NUMERICAL ANALYSIS OF METAL EXPANSION JOINT MANUFACTURED WITH LASER BEAM SUPPORT

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Abstract: In this paper discussion and results of numerical simulation of metal expansion joint manufacturing was presented. Innovative manufacturing process combining mechanical forming supported by laser beam heating was described by authors. Advantages of precise heating of expansion joint surface during forming by laser beam was presented. The authors explained mechanism of expansion joint forming and its main functionality, which is compensate for temperature differences and stresses in construction materials. Stress-strain concentration caused by mechanical and thermal forces occurred during forming process was analyzed. Authors use numerical simulation based on Marc solver to investigate selected properties of manufactured expansion joints. Simulation was performed in order to obtained laser scanning parameters as well. High compatibility of simulation results with experimental studies was achieved. Based on thermo-mechanical analysis stress-strain distribution was investigated. Results of abovementioned analysis shown stress concentration in crest and elevated values in root area. Maximum values of calculated stress-strain distribution, however do not exceed critical values, therefore, no additional heat treatment is required. Obtained results confirm potential of proposed expansion joints forming process.

Keywords: Laser Beam Treatment, Numerical Simulation, MES analysis, Metal Expansion Joint,

I. INTRODUCTION

High-tech civilization require providing of great amount of fossil fuels in basic or converted form. One of major problem is transportation of this mediums, where pipeline installations have significant role. Therefore durability of its components are very important. One of this element is metal expansion joint (MEJ), designated to reduce stress and strain of pipes elements caused by vibration and thermal deformation. The main role of metal expansion joints working as a flexible pipes connector is to compensate of stresses that may appear in structures due to temperature changes. Therefore, manufacturing of proper geometry and kept properties of this expansion joints are relevant. Stress reduction via metal expansion joints prevent of cracks and pipeline deformations, therefore, control of pre-stress occurred in material during manufacturing process are important [1].

Stress-strain state can be estimated using numerical analysis of forming process. Establishing numerical model, where heat source (HS) is estimated, solid model divided into finite elements (FE), process parameters, simulation of metal expansion joints manufacturing can be performed. Numerical analysis based on thermo-mechanical analysis was used to calculate some properties of MEJ after forming process. Simulation based on finite elements method (FEM) with tetrahedral elements was performed using Marc solver. Simulation are established for single MEJ lens. The material used for simulation and for experimental procedure was stainless steel [2].

Controlling stress state in MEJ - crucial component of pipeline installation provide integrity of the system and minimizes the risk of damage. The MEJ play significant role in chemical and petrochemical industries, as well as the machinery industry, where dynamic loads may occur [3].

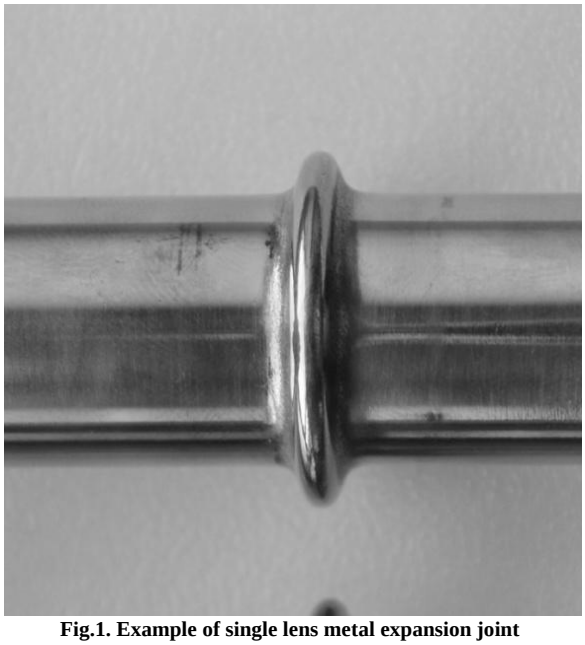

Fig.1. Example of single lens metal expansion joint

Figure 1 shown example of manufactured single lens expansion joint made of stainless steel using proposed by authors method - mechanical forming assisted with laser beam scanning of material surface during forming [4].

II. NUMERICAL SIMULATION OF LASER BEAM EXPANSION JOINT FORMING

2.1. Materials

The base material for numerical analysis as well as experimental procedure was stainless steel pipe made of X5CrNi18-10 (AISI304) steel grade. It is austenitic steel commonly use for the production of MEJ, due to its corrosion resistance, good weldability, and good resistance to high and low temperatures [1]. The pipes specimen diameter is equal to 20 mm, with wall thickness of 1 mm. The chemical composition are presented in Table 1, and thermal properties in figures 2 and 3 [2].

Chemical composition, %wt							
C	Cr	Ni	Mn	Si	P	S	N
<0.07	18.5	10	<2.0	<1.0	<0.045	<0.015	<0.11

Table1: Chemical composition of 304 steel

2.2. Numerical model

Thermo physical material properties are no constant, temperature-dependent parameters, that affect on heat distribution in material during thermal processes. This factor affect as well on calculation results, therefore, material library including this data was used for numerical simulations.

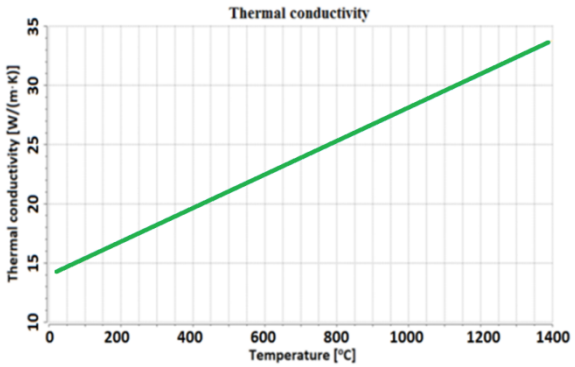

Fig.2. Thermal conductivity characteristic of 304 steel grade

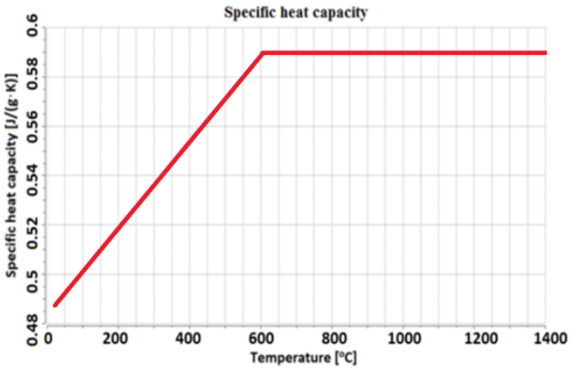

Fig.3. Specific heat capacity characteristic of 304 steel grade

Numerical model for FEM analysis consist of solid model divided into finite elements, in this particular case tetrahedral elements of size equal to 0.2 mm. Procedure of select FE size was conducted according to temperature distribution, where changing FE size same calculations was performed until size of FE do not affect on calculations results.

Another important aspect of numerical simulation is defining HS model (Fig. 4). For laser treatment conical volumetric HS with Gaussian distribution is recommended. This HS can be described by the following equation

$$Q(x,y,z) = Q_0 \exp\left(-\frac{x^2+y^2}{\left(r_i + \frac{r_t - r_i}{z_t - z_i}(z - z_i)\right)^2}\right)$$

where:

Q_0 – the maximum heat flux density in a volumetric heat source,

r_t-r_i – the dimensions of the upper and lower conical radius,

z_t-z_i – the depth of the conical heat source,

x, y, z – the heat source coordinates

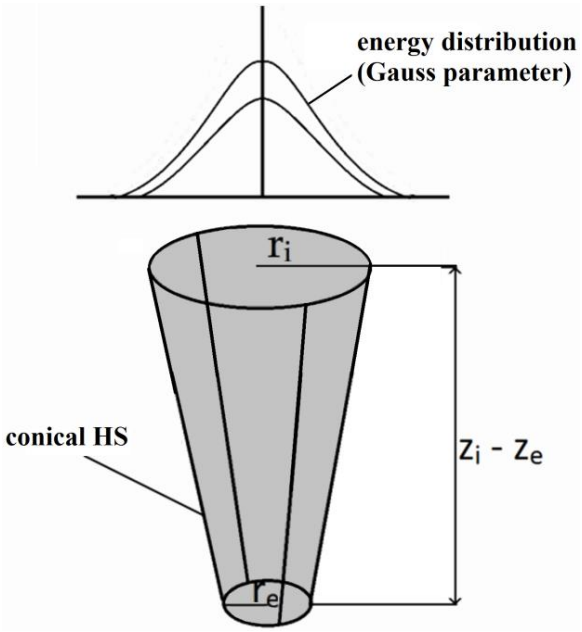

Fig. 4. Model of laser heat source.

Solving the governing heat equation based on Fourier's law for three-dimensional heat conduction. Thermal conductivity, specific heat, and emissivity in the heat transfer analysis depend on the temperature, as was mentioned earlier, however, the used model is based on the assumption that mass density is constant. And by an extrapolating or interpolating procedure, the temperature-dependent properties are averaged. Phase change modelling is a complex process, however using simplification, where latent heat is uniformly released in the solid-liquid range, can be calculated [5-7]. Due to the convection-diffusion effect involved, the Petro-Galerkin model with nodal velocity vectors was used. Effect of

performed numerical simulation are shown below (fig. 5).

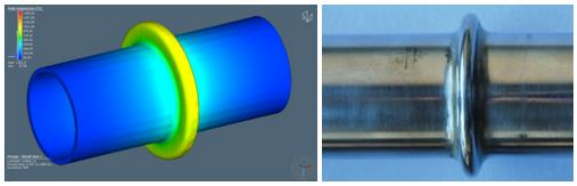

Fig. 5. Comparison of simulation and experiments of formed metal expansion joints.

III. RESULTS AND DISCUSSION

3.1. Numerical simulation analysis

Considering the stress-strain analysis, it is relevant to study the variability of this phenomenon in time. In results of the numerical simulation analysis of MEJ forming, some properties of material after forming was calculated. According to peak temperature shown on figures 5, highest temperature value do not exceed 1000 ^{o}C, therefore, no adverse change of microstructure are expected. Results of numerical analysis in form of surface map distributions, map distribution in cross section and graphs were presented.

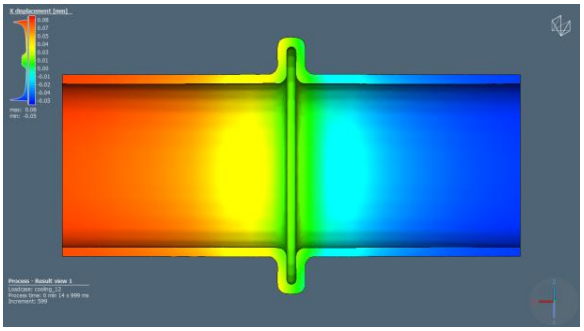

Fig. 6. Material displacement during forming of MEJ.

As shown on figure 6, highest displacement in X direction are related to place where mechanical force was applied, also in lens area value of displacement is elevated.

A maximum principal stress (MPS) analysis, concerning values changing in time, was performed. The points selected for the MPS analysis were related to MEJ characteristic area, at the side and top of a lens, as well as pipe surface near lens. By performing a distribution analysis of the maximum principal stress, the areas of stress concentrations can be identified. These particular areas showed where crack propagation could start when critical material parameters are reached. An analysis of the results can give an answer as to whether the element made with a given parameters did not exceed the MPS critical values [8].

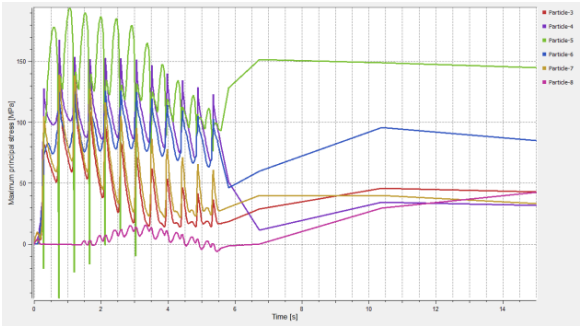

Fig. 7. Maximum principal stress changes during forming of MEJ.

Value of MPS do not exceed 200 MPa, and characteristic monotonic changes are related to multiple scanning process of pipe surface by laser beam.

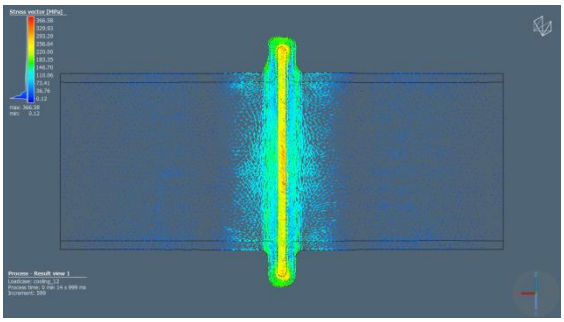

Fig. 8. Stress vector propagation direction.

Stress values of MPS are related to stress vector propagation, presented on figure 8. Stress distribution was characterized by equivalent stress occur during lens forming.

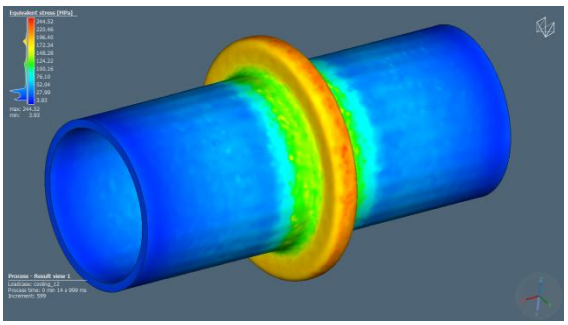

Fig. 9. Map distribution of Equivalent stress in MEJ.

Principal plastic strain is a monotonically increasing scalar value as a function of the plastic component of the rate of deformation tensor. Effective plastic strain increases whenever the material is actively yielding. An analysis of the effective plastic strain results is shown below (fig. 10) [9].

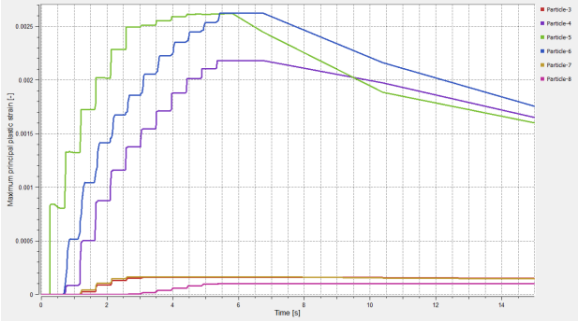

Fig. 10. Maximum principal plastic strain changes.

Extended concept description of proposed method with results of experimental procedure are shown in separate study presented in this publication series. Parameters of laser scanning process were output power equal to 1kW, with scanning speed of 8 m/min.

CONCLUSIONS

Based on the presented research and their analysis, numerical simulation of forming metal expansion joints can provide process parameters and can be used for determine some properties of manufactured MEJ, including stress and strain changes related to laser beam scanning of pipe surfaces during forming process. Calculated values of MPS do not exceed 200 MPa, therefore, there is no risk of MEJ cracking after forming process.

Changes of stress-strain are related to thermal gradient and applied mechanical force. Proposed method of forming metal expansion joints provide some advantages including low stress concentration. Therefore, no additional heat treatment is required, and proposed method have high application potential [10].

ACKNOWLEDGMENTS

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