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Analysing the thermal characteristics of LAMP joining

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Abstract. The increasing utilisation of different material groups (plastic, metal, ceramics) in our advanced construction provides many benefits, but the fastening process is a challenge. LAMP (Laser assisted metal plastic) joining is a new technique in fastening technology. It means an alternative process from the existing techniques like using adhesives, screwing, riveting etc. The authors have been dealing with this technology for years. In this research work some important thermal phenomena were analysed in order to understand the process of joining more thoroughly. The temperature of the steel partner was measured in case of different laser settings and experimental situations with two measuring techniques: thermocouple and infrared camera. The results show the effect of different influencing factors during heating and the applicability of different measuring methods. The received temperature values can be compared to the characteristic temperature of PMMA polymer (decomposition temperature) in order to determine the root cause of bubble forming in the polymer material. From the result the differences between the different applied laser pulse mode for the heating was also determined and it was possible to measure the heating rate during the laser process.

Key words – laser, thermal analysis, PMMA, steel, decomposition

1. Introduction

The increasing trend in application of plastics necessitates the research on, not just the conventional joining (BOKŮVKA O. et al. 2013), but the new fastening technologies too. Laser transmission welding is a well known and used technology in industry, which enables the fast and efficient joining of plastics by exploiting the advantages of laser technology (KAGAN V. et al. 2002). Transparent-absorbent type joining can be applied in the case of different materials as well, as much research has reported, facilitating the simultaneous use of different material's advantages (ACHERJEE B. et al. 2011, ROESNER A. et al. 2011, JUNG K.W. et al. 2013). However, joining metals and plastics brings new challenges due to their diverse material properties, like strength, melting temperature or thermal expansion (FARAZILA Y. et al. 2012). In order to make this new joining technology competitive with widely used technologies, like adhesives and mechanical fastening, the difficulties have to be solved and the process of joining have to be clarified. To achieve this goal in the case of a post-moulding technology, the knowledge of temperature and temperature distribution in the material and at the interface of the bonding is essential.

According to this main motivation, the aim of this work is to determine the characteristic temperatures during the laser joining process of PMMA plastic and unalloyed structural steel, and to investigate the effect of laser settings and material partners on the temperature present during joining

2. Experiments

In the experiments S235 structural steel and poly (methyl methacrylate) (Acriplex PMMA-XT) sheet were used. The thickness of the plastic sheet was 2 mm, the size 15x15mm, the geometry of the steel pin sample and the experimental setup can be seen in Figure 1. The laser beam source was a LASAG SLS 200 type, pulse mode Nd:YAG laser with a maximum pulse power of Pmax=5.5 kW and with an average power of Pa=220 W. The power distribution of the laser beam was Gaussian (TEM0,0). The temperature was measured with a K-type thermocouple with a wire diameter of 0.25 mm, which was welded on the lateral surface of the steel pin, close to the edge of the head surface. The temperature distribution of the surface was observed by a thermovision camera type FLIR A325sc.

The transparent part was PMMA material which has a transparency of about 92% at the applied laser wavelength. Thus, the heated lower material transmits heat back to the upper partner, which melts, and by applying an appropriate compressive force between the joining partners, after cooling down, the joint is created.

To clarify the effect of the plastic sheet on the heating process, three different situations were used: in the situation ’A’, the steel pin was radiated directly at its face side, where the focal spot of the laser beam coincided with the steel pin surface. The diameter of the spot was Ø5 mm in each case. In situation ‘B’, the PMMA plastic sheet was placed 0.5 mm above the steel pin, without touching the pin. In this case, because of the high transparency of the PMMA, the laser beam passes the plastic and will be absorbed on the metal partner, where heat is generated. In situation ‘C’, the steel pin is pushed into the plastic sheet with a clamping force of 3.2 N during laser radiation. The heated face surface transfers heat back to the plastic, which softens and finally melts. As a result of the clamping force, the pin penetrates into the molten plastic, and after cooling down, the joint is created.

Three different laser settings were used in the experiments, to investigate the effect of beam parameters on the thermal process. The settings are listed in Table 1., each setting was used in all three situations, each experiment was repeated 3 times.

In each case 4.75 l/min argon shielding gas was applied. The pins were manufactured by turning, the average surface roughness of the steel pins on the lateral surface was altered between 0.8 μm and 1.4 μm. Roughness values were measured by a Mitutoyo Surftest 301 surface roughness tester. Before the experiment the steel pins were cleaned with acetone

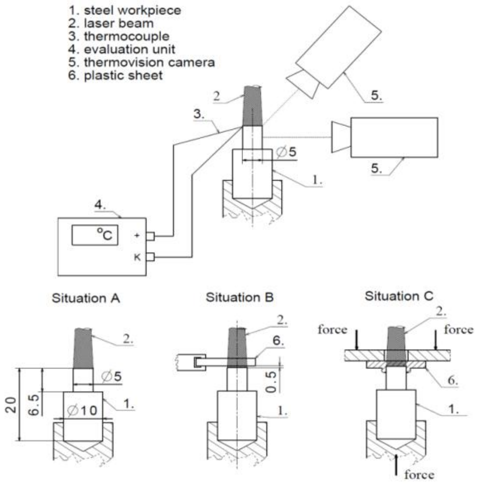

Fig.1. Schematic view of experimental setup in (b) Situation A; (c) Situation B; (d) Situation C

Source: own study.

Table 1. Used laser settings

	Average power (W)	Irradiation time (s)	Pulse frequency (Hz)	Pulse time (ms)	Pulse energy (J)
Setting I	200	4	100	0,5	2
Setting II	200	4	5	9,9	40
Setting III	200	7	100	0,5	2

Source: own study.

3. Results and discussions

Typical thermocouple measured temperature curves are plotted in Figure 1 during heating and cooling in the three different laser settings in situation A. The temperature reaches its maximum value at the end of the laser radiation, and after that, the temperature decreases to room temperature. In line with the expectations, the irradiation time influences the maximum value of the curves: the longer the irradiation time, the higher the maximum temperature. By comparing the curves of setting I and II, the effect on the heating rate and the maximum temperature can be seen: the setting with lower frequency but higher pulse energy increases the heating rate and consequently, the maximum temperature as well.

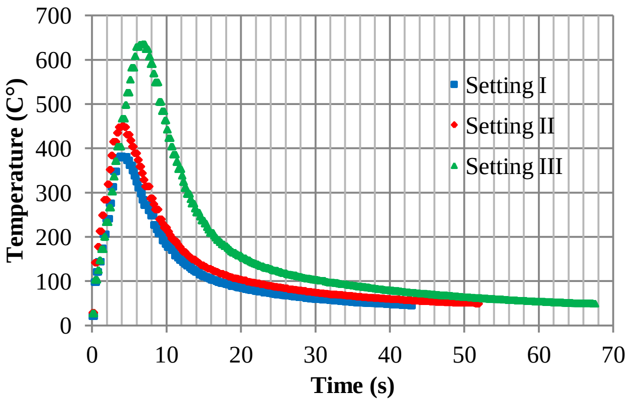

Fig. 2. Characteristic temperature curves in situation A at different laser settings, measured by thermocouple

Source: own study.

In Figure 3 the measured maximum temperatures are illustrated in the case of the 3 different settings and situations. It can be seen, that the PMMA sheet cause less than 10% decreasing in the temperature of the pin: the highly transparent plastic transmits the laser beam, which is absorbed by the metal surface. The values at situation B are consequently lower, than at situation A. If using setting II and III the surface reaches a higher temperature in almost every situation. When using situation C, the temperature decreases more significantly; the steel pin transmits heat back to the plastic during its penetration, which melts and partially degrades. The heat removal caused by the plastic decreases the temperature of the steel. The signs of polymer degradation are the arising bubbles at the plastic surface, which are the decomposition products of PMMA material. These bubbles reduce the transparency of the plastic which also contributes to the lower temperatures of the steel.

The pictures of the infrared camera provide images of the heat distribution on the surfaces. In Figure 4 the heat distribution on the lateral surface of a pin in situation A, at setting I are shown. The first 4 thermograms show the process of heating, in the 4th picture the pin reaches its maximum temperature. In the 5th picture, the pin is in the cooling part of the process.

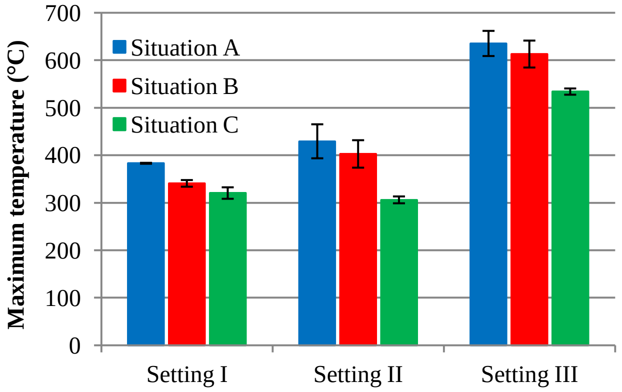

Fig. 3. Maximal temperatures at different laser settings and situations

Source: own study.

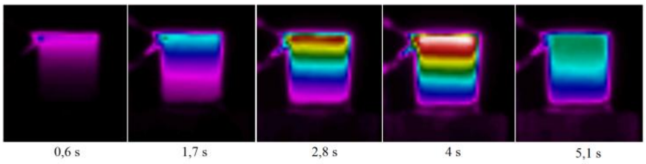

Fig. 4. Temperature time sequences on the lateral surface of the pin in situation A and setting I.

Source: own study.

As Figure 4 shows, the isotherms on the lateral surface are nearly horizontal and symmetric, and are moving downwards on the surface during heating. This means that the temperature on the lateral surface is not influenced by the horizontal position, but is only dependent on the time and the vertical position. The heat distributions of the face surface in situation A and setting I are shown in Figure 5 the same way as in Figure 4. The face surface heats up in line with the Gaussian distribution of the laser beam: the middle of the surface heats up fastest, the edge and the midpoint temperature equalizes only at the end of the heating process. The plastic material in the centre of the pin has to tolerate a longer-term, higher-temperature heating, which can explain the more intensive bubble formation during joining.

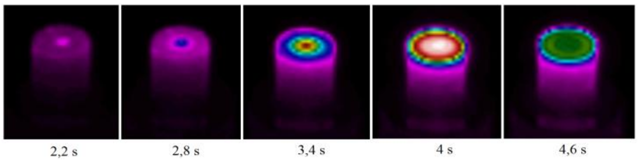

Fig. 5. Temperature time sequences on the face surface of the pin in situation A and setting I

Source: own study.

Figure 6 illustrates the process of temperature increase in the middle of the face surface in the case of settings I and II, using the infrared camera. We can see the difference in the nature of heating: when using low pulse frequency and high pulse energy, each pulse appears separately in the temperature diagram. Therefore, while setting I results in a continuous and consistent increase in the temperature, setting II causes a pulsating thermal effect for both the steel and the plastic material.

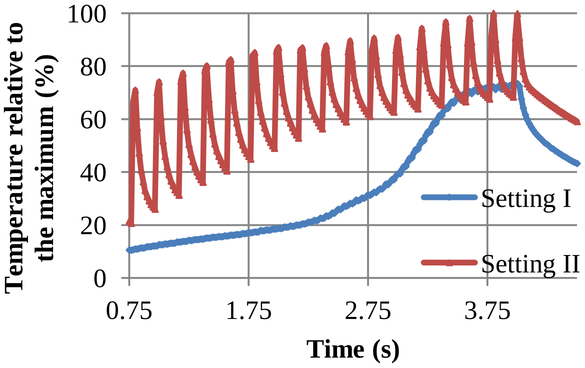

Fig. 6. Difference between the heating process depending on the laser settings

Source: own study.

4. Summary and conclusions

The main conclusions drawn from the measurements described above are as follows:

- The value of maximum temperature and the rate of heating is influenced by the feed out of laser beam: high frequency and low energy pulses cause lower temperature and heating rate, while low frequency and high energy pulses result in higher temperature and heating rate.
- The temperature of the steel pin is reduced significantly by pushing it into the PMMA sheet: the heat needed to melt and partly decompose the polymer and the deteriorating transparency of the material caused by bubble formation results in lower temperatures
- The temperature distribution on the lateral surface of the pin is only dependent on the vertical position and time, but independent from horizontal position.
- The temperature distribution on the face surface of the pin is in line with the Gaussian power distribution of the laser beam; this phenomenon is responsible for the more intensive decomposition and bubble formation in the middle part of the joining as well.
- Laser pulse frequency and pulse energy has a strong effect on the of temperature changes during heating which could have an influence to the polymer degradation process too.

5. Acknowledgement

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