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Effect of carbon nanotubes on laser cutting of multi-walled carbon nanotubes/poly methyl methacrylate nanocomposites

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ABSTRACT

This paper studies the effect of carbon nanotubes on laser cutting of injection molded multi-walled carbon nanotubes/poly methyl methacrylate (MWCNT/PMMA) composite. Also the effect of processing parameters on laser cutting of MWCNT/PMMA nanocomposites is investigated in this study. Design of experiments is performed using full factorial method. Variable input factors are considered as MWCNT wt% in four levels, laser power in three levels and feed rate in three levels. Output parameters of this study are heat affected zone (HAZ), the average kerf width, and the taper kerf of the samples. Continuous wave CO_2 laser is used in the cutting process of the samples. Output parameters are studied in direction perpendicular to the flow direction. Experiments analysis is performed using analysis of variance method. Regarding the HAZ, results show that the most effective parameters are feed rate and the amount of the carbon nanotubes. High available carbon nanotube percentage causes approximately 50% decrease in the HAZ. Findings also clearly show that average kerf width is influenced by the three variable input factors. The tapering kerf of the samples is also significantly depended on the percentage of the carbon nanotube.

1. Introduction

The laser cutting of polymeric composites is a common method in industry. No tool wear and vibration, no need to clamping pieces, high production speed and ease of use are advantages of this process [1–3]. Zhou and Mahdavian [4] estimated depth of the cut in different powers and cutting velocities using a theoretical model. Accuracy of relationship between theory and practical results was studied in different ranges. The most important finding of their research was the possibility of cutting non-metal materials with low power laser. Caiazzo et al. [5] studied laser cutting of three polymers poly carbonate (PC), poly propylene (PP) and poly ethylene (PE). In their study, three gases argon (Ar), nitrogen (N_2) and compressed air were tested as a covering gas and it was proved that compressed air can be used with higher cutting velocity. They also concluded that high power is not necessary for cutting of polymeric material. Al-Sulaiman et al. [6] studied laser cutting of carbon multi-lamelled composites. They found that kerf width depends on laser power and particles orientation. Produced heat also transmits along with the direction of the fibers. Davim et al. [1] studied the effect of power and cutting velocity on PMMA cutting quality. Based on their findings, PMMA can be cut by laser with the HAZ between 0.12 and 0.37 mm and the surface quality of roughness less than 1 μm. They also studied laser cutting of PC, PE and PP composites. Finally, by evaluating obtained results it was proved that PMMA composite has the highest laser cutting quality. Herzog et al. [7] studied heat effects and static strength in laser cutting of Carbon-fiber-reinforced polymer (CFRP). They found that the laser types (Nd: YAG and CO_2) influence on characteristics like bending strength and heat affected zone (HAZ). Eltawahni et al. [2] tested the effect of laser power, cutting velocity and focal point position on upper kerf width, lower kerf width and roughness. Ultra-high-molecular-weight polyethylene (UHMWPE) was used in their experiments. Their obtained results confirmed the influence of three input factors on the ratio between upper kerf and lower kerf. It was also proved that the best surface quality could be obtained when the focal point is located in middle of the work piece thickness. Choudhury and Shirley [3] studied roughness and burr of three materials PMMA, PC and PP which were developed in the CO_2 laser cutting. Their findings show, in case of PMMA, the covering air pressure has the least effect on HAZ. Riveiro et al. [8] studied the effect of continuous wave and pulse mode on carbon

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fiber reinforced plastics (CFRP) using CO_2 laser. Better surface quality in continuous wave mode and decrease in HAZ amount by lowering power and increasing cutting velocity were their important achievements. Chuan and Choudhury [9] studied laser cutting of glass fibers reinforced polyester in single and multiple pass modes. Finally, single pass is suggested for better surface quality and multiple pass for developing kerf with least possible width. Schneider et al. [10] proved that by decreasing time between passes, HAZ intensity will increase in multiple pass laser cutting.

The above mentioned studies and also other previous researches show that Carbon nanotubes, as an additive for plastics, due to their particular mechanical, geometrical, electronic and electromagnetic properties are now extensively studied for various applications. Also the novel multi-wall carbon nanotubes (MWCNT) based poly methyl methacrylate (PMMA) composite is shown to present high attraction because of its light weight, resistance to corrosion, flexibility and processing advantages. Investigation of the effect of carbon nanotubes and also processing parameters on CO_2 laser cutting of MWCNT/PMMA nanocomposites which is thought to be the most important is the focus of the present paper.

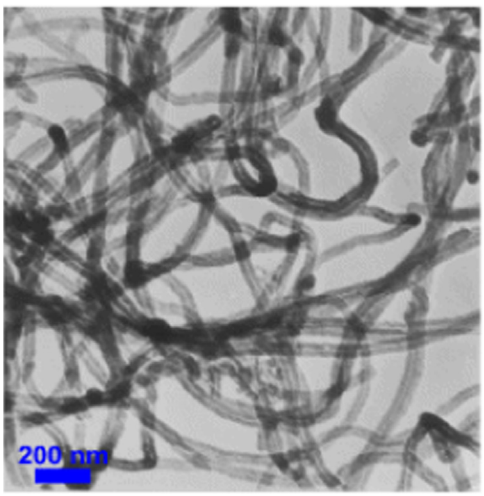

Fig. 1. SEM image of the used MWCNT.

2. Experimental and setup

2.1. Materials

PMMA pellets used in this study are obtained from CHI MEI Corporation (Taiwan), with the grade name of CM205. Melt flow index (MFI) of the used PMMA is 14 ml/10 ml/10 min and its density is 1.19 g/cm^3. The used Carbon nanotube of this research is prepared from Nanostructured and Amorphous Materials Inc. (Texas, USA). The carbon nanotube has been produced by the chemical vapor deposition (CVD) method, with the outside diameter of 30–50 nm, inside diameter of 5–15 nm, length 10–20 μm and purity more than 95%. Its density is 2.1 g/cm^3. Fig. 1 displays the SEM image of the used MWCNT.

2.2. Production of composite sheets

Extrusion as one of the most commercial methods for mixing of materials is used in this research in order to produce the MWCNT/PMMA pellets [11]. For this purpose first both PMMA and carbon nanotubes are dried for 4 h at 80 °C in the oven. Then carbon nanotubes are added to PMMA pellets. Because of the electrostatic phenomenon on the surface of dried PMMA, carbon nanotubes easily stick to the PMMA pellets [12]. Since the mechanical, electrical [13]

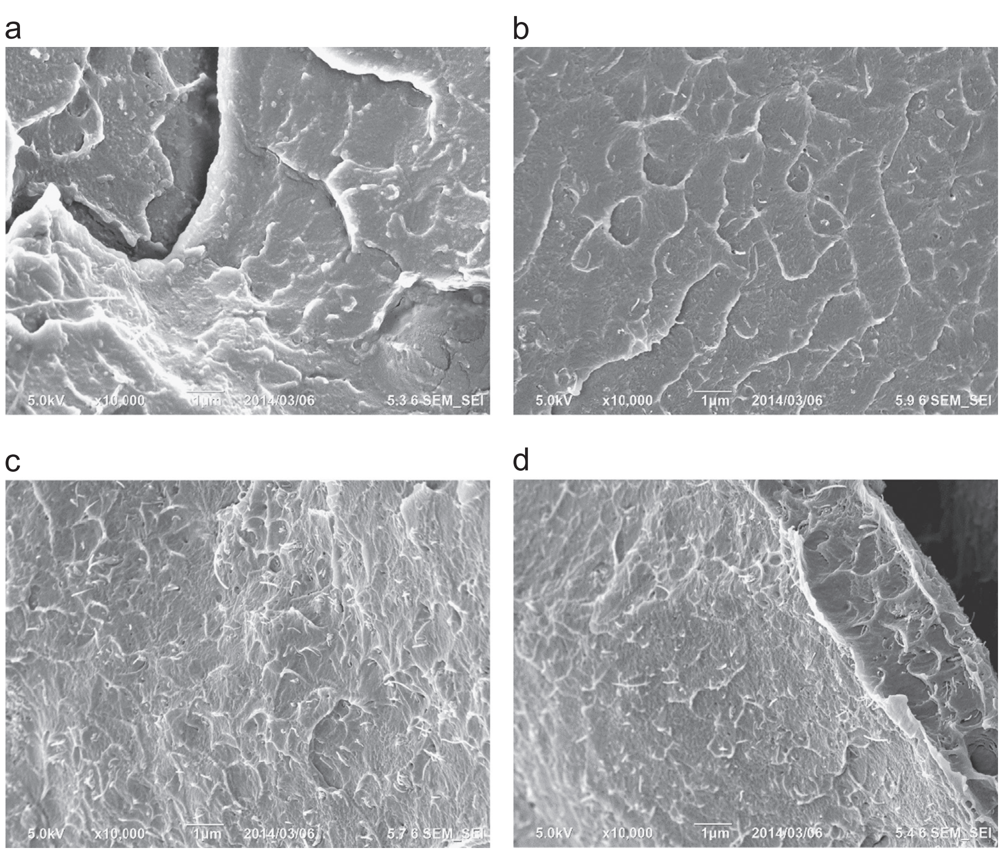

Fig. 2. SEM images of the produced specimens. (a) pure PMMA, (b) PMMA with 0.5 wt% MWCNT, (c) PMMA with 1 wt% MWCNT, (d) PMMA with 1.5 wt% MWCNT.