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RELATIONSHIP BETWEEN OPTICAL PROPERTIES AND OPTIMIZED PROCESSING PARAMETERS FOR THROUGH-TRANSMISSION LASER WELDING OF THERMOPLASTICS

Abstract

Previously we reported to Antec our studies on optical characterization (laser energy transmission, absorption, etc.) at a wide range of infra-red wavelength for various nylon based plastics (un-filled and reinforced) with the influence of various colorants. Later we discussed our analysis on optimized mechanical performance of the laser welded joints. In this current paper, we will try to increase the understanding of the plastics engineering community regarding the relations between optical properties of thermoplastics and optimized processing parameters of through-transmission laser welding (simultaneous welding mode).

Introduction

Infrared/laser through-transmission welding (TTLW) is an innovative method of advanced joining technology for various thermoplastics. Many research and engineering programs were oriented towards optimization of mechanical performance of the weld and evaluation of plastic absorption characteristic [1-6]. Only a few studies concentrated on colored thermoplastics and development of colored plastic grades for various industrial applications [7-11].

This study describes the relationship between comprehensive, optical characterization of colored and non-colored polyamides/nylons and welding processing parameters, focussing on the influence of plastic composition, pigment type, and joint design issues. The results and recommendations will provide a better understanding of the infra-red welding process optimization, plastic selection, materials development, and welding equipment design for industrial applications.

In a family of various semi-crystalline polymers/plastics, non-filled/reinforced nylon has sufficient transmission (Table 1) and mechanical (Table 2) properties. The decrease in transmission is due to increased light scattering. This can be seen in Figure 1, which shows an increase in effective path length {nylon absorbency (1.39 μm)/nylon content (wt. %)} as the fiber-glass content increases from 0 to 63 wt. % GF [3-4]. The increased effective path length at high GF content is a direct consequence of light scattering from the short fiberglass [9, 14, 27].

In general, for the short fiber-glass reinforced nylon 6 (with length of the fibers in average ≈ 180-320 μm and diameter ≈ 10 –13 μm), the transmission decreases monotonically with increased short fiber-glass content from 0 to 63 wt. % (Figure 1). Unfortunately, we did not find published data related to optical characterization of the long fiberglass reinforced nylon for the through-transmission laser welding (TTLW). At this time, we can assume that the parameters of laser energy absorption and laser energy transmittance should be similar to results developed for short fiberglass thermoplastics[1]. With decrease of wavelength from 1060 nm to 830 nm, the transmittance of four colored and natural state non-reinforced/non-filled nylon 6 base decreases (Figure 2). These results are in contrast with previously published data [12] and with the results developed for the blend of nylon 6 with amorphous nylon (Figure 3).

With an increase of the amorphous phase in these blends, the transmittance increases up to 25~27%. For optical (PC type) plastic, the transmission has been unchanged at the 830 to 1064 nm range; similar results are illustrated in [4, 12] for several optical polymers. At the same time, an increase on wavelength had very little effect on transmittance data. Nylon 66 is less transmittable (Figure 4) in compared with the nylon 6 based plastics. These differences increase with high levels of reinforcement (GF ≥ 25 wt.%) and it will affect the level of energy needed for melt-weld preparation and welding time (at the same LW parameters).

Experimental

Welded Materials, Specimens and Dyes

[1] For the same type of used reinforcements, with the same level of the loading wt.%.

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In this investigation, we used various commercially available nylon 6 grades (Table 2):

- Non-reinforced plastics.
- Short fiber-glass reinforced (nylon 6 only, with the two levels of reinforcement (GF in wt.%): 14 and 33.

The two types of injection molded plaques were used for the mechanical and optical characterization of all evaluated thermoplastics:

- Rectangle shape – 150 mm by 62 mm (approximately) at thickness 3.2 mm.
- Rectangle shape – 150 mm by 38 mm at thickness 3.2 mm.

Welding System

A transmission -welding process was performed using a high-power diode laser system IRAM™[2] (Figure 5) with the following processing parameters:

- Wavelength: 810 ± 10 nm.
- Output power: at 100% 2x45 W* 80%).
- Power range: from 80 –100%.
- Work distance: 6 mm – 12 mm
- Beam size: 50 mm ~ 0.25 mm

Discussions: Relations between Optical Properties and Processing Parameters[3]

In general, the multi-criterion optimization of the mechanical performance of welded joint, produced by TTLW technology, requires managing the following basic processing parameters:

- Laser power required for melt-pool formation with the influence of the properties and composition of used thermoplastic(s), joint design (thickness of through-transmissible part) and projected welding time.
- Laser beam focus spot and profile size(s) that correlated to the size of needed width of the weld (melt-pool).
- Melt-pool temperature, which should correlate to type of used thermoplastic(s) and melting point(s) of used plastic(s).
- Welding time and welding speed. Weld time/speed is a function of the first three previously discussed process parameters (laser power, beam spot and melt-pool temperature).
- Welding (clamp) pressure and the thickness of weld inter-phase.

[2] IRAM™ - is a registered trademark of Branson Ultrasonic Corporation.

[3] This analysis is developed for the simultaneous welding mode.

Figure 6 shows [10] high efficiency of diode laser welding for plastics based materials, and projected limits, such as deep penetration welding, cutting and drilling, for metal based materials. Some results of TTLW process analysis and LW process optimization for the simultaneous welding mode are summarized in Figures 7-9 and Table 3. These results were developed for minimum power density and the weld width as a function of short fiberglass content. Un-colored (natural as molded) specimens were welded to the similar by reinforcement laser energy absorbent specimens colored by carbon black (BK-102). The weld time was held constant at 2 seconds[4] and the power required to make a weld with good appearance was determined by iteration. The minimum power requirement is proportional to fiber-glass content. All results presented in Figures 7-9 were developed at near-IR wavelength = 810 nm.

Needs for laser energy power increase by 4 times in analyzed range of reinforcement (from 0 wt. % to 45 wt.%). This is due to the short fiber-glass tendency to scatter the light through internal reflection and refraction, similar to macrostructure (matrix and fiber-glass reinforcements) structures. With an increase in scatter and the weld width of the resulting welds increases (Figure 8 and Table 3). Tensile strength of the weld is equal to tensile strength of non-reinforced (un-filled) plastic (Tables 2 and 4). Similar LW process evaluation studies for un-filled nylon 6 grades were conducted to determine the power density required welding various colored specimens to absorbent (carbon black - BK) specimens. The results of these studies are presented in Figure 9 that are very similar to optical data (on transmittance) of colored nylon 6 (Figure 2). Used red pigment had no effect of the transparency of the nylon 6, while the yellow had a significant effect, and the green pigment absorbed nearly all laser radiation at near-IR wavelength = 900 nm. It is possible that the green pigment used for this evaluation could be utilized as an absorbent pigment and provide a similar function as the addition of carbon black (BK) to the lower specimen. In general, nylon 6 colored in the green may transmit efficiently laser beam energy.

At near-IR wavelength = 900 nm, the white sample did not absorb the radiation but did scatter it to such a degree that weld time as long as 15 S. were required. It should be noted that these results are consistent with physics on the electromagnetic spectrum. The green and blue are the complimentary colors to red (the color of the laser radiation) and thus absorbs red light

[4] It is possible that used welding time = 2 s was too short for this evaluation.

readily and transmits green light. While the red pigments transmits red radiation.

Concluding Remarks

Laser through-transmission welding of nylon/polyamides is a very promising joining process for various industries, where advanced welding methods are used. The flexibility and wide availability of the diode laser for simultaneous welding mode is making this technology cost effective.

Colored nylon/polyamides are high performance thermoplastics with a number of very attractive mechanical and technological properties for various welded parts, where the advances of the laser welding technology may be utilized.

The results and recommendations will provide a better understanding of the infra-red welding process optimization, plastic selection, materials development, and welding equipment design for industrial applications.

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Table 1. Transmission (in %) of infrared (laser energy) for thermoplastics at various thickness (wavelength = 1.060 nm).

Type of Polymer (Thermoplastic)	Thickness = 1 mm	Thickness = 10 mm
PMMA	98.8	88.7
Polyamide/Nylon	85.3	20.4
Polyethylene (PE)	80.9	12.1
Polypropylene (PP)	77.1	7.4

Table 2. Mechanical performance of nylon 6 based plastics with the influence of short glass-fiber reinforcement (in wt.%).

Generic Type of Welded Thermoplastic	**GF, wt.%**	**Tensile Strength of Plastic, MPa**
Nylon 6 (un-filled)	0	82
Nylon 6 (reinforced)	14	125
Nylon 6 (reinforced)	33	185
Nylon 6 (reinforced)	45	210

Table 3. Influence of fiber-glass reinforcement on weld width (nylon 6, thickness of through-transmitting plastic part = 3,2 mm. Laser beam diameter $\mathbf{W_{lb}}$ ~ 2,2 mm)

Trade Name[5] of Fiber-Glass Reinforced Plastics	Fiber-Glass (GF), % by weight	Range of the size (maximum width of the heat effective zone $\mathbf{w_{HAZ}}$)
Capron 8202	0	2.5 – 2.8

[5] Capron® - is a registered trademark for BASF Corporation nylon based products.

Capron 8231G	14	3.2 – 3.5
Capron 8232G	25	3.5 – 3.9
Capron 8233G	33	4.1 – 4.4
Capron 8234G	45	4.3 – 4.6

Table 4. Efficiency of laser welding technology for nylon 6 grades (at optimized processing conditions)

Welded Nylon 6 Based Plastics	**Tensile Strength of Joint, MPa**		
	Vibration	**Traditional**	**Clear** [6]
GF = 0 wt.%	81	≥ 82	≥ 82
GF = 14 wt.%	90.7	77.2	84.3
GF = 33 wt.%	83.6	75.4	83.7

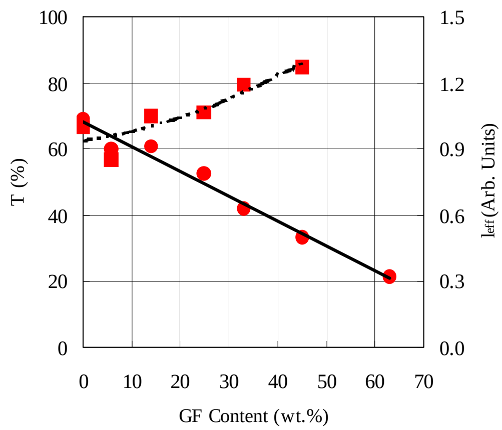

Figure 1. Transmittance (T) and effective pathlength (l_{eff},) at wavelength 1.06 μm of nylon 6 with the influence of fiber-glass (GF) content (wt. %). Effective pathlength is normalized to 1.0 at 0 wt.%GF content). Thickness of the specimens is 3.2 mm.

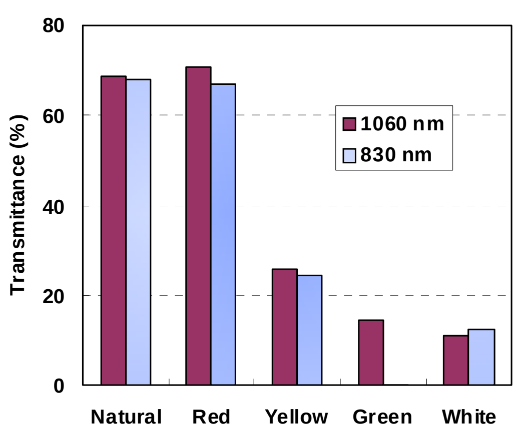

Figure 2. Influence of wavelength (at 830 and 1060 nm) on transmittance (T) properties for the following versions of colored nylon: red, yellow, green, white and natural. The thickness of the specimens is 3.2 mm.

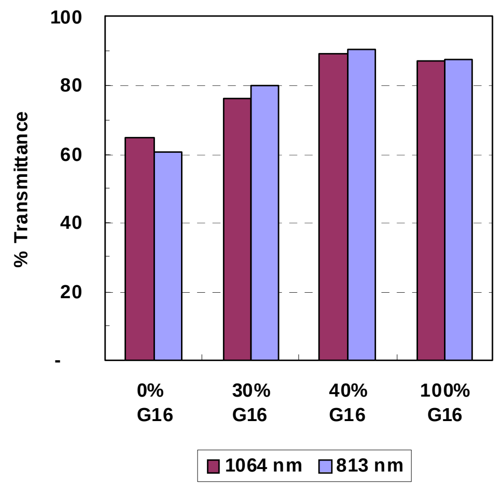

Figure 3. Influence of wavelength (at 1064 and 813 nm) on transmittance (T) properties for the blends of nylon 6 (Capron® un-filled grade) with amorphous nylon (Grivory®[7] grade). Thickness of the specimens is 3.2mm. Color version: natural state.

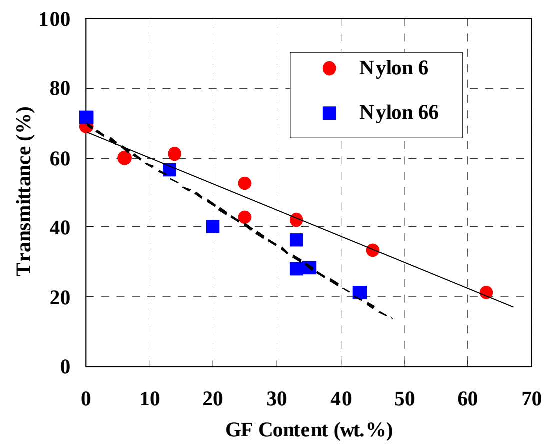

Figure 4. Transmittance of nylon 6 vs. nylon 66 based plastics (natural state) with the influence of fiberglass reinforcement at 830 nm. Specimen Thickness is 3.2mm.

[6] For the details see report to Antec 2002 – Val A. Kagan and Nicole M. Woosman “Efficiency of Clear-Welding Technology for Polyamides”.

[7] Grivory® - is a registered trademark for EMS-CHEMIE AG plastic products

Figure 5. Laser Welding System IRAM™

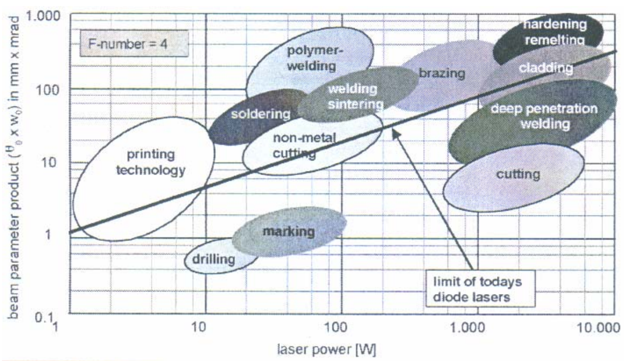

Figure 6 Relations between laser beam quality and power.

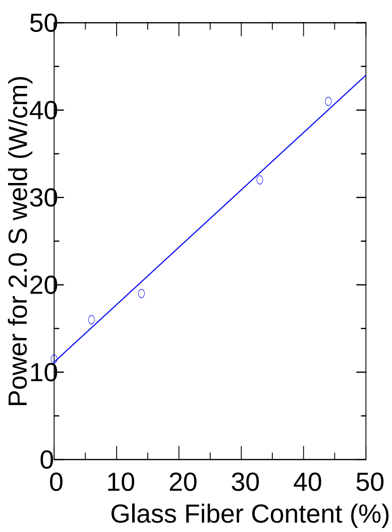

Figure 7. Influence of glass-fiber reinforcements (in %, for nylon 6, part thickness = 3.2 mm) on power requirement to make a weld in 2.0 S. Legend: short fiber-glass reinforcement from 6 wt. % to 45 wt. %.

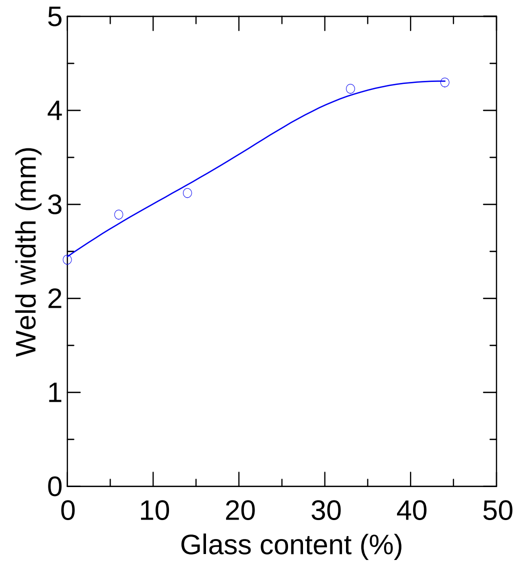

Figure 8. Effects of fiber-glass content (in %) on weld width (in mm for nylon 6, part thickness = 3.2 mm). Legend: short fiber-glass reinforcement from 6 wt. % to 45 wt. %.

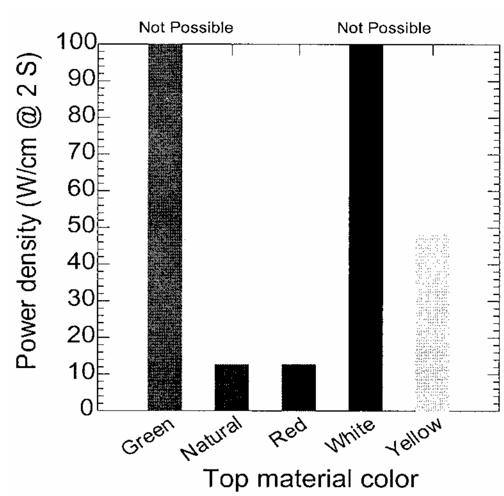

Figure 9. Power density needed to weld different colored un-filled nylon 6 specimens (thickness = 3.2 mm).

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