# MOMENT-CURVATURE RELATION FOR LASER-ASSISTED BENDING OF THIN INCONEL 718 BEAM

**Jacek WIDLASZEWSKI[1], Marcin NOWAK[1], Zdzisław NOWAK[1], Piotr KURP[2]**

[1] Institute of Fundamental Technological Research Polish Academy of Sciences, Warsaw, Poland; jacek.widlaszewski@ippt.pan.pl (J.W.); nowakm@ippt.pan.pl (M.N.); znowak@ippt.pan.pl (Z.N.))

[2] Center for Laser Technology of Metals, Kielce University of Technology, Kielce, Poland; pkurp@tu.kielce.pl

## 1. Introduction

Materials with high-temperature strength may cause difficulties both in cold-shaping and hot-working. The interest in thermally-based forming is a response to the needs and challenges involved with the cots-effective and robust manufacturing of sheet metal based products. Laser beam is a heat source offering exceptional opportunity to precisely control heat input to the work piece both in time and space. Hence, the laser-assisted manufacturing processes gain ever increasing attention in recent years [1]. However, for successful development of new forming methods, the thermomechanics of the heat-assisted plastic deformation process should be thoroughly analysed and well understood.

Inconel 718 is a precipitation-hardenable nickel-based alloy having exceptionally high yield, tensile and creep-rupture properties at temperatures up to 700°C (homologous temperature 0.63), combined with good oxidation resistance. The alloy is usually provided in the solution annealed or the precipitation hardened condition. The relatively slow precipitation hardening response of Inconel 718 permits annealing and welding without spontaneous hardening during heating and cooling, as well as repair welding even in the age condition. The outstanding resistance to post-weld cracking indicates feasibility of laser-assisted forming application in manufacturing components made of Inconel 718.

## 2. Experiment

Experiments were conducted on beams, 1 mm thick, 20 mm wide, made of commercial solution annealed Inconel 718. Mechanical load was introduced with the gravity acting on weights mounted at the free end (Figs. 1 and 2). The vertical dead load F was 3.04 N for the elastic pre-stress.

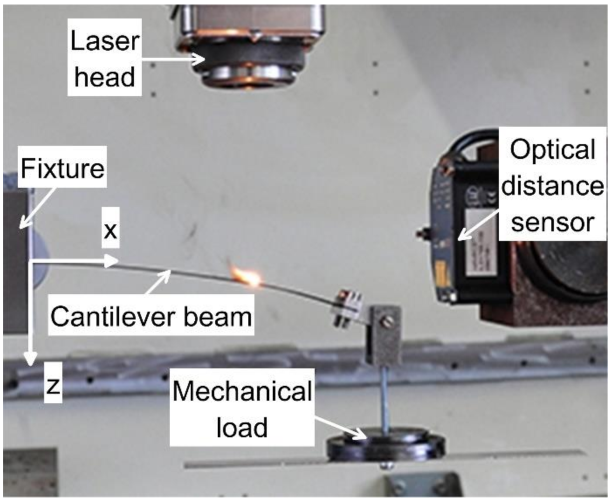

**Fig. 1.** Experimental setup.

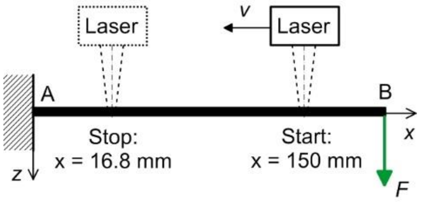

**Fig. 2.** Laser-assisted bending scheme.

Pre-stressed beam was subsequently subject to heating with a moving laser beam of power 500 W. The TruFlow6000 $CO_2$ laser operating in the continuous-wave (CW) mode was used. A rectangular 20 mm × 2 mm laser spot had velocity 3.33 mm/s. Samples were covered with absorptive layer (a black paint) in order to improve the transfer of the laser beam energy into the material. The thermo-mechanically induced deformation was measured with a non-contact optical displacement sensor MicroEpsilon LLT1700.

## 3. Numerical modelling

Numerical modelling using the Finite Element Method (FEM) is an effective tool to gain insight into the process thermomechanics and the impact of processing parameters. Particular role in thermo-mechanical modelling plays application of a suitable material constitutive model with accurate strain rate and temperature dependency. The Johnson-Cook material model was applied in the study (Table 1) [2].

**Table 1.** Parameters of the Johnson-Cooke model.

| A (MPa) | B (MPa) | C | m | n |
|---|---|---|---|---|
| 450 | 2100.95 | 0.02 | 1.5 | 0.76 |

Thermo-mechanical bending experiments were modelled numerically using the ABAQUS finite element program. Experimental validation of the numerical model is crucial for the analysis value Figure 3 presents a good agreement between experimental and theoretical modelling results.

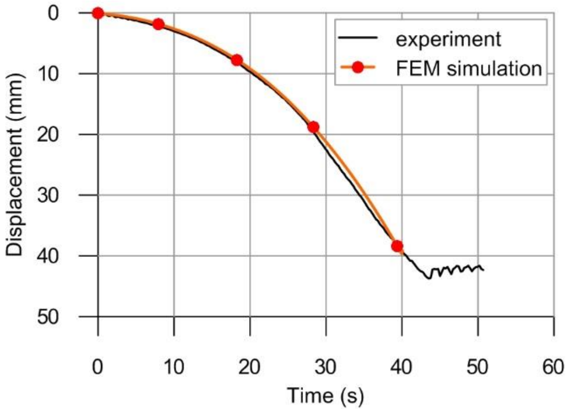

**Fig. 3.** The free-end deflection of the beam during laser-assisted bending.

The developed numerical model was used to simulate thermomechanical behavior of the Inconel 718 beam both with elastic pre-stress and without it. Beam curvature was calculated from the FEM solution. To account for large displacements the parametric configuration representation was used.

## 4. Results and Discussion

Even without mechanical pre-stress, the beam undergoes a considerable plastic deformation, solely due to the laser heating. The related curvature is described with “laser bending” in Fig. 4. The so-called convex deformation occurred [3].

The calculated curvature due to mechanical elastic pre-stressing agrees well with the solution of the classical Euler-Bernoulli beam theory. Beam curvature resulting from the laser heating and still under mechanical load is described in Fig. 4 as “thermo-elastic-plastic”. The final curvature, i.e. after subsequent releasing the beam from the free-end force, is denoted as “plastic”.

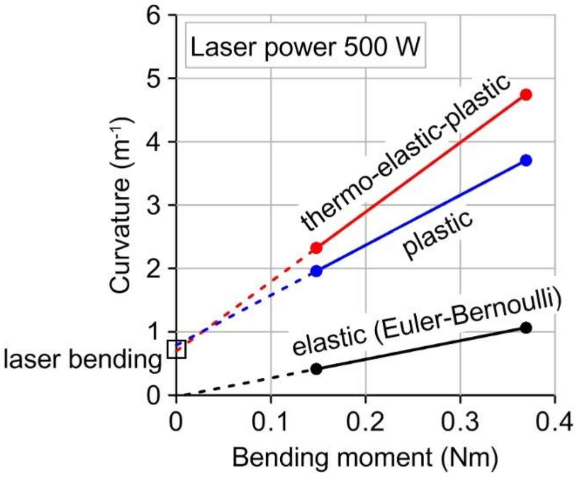

**Fig. 4.** Components of the moment-curvature relation.

Characteristic presented in Fig. 4 suggests that the considered thermo-mechanical processing results in permanent change of curvature that is linearly dependent on the applied bending moment. Curvature produced solely due to laser heating additively contributed to the final deformation in thermomechanical bending.

## 5. Conclusions

Phenomenological moment-curvature relation for the laser-assisted bending of thin Inconel 718 beam was formulated using experimentally-validated FEM model. Calculations revealed the presence of the pure thermally induced deformation in the final change of curvature. For the effective laser-assisted bending, the external mechanical load should be applied consistently with the deformation effect of the heat source alone.

## References

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