h	Binner & Al-Dawery (1998)
Zeolite synthesis	170 ºC in 30s	170ºC in 60min	Jansen 2004
MgB_2	11min	-	Dong et al. 2007
$NaAlH_4$	2h	8h	Krishnan et al. 2009
$La_{0.2}Sr_{0.8}Mn_{0.8}Fe_{0.2}O_{3+\Delta}$	3h	3 days	Chandra (unpublished)

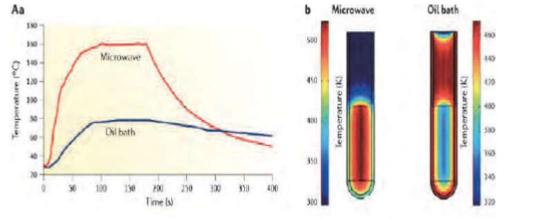


FIG 8 Temperature Profiles For Ethanol Under Microwave Radiation And Open Vessel Oil Bath Condition And Temperature Gradient 1Min. After Heating

Interaction of microwaves with materials

Two factors are important to select the frequency of microwave radiation to heat the materials (i) power absorption in the matter, and (ii) depth of penetration. In electromagnetism, materials are divided into two categories: (i) conductors and (ii) insulators or dielectrics. The distinction between them is not very sharp. The same material may behave as a conductor in one part of electromagnetic frequency and as a dielectric in another. According to Maxwell's theory, the ratio

$$\varepsilon = \varepsilon' + j\varepsilon'' \quad (1)$$

where ε' = the real component of permittivity

ε'' = the imaginary component of permittivity

The real part or relative permittivity represents the degree to which an electric field may built up inside a material when exposed to the electric field while the imaginary part or dielectric loss is a measure of amount of the field transformed into heat. The Loss angle

$$\tan\delta = \varepsilon'' / \varepsilon'$$

(2)Thus the $\tan\delta$, the dissipation factor determines the ability of material to transform absorbed energy into heat.

In terms of microwave interaction, the materials can be classified into three categories:

I. Microwave reflectors e.g. metals

ii. Microwave transmitters – transparent to microwave radiations e.g. fused quartz, ceramics, zircon etc.;

iii. Microwave absorbers taking up energy from the microwave field and heating the materials rapidly.

The electromagnetic energy absorption in dielectric materials primarily is due to the existence of permanent dipole moment of the molecules which tend to orient and reorient under the influence of electric field of microwave. The reorientation loss mechanism originates from the inability of the polarization to follow extremely rapid reversals of the electric field. In the low frequency (up to 100 MHz) electric field, the dipoles easily follow the changes in the field and their orientation changes in phase with the field. At higher frequencies the inertia of molecules and their interactions with neighbours make changing orientation more difficult and the dipoles lag behind the field. As a result, the conduction current density has a component in phase with the field and therefore power is dissipated in the dielectric material. At very high frequencies (1- 10 Thz), the molecules can no longer respond to the electric field. At GHz frequency (ideal working range) the phase lag of the dipoles behind the electric field absorbs power from the field and therefore pronounced as dielectric loss due to dipole relaxation. Another important parameter for microwave heating ,penetration depth Dph is defined as the depth into the material where the power is reduced to ~ 1/3 of the original intensity. The absorption coefficient α of dielectric material is related to imaginary parts of dielectric constant ε'' or the refractive index. The depth of penetration Dph of electromagnetic waves in matter is related to α as Dph $=1/\alpha$. Thus a material with higher dissipation factor will have lower penetration depth.

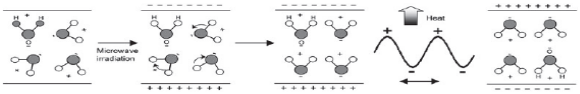


Fig 9 Heating Mechanism Of Water

Thus a material with higher dissipation factor will have α lower penetration depth. The wavelength of the radiation also has influence on penetration depth. For microwave prone materials the absorption coefficient at 2.45 GHz is moderate and depth of penetration is of the order of 10 cm to 1m which results in absorption of microwave everywhere in material.

Heating mechanism of water due to microwave field.

A good absorber has $\tan\delta, \geq 0.1$ while those with $\tan\delta, \leq 0.1$are transparent to microwave. Materials with high loss factor at the frequency of the incident radiation will heat at a faster rate from core to surface. Fused quartz, zircon, several glasses, ceramics and Teflon are good transmitter while in SiO_2 , dielectric constant and losses do not show much dispersion hence no heating occurs. Tap water is microwave active as compared to distilled water. Alumina is microwave transparent at room temperature at 2.45 GHz but heats up efficiently at 10000C becoming highly susceptible at 15000C. SiC, on the other hand usually heat well at moderate frequency. Microwave susceptors are fabricated by depositing very thin layer of aluminium on polyester(PET) sheets. The thin layer of aluminium absorbs part of microwave energy creating currents in the metal. The thickness of the layer limits the currents hence preventing arcing however the currents are high enough to heat the susceptor to a high temperature. Such arrangements are popular in food industry. A list of materials useful during microwave heating process is tabulated in Table 2.

The behaviour of bulk metal pieces and metal powder under microwave radiation are different. Skin depth in metal is very low and varies as $(\sigma)^{-1/2}$ showing less penetration of microwaves. In large metals and metal films, electric field gradients occur in the microwave cavity giving rise to electric discharge. In metal powder, due to eddy currents and plasma effects, very rapid heating takes place without any discharge.

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