Carbon Black Selection for Successful Through Transmission Laser Welding and Joining

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Abstract

Laser welding is used in a wide range of applications to join thermoplastics because it is a noncontact heating method with short cycle times and lower cost. For both surface heating and through transmission heating, carbon black is the most frequently used colorant. It was found that carbon black types with low particle aggregation and distribution were most effective for laser heating. Experiments with laser line beam scanning showed that a slight tilt in the laser head could produce different heating when traveling forward as compared to backward. For dissimilar polymer joining, it was found that surface texturing increased the adhesion joint area and the amount of mechanical interlocking, resulting in superior joints.

Introduction

Laser welding of thermoplastics can be achieved using two different heating methods: surface heating and through transmission heating [1-5]. For both surface heating and through transmission heating, a colorant is added to the polymer for laser absorption. Carbon black is the most frequently used colorant, but most of the literature on laser heating of polymers does not discuss the different types of carbon black. Therefore, in this work, we will review the different types of carbon black and their laser absorption performance. In addition, the effects of surface texturing and laser travel direction on joining also will be discussed in an experimental study of laser joining of ABS.

Laser heating

As mentioned earlier, laser heating is possible with both surface heating and through transmission heating [5]. As shown in Figure 1, surface heating can be accomplished by expanding the laser beam and simultaneously heating the surfaces of both parts using mirrors. It also is possible to use a laser line beam or laser spot with a scanning mirror to rapidly scan and heat the surfaces of the parts, as shown in Figure 2. In either case, an absorber, such as carbon black, needs to be incorporated into the plastic part for laser absorption and heating.

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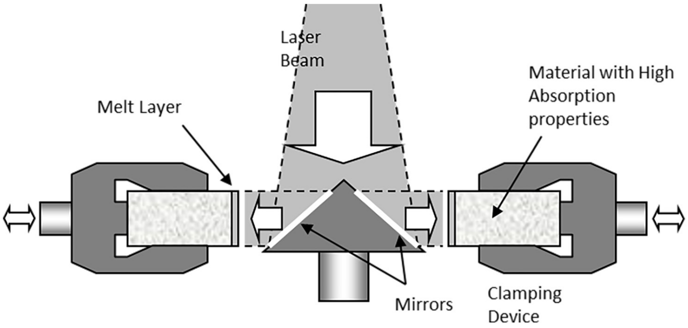

Figure 1. Simultaneous surface heating using expanded laser beam

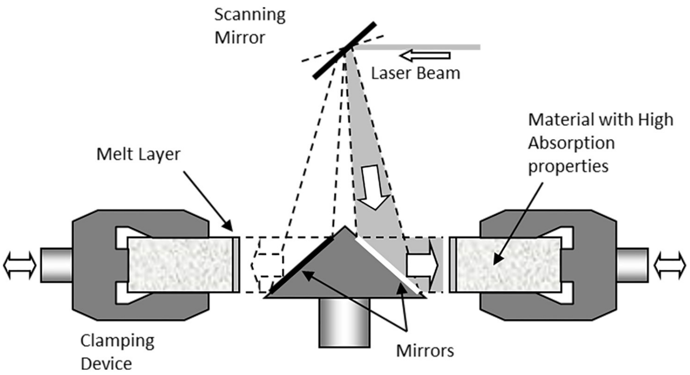

Figure 2. Surface heating by laser scanning using scanning mirror

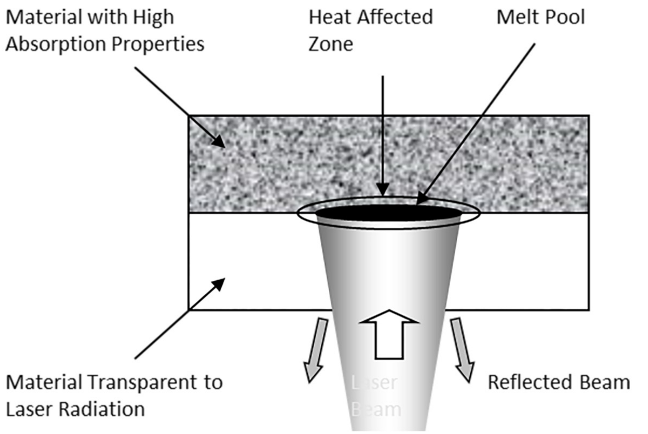

Figure 3. Through transmission laser heating, where the laser beam passes through the transparent part and is absorbed on the surface of the absorbing part

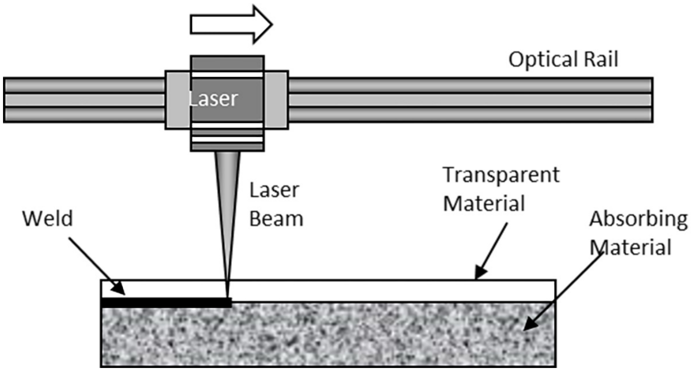

Figure 4. Through transmission laser scan heating

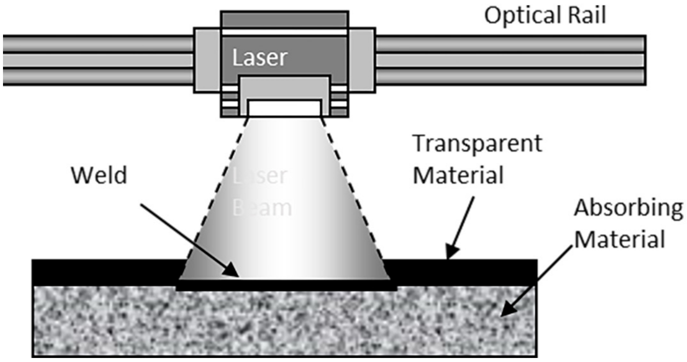

Figure 5. Through transmission laser simultaneous heating

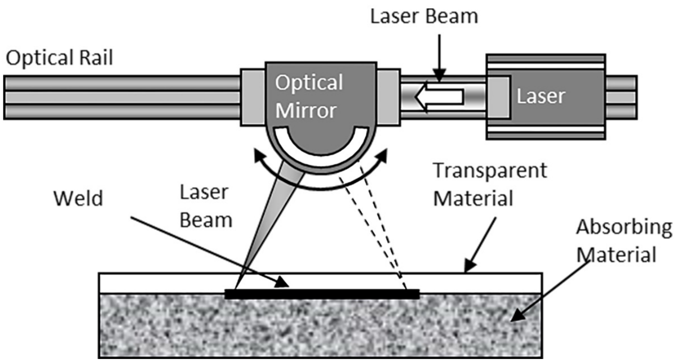

Figure 6. Through transmission laser quasi-simultaneous heating

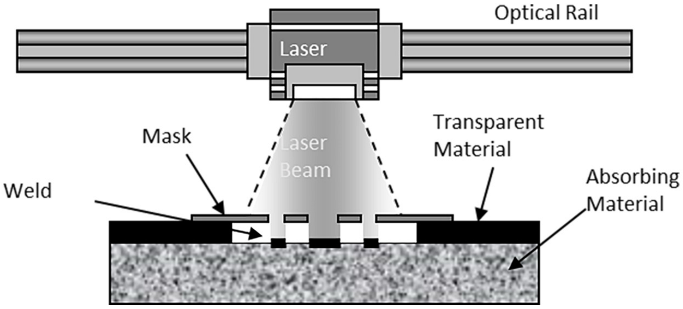

Figure 7. Through transmission laser mask heating

For through transmission laser heating, one part is transparent to the laser while the second has an additive, such as carbon black, to absorb the laser radiation and convert it into heat (Figure 3). There are multiple ways to use through transmission laser heating. In scan heating, the laser beam scans the joint lines by either moving the laser or using scanning mirrors (Figure 4). For simultaneous heating, the laser beam is either expanded or multiple laser sources are used in conjunction with optical fiber bundles to simultaneously heat the whole joint area (Figure 5). In quasi-simultaneous heating, a high-speed scanning mirror is used to rapidly scan the joint area, simulating simultaneous heating using a single, high-power laser beam (Figure 6). Another option is to use simultaneous heating with masking to only heat the joint area while blocking the laser beam from reaching other areas (Figure 7). Here too, the absorbing part includes a colorant, such as carbon black, to absorb and convert the laser radiation into heat.

Carbon black

For many applications, adding small amounts of carbon black (typically ranging from 0.1 percent to 1 percent by weight) is an effective way of incorporating a laser absorber into one of the plastic parts. Usually, the type of carbon black that is used in not considered – just the weight percent [6]. However, the different types of carbon black vary greatly, and they can influence the absorption and conversion of laser energy into heat.

Process	Particle size (nm)	Particle aggre.	Particle distrib.	Specific surface
Furnace black	10-80	Variable	Variable	Variable
Gas black	10-30	Low	Narrow	High
Lamp black	60-200	Substantial	Broad	Low
Thermal black	100-500	Very low	Low	Low

Table 1. Carbon black types and grades [7]

First, it is important to recognize that carbon black and soot are very different substances. Soot forms when a polymer or other substance is not burnt completely. Soot is generally an amorphous carbon in powder form with much lower surface area than carbon black. Carbon black is produced from incomplete burning of heavy petroleum products followed by extraction of organic compounds, resulting in over 97 percent elemental carbon. As shown in Table 1, carbon black is frequently categorized based on the manufacturing process [7]. Carbon black types that have low particle aggregation and distribution were most effective for laser heating.

The combination of carbon black type together with weight percent of carbon black in the polymer will influence the laser absorption. For a given carbon black type, using lower weight percentages (0.1 percent or 0.15 percent) of carbon black results in partial transmission into the part, yielding sub-surface heating. This is beneficial when thicker melt layers are needed without surface degradation. Alternatively, when using high weight percentages (0.5 percent and higher), most of the absorption is near the surface, which results in thinner melt layers.

Through transmission laser joining of ABS

Experiments evaluating the laser joining of ABS to PTFE/PET films were performed using laser line beam scans. ABS plaques were molded with different types and levels of carbon black. It was found that using 0.1 percent weight carbon black was most effective for this application because it produced thicker layers that exceeded the glass transition temperature (Tg). This allowed the ABS to flow more readily and improved adhesion to the PTFE/PET film.

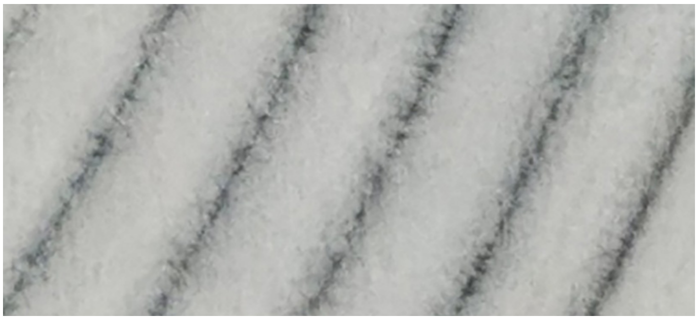

Figure 8. Textured ridges in the ABS plaque enhanced adhesion

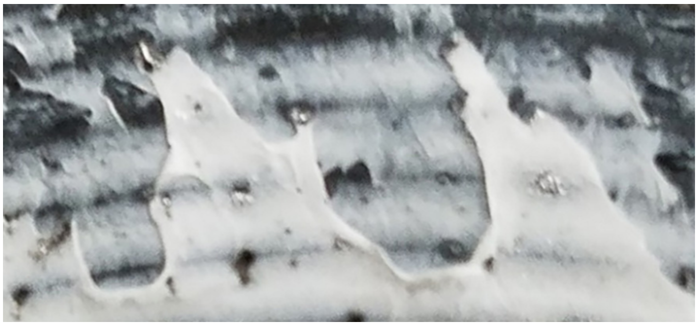

Figure 9. Example of cohesive failure in the PTFE/PET film

Texturing of the ABS surface to produce ridges or cross-hatching showed promising results (Figure 8). The textured surface had a larger area, and it increased the mechanical interlocking at the interface. Manual peel strength felt generally high, especially when peeling perpendicular to the ridges. Visual inspection of these joints was very promising, showing extensive amounts of cohesive failure in the PTFE/PET film (Figure 9).

Heating of the ABS was done using a Leister 800 laser line beam head mounted on a Fanuc robot. The laser head was slightly tilted in one direction so that the intensity is slightly different when traveling in one direction versus the opposite direction, referred to as push and pull directions, as shown in Figure 10. To evaluate the effect of the tilt, a Pico Technology USB TC-08 thermocouple data logger was used to measure the temperature history during push-pull heating.

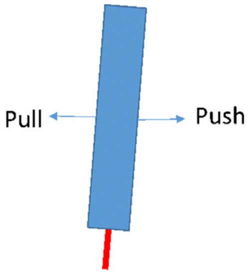

Figure 10. Push and pull directions for the tilted laser head

As shown in Figure 11, the temperature in the push direction is significantly lower than in the pull direction. Similarly, the temperature also was measured for push-push (Figure 12) and pull-pull (Figure 13). In both cases, the temperature variation between passes was smaller, and pull-pull resulted in slightly

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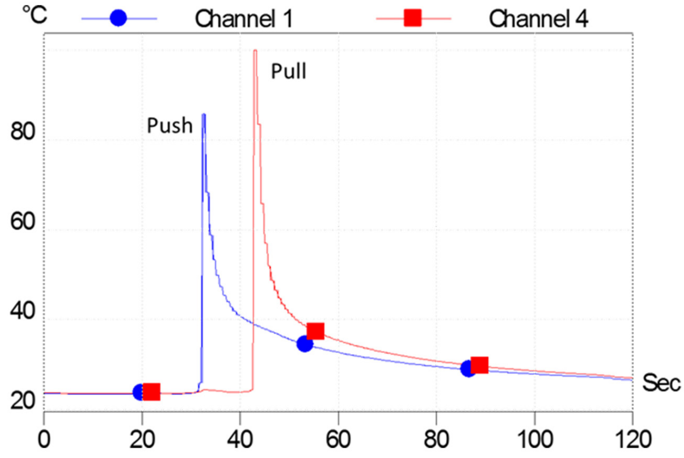

Figure 11. Temperature history for push-pull laser heating

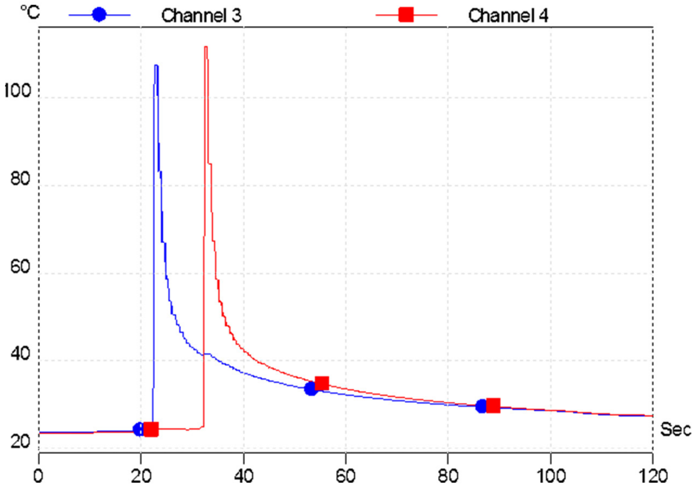

Figure 12. Temperature history for push-push laser heating

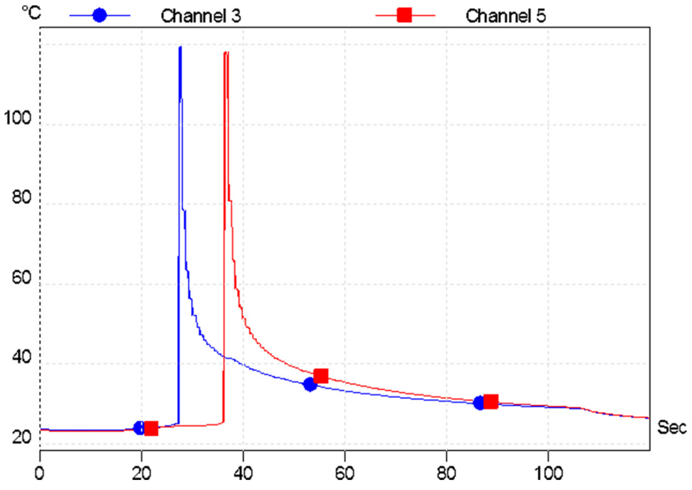

Figure 13. Temperature history for pull-pull laser heating

higher surface temperatures. In general, the temperatures that were measured were lower than expected, probably because the thermocouples were large and just placed on top of the surface. Using smaller thermocouple wires and pressing the tip into the ABS surface with a heated tool would improve the measurement accuracy.

Conclusions

Laser heating for welding and joining of thermoplastics was studied to determine the effects of carbon black type and content level, surface texturing and laser travel direction on joint quality. For both surface heating and through transmission heating, carbon black is the most frequently used colorant. It was found that carbon black types that have low particle aggregation and distribution were most effective for laser heating. Experiments with laser line beam scanning with ABS showed that a slight tilt in the laser head could produce different heating when traveling forward (or pull direction) as compared to backward (or push direction). For dissimilar polymer joining of ABS to PTFE/PET film, it was found that surface texturing increased the adhesion joint area and the amount of mechanical interlocking, resulting in superior joints.

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Acknowledgments

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