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The infrared thermography control of the laser welding of amorphous polymers

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Abstract

In laser welding technique, a real-time control of temperature distribution inside the irradiated materials is essential when attempting to optimize the process. For all laser welding methods that operate by the transmission principle, the difficulty of recording the developed temperature at the interface derives from the fact that materials to be welded are in contact throughout the entire process. In the present study, in order to overcome this issue, a contact-free method such the infrared thermography is used for surface temperature measurement. Corroborating this data with a numerical simulation of the temperature field evolution inside the components, an assessment of optimal process parameters is possible. The experimental investigations are made on amorphous polymers, in a typical configuration for through-transmission laser welding. The fine agreement obtained between the experimentally and calculated data, validate the infrared thermography as a non-destructive method for real-time monitoring of the welding process.

Keywords: Infrared thermography; Laser welding; Thermal modeling; Amorphous polymer

1. Introduction

Manufacturing with plastics often involves a bonding step, from small electronic or medical devices to large scale projects in aerospace, automotive, or construction industry. Being a continually developing field, the major interest on joining plastics concerns the best methods and options for different applications and the process optimization [1–3].

The so called ''through-transmission'' laser welding technique requires an optically transparent part at the laser wavelength and an absorbing one and a preferential deposition of energy in the interfacial zone. The bonding between the two components occurs by the interpenetration of the molecular chains in this area. Since this phenomenon is very active in a ''fluid'' state of matter, the temperature at interface has to be between the temperature of solid–liquid transition and the initial temperature of degradation of the thermoplastic materials [4].

Comparing to the traditional welding techniques, the laser welding of polymers has the advantage of being a non-contact, non-contaminant process, with no thermal stresses and particle release [5] but its efficiency is strongly dependent on the materials properties. In consequence, obtaining a high-quality weld joint is conditioned by a good understanding of the material behavior under laser irradiation, based on a clear identification and modeling of the optical and thermal phenomena involved [6,7].

Actually, in modeling the optical phenomena, a linear behavior of the material is considered, so the laser beam attenuation into the irradiated materials is described by the well-known Beer–Lambert law. The thermal modeling of the laser–polymer interaction is based on conductive and convective heat transfer [8,9] but ignores the variation of the materials optical properties with the temperature. Since the accuracy of the numerical results depends on a good knowledge of the materials thermo-physical properties and their variation with temperature, an experimental

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"calibration" of the model is often used in establishing equivalence between the simulated and the real behavior of the considered system.

Infrared (IR) thermography [10,11] is among the promising methods for non-destructive, real-time monitoring of thermal field distribution and it can be successfully used, in corroboration with numerical data, in process optimization and weld quality control.

2. Experimental procedure

2.1. Materials

For experimental investigations, two thermoplastic materials were selected. The first component is a semi-transparent *PMMA* (*red*) and the second one is an *ABS/PC* alloy (*red*), opaque in near-IR spectrum. Both polymers are widely used in industrial applications.

The geometrical and general optical and thermal characteristics for the two materials are listed in Table 1. The values are given at ambient temperature ($\approx 24\,°C$).

Table 1
Geometrical, optical, and thermal properties of selected polymers

Properties	Dimensions	Polymers	
		PMMA red	ABS/PC red
Length	l (m)	8×10^{-2}	8×10^{-2}
Width	w (m)	4×10^{-2}	4×10^{-2}
Thickness	z (m)	2.25×10^{-3}	2.16×10^{-3}
Reflection factor[a]	R (%)	4.5	4.3
Transmission factor[a]	T (%)	96	6
Absorption factor[a]	A (%)	1.45	78
Linear absorption coefficient	α (m^{-1})	6.8	380.1
Density	ρ (kg m^{-3})	1190	1060–1150
Heat capacity	c_p (J kg^{-1} C^{-1})	1350	1330
Thermal conductivity	λ (W m^{-1} C^{-1})	0.19	0.2
Glass transition temperature	T_g (°C)	110–135	105–115

[a]The values are given for $\lambda = 0.940\,\mu m$.

2.2. Laser welding of polymers

The experiments were carried out using a diode laser LASERLINE with a maximum output power of 100 W and a focal length of 150 mm. The laser wavelength is 0.940 μm and the focal spot has an ellipse shape with an area of $1.31 \times 1.72\,mm^2$.

To improve the contact between the two polymers a specially designed aluminum table has been used. The experimental setup is shown in Fig. 1.

The optimization of the process parameters was based on microscopic observations and mechanical testing (by means of the tensile-testing machine) of the welded zone. The optimal values were 0.0067 m/s for the laser speed and 48 W for the incident power. The total welding time was 6 s.

2.3. IR thermography measurements

The evolution of the temperature field was recorded using a powerful IR camera FLIR THERMACAM S40 with a spectral range 7.5–13 μm (Fig. 1 on the left). The 320×240 uncooled FPA (focal plane array) detector delivers crisp, high-resolution images with over 76.000 picture elements. The thermal sensitivity given by the constructor is 0.08 °C at 30 °C and the acquisition frequency is 60 Hz. The camera is equipped with a macro lens which assures a spatial resolution of 100 μm.

The IR images were analyzed with the ThermaCAM Researcher software. Fig. 2 shows an IR camera image after laser irradiation of the PMMA-ABS/PC couple. The irradiation time was 6 s with a laser power of 48 W.

In order to obtain an accurate measurement of the polymer surface temperature the polymer emissivities were determined by comparing the signal received from a clean surface of the polymers with the signal received from a surface zone covered by a black paint with known emissivity. Unfortunately, this parameter is the most difficult to ascertain, as it depends on many factors [12]. The obtained values for emissivity were 0.96 for PMMA and 0.91 for ABS/PC.

3. Thermal simulation

The main purposes of the simulation are to estimate the evolution of the temperature fields inside the polymer

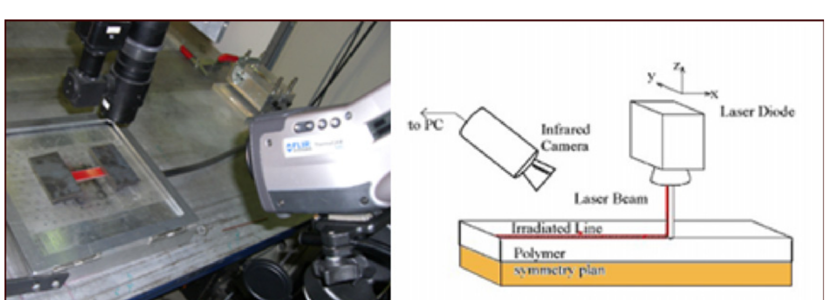

Fig. 1. Equipment for IR image recording during laser welding.