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Microwave welding of thermoplastics using inherently conducting polymers

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Inherently conducting polymers have been used as microwave absorbers to weld thermoplastic materials. The welding takes place in 2–120 s with lap shear strengths as high as 19.0 ± 2.0 N mm^{-2}. The method can be applied to any thermoplastics.

(Keywords: microwave; welding; thermoplastics)

Introduction

Welding of thermoplastics for a variety of uses is a daily occurrence and is performed by techniques based on resistive implantation, ultrasonics, infra-red heating vibration, etc.[1]. Microwave welding is a largely neglected area because of a lack of suitable microwave absorbers and the fact that microwave engineering has only recently been developed adequately. Welding of thermoplastics by microwave heating using inherently conducting polymers (ICPs)[2] has been suggested. Use of ICPs as microwave absorbers has also been reported[3]. ICPs are good absorbers of microwaves[3] and their microwave characteristics can be altered by suitable choice of dopants and the degree of doping[4]. The 'organic' nature of the ICPs helps form good bonds between the thermoplastics to be welded[5].

Experimental

In a typical experiment, a small amount of ICP (either as powder (20 mg) or tape (two strips with dimensions 20 mm × 2 mm × 40 μm)) was placed on the upper surface of the plastic (10 cm × 2 cm × 0.1 cm). Then a second piece of plastic was placed on top and clamped in a device made out of pyrophillite ceramic material which does not absorb microwaves. *Figure 1* shows the process schematically. The clamp assembly was then placed in a microwave oven with a total power of 500 W and a cavity size of 30 cm × 20 cm × 20 cm. Typical welding time ranged from 2 s to 2 min.

Results and discussion

Table 1 summarizes some welding experiments carried out using conducting polypyrrole and polyaniline on

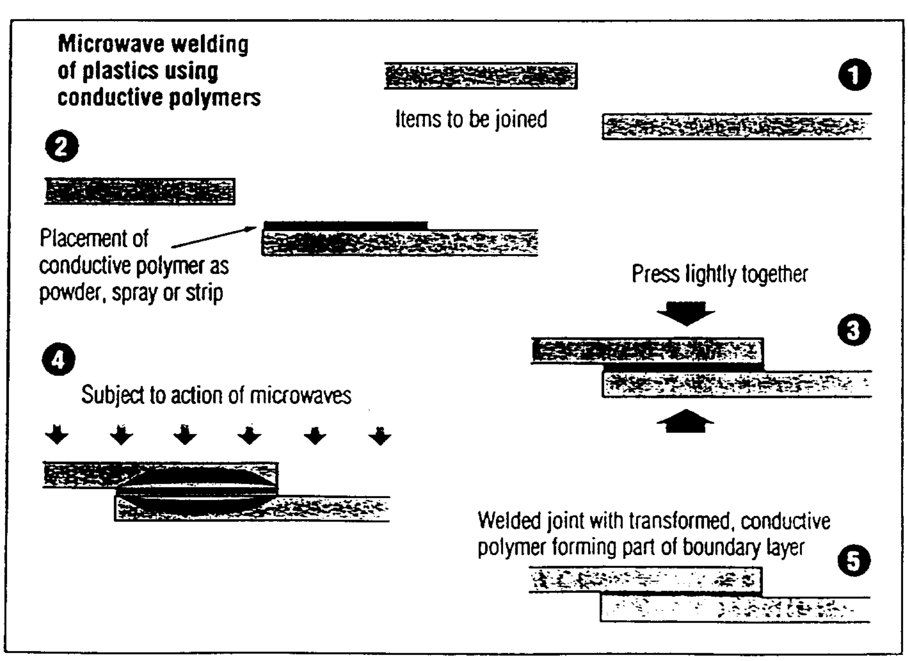

Figure 1 Schematic representation of microwave welding with inherently conducting polymer (ICP)

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Table 1 Microwave welding of thermoplastics using inherently conducting polymers

No.	Substrate to be welded	Conducting polymer[a]	Conductivity (S cm^{-1})	Time to weld (s)
1	Polycarbonate	PPPTS(p)	22.0 ± 2.0	100 ± 10
2	Polycarbonate	PAPTS(p)	9.0 ± 1.0	120 ± 5
3	Polycarbonate	A(t)	1.0 ± 0.1	5 ± 1
4	Polycarbonate	B(t)	12.0 ± 3.0	2 ± 1
5	Polycarbonate	C(t)	$(5.7 \pm 0.3) \times 10^{-2}$	40 ± 2
6	Polypropylene	A(t)	1.0 ± 0.1	5 ± 1
7	Polypropylene	B(t)	12.0 ± 3.0	2 ± 1
8	Polypropylene	C(t)	$(5.7 \pm 0.3) \times 10^{-2}$	60 ± 5
9	Polyethylene	PPPTS(p)	22.0 ± 2.0	5 ± 2
10	Polyethylene	PAPTS(p)	9.0 ± 1.0	15 ± 2
11	Polyethylene	A(t)	1.0 ± 0.1	30 ± 5
12	Polyethylene	B(t)	12.0 ± 3.0	2 ± 1

[a] PPPTS = polypyrrole *p*-toluenesulfonate; PAPTS = polyaniline *p*-toluenesulfonate; p = powder (thickness of powder on the weld 100 μm); t = tape; A(t) = non-woven polyester tape impregnated with PPPTS (thickness 110 μm); B(t) = microporous polyethylene impregnated with PPPTS (thickness 40 μm); C(t) = non-woven polyester impregnated with carbon black (110 μm)

polycarbonate, polypropylene and polyethylene. Lap shear strengths of 19.0 ± 2.0 N mm^{-2} have been obtained for cases where non-wovens or microporous membranes impregnated with polypyrrole were used, while the polypyrrole powders gave a lap shear strength of 15.0 ± 1.0 N mm^{-2}. Polyaniline gave an even lower lap shear strength of 12.0 ± 1.0 N mm^{-2}. The carbon impregnated non-woven polyester produced a lap shear strength of only 4.0 ± 1.0 N mm^{-2}. From inspection of *Table 1* it is clear that the weld time is dependent on conductivity and thickness of the conducting material. This is because the absorption of electromagnetic radiation is given by

$$\text{Absorption} = Kd\sqrt{f\mu_r\sigma}$$

where K = constant, d = thickness, f = frequency of electromagnetic radiation, μ_r = relative magnetic permeability and σ = electrical conductivity. Thus, the weld time will not only depend on conductivity, magnetic permeability and thickness of the material but also on the frequency of electromagnetic radiation. In this particular case, $f = 2.45$ GHz as this is the legally permitted frequency for a microwave cooker. Thus at constant frequency and assuming that $\mu_r = 1$, the weld time should decrease with $\sqrt{\sigma}\,d$. This was indeed found to be the case. The relationship was not linear as the welding process requires melting of the thermoplastic base and the energy requirement for this purpose varies quite considerably with the nature of the thermoplastic material.

The high lap shear strength for the weld produced by polypyrrole impregnated non-wovens or membranes can be explained on the basis of diffusion of polymer melts through the pores, forming bonds as soon as the polymer is melted. The powder samples gave inferior lap shear strength, probably due to the fact that the bonds are random rather than oriented as in the case of non-wovens or microporous membranes. Carbon loaded polyester non-wovens produced the poorest weld strength. This is probably due to the fact that in the case of ICPs, the ICPs themselves can form covalent bonds with the polymer melt, forming a network. This is presumably absent in the case of carbon loaded polyester non-wovens.

In conclusion, it has been shown that ICPs can be used in the microwave welding of thermoplastics. Further work is under way to understand the fate of the ICPs during and after welding and the effect of the nature of the substrate on the welding process.

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