STRENGTH TESTS OF METAL EXPANSION JOINT MANUFACTURED BY MECHANICALLY ASSISTED LASER FORMING

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Abstract - The presented article describes the general principle of operation of metal expansion joint (MEJ) manufactured by mechanically assisted laser forming. These details are important elements designed to compensate for temperature differences and limitations of construction materials. The authors described and analyzed the traditional method of producing metal expansion joints and drew attention to its limitations and potential problems. This work mainly focused on strength tests. The resistance of the MEJ to tensile forces was tested. The rest of the article presents the results of strength tests of the proposed method of hybrid production of MEJ. The authors focused mainly on the recorded parameters of the testing machine and the stretching process. The results are presented in graphs. The results of the 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 bellows, also known as metal expansion joints(MEJ) or expansion joints, are elements used in various industrial applications and installations to compensate for temperature fluctuations, displacements, deformations and vibrations in pipes, cables and other structures. They are designed to compensate for differences in the length and shape of the structure as temperature or pressure changes, helping to maintain system integrity and avoid damage.

Metal expansion joints are usually made of various types of metal, such as stainless steel, carbon steel, titanium. The choice of material depends on the specific application and operating conditions [1].

Expansion joints come in a variety of shapes and designs, such as corrugated, tapered or reshaped, depending on the application requirements. These different shapes allow for the compensation of displacements and stresses in different directions.

One of the main uses of metal expansion joints is to compensate for temperature changes in pipes and ducts. As temperatures change, pipes can expand or contract, and expansion joints allow the pipes to flexibly accommodate these changes without causing stress.

Metal expansion joints can also compensate for displacements resulting from movement or deformation of the structure. For example, in pipeline systems that experience vibration or ground movement, expansion joints help maintain system integrity.

Metal expansion joints are widely used in the chemical, petrochemical, energy, gas, food and many other industries. They can be used in cable installations, boiler rooms, chemical reactors, power plants and many other places.

Well designed and properly installed expansion joints can significantly extend the life of the system by minimizing stress and damage. Maintenance and regular condition checks are key to maintaining their effectiveness.

It is worth noting that the selection of the appropriate type of expansion joints depends on the specific application, such as temperature, pressure, type of medium and other environmental factors. Therefore, a structural engineering expert should always be consulted before using metal expansion joints in a given system [2-4].

Strength testing of metal expansion joints is necessary to ensure their reliability and durability in various industrial applications. This research includes a series of laboratory tests and real-world evaluations to ensure that the expansion joints meet the specified standards and meet the requirements of the specific application.

The first step is usually to evaluate the material from which the expansion joints is made. These tests include determining mechanical properties such as yield strength, tensile strength, hardness, and more. For some applications, such as the chemical industry, a corrosion resistance assessment may also be needed.

Metal expansion joints are often subjected to cyclic loads and deformations, especially in systems that are

subject to frequent changes in temperature or pressure. Fatigue testing helps determine how long the expansion joints will maintain its strength under repeated deformation.

For expansion joints used in gas or oil applications, pressure testing is performed to ensure that they can withstand the specified operating pressure without leaking or failing.

In applications where expansion joints are used to compensate for temperature changes, tests are performed that simulate extreme temperature conditions. This allows you to assess how the MEJ behaves in extreme temperature ranges.

For applications where vibration is present, MEJ are tested for their ability to maintain system integrity and durability under vibration conditions.

Strength tests also include assessing the durability of the expansion joints over a longer period of operation. This may include monitoring its health and performance while operating under real-world conditions.
Depending on the application, there are various standards and regulations that specify requirements for strength testing of metal expansion joints. These must be followed to ensure compliance with regulations and industry standards.

Strength testing of MEJ is crucial to ensuring the safety and reliability of the systems in which they are used. Therefore, manufacturers and users should follow appropriate testing procedures and standards to ensure that expansion joints are fit for purpose.
An example of a typical MEJ is shown in the figure. 1 [5].

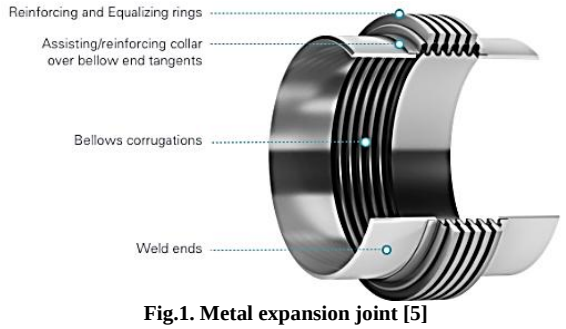

Fig.1. Metal expansion joint [5]

After analyzing many needs of the current industry, the authors of this article decided to develop a method of producing MEJ using a laser beam supported by external mechanical forces. The use of lasers in industry has been common for many years in various technological processes [6-10] and continues to find new applications, including: for the production of MEJ. An explanation and description of the proposed MEJ production technology using laser technology is presented in the article [11]. In this article, the authors focused on the strength tests of MEJ prepared in accordance with the developed technology.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

The basic material used to produce MEJ is a pipe made of high-quality X5CrNi18-10 stainless steel. The steel used is commonly used to produce similar elements thanks to its corrosion resistance and good weldability as well as resistance to high and low temperatures [12]. The pipe diameter used was d = 20 mm and its thickness g = 1 mm. Table 1 shows the chemical composition and selected properties of the material used [13].

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/m^3	α, 1/K	C_{p20}, J/kgK	λ, W/mK
8020	14.2x10^{-6}	480	15

Table1: Chemicalcomposition and mainphysicalproperties of X5CrNi18-10 austeniticsteel [11]

To carry out the planned process, a laser beam with a rectangular shape and a width equal to the diameter of the pipe was directed at the pipe, which was rotating around its own axis. This allowed for precise control of the area undergoing treatment. This minimized heat losses and ensured even heating of the treated surface. The most important aspect of this method was the real-time control of the laser beam power using a pyrometer, which provides feedback to the laser resonator. The use of this feedback is to control the temperature of the element, which is monitored in real time and is maintained in a precisely defined temperature range from 1000°C to 1100°C. The temperature range (plasticizing temperature) is very important. It allows the material to achieve a sufficiently low yield strength, which in turn requires less force for plastic deformation. The change in yield strength depending on temperature is shown in Fig. 2 [14].

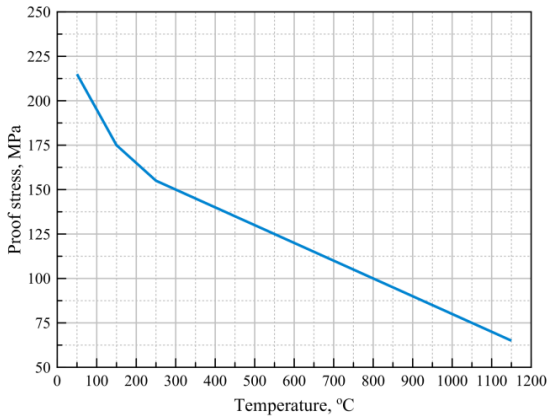

Fig.2. Change of proof stress according to temperature [12].

The temperature range from 1,000 to 1,100°C causes hardening of the X5CrNi18-10 steel, which is important for maintaining the austenitic structure of the material after the laser forming process. This causes MEJ to retain its mechanical properties and corrosion resistance.

Experimental tests of the compensating joints were carried out on a Zwick/Roell Z100 testing machine. The machine can generate a compressive or tensile force of 100 kN, while the maximum working space is 750 mm. It is equipped with an automated control and data recording system.

2.2. Scope of the experiment

The aim of the work was to carry out strength tests of the obtained elements - compensators.

The uniaxial tensile test was performed using wedge grips. During the test, the force signal from the measuring head and the displacement value from the extensometer were recorded. The measurement base of the displacement sensor was 50 mm. The view of the sample during the static tensile test is shown in Fig. 3A.

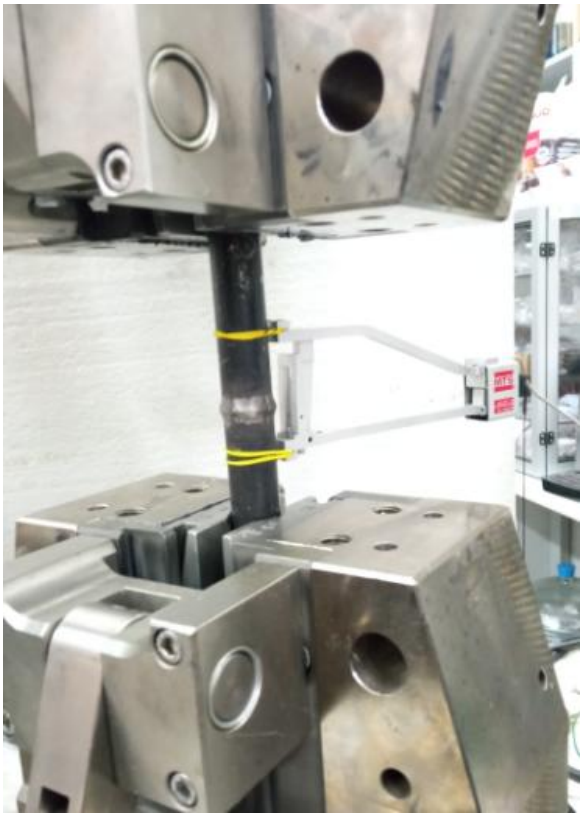

Fig. 3A. View of the sample mounted in the jaws of the testing machine with the displacement sensor installed - before the test.

The tests were carried out until the sample was completely destroyed, which occurred in close proximity to the compensation joints (Fig. 5B).

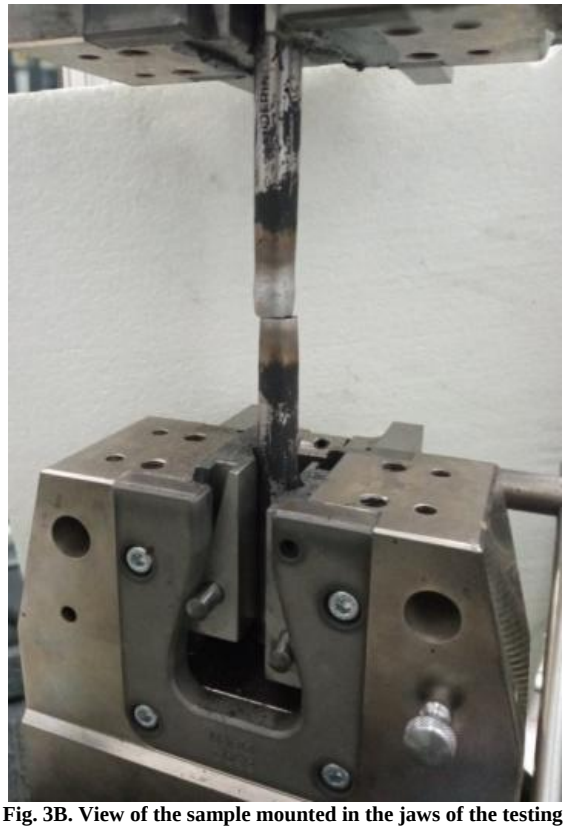

Fig. 3B. View of the sample mounted in the jaws of the testing machine - after the test with a visible tear.

The aim of the experiment was to check whether it is possible to obtain an expansion joint with the desired strength properties with the previously described process parameters. Thanks to this study, it is possible to assess the quality and performance of the MEJ and determine whether it meets the required design assumptions.

III. RESULTS AND DISCUSSION

The result of the experiment was the bursting of a pipe with MEJ produced according to the previously described procedure. The force signal from the measuring head and the displacement value from the extensometer were recorded. The measurement base of the displacement sensor was 50 mm. The process flow chart is shown in Fig. 4.

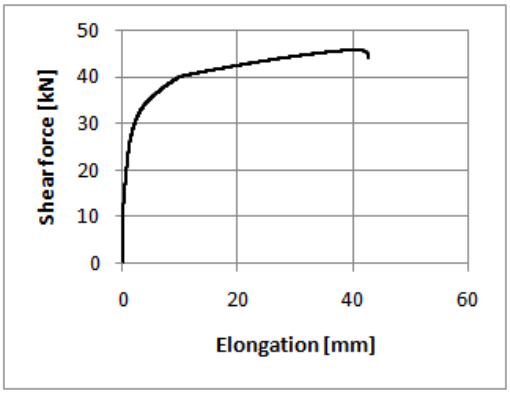

Fig. 4. Force-elongation diagram of tested sample.

When conducting MEJ fatigue tests, it was decided that the sample would be cyclically stretched through a set displacement value of ±1 mm and a tensile force would act on the sample (due to the specification of the wedge grips). The displacement set value was read from an extesometer mounted symmetrically in the joints area. The process flow chart is shown in Fig. 5.

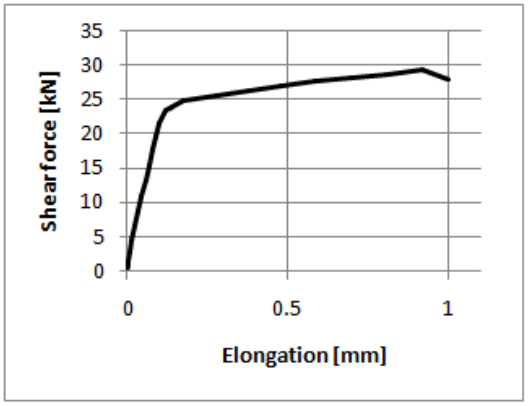

Fig. 5. Tensile diagram (one cycle) force-elongation for a declared displacement of 1 mm.

The plastically deformed joints was again subjected to fatigue tests. It was decided to apply a much smaller displacement value of ±0.1 mm to the deformed joints. In this range, the joints deformed elastically. The chart below shows several dozen fatigue cycles - Fig. 6.

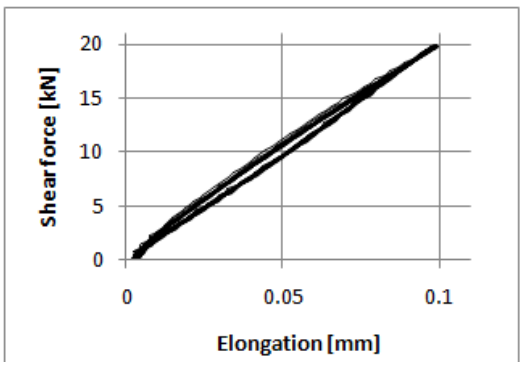

Fig. 6. Tensile diagram (one cycle) force-elongation for a declared displacement of 0.1 mm.

IV. CONCLUSIONS

Analyzing the obtained results, it can be seen that the force needed to tear the MEJ created in accordance with the proposed technology is, at its lowest value, approximately 20 kN for strength tests with a displacement of 0.1 mm. As the displacement increases to 1 mm, the force value also increases and amounts to over 25 kN. The force needed to tear the MEJ created in accordance with the proposed technology reaches the highest value (for the test performed) of approximately 45 kN while compensating for the largest displacement of approximately 45 mm.

This may indicate the ability to compensate for significant deformations of the structure, which is a desirable result considering the specification of technological structures that use MEJ during their operation.

The obtained experimental results show that the proposed method of producing metal compensators (MEJ) is efficient and quite profitable. Compensators made by this method can be used in various industries, providing benefits in terms of efficiency and durability of the structure.

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