

THE MATERIAL'S TEMPERATURE INFLUENCE ON ABSORPTION DEGREE OF LASER RADIATION IN TECHNOLOGICAL PROCESSES

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Aceasta lucrare prezinta o etapa de studiu privind influenta anumitor factori asupra gradului de absorbtie a radiatiei laser in material, in procesele tehnologice. Studiul prezentat propune utilizarea unui dispozitiv care modifica proprietatile optice ale materialului prelucrat prin incalzire, conducand la o mai buna cuplare energetica intre fasciculul laser si material.

This paper presents a study stage regarding the influence of certain factors on absorptivity of laser radiation in the manufacturing processes. The current study, presented in this paper, proposes a device that alters the optical properties of the material by leading the heating process to a good energetic coupling between the laser beam and material.

Keywords: Laser manufacturing, Laser absorption, Optical properties, Laser processing.

1. Introduction

The use of laser in technology started once with the inventing of this system that generates and controls the optical energy. Over the time various means of generation were invented and perfected and in now days the technology allows generation of various wavelengths and large power beams, from the

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ultraviolet to far infrared spectrum. At the same time, new ways to use the laser power were invented and perfected over the time in order to use this special form of energy in manufacturing processes, from cutting of the hard materials to microelectronics manufacturing. The major advantage of the laser radiation that makes it so attractive to technologic applications is the intensity that can reach values of around 10^6W/cm^2 [1]. This high density of power allows welding, engraving and cutting of different materials.

However, a major problem appears in case of laser processing: the laser absorption in the material, respectively, the energy transfer from the laser beam to the material.

Absorptivity is the optical property of a material to absorb an electromagnetic radiation and is defined as: $A = 1 - R$, where R is the reflectivity of the material submitted to a certain radiation.

Laser interaction with the material is a complex process and only in the simplest cases the laser may be approximated to a heat source. The numerous faces of the laser interactions with the material was the main subject to study by the physicists immediately after the first laser was powered. Absorption, heating, melting, vaporisation, plasma formation, wave of radiation absorption, Maragoni convection and Kelvin-Helmholtz instability are the main aspects of the laser radiation interaction with materials, and are necessary to take into account in order to understand in detail the effect of laser over the various layers of material [2].

For the typical wavelengths of the laser (from near infrared to ultraviolet), photons are absorbed via inter-band and intra-band transitions. For that, the laser radiation induces an electronic disequilibrium that leads to heating by the electron-electron and photon-electron interactions. Heating by electron-electron interactions may be complex depending on the electronic structure of the irradiated material.

For metals, the free electrons allow a quick movement of femto-seconds order, and such the electronic heating may be extremely fast. The simplest approach is given by the Drude model. Drude formalism is based on the assumptions that metal contains free electrons subjected to the action of the electric field of the incident radiation in viscous medium, characterized by a phenomenological attenuation parameter, τ , of whose value is determined by the electrons interaction with impurities, imperfections and the crystalline network [3].

The problem of absorptivity is the one that is still of great importance because, if we think on the energetic efficiency of a laser processing system as a whole, it is easy to see that this is quite low. A typical laser generator, such as a Nd:YAG generator may have an energetic efficiency of converting the electricity into laser radiation of around 2% in case of flash lamp pumping and about 20-30% in case of laser diode pumping. The CO_2 laser presents an conversion

efficiency of around 20%. Laser diodes, of new types, may reach a conversion efficiency of over 50%, but they are still not popular in technologic applications due to their sensitivity to current variations and environment factors and the special need to dissipate the heat and the power in the whole mass of the gain medium.

It is easy to observe that percent of converting the primary source of energy into laser radiation is fairly low, and furthermore, it is noticeable a bigger power loss when the radiation interacts with the material.

Interaction is governed by the absorption coefficient of the laser radiation. This coefficient depends of some major factors: the wavelength of the laser radiation, the surface finishing of the material and the energetic state of the material (thermal condition).

As shown in the fig. 1, it is visible from the evolution of reflection coefficient depending on the wavelength that the reflection grows with the wavelength of the laser, in conclusion, the absorptivity decreases.

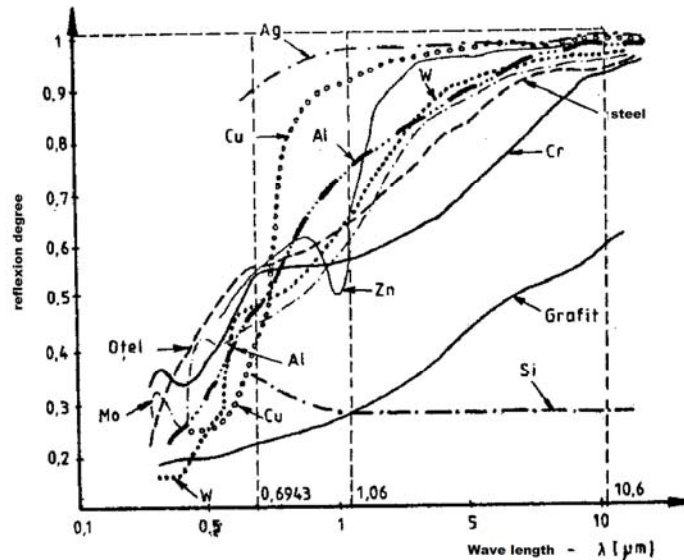


Fig. 1. The evolution of reflectivity depending on the radiation wavelength for some materials.

In consequence, it is visible that, although the generation efficiency for a CO₂ laser ($\lambda=10.6\mu\text{m}$), is better than a Nd:YAG laser ($\lambda=1.06\mu\text{m}$), the absorption factor is lower.

Various studies and researches [4] showed an aluminium absorptivity at $\lambda=10.6\mu\text{m}$, of 5% and a steel absorptivity of 10%, so a small percentage from the primary energy is effectively used in the processing purpose.

One of the technologic interesting approaches to enhance the absorption coefficient of the material for the laser radiation is to modify the thermal condition of the material in the purpose of altering this optic property.

2. Experimental setup and procedure

In order to show the modification of material absorptivity coefficient but also to verify a proposed technical solution, an experimental welding process was considered using a laser welding installation ROFIN STARWELD (fig. 2).

It was proposed to weld some stainless steel plates, butt weld joint. The plates were made of an austenitic stainless steel, type 304, 0.8mm thickness, with the chemical composition presented in table 1 [5]. The set-up requires the use of the same material, with the same surface finishing and use of the same laser parameters but on different temperatures of the base material. The welding parameters set for this research were:



Fig. 2. Laser welding installation ROFIN STARWELD.

Table 1

Chemical composition of the base material, %							
C	Si	Mn	Cr	Ni	Mo	N	PREN
0.03	0.9	0.8	23.0	9.0	3.2	0.17	≥ 35

Table 2

Laser parameters					
Discharge voltage of the lamps	Pulse duration	Repetition frequency	Focal spot	Pulse energy	Energy density
300V	2.5 ms	1.9Hz	F 1.4	6.6 J	1250J/cm ²

During the welding there were used thermocouples placed on the welding material in order to monitor the temperature variations of the material. The thermocouple system allows connecting to a computer and measuring and recording in continuous mode the temperature values.

In order to modify the thermal condition of the material it was designed and constructed an experimental device presented in Fig. 3.



Fig. 3. Device for material heating during laser processing.

The heating device has a body made of black anodized aluminium, with a special shape that allows a minimum dissipation of the heat in the processing area. The equipment contains an resistive element with a 200W power. The main body contains, radial, orifices of 2.4 mm in diameter that have the purpose to evenly dissipate the heat in the mass of the body and as well the role of overheat protection for the resistive element.

Using the thermocouple systems that allow wireless communication and data acquisition in real time by the computer, some measurements were performed to observe the thermal behaviour of the device.

For measurements, a thermocouple was placed in the resistive core of the device, a thermocouple was placed on the lower surface of the device, other three thermocouples were placed on the upper surface of the device starting from the centre and placing one at each 15mm. A fifth thermocouple was placed on the outer surface of the device.

From the measurements of a heating and cooling cycle, the temperature profile (fig. 4) that presents an uniform rise in temperature in all the device's mass with a temperature difference of maximum 15°C in various points from the device. The area in which the material should be placed presents a radial temperature distribution with a variation of only 10°C between the measuring points at the heating moment with the maximum temperature achieved on a circle on the upper face of the device with a radius of 15mm from the centre.

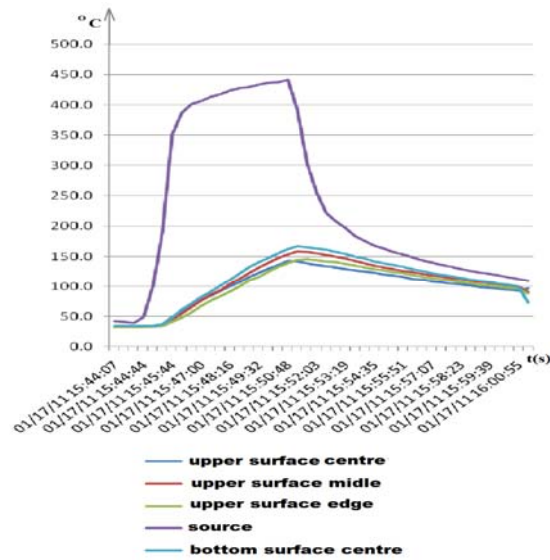


Fig. 4. Temperature profile for a heating and cooling cycle.

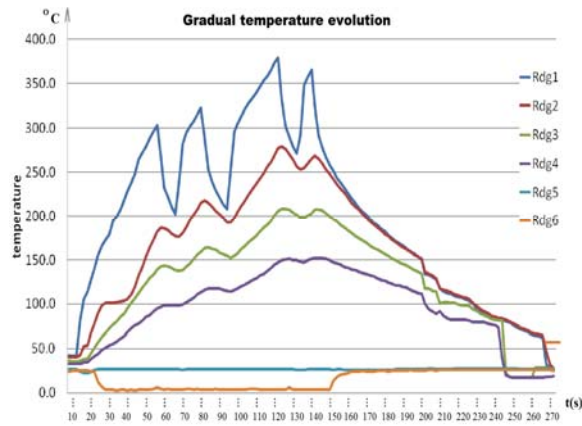


Fig. 5. Temperature evolution on a heating cycle in steps. Rdg 1 –thermocouple placed on the resistive element, Rdg 2- thermocouple placed on the lower face of the device, Rdg 3- thermocouple placed on the upper surface of the device, Rdg 4 – thermocouple placed on a test material.

In order to improve the thermal transfer between the resistive element and the body of the heating device a new set of measurements was performed, this time using thermoconducting paste between the resistive element and the body of

the device. Also, a heating cycle was tested in order to improve the maximum temperature that can be reached on the surface of the device and also to verify to possibility of an automatic system to controll the heating process. The cycle consists in turning on the resisitive element when the core temperature reaches the upper surface temperature, and turning off when the resistive core reaches 300-350°C.

The measurements (fig. 5), show a fast rise of the body temperature due to thermal conductive paste and the possibility to obtain 150°C on the surface of the material.

2.1. Experimental stage

After validating the capabilities of the device, the actual laser welding of the material was performed (fig.6). There were performed more welding tests using the same laser parameters, respectively a pulse energy of 6.6 J and a energy density of 1250 J/cm², but every probe had a different initial temperature.

Using the thermocouple system, the temperature of the resistive element, upper surface temperature and the temperature of every part to be welded was monitored.

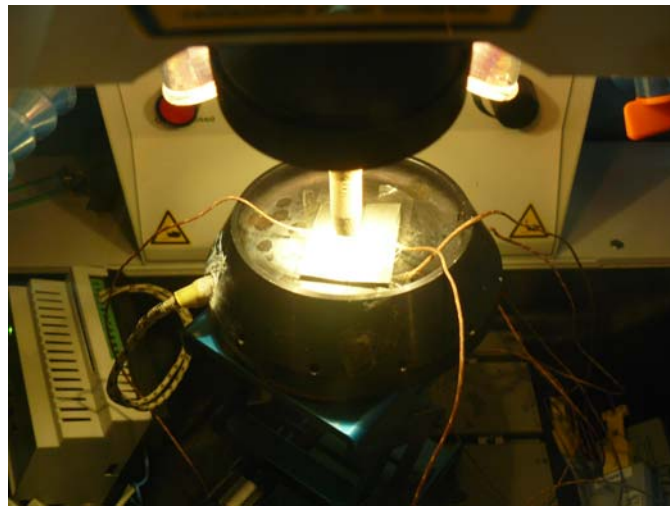


Fig. 6. The experimental setup, view from the welding chamber.

2.2. Welding test 1

First welding test was performed without pre-heating the material, the recorded variation presented in fig. 7 is caused by the laser welding process. In

this case, though the welding track seemed uniform and consistent, the laser beam was too low to assure a full penetration of the melted area in the depth of the material.

The metallographic analysis showed a weak penetration of the material, resulting a penetration on the surface with the width of 919.56 μm and an width on the bottom surface of 252.28 μm (fig. 8).

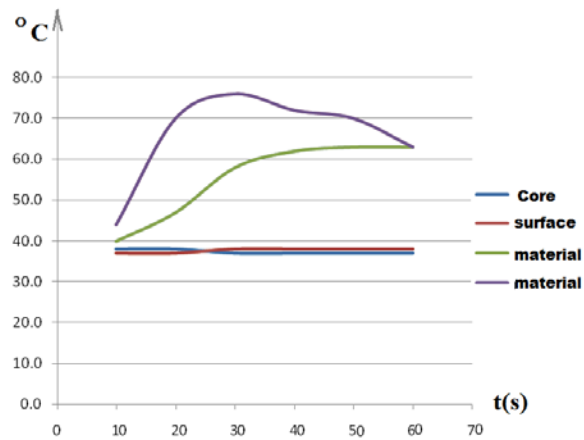


Fig. 7. Temperature evolution on the welding process.



Fig. 8. Welded probe cross-section and dimensioning.

2.3. Welding test 2

Welding test was subject to heating up to 120°C, moment at which the resistive element was stopped and the welding process started. The temperature at the end of the welding process reached 140°C (fig.9).

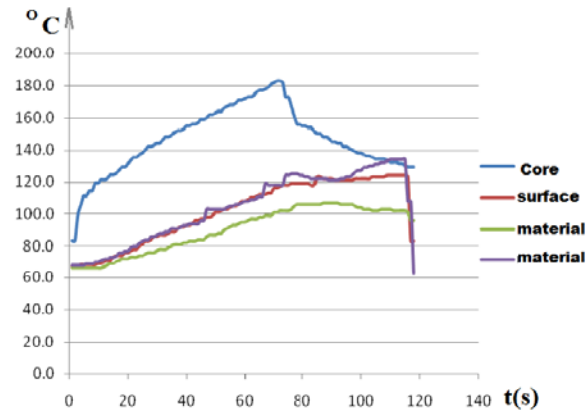


Fig. 9. Temperature evolution on the welding process.

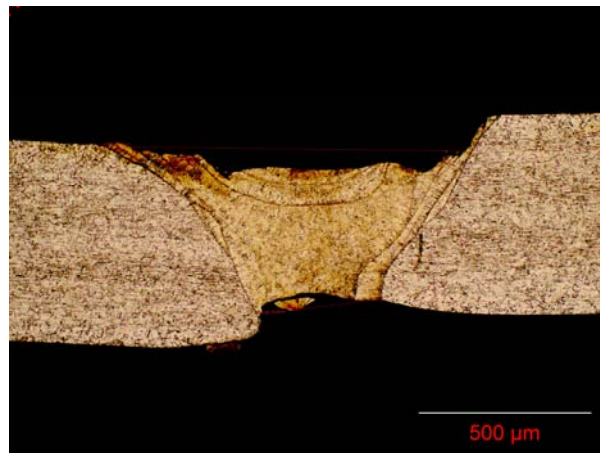


Fig. 10. Welded probe cross-section and dimensioning.

The welded probe presented the deepest penetration of the laser beam, on the lower face of the material was easy to see a remelting area and in some points some breaking of the welding track was easy to notice and also a full penetration of the material.

The metallographic analysis showed a weak penetration of the material, resulting a penetration on the surface with the width of 1071.76 μm and an width on the bottom surface of 355.95 μm (fig.10).

3. Conclusions

After performing the welding tests it is easy to observe a variation of the penetration depth and a improve of welding quality depending on the preheating of the material. The dependence cannot be entirely caused by the thermal energy stored in the materials but is noticeable an influence on the optical properties of the material.

This absorption dependency, one of the most important of the temperature dependencies analyzed, was first taken into account by Libenson [2, 5].

Starting from the presumption that inter-band and impurity absorptivity doesn't depend on temperature, the absorption depends linearly on temperature, using those theories and the results of Drude model for the calculus of absorption value, the variation of thermal conductivity and heat capacity per volume unit don't exceed 10% on the temperature domain considered by the tests.

It can be mentioned, without entering in calculus details that taking into account the absorption variation depending on temperature leads to values of the superficial temperature significantly higher than those estimated by the classical calculus relations. As a result, various thresholds values of superficial destruction, evaluated in those calculus cases, vary up to 4-5 times [2, 5].

The preliminary tests presented in this paper sets the path to a research regarding the alteration of optical properties by modifying the thermal condition of the material in order to reduce the amount of energy required from the laser beam and to improve the overall energetic efficiency of the laser.

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