MICROWAVE FORMING AND WELDING OF POLYMERS

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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. However, most polymers exhibit very low dielectric losses in the GHz region which means that it is difficult to heat them efficiently by this means. We have therefore studied the use of fillers such as talc, zinc oxide and carbon black as a way of increasing the susceptibility of common polymers to microwave processing. Carbon black was found to be the most efficient susceptor for high density polyethylene and its efficiency was directly proportional to its surface area.
KEYWORDS: carbon black, polyethylene, susceptors, thermoplastics, welding

INTRODUCTION

Microwave radiation is a rapid and highly specific means of heating materials. Microwave heating has been used in many applications successfully, such as cooking of foodstuffs, chemical synthesis, ceramics sintering and medical therapy. In the area of polymer technology, microwave heating has been used for vulcanizing rubber [1,2], joining and welding plastic parts [3-5], polymerisation [6], and the preparation of polymer foams [7,8]. Our particular interest is the area of localised melting and welding of thermoplastics as a means of rapid processing and shaping.

Most thermoplastics are relatively transparent to microwaves; i.e. they do not absorb microwaves to a sufficient extent to be heated. Previous work has concentrated on the dielectric properties of thermoplastics [9-11], and although a few studies involved the heatability of some thermoplastics [5,10,12,13] there has been little emphasis on improving the microwave response of thermoplastics with low dielectric properties. The aim of our research is to investigate the effect of use of fillers such as talc, zinc oxide and carbon black on improvement of microwave response of high-density polyethylene (HDPE) without significantly compromising the mechanical properties of the virgin polymer.

EXPERIMENTAL

Materials

High density polyethylene (HDPE) molecular weight 2.2×10^5 g/mol, melt flow index 0.3g/min (190°C, 2.16kg), Borealis BS2581 was used as the matrix. Carbon Black was supplied by the Columbian Chemicals Company, talc (Luzenac A3 C) from Lusenac Europe SAS and zinc oxide from US Zinc.

Sample preparation and characterisation

A Haake PolyLab Rheomix was used to mix the HDPE with different amounts of carbon black. The mixing temperature was 180°C, mixing time was 10 minutes and rotational speed was 40 rpm. The materials were then made into sheets 1.5 mm thick by compression moulding at 180°C.

Microwave heating

A modified 800W domestic microwave oven was used for microwave heating experiments. The oven was modified so that the magnetron could be operated continuously on reduced power. Test specimens of filled polymer sheet (1 cm x 5 cm x 0.15 cm) were oriented vertically in the centre of the oven turntable using a block of ceramic foam as support. The initial and final temperature of the sample was recorded using a thermal imaging camera with the oven door opened to allow viewing (FLIR Systems Thermovision® A40).

Other tests

Mechanical properties of dumbbell specimens were measured using a tensile testing machine. Scanning electron microscopy was used to examine the fracture surfaces of the test specimens in order to establish the mode of failure.

RESULTS & DISCUSSION

Table 1 shows the relative temperature rise for carbon black, zinc oxide and talc at the same volume % loading for exposure to 200 W of microwave power for 60s. Tests on unfilled HDPE under the same conditions gave no significant temperature rise.

Table 1: Relative temperature rise for HDPE at 16% v/v loading of different fillers

Filler	Temperature rise (°C)
Carbon Black N550	177±10
Zinc Oxide	30±5
Talc	3±1

It is clear from this preliminary screening that carbon black is the most effective filler for imparting microwave heatability to HDPE therefore more extensive measurements were carried out on this (and other grades) of carbon black as shown in table 2. For subsequent experiments a higher power setting of microwave energy (800W) was employed for 15s seconds duration.

Table 2: Relative temperature rise for HDPE filled with different carbon blacks

product code	surface area (m^2/g)	oil absorbtion (cc/100 g)	ΔT/°C at different carbon black loading (% w/w)				heating efficiency (°C/%)
			5	10	20	30	
MT	7.5	41	1	1	3	22	0.8±0.3
N550	39	121	3	5	62	90	3.8±0.6
C7055	67	166	3	10	91	137	5.8±0.7
N330	77	102	4	34	85	156	6.0±0.3
N326	78	72	4	21	92	186	7.4±0.7
N339	92	120	4	23	87	215	8.3±1.3
N115	137	113	16	66	174	>400	10.5±0.2

The last column of table 2 represents the slope of a linear regression of ΔT versus carbon black content. Figure 1 shows a plot of this parameter versus the surface area (from manufacturer's data). There is a good correlation between surface area of the carbon black and the extent which it promotes microwave heating, whereas the oil absorbtion (or "structure") of the carbon black did not correlate with its effectiveness under microwave irradiation.

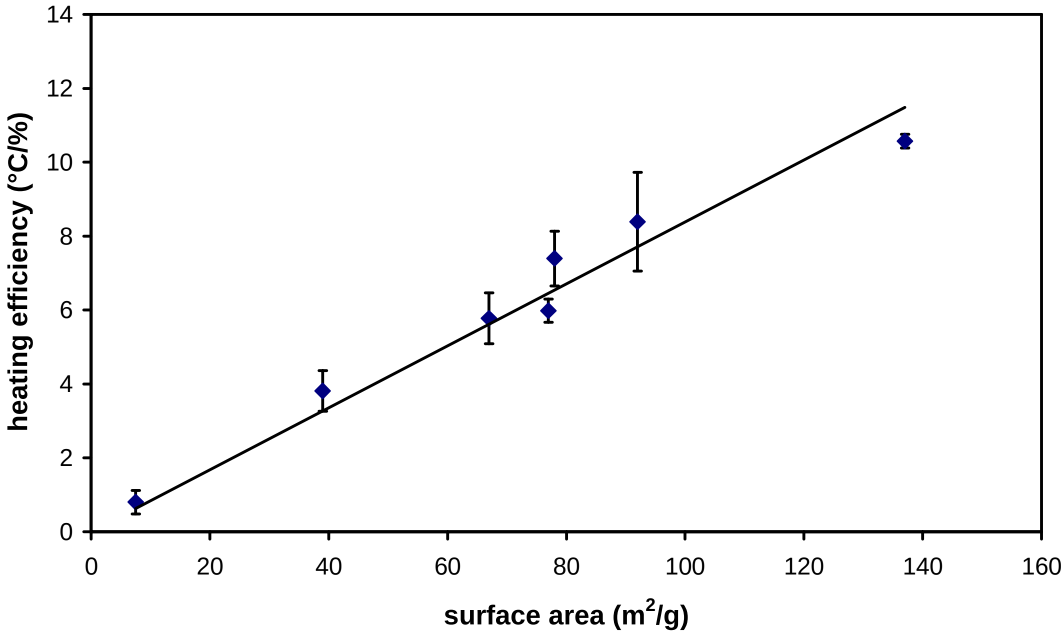

Fig. 1: Relationship between microwave heating efficiency and surface area for carbon black.

Mechanical testing on all of the filled HDPE compositions that were prepared showed that at low filler content the tensile strength and elongation at yield were unaffected by the incorporation of an additive. However, beyond 10-15% filler the material rapidly became very brittle.

CONCLUSIONS

Tests on carbon black, zinc oxide and talc indicated that carbon black was the most efficient susceptor for high density polyethylene. The efficiency by which carbon black improved the heatability by microwave irradiation was directly proportional to is surface area and loading. Above 10-15% carbon black had a detrimental effect on the mechanical properties of the HDPE. Selecting a carbon black with a high surface area which can be used at low loading without significant deterioration in the mechanical performance of the product would appear to be a good choice.

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REFERENCES

1. B. Krieqer, Polymeric Materials Science and Engineering, Proceedings of the ACS Division of Polymeric Materials Science and Engineering, 66, p 339-340 (1992)
2. D. Martin; D. Ighigeanu; E. Mateescu; G.. Craciun; A. Ighigeanu, Radiation Physics and Chemistry, **65** 63 (2002).
3. E. Siores and P. Groombridge, 6th International Conference on Manufacturing Engineering, 635-640 (1995).
4. H. S. Ku, F. Siu, E. Siores, J. A. R. Ball, Journal of Materials Processing Technology, **139** 291 (2003).
5. H. Potente, O. Karger and G. Fiegler, Welding in the World, **47** 25 (2003)
6. J. Jacob, L. H. H. Chia and F. Boey, J. Mat. Sci., **30** 5321(1995).
7. B.Wongsuban, K.Muhammad, Z.Ghazali and K.Hashim, Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, **211**(2) 244 (2003).
8. S. W. Lye, H. Y. Yeong and S. G. Lee, International Journal of Advanced Manufacturing Technology, **12** 87 (1996).
9. A. J. Bur, Polymer, **26** 963 (1985).
10. M. Chen, E. J. Siolchi, Polymer Engineering and Science, **33** 1092 (1993).
11. W. Riddle, J. Baker-Jarvis, IEEE Transactions on Microwave Theory and Techniques, **51** 727 (2003).
12. M. Chen, J. W. Hellgeth, Polymer Engineering and Science, 33(17) 1122 (1993).
13. H. S. Ku, M. MacRobert, Plastic, Rubber and Composites, 29(6) 278 (2000).