EXPERIMENTAL AND NUMERICAL INVESTIGATION ON LASER-ASSISTED BENDING OF PRE-LOADED INCONEL 718 BEAMS

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1. Introduction

The polycrystalline nickel-based superalloys are typically used in components that work at elevated temperature in aggressive media. The key feature of these alloys is that they are able to keep their mechanical properties at relatively high temperatures. This makes them ideal candidates to manufacture aircraft engine components such as casings, diffusers or blades. The operating temperatures of turbine casings generally range from 400 °C to 800 °C. Increase of working temperature leads to the reduction of deformation resistance. The aim of this paper is to present experimental investigation and numerical simulation of laser-assisted bending of Inconel 718 alloy. The research is directed towards applications of hybrid thermal-mechanical forming in manufacturing of thin-walled components of aircraft engines [1], [2]. A good understanding of deformation behavior of Inconel 718 sheet metal within wide range of temperatures is a prerequisite for reliable numerical simulation of laser-assisted bending process and for processing parameters optimization.

2. Material and experiment

The chemical composition of the used Inconel 718 alloy (wt%) is the following: 52.9 Ni, 19.83 Cr, 3.12 Mo, 4.83 Nb, 0.05 Co, 0.29 Mn, 0.14 Si, >17.1 Fe, 0.60 Al, 1.04 Ti. A commercial Inconel 718 sheet blank in the as-received state, with an average initial grain size of 17.5 μm, was used in this work. The 1.0 mm thick and 20 mm wide specimens tested in the present investigation were laser-cut from the rolled sheet metal.

The experimental setup for laser-assisted bending of thin beams under mechanical load and heating with a moving laser beam is presented in Fig. 1 (left) (1 - sample, 2- laser beam, 3 - holder of the weights, 4 - auxiliary plate, 5 - the optical displacement sensor).

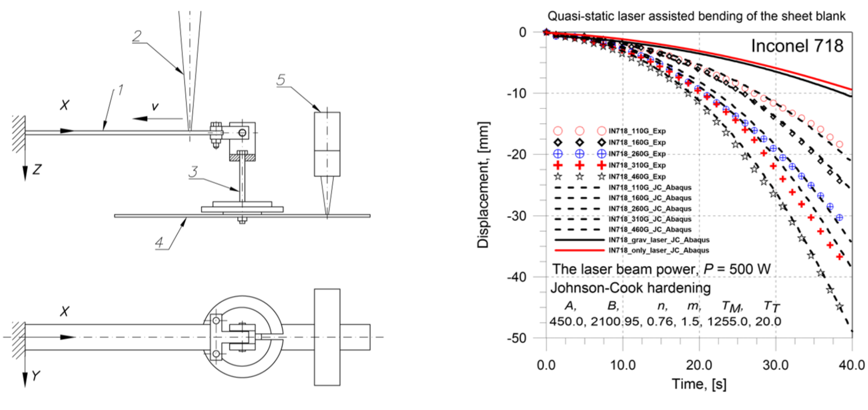

Figure 1: The scheme of laser-assisted bending of thin beams under mechanical load and heated with a moving laser beam (left) and a comparison of the free-end deflection U as a function of time, measured in experiments and calculated numerically for different mechanical loads.

In experiments of laser-assisted bending a CO_2 TRUMPF TruFlow6000 laser operating in the continuous wave (CW) mode and emitting radiation of 10.6 micrometres wavelength was used. The applied optical head produced approximately rectangular 20 x 2 mm laser spot on the material surface. The laser spot covered the whole width of the laser-treated specimen. Laser beam of power 200 W had velocity 200 mm/min (3.33 mm/s) with respect to the specimen. In order to increase coupling of laser power, each specimen was coated with a black paint. The laser processing parameters were chosen so as to obtain the highest material temperature of 750 °C.

Deformation of the specimen was measured using an optical displacement sensor MicroEpsilon LLT1700. The gravitational load of the sample originated from its own weight and from the weights (external load Q) attached to its free end, at a distance of 175 mm from the fixture. A series of experiments was conducted with different values of the external load Q in the range from 1.1 N to 4.5 N (110 to 460 G). After the specimen had been loaded mechanically by its own weight and the external load Q (gravitational load), it was heated with a laser beam moving along longitudinal axis x, starting from the position x = 150 mm towards the fixed end of sample (x = 0).

3. Numerical simulations and results

In order to study the behavior of the Inconel 718 alloy during laser-assisted bending under static mechanical load, a series of computer simulations was performed. Different constitutive models were used in the simulations. It was concluded that for the process of hybrid thermal-mechanical bending a good agreement between calculations and experimental results is obtained using the isotropic strain hardening model with the Huber-Mises-Hencky yield criterion and the flow stress (σ) described by the Johnson-Cook model [3], which is defined as a function of plastic strain (ε^{pl}), the strain rate (here $\dot{\varepsilon} = 0.003\ 1/s$) and temperature ($T$) in the form $\sigma = (A + B \cdot (\varepsilon^{pl})^n)(1 + C \cdot ln(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}))(1 - (T^*)^m)$, where $\dot{\varepsilon}_0$ (0.001 s^{-1} in this work) is the reference strain rate, $T^* = (T - T_r)/(T_m - T_r)$, T_m is the melting temperature (1250 °C in this work) and the reference temperature T_r is determined as 20 °C in this work. The values of A, B, n, C and m are obtained from the fitting based on experimental data, and are as following: A=450 MPa, B=2100.95 MPa, n=0.76, C=0.02 and m=1.5.

Numerical simulations were conducted using the commercial finite element method program ABAQUS. The influence of the plastic deformation on material temperature and thermal effects due to microstructural changes were neglected for the considered nickel-based superalloy. The thermal-mechanical sequentially coupled quasi-static analysis was conducted in two separate steps: (1) determination of temperature field under prescribed heat load and boundary conditions, and (2) elastic-plastic incremental analysis of stress and strain due to the mechanical load and thermal load, using the calculated temperature field. Symmetry condition in the thermal problem was accounted for by considering the plane of symmetry as adiabatic, whereas heat convection and radiation was allowed on all other surfaces of the model. The DC3D8 elements for the thermal problem, and compatible elements C3D8 for mechanical analysis were used. A comparison of the free-end of sample deflection U as measured in experiments and calculated numerically as a function of time for mechanical loads Q 110 G (1.08 N), 160 G (1.57 N), 260 G (2.55 N), 310 G (3.04 N) and 460 G (4.51 N) is presented in Fig. 1 (right).

Experimental study and numerical simulations showed that forming performance of Inconel 718 plates can be significantly improved by laser heating under mechanical pre-loading. With the identified model of the constitutive response of Inconel 718 sheet blanks various forming processes with similar conditions can be studied.

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