Experimental Results of Helical Metal Expansion Joints Fabrication

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Keywords: Laser Forming, Metal Expansion Joints, Laser Treatment, Pipeline Compensation

Abstract. This paper discusses the technological assumptions for the production of helical metal expansion joint as a new type of expansion joints used to eliminate torsional deformations of industrial pipelines. The method of mechanically assisted laser forming, which was used as a manufacturing technology, was presented as well. Furthermore, technological parameters and experimental results obtained during the fabrication of helical metal expansion joints were presented. Mainly presented and discussed are the results such as: obtained geometry, forces necessary to produce the product, processing temperature, strain rate and others. Satisfactory treatment results were obtained, which are illustrated below.

Introduction

Metal expansion joints are pipeline components designed to compensate for installation deformations related to changes in operating parameters such as temperature and pressure. Without compensating for this type of deformation, the piping installation would fail quickly. In addition, compensators eliminate the assembly inaccuracies of such an installation. The deformations that are compensated are [1-3]:
- lateral deformation,
- axial deformation,
- angular deformation.

There are two main types of metal expansion joints described above [4, 5]:
- bellows expansion joints,
- lens expansion joints.

Examples of metal expansion joints produced by ENERGOMET Wrocław are shown in Fig.1.

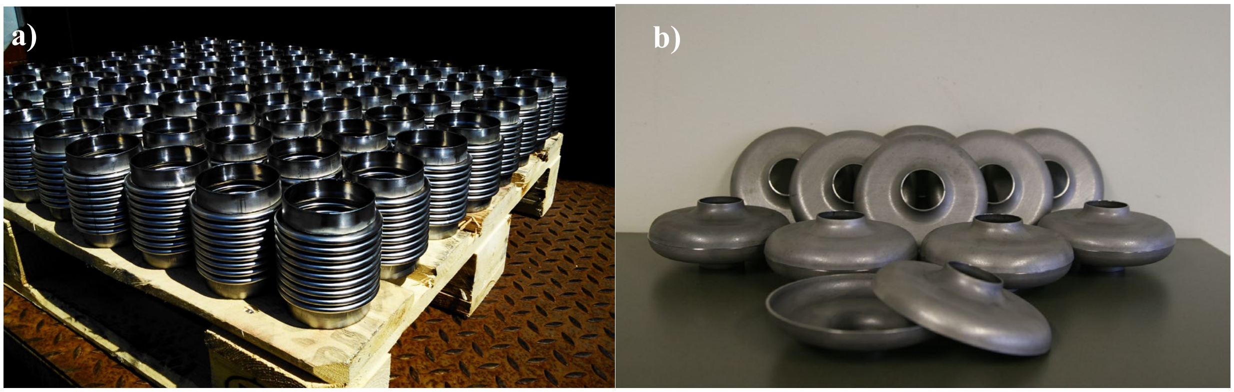

Fig. 1. *Typical metal expansion joint: a) bellows expansion joints, b) lens expansion joints [6].*

The mentioned components do not compensate for deformations generated by torques, which are the result of the operation of fittings, main pumps, etc. installed in the pipeline. To come up with the idea of manufacturing helical metal expansion joints, a task should be used to compensate for this type of deformation.

The fabrication of this type of components is carried out mainly by various types of cold plastic forming methods [1]. The authors of this paper will present the results of tests on the fabrication of metal expansion joints using the mechanically assisted laser forming method. Laser treatment is now a widely used fabrication method. It covers a whole range of various types of technologies such as: cutting, welding, surfacing, surface treatment with and without remelting, micromachining, additive technology and many others [7-9].

Laser forming uses induced internal stresses caused by the temperature difference between the areas of the component heated by the laser beam and the rest of the material. This method uses the phenomenon of thermal expansion, specifically the differences in expansion between "warm" and "cold" areas. In the literature, there are three basic mechanisms of laser forming, described in the mid-1990s, they are [10]:

- Temperature Gradient Mechanism (TGM),
- Upsetting Mechanism (UM),
- Buckling Mechanism (BM).

However, the laser freeform forming method (as we can call it) is a very time-consuming process. Therefore, the authors will present the results of research into the fabrication of helical metal expansion joints using a hybrid method of mechanically assisted laser forming.

Production and use of compensators are of significant importance for the reliability of pressure systems, which are widely utilized in industries as well as in many commonly used devices and machinery. This influences the quality [11-13] and safety of the functioning of the equipment and machinery that utilize them [14-16]. Material and thermomechanical equations allow for the solution of a straightforward issue: calculating deformations based on a given energy stream. However, the appropriate shaping of a compensator using a focused laser energy beam [17] requires solving a highly complex inverse problem, which is time-consuming and usually involves the method of successive approximations [18].

The installation of a compensator reduces the risks arising from the geometric imperfections of piping systems and their deformation under the influence of pressure and temperature changes. However, it also introduces new risks associated with corrosion [19,20] and biocorrosion [21], as well as joint fatigue [22,23] and wear [24,25]. The remedy for these problems lies in the proper selection of materials, both commonly used [26-28] and special alloys [29]. Their technological properties can be adjusted towards desired values by applying appropriate protective coatings [30-32] or modifying the surface layer [33]. Here, increasingly popular techniques such as electrospark deposition [34-36] and diamond-like carbon coatings [37-39] can be mentioned.

The benefits derived from such shaping techniques for compensators include energy consumption reduction [40] and less environmental pollution through waste separation [41]. The reliability of machinery [42] equipped with them, including railway rolling stock [43], significantly increases. This increased reliability does not go unnoticed by a customer known for their exceptionally high-quality standards: the military [44].

Sophisticated technological procedures often necessitate a decrease in the quantity of examined variables [45,46], enabling subsequent process optimization and stabilization through the utilization of statistical methodologies. These methodologies may take the form of classical approaches [47-49] such as factorial design, response surface methodology (RSM), and Taguchi methods, or nonparametric techniques [50-52], even with resampling support [53].

Technology and Materials

Ideas and assumptions about technology were presented in the article [54]. The technology will be briefly described below to introduce the reader to the subject. The helical metal expansion joint has bellows in the form of a spiral on its circumference. This spiral is analogous in appearance to a thread. It can be both right and left-handed. In short: in order to make this type of metal expansion joint using the hybrid method of mechanically assisted laser forming, it is necessary to bring part of the pipe to the plasticizing temperature by heating it around the perimeter in a spiral, and then compressing the pipe with the appropriate force. The diagram of the technology is shown in Fig.2 and Fig.3.

Fig. 2. *Diagram of the method of heating the element*
(for better illustration, the pipe has been presented as transparent)

The output material for the experiment was a pipe made of X5CrNi18-10 grade stainless steel with dimensions ϕ50x1.5 mm. The chemical composition and selected material properties are presented in Table 1 [55]. The research stand and the results of the experiment are presented below.

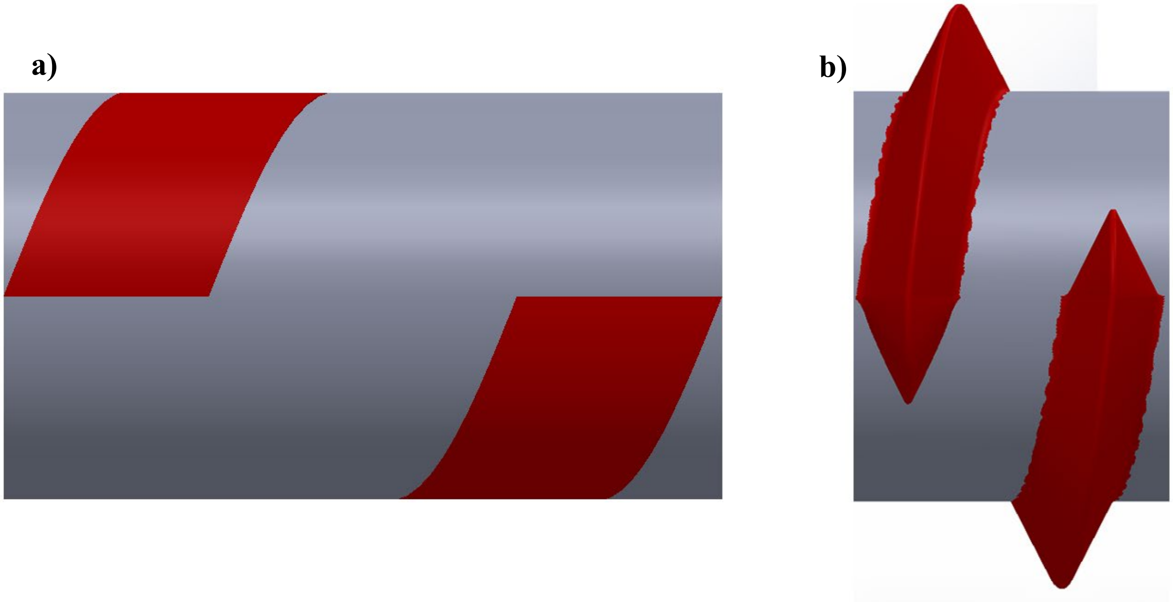

Fig. 3. *Scheme: a) output pipe heated in a helix, b) component after compression.*

Table 1. *Chemical composition and main physical properties of X5CrNi18-10 austenitic steel [12].*

Chemical composition							
C	Cr	Ni	Mn	Si	P	S	N
<0.07	17.5÷19.5	8.0÷10.5	<2.0	<1.0	<0.045	<0.015	<0.11
Density ρ, kg/m^3		**Thermal expansion coefficient α, 1/K**		**Heat capacity C_{p20}, J/kgK**		**Thermal conductivity λ, W/mK**	
8020		14.2x10^{-6}		480		15	

Experiment and Results

The test stand presented in Fig. 4 consisted of a TRUMPF TruFlow 6000 CO_2 laser generating a rectangular laser beam with a wavelength of λ=10.6 µm.

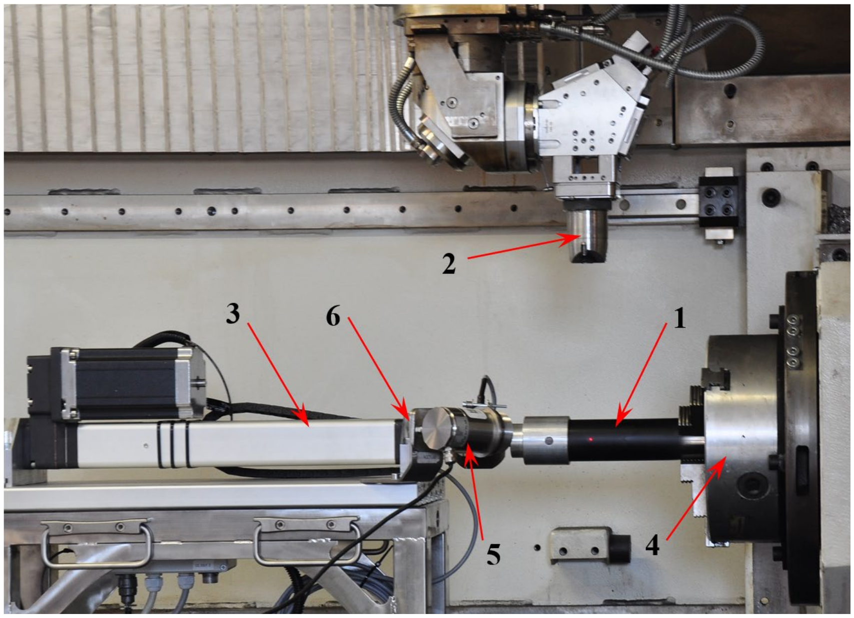

Fig. 4. *View of the test stand: 1 - pipe, 2 - laser head, 3 - actuator, 4 - swivel chuck, 5 - force sensor, 6 - pyrometer.*

A tubular pipe was installed between the actuator and the swivel chuck. The process temperature was controlled by a monochromatic pyrometer, the laser power was controlled by feedback to the pyrometer readings to keep the zone temperature constant. The surface of the sample was covered with a special absorber (matt black enamel) in order to increase the laser radiation absorption coefficient. The laser processing parameters are listed below:

- process temperature: approx. T = 1100°C,
- laser power: depending on element temperature $P \in <900, 2500>$ W
- compressive length (total): s = 15 mm,
- initial beam pitch: p_1 = 140 mm,
- pipe compressive speed: v = 10 mm/s.
- initial beam pitch: p = 80 mm,
- number of coils: i = 3.

Due to the upsetting of the helix during the process, the pitch of the helix was corrected six times. Each time the correction was by 10 mm. The results of the experiment and their discussion are presented in the paragraph below.

Results

The result of the experiment was the DN50 helical metal expansion joint fabrication shown in Fig. 5. As can be observed in Fig. 5, upsets (below) were formed around the circumference of the pipe. Force needed to create a helix around the pipe circumference is shown in Fig.6. The results of the experiment are discussed in the paragraph below.

Discussion and Conclusions

Experimental studies confirmed the possibilities of the new technology in the aspect of helical metal expansion joints fabrication. On the basis of previously performed experimental studies, it was possible to select the parameters of the laser treatment, which allowed for the formation of a helix on the surface of the pipe element. Macroscopic examinations allow the assessment of the obtained helical metal expansion joint at the correct level. No cracks, kinks, unfavorable corrugations, etc. were noticed on the surface. The helix obtained is symmetrical and repeatable, no defects in the upset geometry were noticed.

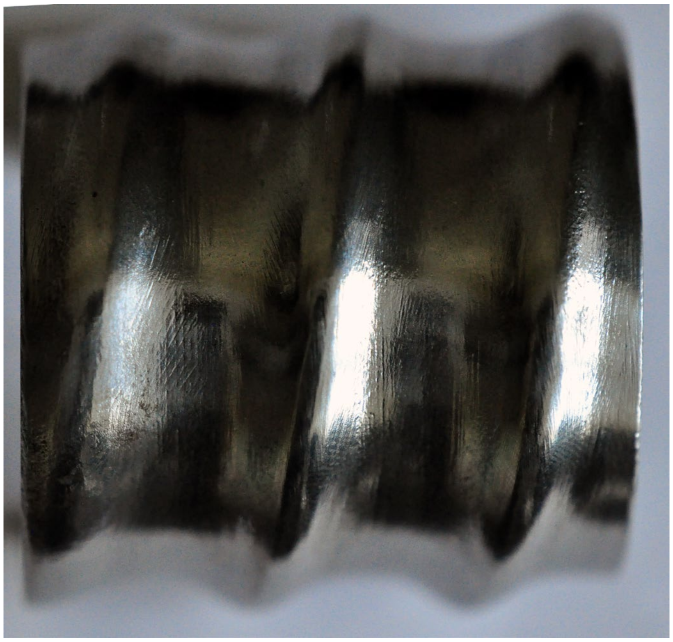

Fig. 5. *View of the DN50 helical metal expansion joint surface.*

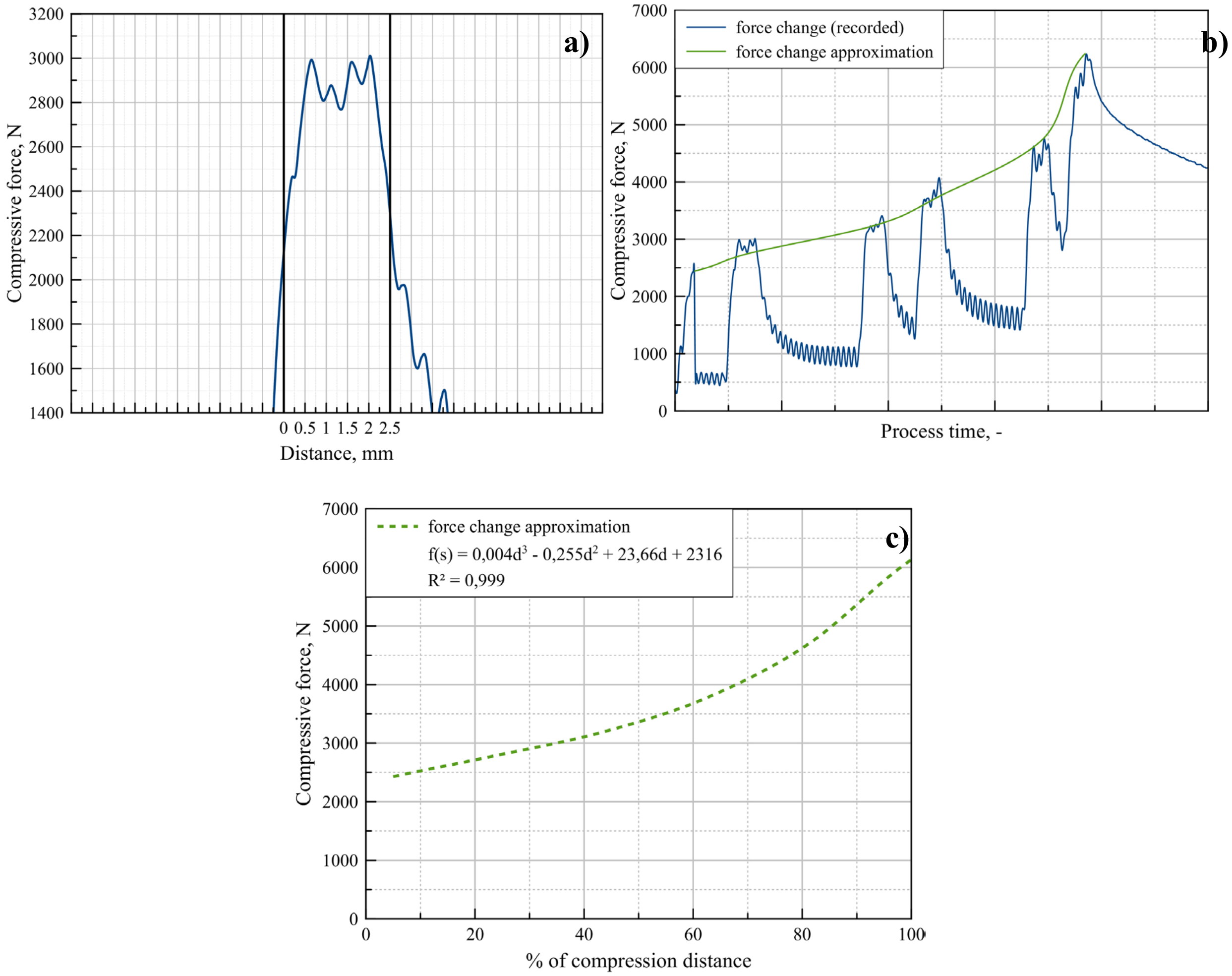

Fig. 6. *Force needed to create a helix around the pipe circumference: a) for a single pass, b) for six passes, c) approximated force needed to produce a complete metal expansion joint for given technological parameters.*

Recorded force show an increase in the force needed to make a hel;ix with each successive pass. Most likely, this is due to the distribution of forces in the emerging upset, which must be overcome in order to increase the resulting upset. As noted from the graphs (Fig.6), the increase in force can be described by an exponential function in the form (for the correlation coefficient R^2=0.999):

$$f(s) = 0.004\ d^3 + 0.255\ d^2 + 23.66\ d + 2316, \tag{1}$$

where: d - compressive distance.

Of course, the values of the *d* term in the formula (1) will depend on the values of the forces, which will be different for different diameters and thicknesses. The results of the experiment may be helpful in planning and developing technology for making this type of metal expansion joints. In order to check the possibility of compensating the torsional torques by the expansion joint, additional tests should be carried out. Such studies are planned for the future.

Acknowledgement

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

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