LASER-MECHANICAL HYBRID FORMING OF THIN-WALLED ELEMENTS

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Abstract

The authors of this paper present assumptions and preliminary results of experimental investigations and FEM numerical simulations of laser-mechanical hybrid forming process of thin-walled elements. An experimental stand was designed and manufactured to investigate and develop new methods of bending of thin-walled tubes and conical diffusers, which are used in the construction of aircraft engines. Testing of the stand and the hybrid forming method under laboratory conditions, as well as results of numerical show new possibilities of thin-walled elements forming.

Keywords: Laser forming, hybrid laser forming, laser treatment

1. INTRODUCTION

Investigations on application of the laser beam for controlled induction of permanent changes in shape without external forces, but only due to the phenomenon of thermal expansion, have been carried out since the 1980s [1-4]. This technology can be termed incremental [5, 6] because the total plastic strain is usually obtained by adding up small strains caused by the local action of the laser beam on the material being processed. In the case of laser forming, there is no mechanical contact between the shaping tool and the workpiece. This technique also gives the possibility of remote (i.e. at a distance) forming of elements.

The title method, which is being developed as part of research according to NCBiR research grant No. PBS3/A5/47/2015, relies on hybrid thermo-mechanic forming through the simultaneous operation of a laser heat source and external forces. The goal of this project is therefore to use external forces with laser forming. The utilitarian purpose of the project is, in particular, to develop a thin-walled elements forming method, among others for the aviation industry (example in **Figure 1**), manufactured from high-temperature alloys such as Inconel 625, Inconel 718 nickel super alloys, as well as high-alloy martensitic steels AISI 410 and AISI 325. Successful attempts of flat bars hybrid forming (made of mentioned materials) with gravitational load assist were presented in [7].

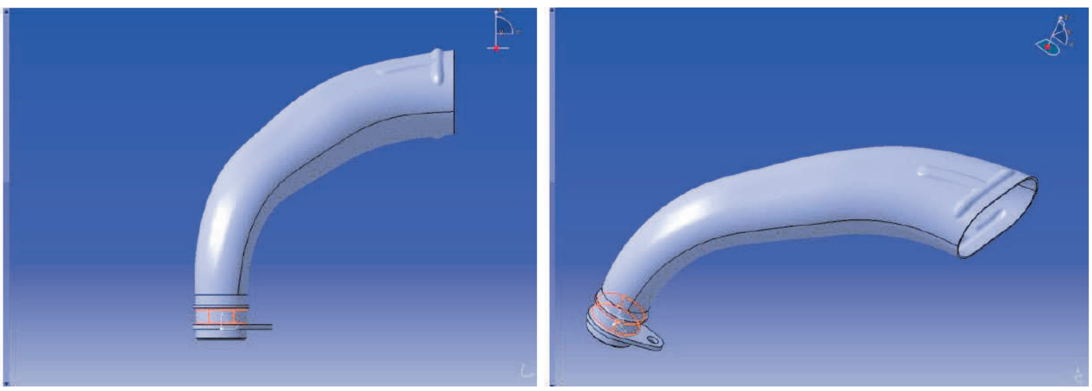

Figure 1 Diffuser turboprop engine, currently made by traditional methods: press forming of two halves and welding

In order to accomplish this task, a scientific consortium was established from scientific centers selected according to their experience and competence in relevant research areas. The consortium members were: Kielce University of Technology - Project Leader, Institute of Fundamental Technological Research PAS Warsaw, Metal Forming Institute from Poznań and Rzeszów University of Technology.

2. ASSUMPTIONS

Let's consider tube bending for a given bending angle α and the bending radius R from a straight tube as the starting material. In the case of classical mechanical bending of the element, the applied external forces usually produce a strain of considerable value and plastic deformation in a large area of the formed element. However, in the case of laser bending, the deformation is located near the trajectory of the laser beam on the formed part. The hybrid approach, i.e. forming with the participation of external forces and laser heating, gives the possibility of incremental induction of plastic deformation locally, in selected and well-defined zones of elements being shaped.

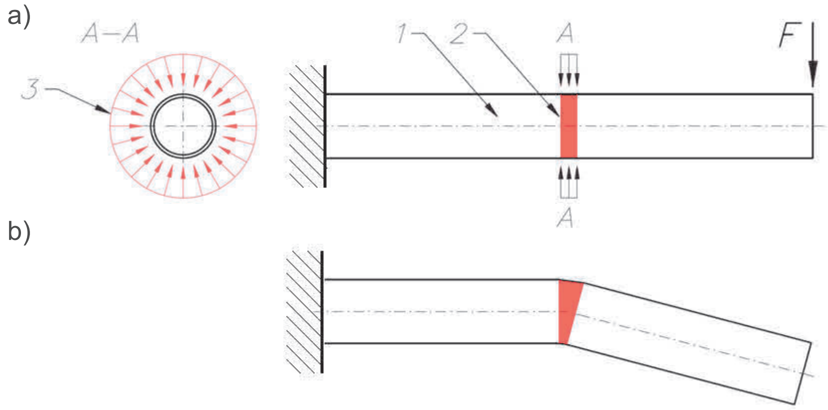

Figure 2 Laser-mechanical forming scheme: 1 - tube element subject to bending, 2 - area around section A-A of the element laser heated to the prescribed temperature, 3 - example of uniform heating of the tubular element on its circumference, F - applied external force, a) element during heating, b) element after bending

The idea of the laser-mechanical hybrid forming process is based on the assumption that only a part of the element, which is subject to the laser beam, will udergo bending. The laser beam heats the selected area of the element to a certain set temperature, which improves the plastic properties in this area. Due to the application of the external force F, the area at the suitable temperature becomes plasticized and deformed. The remaining part of the formed element, which has a lower temperature, is not deformed, and in this phase of the plastic deformation process only the thin "strip" of the element undergoes deformation. The width of this "strip" depends on the diameter, power and scanning speed of the laser spot on the surface of the element. The scheme of this idea according to the above assumptions is presented in **Figure 2**.

3. IDEA

Several process ideas were developed during investigations. The so-called free bending arm concept was chosen for detailed studies - **Figure 3**.

According to this idea, the workpiece 1 (intended to forming) is installed between the pushing actuator 2 and the free bending arm 3. The laser beam coming form the head 4 heats the element circumferentially in the bending plane containing the laser beam trajectory and the pivot point of the bending arm. At the same time, the actuator 2 pushes the element 1 with force F. As a result of plastic deformation development, the tubular element bends with radius R defined by the distance of the tube axis to the axis of rotation of the arm 3. This concept is based on the assumption that the actuator 2 will produce the driving force, while motion of the bending arm 3 will be the resultant movement (free bending arm).

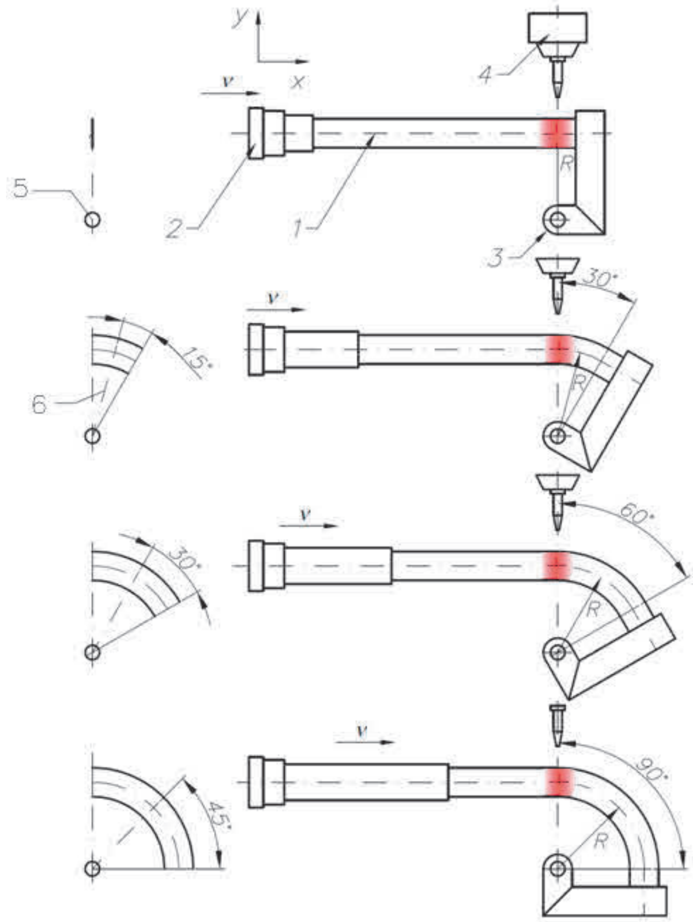

Figure 3 Stages of forming according to the concept with a free bending arm - a scheme: 1 - tube element subject to bending, 2 - pushing actuator, 3 - free bending arm, 4 - laser head, 5 - rotation center

4. DESIGN

Based on the chosen idea, the technical design of the device was made. In the first phase, taking into account technical capabilities and research needs, a concept was developed in the form as shown in **Figure 4**.

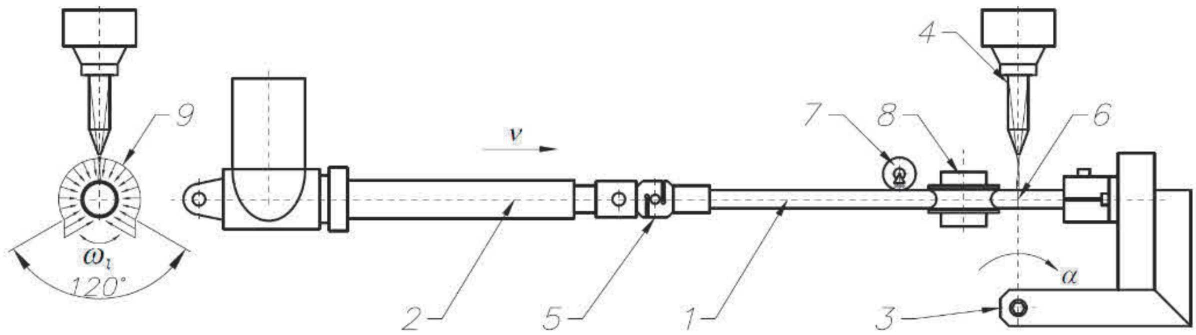

Figure 4 Scheme of the main components of the device: 1 - workpiece, 2 - pushing actuator, 3 - free bending arm, 4 - laser head, 5 - force sensor, 6 - plane of bending, 7 - reaction roller, 8 - guide roller, 9 - trajectory of heating in the plane of bending

The conceptual design of the device is presented in **Figure 5**.

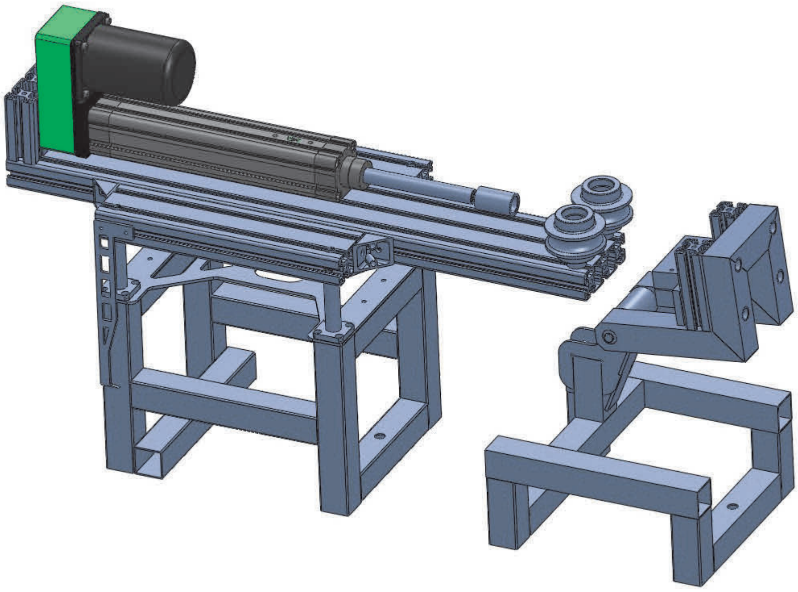

Figure 5 Conceptual design of the device - the main elements

On the basis of the technical design, the device was made and the test stand was assembled.

5. RESEARCH

Experimental tests of bending were carried out on tubular elements of 20 mm OD and 1 mm wall thickness, made of X5CrNi18-10 stainless steel. The bending radius R was 215 mm. One end of the tubular element was rigidly fixed in the handle of the bending arm.

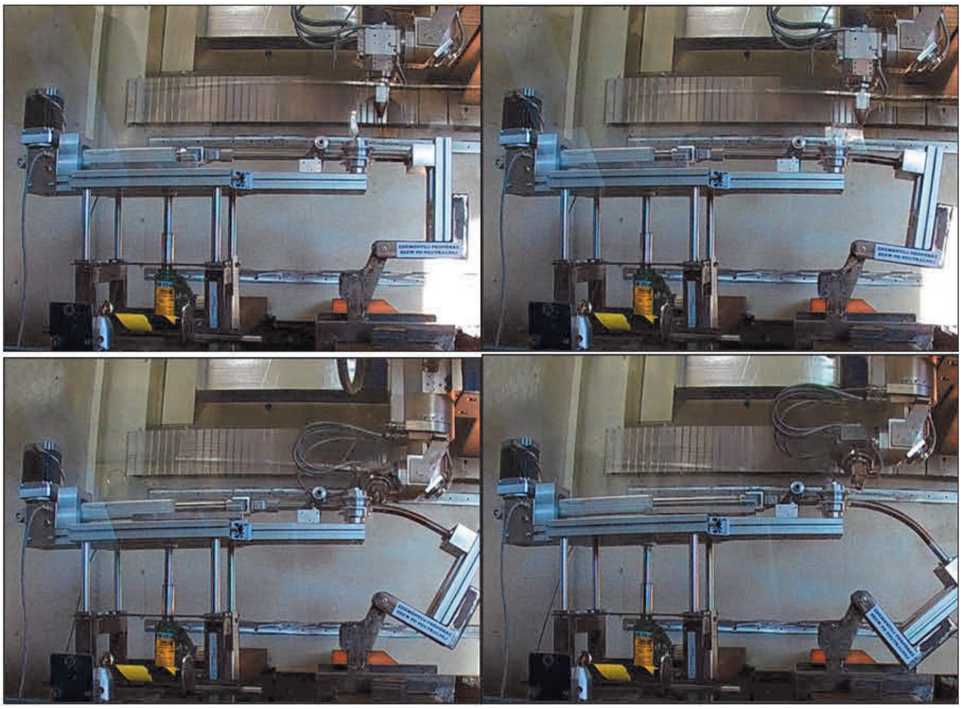

Figure 6 Stages of the bending process

The fastened tube was heated with a laser beam oscillating in the bending plane. The set beam trajectory on the surface of the element was limited by the useable motion range of the CO_2 Trumpf LaserCell 1005 5-axis laser machining center. The operating laser parameters were: power P=400 W, linear velocity of the laser spot on material's surface ω_l 4,000 mm/min (66.7 mm/s). Simultaneously with the laser heating, an actuator was pushing the workpiece towards the bending arm. The actuator feed speed ν was set to 20 mm/min (0.33 mm/s). At the maximum permissible extension of the actuator l of 195 mm, the bending angle α of 50° was obtained. **Figure 6** shows the stages of the process. The bent elements and bending force diagrams are presented in **Figure 7**.

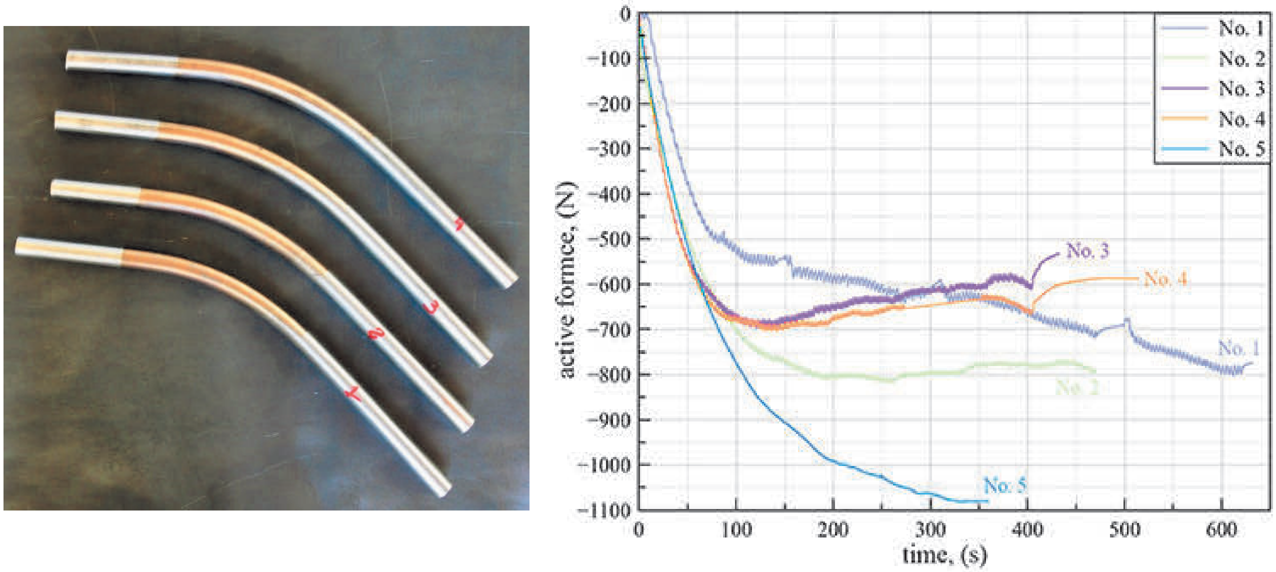

Figure 7 Tubes after forming process (left) and charts of actuator force during process (right)
No.1 - No.2 - laser-mechanical hybrid bending forces, No. 5 - mechanical bending force

6. FEM SIMULATIONS

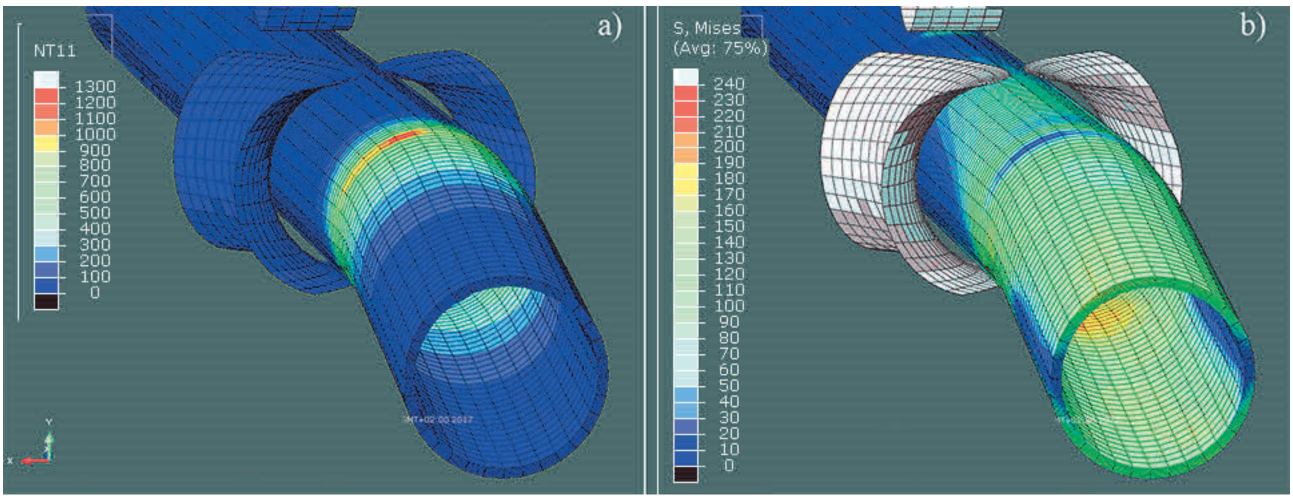

Figure 8 Temperature distribution (a) and equivalent HMH stress distribution (b) during laser-mechanical hybrid forming of thin walled element

The process was modeled numerically to get insight into thermo-mechanics of hybrid forming. Temperature, stress and strain fields during thermo-mechanical loading of tubes were determined in the sequentially coupled analysis. First, the temperature field generated by the moving laser spot, treated as the surface heat source, was calculated. Then this temperature field was used as a thermal load in quasi-static mechanical analysis taking into account the external mechanical load. Details of the numerical model are described in [7].

An example of the calculated temperature distribution on the workpiece surface is presented in **Figure 8a**. The distribution of equivalent Huber-Mises-Hencky (HMH) stress is shown in **Figure 8b**. Results of numerical simulations explain effects of localized heating of the workpiece by the laser beam. The distribution of the equivalent stress shows the effect of local material yield point reduction along the laser path, which induces the desired locallised plastic deformation in consecutive process stages.

7. CONCLUSIONS

The developed laser-mechanical hybrid forming concept was tested on a specially designed and built. experimental stand. Using the relatively low laser beam power, the tube bending effect was obtained. Further reduction of the required beam power can be obtained by using a laser beam of wavelength shorter than that of CO_2 laser (wavelength 10.6 micrometers). The energy of a diode, Nd:YAG or fiber laser with a wavelength of about 1 micrometer, is much better absorbed by metallic materials. Further research will allow to determine possibiliities and parameters for shaping elements with different initial shapes.

The developed method and device for the hybrid forming of thin-walled profiles have been described in an application submitted to the Patent Office of the Republic of Poland (application number PL421537, date 10/05/2017).

ACKNOWLEDGEMENTS

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