THERMOGRAPHIC METHODS OF DIAGNOSTIC AND INSPECTION FOR LASER WELDING TECHNOLOGIES

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Abstract

The contribution deals with possibilities of using infrared thermography for inspection, diagnostics and control in laser welding technologies. Laser welding methods and infrared thermography inspection methods are also introduced. Possibilities of non-destructive infrared thermography testing are demonstrated on examples of laser welded plastic samples and inspection of protective glasses of laser scanning heads used in laser welding technologies.

Keywords: Thermography, infrared, inspection, laser, welding

1. INTRODUCTION

Industrial laser systems belong to modern tools for material treatment. Lasers are used in many industrial technologies, e.g. for cutting, engraving, marking, welding or heat treatment [1, 2]. Standard industrial laser systems mostly consist of a laser source, an optical path and a technological (processing) head. The laser source generates a laser beam which is conducted by the optical path to a laser technological head. The laser beam coming out of the laser head afterwards interacts with the surface of a treated material. The laser head can modulate the beam in such a way, so that it has optimal properties for a given technology.

Laser scanning heads are modern type of laser technological heads. These heads contain active optical components, which make it possible to scan a laser beam across a working area. Movement of the laser beam can be very fast (m/s), which allows to achieve high processing speeds. The laser scanning heads are often mounted to an industrial robot, which enhances a flexibility of a specific technology. Laser beam welding (LBW) is one of the technologies which can profit from advantages mentioned above. It is referred to as remote laser beam welding (RLBW), if the LBW technology uses a laser scanning head.

Laser beam welding [3, 4] is an advanced technology of a fusion bonding of the material. This technology is usable for a wide range of materials (aluminium alloys, steels, plastics and other) and applications. It is commonly used for example in automotive industry [5]. Laser beam welding is a complex physico-metallurgical process based on a rapid local heating of materials to be joined. The materials are heated above the melting temperature, which boosts diffusion processes and formation of a metallurgical bonding. The main advantages of LBW are that it brings a possibility of fast, precise, well controllable local heating by a laser beam of specific properties. It makes possible to perform laser beam welding with high efficiency and small weld heat affected zone (HAZ). It also brings a possibility to use welding technology in new applications, for example for products of complex geometry or products made of special materials, where it would be complicated or impossible to use conventional welding technologies.

High-quality welds can be achieved only in the case of a choice of suitable processing parameters and precise process control. Efficiency and reliability of the technology and a quality of final products can be therefore significantly influenced by using suitable tools for diagnostics of process parameters and quality inspection of final products. Thermography appears to be a suitable tool for inspection and diagnostic because of the technological principle, which is the thermal effect of the laser beam.

Infrared (IR) thermography is an analytical method for non-contact measurement of temperature fields [6]. Thermography can be generally classified as active or passive. The passive thermography deals with observation of a natural temperature or temperature changes of inspected objects. Active thermography [7] applies an external excitation to an inspected object and analyses a thermal response of the object to the excitation. There is a number of different methods and sources usable for the excitation: direct heat sources acting by a single pulse (for example flash lamps or pulsed lasers) or periodically (for example halogen lamps or continuous lasers), internal excitation connected with a temperature response (for example ultrasound or electro-magnetic methods) and other methods. These methods are applied especially in infrared non-destructive testing methods [8]. Thermography diagnostics of technological processes represents a boundary between the active and passive thermography. In the case of thermography diagnostics, the technological tool itself represents also the excitation source - that means for example laser beam in the case of laser welding.

Thermography can be also classified as quantitative or qualitative. Exact temperature at measured positions is evaluated in the case of quantitative thermography. Temperature differences resulting in some contrast on a graphical representation of measured temperature field (so called thermogram) are evaluated in the case of qualitative thermography. Both passive and active thermography can be performed in the both quantitative and qualitative approaches based on application requirements.

2. THERMOGRAPIC QUALITY CHECKING OF LASER WELDING OF PLASTICS

Laser beam welding of plastics [9, 10] is a modern technology for joining of plastics parts. The main advantages of the technology are processing speed, reliability, flexibility and cleanliness of a production process. The principle of the technology, which is called "transmission welding", is schematically shown in **Figure 1**.

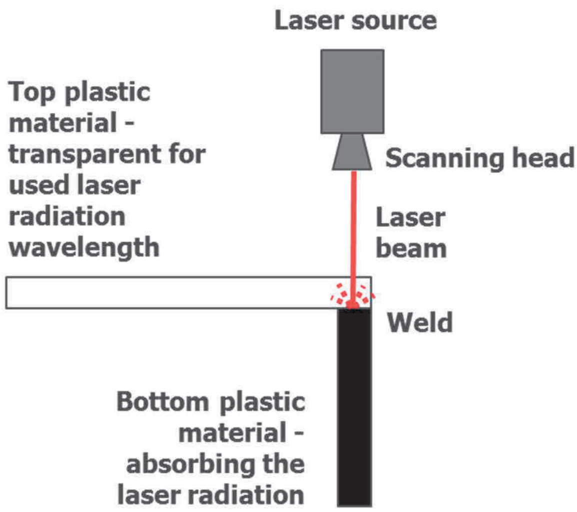

Figure 1 Schematic representation of laser plastics welding principle.

Two different materials are commonly used for the laser welding of plastics: a top part and a bottom part. The top plastic part is made of a material, which is transparent for the laser beam of a given wavelength. The bottom plastic part is made of a material, which absorbs the laser radiation (it is not transparent for the laser beam of the given wavelength). Alternatively, a configuration with two transparent materials with an additional “absorbent” inserted between them can be used. It is important to ensure a good contact of both parts. Thus, the parts are clamped under a certain pressure together. The laser beam passes through the top part and it is absorbed by the bottom part at the parts interface. The bottom part is heated up by the laser beam and the top part is consequently heated at the parts interface by a conduction heat transfer. Both parts are then melted and a weld joint is formed as they are still pressed together. The laser wavelength is dependent on the used laser system. It means that an appropriate laser system should be used for specific materials.

Two common problems are observed at laser plastics welding: poor contact and contamination of top part surface. The poor contact problem occurs if the welded parts are not in a right contact at some positions along the weld-line. It can be caused by shape imperfections of the welded parts or due to an insufficient pressure pressing the parts together. The bottom part is then heated but the heat is not transferred to the top part and the weld joint is not formed. The contamination of the top part causes absorption of the laser beam at the contaminated surface. As a consequence, the interface of both plastics parts is not heated sufficiently and the weld joint is not formed. On the other hand, the surface of the top part is often degraded by the laser beam incidence. Both these problems are reflected in different temperature profile of the weld-line compared to a correct welding procedure.

Problems in the welding process can be detected by a thermography inspection. A temperature field of a laser weld-line is recorded by an infrared thermographic camera in a short time (several seconds) after the welding process. A reference weld-line temperature profile has to be initially found by help of a post-production inspection (destructive tests, microscopy etc.), where a good weld-joint is verified. Each following welded part is then checked by the infrared camera and the record is compared with the reference one. A correctness of the welding process is then evaluated based on developed algorithms. An example of inspection results showing a correct weld and a weld with an overheated area is presented in **Figure 2**.

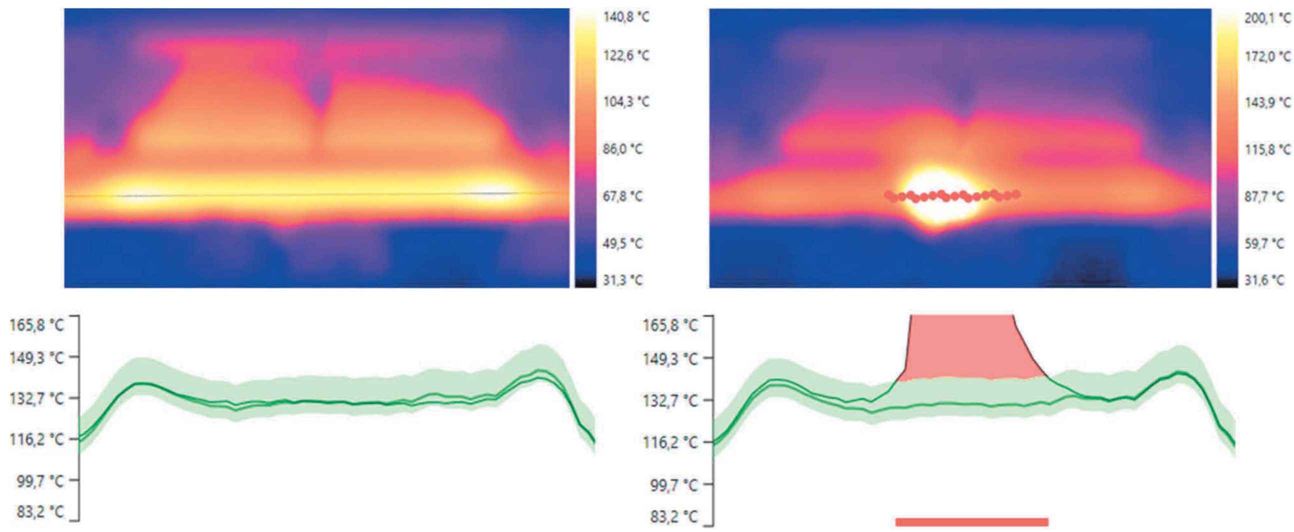

Figure 2 Thermography plastics laser welds inspection demonstration. Left: correctly welded parts. Right: A weld with an overheated area - red points show the weld parts with too high temperature.

The above mentioned problems occur also in industrial production lines. It can occur if a new production process is implemented, if parameters of a standard production process are modified, but also during a standard operation of the production lines (e.g. new batch of material). The main advantage of the thermography inspection/monitoring is speed and reliability of the inspection and an ability to identify exact positions of defects (overheating or insufficient heating). It is therefore usable for a welding-processing parameters tuning as well as for a continuous production process quality monitoring.

3. INSPECTION OF PROTECTIVE GLASS OF LASER SCANNING HEADS

A contamination of working space by by-products of the technology (for example small particles of a treated material or fumes) can occur in laser technologies like laser cutting or laser welding. Thus, if a laser scanning head is used, sensitive and expensive optical components inside the scanning head are protected by a protective glass. The glass protects the internal space of the scanning head against contamination. Along with it the glass should have maximum transparency for a specific radiation wavelength of the used laser.

Transparency, cleanness and quality of the glass can be inspected after its production. However, the glass outer side can be contaminated during the laser head industrial operation. The contamination reduces transparency of the glass and thus affects a quality of the laser beam and thereby a quality of the technological process. Absorption of the laser beam on the contaminated glass can lead to local overheating of the glass. It can accelerate its degradation that can result in serious problems in the production process, damage of the glass or damage of the laser system. These problems can occur also if active methods of glass protection are used (compressed air or gas cross-jet for example). Inspection and early detection of the protective glass contamination is therefore an important task especially in the case of high-capacity production lines.

The inspection of the glass can be performed by visual methods. Such an inspection is however influenced by skills of an operator. Making an inspection record is time consuming and technically complicated - it is necessary to disassemble the glass from the scanning head and to use a special scanner or photographical set-up. Other disadvantage of the visual inspection is related to wavelength differences. The visual inspection is limited to a visible wavelength range whereas technological lasers operate often in different wavelength ranges, for example in an infrared range. It is therefore preferable to use an infrared thermography inspection [11].

The experiments of an inspection of laser scanning head protective glasses were performed using two methods: flash-pulse inspection and laser thermography inspection. An inspected glass is excited by a light/thermal source and a response is observed and recorded by an infrared camera in both cases. The inspection method is based on a presumption that a contamination on the glass surface affects absorption of a transmitted excitation radiation, similarly as in the case of a laser beam in a real technological process. The absorption leads to a thermal response, which can be detected by the infrared camera.

A flash lamp was used for the excitation and the response was recorded by a high-speed infrared camera in the case of the flash-pulse method. An evaluation was made using advanced evaluation methods [12]: PPT - Pulse-Phase Thermography and TSR - Thermographic Signal Reconstruction. The same laser beam as the one for the welding technology was used for the excitation in the case of laser thermography inspection. Parameters of the laser beam were adjusted for the inspection purposes and scanning over a whole inspected glass area was performed together with a continuous thermographic recording. A standard bolometric infrared camera was used for the laser thermography testing. Measurement results were evaluated using a special algorithm, which made it possible to evaluate maximal temperature in a time interval for each pixel.

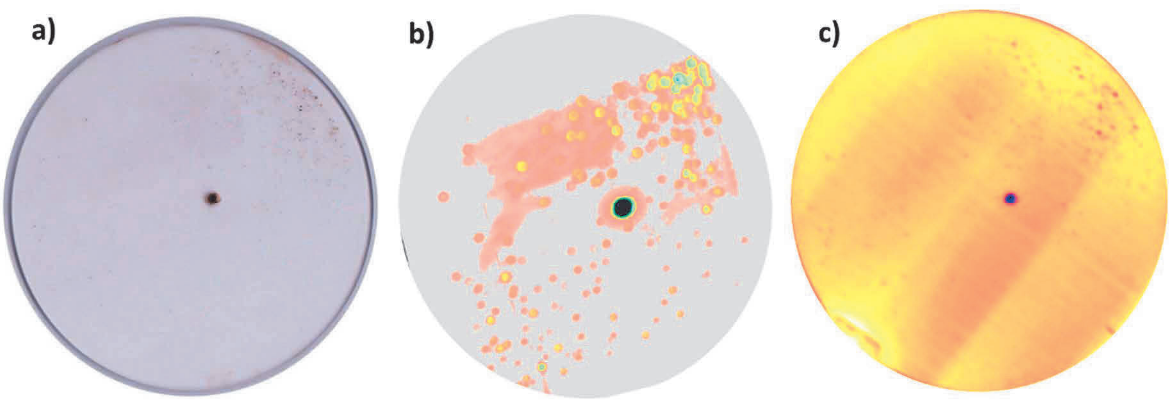

Figure 3 Example of an evaluation of laser scanning head protection glass contamination: a) optical scanner record, b) laser thermography inspection, c) flash-pulse thermography inspection

Results demonstration of inspection of contaminated and partially damaged laser scanning head protection glass is shown in **Figure 3**. A comparison of results of three inspection methods is shown in the picture: a) optical scanner record, b) laser thermography inspection, c) flash-pulse thermography inspection. A contamination and damage is apparent as individual points, clusters of points or areas. Larger areas are detectable also by the visual (optical scanner) inspection. However, the comparison shows that smaller points (spots) are not as evident by the visual inspection as by the thermography methods. When the external flash or laser excitation is used, a higher absorption of the excitation radiation at contaminated/damaged areas causes a response, which is detectable by the infrared camera. The contaminated or damaged areas can be then identified by flash-pulse evaluation methods or by local-maximums evaluation in the case of the laser thermography inspection. Detailed description of the experiments and results can be found in [11].

4. CONSLUSION

The contribution briefly presents remote laser beam welding. Two methods of infrared thermography inspection are presented: detection of imperfect welds of plastic parts and inspection of a contamination and damage of laser scanning heads protective glasses.

Possibilities of infrared thermography for welded plastics part inspection in the plastics laser welding technology are presented. The thermography inspection method is fast, reliable and makes possible to detect an exact position of the defect during the welding process. The method is therefore suitable for an inspection during a tuning of the welding procedure as well as for a continuous quality checking of welded parts in an industrial production line.

Two infrared thermography methods for inspection of laser scanning heads protective glass are presented. The flash-pulse excitation and the laser excitation were used. Both methods indicate contamination or damage of the protective glass. The experiments were performed in laboratory conditions; however, both methods could be adaptable for an industrial usage. Flash-pulse method is suitable namely for a random inspection. The laser thermography method allows using the same laser as for the technological process and it is therefore more advantageous if an integration to a production technology is required. The presented applications show possibilities of infrared thermography for diagnostics of optical components of laser systems. However, the methods presented can be used for inspection of transparent materials in general.

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