technical transactions

No. 2022/008

mechanics

sciendo

Metal expansion joints manufacturing by a mechanically assisted laser forming hybrid method – concept

Piotr Kurp

pkurp@tu.kielce.pl | https://orcid.org/0000-0002-1001-5033

Hubert Danielewski

e-mail: hdanielewski@tu.kielce.pl | https://orcid.org/0000-0003-4675-6236

Faculty of Mechatronics and Mechanical Engineering,
Kielce University of Technology

Scientific Editor: Jacek Pietraszek, Cracow University of Technology
Technical Editor: Aleksandra Urzędowska, Cracow University of Technology Press
Language Verification: Timothy Churcher, Merlin Language Services
Typesetting: Małgorzata Murat-Drożyńska, Cracow University of Technology Press

Received: December 3, 2021
Accepted: June 1, 2022

Founding: The research reported herein was supported by a grant from the National Centre for Research and Development. Program title: Lider XI, grant title: Development of new type metal expansion joints and their manufacturing technology, contract number: LIDER/44/0164/L-11/19/NCBR/2020.

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing interests: The authors have declared that no competing interests exist.

Citation: Kurp, P., Danielewski, H. (2022). Metal expansion joints manufacturing by a mechanically assisted laser forming hybrid method – concept. *Technical Transactions, e2022008*. https://doi.org/10.37705/TechTrans/e2022008

Abstract

This paper presents the concept of metal expansion joints manufacturing using a mechanically assisted laserforming hybrid method. The metal expansion joints are made of a metal tube of an appropriate diameter and wall thickness with a combined bellow-lens shape. The concept assumes using a CO_2 laser to implement such expansion joints. The laser beam heats the selected area of the rotating tube, mounted on a swivel handle on one side and the actuator handle on the other end. After reaching the plasticising temperature, the actuator compresses the element. As a result, a bellow-lens shape is formed at the plasticization area. Initial experimental studies confirmed the validity of the concept. The bellow-lens metal expansion joint (type DN20) was obtained as a final result. The presented idea and the element manufacturing method were submitted to The Patent Office of RP.

Keywords: laser forming, metal expansion joints, pipe treatment

1. Introduction

Laser technologies are widely used and thus remains under constant development nowadays in many industries and medical applications. In the aspect of mechanical engineering, the author of this publication is most interested in laser technologies utilised in the machine and metal manufacturing industries. Engineering practices of laser beam utilisation are being used in such technologies as cutting, welding and surface treatment – examples can be found in the literature (Antoszewski, 2015, 2021; Banak, 2017; Danielewski, 2020; Nowakowski, 2016; Nowakowski, 2017; Radek, 2014; (Tofil, 2021; Witkowski, 2020).

One of the lesser-known laser technologies is laser forming. This is a contactless, thermal method of stress induction in the material leading to permanent plastic strain. The mechanism that makes this possible is the thermal expansion phenomenon. As a result of this phenomenon, it is possible to induce thermal stresses sufficient to obtain permanent deformations. This process involves creating internal thermal stresses in the material. Therefore, this method does not require external forces from tools, for example, punch and die, to be exerted on the material. Thus, this type of forming can be named “free laser forming”. In the research on laser forming performed to date, three main mechanisms leading to the deformation of materials due to thermal expansion have been distinguished (Vollertsen, 1994):

- temperature gradient mechanism – TGM,
- upsetting mechanism – UM,
- buckling mechanism – BM.

This technology can be used for the laser forming of developable surface elements (like elements made from plates) (Silve, 2009; Shi, 2007), non-developable surface elements (like pipes and profiles) (Safdar, 2007; Li, 2007), laser forming of shape memory, brittle and non-metallic materials and composites (Birnbaum, 2006; Carey, 2007) as well as for precise laser forming in precision mechanics and electronics (Palmern, 2006; Bechtold, 2007).

This technology, however, has a significant disadvantage – it is very time-consuming. Such an approach has improved this technology and, as a result, created and developed a hybrid method called mechanically assisted laser forming. This technology is currently being developed, inter alia, in the Laser Processing Research Centre of Kielce University of Technology and Polish Academy of Sciences (Kurp, 2018; Widłaszewski, 2019), and consists of forming process acceleration by applying additional external force.

Metal expansion joints are part of industrial pipeline installations. The main task is to compensate stresses resulting from the thermal expansion of the material (compensation of axial, lateral, and angular displacements). These are made from the pipe, on which there are upsets in the form of bellows or lenses. These parts function as “springs” to compensate for the aforementioned deformations. Currently, these elements are mainly made by plastic cold working using roller systems (Standards of EJMA 10th Edition). This paper presents the idea of manufacturing such expansion joints using a mechanically assisted laser forming hybrid method.

2. Concept

The concept of creating expansion joints by the mechanically assisted laser forming hybrid method is based on the assumption that only part of the pipe subjected to the laser beam at a given moment is deformed. The laser beam heats the selected area of the pipe to a specific, preset temperature, which improves the plastic properties of the heated region. The element is evenly and uniformly heated along its circumference by quickly rotating around its axis. At the same time, an axial force acts on the element, which causes pipe upsetting in the plasticised zone (heated by the defocused laser beam). The remaining

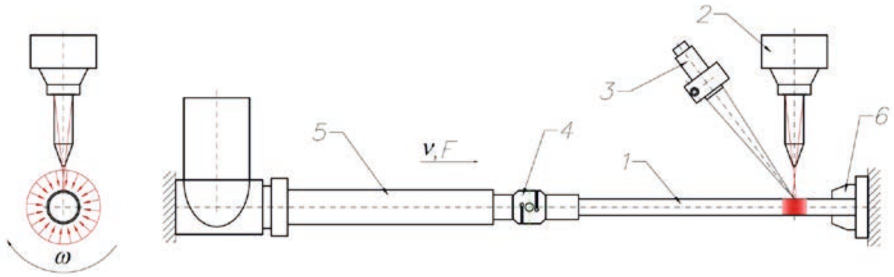

Fig. 1. Scheme of the execution and measurement stand: 1 – pipe quickly rotating around its axis, 2 – laser head (pipe heating), 3 – pyrometer, 4 – force sensor, 5 – axial thrust actuator, 6 – swivel handle

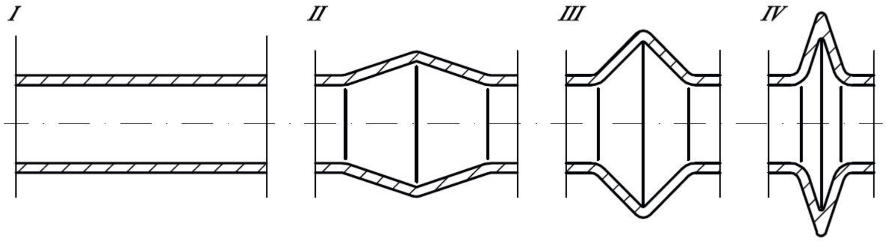

Fig. 2. Individual steps of bellow-lens forming (concept): I – straight output pipe, II, III – pipe upsetting, IV – the final bellow-lens shape

part of the formed pipe, which has a lower temperature, does not deform; only the "selected girdle" of an element is upset at this time. The width of this "girdle" depends on laser beam focal point dimensions incident on the element's surface. This, in turn, affects the possibility of obtaining the appropriate geometry of manufactured expansion joints (Fig. 1 and Fig. 2).

As shown in the Fig. 1 scheme, a test stand was prepared, and an experimental procedure was conducted to validate the presented concept.

3. Experiment

The material used in the experiments were pipes made of grade X5CrNi18-10 stainless steel, with dimensions of ϕ20×1 mm (diameter × wall thickness) and 250 mm in length. The pipe was installed between the axial actuator with a maximum pressure force of 5kN (4) and a swivel handle (6). The sample's surface was covered with a special absorber (matt black enamel) to increase the uniform absorption coefficient of the laser radiation. The experiment was performed by using the CO_2 laser TRUMPF TruFlow 6000 with maximum output laser power equal to 6kW. The treatment parameters were as follows:

- laser wavelength: $\lambda = 10.6\ \mu\text{m}$,
- CW laser mode,
- laser power: P = 900–1,100 W,
- process temperature: approx. T = 1,050–1,100°C,
- pipe compressive force: max. F = 600 N,

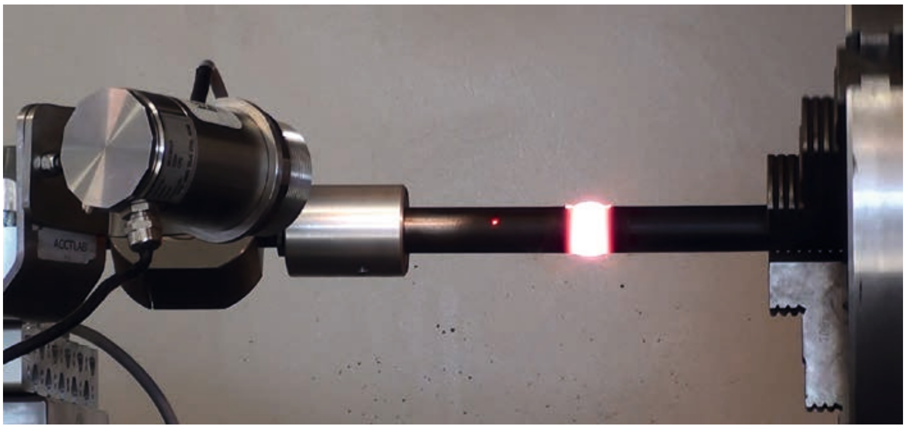

Fig. 3. Pipe in the course of the experiment: heating and compression process

- compressive length: $s = 10–20$ mm,
- pipe rotation speed: $\omega = 10{,}000°/\text{min}$,
- pipe compressive speed: $v = 10$ mm/s.

The linear polarised laser beam was positioned perpendicularly to the pipe's surface so that the beam width coincided with the pipe axis. The laser beam width on the pipe's surface was about 20 mm, which was both a heating and plasticizing zone of the pipe around its entire circumference. Simultaneously, the pipe was rotated at speed ω. After obtaining the appropriate plasticisation temperature T, measured by a temperature sensor (3), the actuator (5) was started. The actuator pressed on the pipe axially with the force F (4) applied at speed v. The experiment was performed for two actuator strokes s. The element during the investigation is presented in Fig. 3.

After the experiment, the pipe was cooled down freely and the formation of a specific bellow-lens on the periphery was observed. Geometric differences were noticed related to the process parameters (actuator stroke s). The element was then subjected to geometric measurements and macroscopic evaluation.

4. Results and Discussion

Macroscopic analysis was performed using photographic devices with recording functions. The shapes were measured using a digital calliper. Example shapes of the obtained expansion joints are shown in Fig. 4.

These two photos show that the proper expansion joint shape is only for compression length $s = 10$ mm. For the given plasticisation zone (approx. 20 mm), the compression length $s = 20$ mm was too large, which caused a burst of the element. There was no creation of a bellow-lens shape but a tight ring in this case. Further compression led to the rims of the ring bursting. Moreover, it should be assumed that an excessively compressed shape would not fulfil the compensation function.

For a correctly made expansion joint, the shape geometry was measured. Elements after polishing are presented in Fig. 5 and the measured data is shown in Table 1.

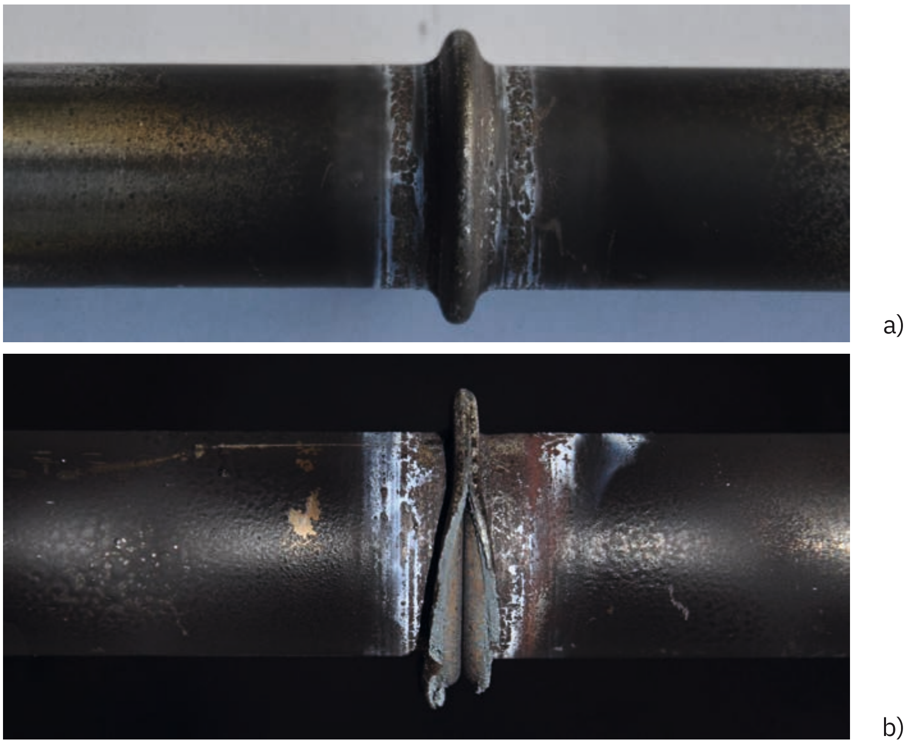

Fig. 4. The final products manufactured during the experiment: a) compressive length $s = 10$ mm, b) compressive length $s = 20$ mm

Fig. 5. Correctly made final expansion joints after polishing

Table 1. Summary of measurement results

Measurement number	Expansion joint diameter d_k, mm	Expansion joint width w_k, mm	Standard deviation, δ	
1.	28.12	5.99	dk	wk
2.	28.15	6.00	0.027737	0.003887
3.	27.92	6.01		
4.	28.20	6.01		
5.	27.98	5.98		
6.	28.09	6.02		
7.	28.08	6.00		
8.	27.99	6.01		
9.	28.00	6.01		
10.	28.01	5.99		

The average diameter of the expansion joint is d_k^{avg} = 28.05 mm, while its width is w_k^{avg} = 6.00 mm. The tests performed for the selected parameters indicate the high repeatability of the process.

5. Conclusions

The proposed hybrid method of mechanically assisted laser forming is justified and effective according to the experiment. Moreover, the concept's validity presented in Section 2 of this paper was confirmed. Selection of the appropriate heating zone and process temperature, as well as the force and speed of compression lead to the formation of a bellow-lens expansion joint. The obtained results are reproducible, which confirms the industrial application potential of the technology mentioned above. Control of the material temperature and compression length are essential elements of the investigated technology. The incorrect selection of these parameters will lead to burnout and/or burst of the bellow-lens rim. Excessive compression of the pipe will lead to a flat ring forming around the pipe, which will not fulfil the functions assigned to this element type.

The investigation results are optimistic and stimulate further research. It is planned to perform experimental tests with different process parameters for DN20, DN50, and DN100 pipe diameters. It is intended to develop technological nomograms with process parameters. Furthermore, the authors are planning to perform the following tests shortly: microstructure analysis (possibly post-process heat treatment development for X5CrNi18-10 stainless steel), FEM analysis of the temperature-distribution field, stresses and strain-state analysis during and after the process, and strength tests of finished elements such as compression, tension, and fatigue.

The concept presented in this paper and performed investigations contributed to the patent application on September 17, 2021, to The Patent Office of RP entitled *Method and device for the production of metal expansion joints*[1], patent application number: P.438965.

References

Antoszewski, B., Danielewski, H., Dutkiewicz, J., Rogal, L., Węglowski, M.S., Kwieciński, K., Śliwiński, P. (2021). Semi-Hybrid CO_2 Laser Metal Deposition Method with Inter Substrate Buffer Zone. *Materials*, Vol. 13: 1–14.

Antoszewski, B., Sęk, P. (2015). Influence of laser beam intensity on geometry parameters of a single surface texture element. *Archives of Metallurgy and Materials*, Vol. 60: 2215–2219.

Banak, R., Mościcki, T., Tofil, S., Antoszewski B. (2017). Laser Welding of a Spark Plug Electrode: Modelling the Problem of Metals with Disparate Melting Points. *Lasers in engineering*, Vol. 38: 267–281.

Bechtold, P., Schmidt, M. (2007). Non-thermal Micro Adjustment Using Ultrashort Laser Pulses, *JLMN-Journal of Laser Micro/Nanoengineering*, Vol. 2, No. 3: 183–188.

Birnbaum, A.J., Yao, Y.L. (2006). The Effects of Laser Forming on Superelastic NiTi Shape Memory Alloys. (In) *NSF under DMI-0355432*, Columbia University.

Carey, C., Cantwell, W.J., Dearden, G., Edwards, K.R., Edwardson, S.P., Watkins, K.G. (2007). Low Power Laser Forming of Glass Fibre Based Fibre Metals Laminates. (In) *Proceedings of LANE 2007 (Laser Assisted Net Shape Engineering 5)* (pp. 645–655). Erlangen: Meisenbach.

Danielewski, H., Meško, J., Nigrovič, R., Nikolić, R.R., Hadzima, B., Gubeljak, N. (2020). Laser cutting of ductile cast iron. *Materials Testing*, Vol. 62: 820–826.

Kurp, P. (2018). Mechanically-assisted laser forming of flat thin beams made of Inconel 627 and Inconel 718 alloys. *Materials Research Proceedings*, Vol. 5: 25–30.

Li, W., Yao, Y.L. (2001). Laser Bending of Tubes: Mechanism, Analysis, and Prediction. *Journal of Manufacturing Science and Engineering*, 674–681.

Nowakowski, L., Wijas, M. (2016). The evaluation of the process of surface regeneration after laser cladding and face milling. *Engineering mechanics*, 430–433.

Nowakowski, L., Wijas, M. (2017). Finishing surface after regeneration with laser cladding. *Proceedia Engineering Transcom 2017*, Vol. 192: 1012–1015.

Palmer, J.A., Knorovsky, G.A., MacCallum, D.O., Steyskal, M., Scherzinger, W.M., Wong, C.C., Lehecka, T.M. (2006). Laser Based Micro Forming and Assembly (In) *Sandia Report SAND 2006* (pp. 7239). Albuquerque: Sandia National Laboratories.

Radek, N., Pietraszek, J., Antoszewski, B. (2014). The average friction coefficient of laser textured surfaces of silicon carbide identified by RSM methodology. *Advanced Materials Research*, 874: 29–34.

Safdar, S., Li, L., Sheikh, M.A., Liu, Z. (2007). Finite element simulation of laser tube bending: Effect of scanning schemes on bending angle, distortions and stress distribution. *Optics & Laser Technology*, Vol. 39: 1101–1110.

---

[1] in Polish: *Sposób i urządzenie do wytwarzania kompensatorów metalowych.*

Shi, Y., Shen, H., Yao, Z., Hu, J. (2007). Temperature gradient mechanism in laser forming of thin plates. *Optics & Laser Technology*, Vol. 39, Issue 4: 858–863.

Silve, S. (2009). Multiple meanings in transdisciplinary collaboration: Using laser forming for a community arts sculpture. (In) *8th European Academy of Design Conference*, Aberdeen: The Robert Gordon University.

Standards of the Expansion Joint Manufacturers Association, Tenth Edition 10th EJMA.

Tofil, S., Danielewski, H., Witkowski, G., Mulczyk, K., Antoszewski, B. (2021). Technology and Properties of Peripheral Laser-Welded Micro-Joints. *Materials*, Vol. 14: 1–16.

Vollertsen, F. (1994). Mechanisms and Models for Laser Forming. (In) *Laser Assisted Net Shape Engineering, Proceedings of the LANE'94* (pp. 345–360), Bamberg: Meisenbach-Verlag.

Widłaszewski, J., Nowak, M., Nowak, Z., Kurp, P. (2019). Laser-assisted thermomechanical bending of tube profiles. *Archives of Metallurgy and Materials*, Vol. 64: 421–430.

Witkowski, G., Tofil, S., Mulczyk, K. (2020). Effect of laser beam trajectory on pocket geometry in laser micromachining. *Open Engineering*, Vol. 1: 830–838.