STUDY ON METAL EXPANSION JOINT MANUFACTURING WITH LASER AND FORCE

[1]PIOTR KURP, [2]HUBERT DANIELEWSKI, [3]SZYMON TOFIL

[1,2,3]Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering,
Laser Research Centre, al. Tysiąclecia P.P. 7, 25-314 Kielce, Poland
E-mail: [1]pkurp@tu.kielce.pl, [2]hdanielewski@tu.kielce.pl

Abstract - In this paper, the authors discussed the principle of operation of metal expansion joint and presented traditional methods of their production. Moreover, they discussed the innovative concept of producing these elements using a laser beam and external forces. The authors explained that these are elements intended to compensate for temperature differences and stresses in construction materials. The authors then analyzed traditional methods of producing metal expansion joints, highlighting their limitations and potential difficulties. They indicated that there is a need to look for new, more effective production methods that can increase the efficiency and quality of these elements. The main part of the article discusses a new concept of producing metal expansion joints using a laser beam and external forces. The authors described in detail the manufacturing process in which the laser beam is precisely controlled to shape the metal material according to the required compensator geometry. At the same time, external forces are applied to accelerate the process. This approach allows for the accuracy and repeatability of manufacturing, which is crucial for the effectiveness of metal expansion joints.
The rest of the article presents the results of research on this new manufacturing method. The authors focused mainly on the recorded processing parameters, such as laser power, processing speed, acting forces, and geometry of the obtained elements. The results of these tests confirmed that the proposed method is effective and efficient, enabling precise control of the production process of metal expansion joints.

Keywords - Laser Treatment, Laser Forming, Metal Expansion Joint,

I. INTRODUCTION

Metal expansion joints (MEJ) are extremely important structural elements, especially in the context of pipelines and other structures where dynamic changes in stress, deformation, and vibration occur. Their role in ensuring the integrity and durability of structures is crucial, and their use is versatile, covering various industrial fields. MEJ are designed primarily to compensate for stresses that may appear in structures due to temperature changes. They act as flexible connections that allow structures to freely adapt to expansion or contraction in response to changing thermal conditions. Thanks to this, they prevent stresses that could lead to cracks or deformations of materials. MEJ consist of a key flexible part called a compensation ring (in the form of a so-called bellows or lens) [1]. This ring is typically made of a highly flexible material such as stainless steel or carbon steel. The choice of material depends on the specific application and requirements for durability and corrosion resistance. The expansion ring is designed with precision to absorb stresses that result from structural movements and temperature changes. This maintains the integrity of the system and minimizes the risk of damage. It is worth noting that MEJ are used in various industries. They are an integral part of structures in the chemical industry, where changes in temperature and pressure are common and the integrity of the systems must be maintained. In the petrochemical industry, where corrosion is a problem, stainless steel is often the construction material of choice. In the energy industry, metal expansion joints help compensate for stresses in pipelines and transmission systems. They are also used in the machinery industry, where dynamic loads may occur in machines and devices [2-4]. The typical below MEJ is shown on Fig. 1 [5].

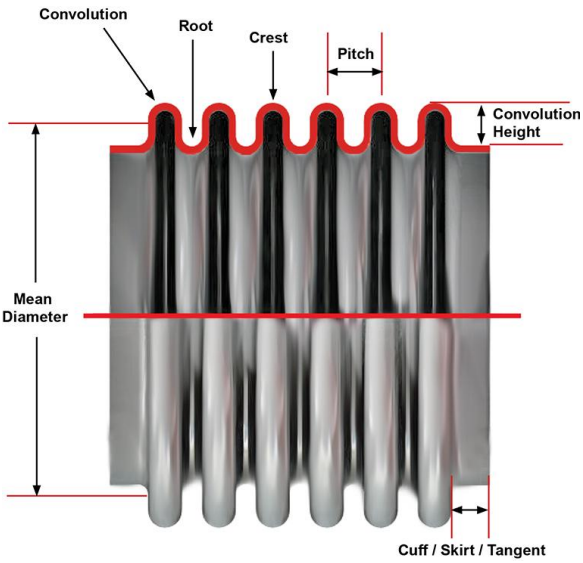


Fig.1. Below metal expansion joint example [5]

These elements mainly compensate as follows [1, 6]:

1. Axial deformations - i.e. changes in length along the axis of the structure when the temperature increases, the construction material can expand, leading to the elongation of the structure.
2. Lateral deformations - in pipelines, lateral movements or twists caused by temperature changes can lead to lateral shifts.

3. Angular deformations - in situations where structures consist of different segments, changing conditions may lead to changes in the angles between them.

Standard manufacturing methods for MEJ include a variety of techniques that allow the production of expansion elements of various shapes and dimensions, tailored to specific needs and applications. Some of these standard methods are described follow [1]:

1. Expansion forming (expansion mandrel). This method involves expanding or stretching the pipe to achieve adequate flexibility and compensation for stress. Expansion is carried out using appropriate tools and machines.
2. Hydraulic forming. This technique uses hydraulic pressure to shape and form expansion elements. Using special tools, the shape and size of the compensator can be precisely controlled.
3. Elastometric forming.
4. Pneumatic pipe forming. This technique involves blowing air or gas into the pipe, which expands or narrows the pipe to conform to the required geometry.
5. Roll forming. The rollers precisely roll over the material, giving it the right shape.
6. Rolled ring. This process involves rolling the material into a ring that can be used as a compensating element.
7. Rolled convoluted sheet. This method involves rolling a flat sheet of metal in a corrugated form, thus creating a flexible compensating element.
8. Press-brake forming. A press-brake is used to bend and form the edges of the compensating material in a way that allows it to absorb stresses and movements.
9. Combined forming. Some manufacturing methods may combine several of the techniques listed above to produce specialized compensation components that meet specific application requirements.

Manufacturing of MEJ using standard methods can be effective in many cases, but it is also associated with certain disadvantages, limitations, and potential drawbacks: limited flexibility in design, limited precision, size, sensitivity to corrosion, required maintenance, limited tolerance to extreme conditions, It is worth pointing out that many of these disadvantages can be overcome with appropriate design, materials, and quality control in the production process. However, in some cases, especially when compensators with extremely complex shapes or under extreme operating conditions are required, more advanced manufacturing techniques may be preferred, such as manufacturing the compensators using a laser beam or other advanced processes.

For this reason, the authors decided to develop a method using a laser beam supported by mechanical forces. The use of lasers in the industry is widely known and has been used for years for various operations and processes, due to their ability to precisely cut, weld and braze, marking, surface treatment, microstructuring, 3D additive machining etc [7-10]. An overview of the proposed technology will be presented later in this paper.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

The base material for the manufacturing of MEJ was a pipe made of high-quality X5CrNi18-10 stainless steel grade. This steel is commonly chosen for the production of this type of element due to its corrosion resistance, good weldability, and resistance to high and low temperatures (it retains its mechanical properties over a wide temperature range, which is important in applications where temperature changes occur) [1]. The pipe diameter d=20 mm and its thickness g=1 mm were adapted to the project requirements. The chemical composition and selected properties of the material are presented in Table 1 [11].

Chemical composition, %w							
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	**Thermal expansion coefficient**		**Heat capacity**		**Thermal conductivity**		
ρ, kg/m³	**α, 1/K**		**C_{p20}, J/kgK**		**λ, W/mK**		
8020	14.2×10^{-6}		480		15		

Table1: Chemical composition and main physical properties of X5CrNi18-10 austenitic steel [11]

The authors proposed a new method of MEJ manufacturing. The process begins with local heating of the prefabricated element, which is a pipe, using a laser beam. For this purpose, a rectangular laser beam with the width of the pipe diameter is directed onto a pipe rotating around its own axis. This advanced approach allows for precise control of the area being treated, minimizing heat loss and ensuring uniform heating. A key aspect of this method is real-time control of the laser beam power using a pyrometer that is feedback to the laser resonator. Thanks to this, the temperature of the element is constantly monitored and maintained within a precisely defined range of 1000°C to 1100°C. This temperature range (called plasticization temperature) is important because it allows the material to achieve a sufficiently low yield point, which in turn requires less force for plastic deformation. Change of proof stress according to temperature is shown in Fig. 2. [12].

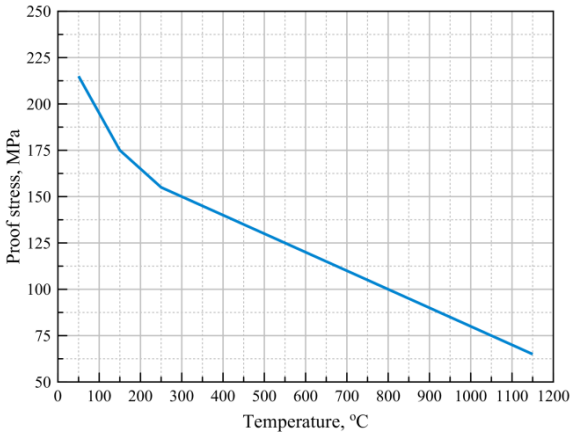


Fig.2. Change of proof stress according to temperature [12].

Moreover, the temperature in the range of 1000-1100°C corresponds to the hyperquenching temperature of X5CrNi18-10 steel, which is crucial for maintaining the austenitic structure of the material after the forming process. Thanks to this, the MEJs retain their mechanical properties and corrosion resistance. To ensure proper absorption of laser radiation by the pipe material, its outer surface was covered with a special absorbing black enamel.

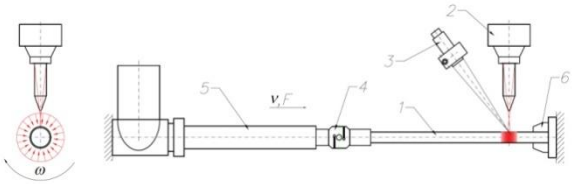


Fig.3. Scheme of the execution and measurement stand: 1 - rotating pipe, 2 - laser heating source, 3 - pyrometer, 4 - force sensor, 5 - axial actuator, 6 - chuck.

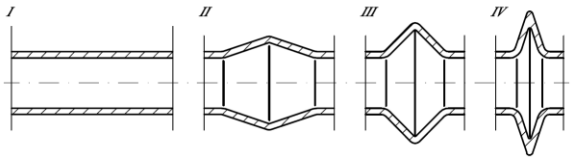


Fig.4. Individual steps of hoop forming: I - straight output pipe, II, III - pipe hoop creation, IV - the final hoop.

After reaching the plasticization temperature, the process moves to the next stage, which involves compressing the pipe with axial force. This stage is intended to create a hoop around the perimeter of the prefabricated element, which will act as a expansion joint. It's worth pointing out that the parameters of this process are strictly controlled by the operator using a specially designed computer program. The operator determines both the temperature to which the material is to be heated and the displacement of the actuator, which is responsible for exerting an axial force on the pipe. These parameters are crucial because they influence the final shape and properties of the compensator. The resulting axial force is recorded continuously during the process. A diagram of the experimental setup and the concept of the compensation hoop creation process can be found in Fig. 3 and Fig. 4. These illustrations show the device layout and describe the stages of the manufacturing process.

2.2. Scope of the experiment

As part of the scope of the experiment, the task was to create a metal expansion joint that would consist of four hoops arranged around the circumference. The purpose of this experiment is to test and confirm or disprove experimental assumptions regarding the manufacturing process. The process parameter values that were adopted for the experiment include: the process temperature T is to be maintained in the range of 1000°C to 1100°C, the actuator stroke p was set at 10 mm, which is one of the basic experimental assumptions (affects the degree of compression of the pipe and the shaping of the hoops), the laser beam heating line s is equal 20 mm, which is also an experimental assumption (it is responsible for local heating of the material to the appropriate temperature). The compressive force F that results from the action of the actuator on the material is recorded in real time.

This experiment aims to verify whether it is possible to obtain a expansion joint with the desired properties with the above-mentioned process parameters. After completing the experiment, it will be possible to assess the quality and performance of the MEJ and determine whether it meets the design assumptions.

III. RESULTS AND DISCUSSION

The result of the experiment was a successful production process of a MEJ with four hoops arranged around the circumference. The finished element, which was the goal of the experiment, was successfully produced and is shown in Fig. 5. It could be observed the finished four-hoop expansion joint, presents a complex and precise structure. This structure is the result of meticulous control of process parameters such as temperature, actuator stroke, and laser beam heating line, which were previously determined as experimental assumptions.



Fig.5. Final four-hoop metal expansion joint.

The cross-section of the hoop that was produced as a result of the experiment is presented in detail in Fig. 6. It can be seen that the hoop is uniform and does not show any visible flaws or defects that could be observed under a microscope. This is very important because the uniformity and quality of the material

structure are a key element in the case of MEJs that are intended to operate in difficult operating conditions. These positive features give grounds to assume that the hoop will effectively compensate for stresses, deformations and vibrations in the structure to which it is used.

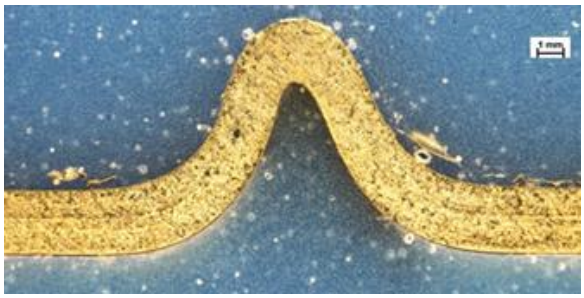


Fig.6. The cross-section of the manufactured hoop.

The graph of the recorded force during the process is presented in Fig. 7.

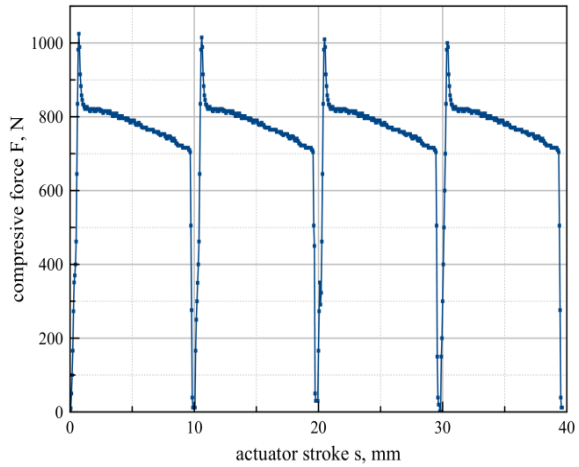


Fig.7. Recording of forces occurring during the forming process.

Analysis of this graph provides valuable information regarding the behavior of the material and the manufacturing process. The graph shows that at the beginning of the formation of each hoop, there is a maximum force of approximately 1 kN. This is the moment when the material is subjected to the greatest load and deformation, which is related to the forming process. It can then be seen that the force decreases linearly throughout the remainder of the process, going from about 800 N at to about 700 N at the end of hoop formation.

This decrease in force is the result of material deformations that occur as the hoop is formed. Moreover, the graph shows the repeatability of the forming process for each hoop. This chart is an important diagnostic tool that helps to analyze production process and evaluate its effectiveness. It can be used to improve the production technology of metal expansion joints and adapt the process parameters to specific design requirements.

IV. CONCLUSIONS

Based on the presented research and their analysis, the following conclusions can be drawn:

1. The experiment confirmed the effectiveness of the production process of a metal expansion joint with four hoops arranged around the circumference. The production of this item was the goal of the experiment, and its successful completion demonstrates the effectiveness of the production method used.
2. The finished element, i.e. the four-hoop expansion joint, has a complex and precise structure. This is the result of meticulous control of process parameters, such as temperature, actuator stroke, and laser beam heating area. This design is crucial for the element to fulfill its compensatory function.
3. The cross-section of the hoop does not show any visible defects or damage that could be observed under a microscope. This proves the homogeneity and quality of the material structure, which is important, especially in applications where compensation elements must operate reliably in difficult operating conditions.
4. Due to the quality and homogeneity of the structure and the properties of the material, it can be assumed that the hoop will effectively compensate for stresses, deformations, and vibrations in the structure to which it is used.
5. The graph of the force recorded during the forming process shows the repeatability of the forming process for each hoop. This is important to ensure consistent quality and performance of each expansion joint.

The experimental results obtained are promising and suggest that the new method of producing metal expansion joints may be effective and profitable. While maintaining high quality and uniformity, expansion joints manufactured using this method can be used in various industrial fields, bringing benefits in terms of efficiency and durability of the structure.

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