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APPLICATION OF THE INHERENT STRAIN METHOD IN MODELING OF LASER THERMAL FORMING

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1. Thermal forming processes and their modeling methods

Processes of controlled producing plastic deformation of metal and non-metal objects by local heating are considered in the paper. Flame heating has been applied in shaping and shape correction of metal sheet and plates in manufacturing and repairs since a long time [1, 2]. Metal forming by a moving heat source has been recognized as an effective and economical method for forming flat metal plates into three-dimensional shapes for plating of ships, trains, airplanes, and for rapid prototyping of complex curved objects [3]. Application of the laser beam as a heat source in thermal forming processes results in reduction of the heat-affected zone and material degradation [4].

The non-contact method of controlled producing small deformations and displacements has found considerable interest and applications in the electronic industry for precise positioning, adjustment and alignment of micromechanical, optical and electronic parts and subassemblies in mass production [5, 6]. The technology of micro-adjustment with a laser beam and dedicated on-board structures (laser-driven actuators) overcomes difficulties related to the limited access for mechanical tools and to inaccuracies inherent to the production of individual elements and joining them together during the product assembly [7].

Modeling of thermal forming processes is necessary for better understanding the techniques once applied only manually by highly experienced and specialized workers, for the automation and improvement in today's applications, and for development of new manufacturing and repair methods. Even with the current performance of computer systems and commercially available software packages, the full 3D Finite Element Analysis (FEA) of industry-relevant thermo-elastic-plastic problems often requires too much time and cost. Therefore, simplified modeling methods are needed, that would enable effective process analysis, planning and optimisation. One of the approaches originates from analytical modeling of welding distortions [8] and can be generally termed the inherent strain method.

2. The inherent strain method

The method basically consists in estimation of thermoplastic deformation of a structure using the solution of the elastic problem with imposed plastic strain, which is produced in the heated zone (the inherent strain). The considered plastic strain results from thermal expansion under internal or external constraints (thermal upsetting).

Plastic strain can be estimated from thermal strain under condition that thermal stress has reached the material yield stress value. The size of the plastic zone is determined by the maximal extent of the isotherm of the so called critical temperature of the material. In some formulations the value of this temperature is defined as the temperature at which the material yield stress value becomes negligibly small.

The inherent strain approach is used both in analytical solutions and in numerical calculations. The method has a number of variants and implementations, e.g. in estimation of thermally-induced residual stresses. The operation of imposing plastic strain to the structure model can be performed with the use of shrinkage forces and moments which produce equivalent straining. Another technique applied in numerical calculation of thermally-induced permanent deformation is the Artificial Temperature Field Analysis (AFTA), i.e. simulation of linearised plastic strains by the equivalent thermal contraction, combining artificial thermal expansion coefficient and temperature. In this case the linearised plastic strain is calculated from experimental or numerical results, and is collected in a data base of process parameters and corresponding plastic strains.

A short review of applications of the inherent strain approach for estimation of welding distortions [8], flame forming by line heating [9] and laser bending [10, 11] is presented in the article. Almost entirely analytical solution for laser adjustment using the two-bridge actuator is described [12]. Analytical modeling of such complex thermo-elastic-plastic processes seems to be impractical, if not impossible at all. However, closed form solutions that explicitly show the role of each significant process parameter are of great value for practicing engineers, who are involved in the application and development of new technologies. The analytical approach is able to extent our understanding of the basic physical mechanisms involved in the processes of interest [13]. The formulae derived due to the application of the inherent strain approach explicitly show the role of actuator design parameters, processing parameters (laser power and heating duration) and material data in thermo-elastic-plastic response of the structure to the laser pulse.

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