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Determination of Johnson-Cook material model parameters by an optimization approach using the fireworks algorithm

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Abstract

The accurate description of materials behavior is essential when investigating the application of these materials in the industrial practice. For this purpose, experimental data are fitted to suitable constitutive laws using various methods. In this paper, the determination of Johnson Cook material model parameters for AISI 316L stainless steel is performed using an optimization approach. More specifically, the Fireworks algorithm is employed to determine the appropriate material parameters for AISI 316L steel. The results indicate a sufficient performance of the optimization approach, which can be further developed and applied for other types of materials as well.

Keywords: stress-strain relationship; Johnson-Cook material model; artificial intelligence; Fireworks algorithm; optimization; AISI 316L stainless steel.

1. Introduction

Nowadays, the development of new alloy materials and generally, the need for using new materials in high end applications, such as aerospace industry, leads to a consequent development regarding the theoretical studies of the behavior of these materials. Thus, considerable work is conducted in order to determine the material behavior of new materials using existing, modified or new constitutive material models. After the parameters of the models are

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determined, the characteristics of these new materials and the applicability of them in various manufacturing processes can be investigated using numerical simulations such as Finite Elements (FEM) simulations.

The determination of suitable constitutive model parameters according to experimental data can be conducted using methods such as regression analysis [1]. One promising category of methods is pertinent to Soft Computing, which comprises methods such as Artificial Neural Networks (ANN). In the relevant literature, several works exist which employ soft computing or even optimization methods for the prediction of stress-strain relationship. For example, Gupta et al. [2] studied the flow stress of 316 stainless steel during dynamic strain aging regime with the use of an ANN model. In their model, data from tests covering a temperature range of 350-650°C and strain rate range of 10^{-4} and 10^{-2} s^{-1} were employed. Kong et al. [3] used an ANN model combined with a phenomenological model (Estrin-Mecking model) and found out that this approach was superior to other constitutive models, even at conditions outside the range of experimental data which were used to develop their model.

Furthermore, various works also exist, where an optimization method is employed for the determination of material behavior based on experimental data. For example, Dimatteo et al. [4] used genetic algorithms (GA) for the prediction of Mean Flow stress during rolling process. At first, they obtained results using models available in the literature and then, using GA, they derived optimum values for the existing models and compared the results. It was found that optimized models outperformed the original models and the results were consistent with industrial measurements. Özel and Karpat [5] also employed an optimization approach in order to derive the Johnson-Cook material parameters for 4 different materials, namely AISI 1045 and 4340 steels, AA 6082-T6 aluminum alloy and Ti6Al4V titanium alloy. For this purpose they employed a swarm intelligence method (cooperative Particle Swarm Optimization) and found out that this method outperformed simpler Particle Swarm Optimization variants. Lin and Yang [6] were able to fit their experimental data for Ti6Al4V alloy at 927°C to viscoplastic constitutive equations using a Genetic Algorithm multi-objective approach and noted the excellent capabilities of this approach to provide material parameters for several material behavior models. Huang et al. [7] employed a cluster global optimization algorithm to obtain material properties for two types of steel and they managed to obtain high levels of accuracy for their predicted stress-strain curves.

Finally, as material modeling is also very important for numerical simulations of manufacturing processes, some researchers employ their derived model to actual manufacturing processes simulation or even attempt to predict suitable material model parameters by matching the simulation results to the experimental ones. Chen et al. [8] derived a Johnson-Cook material model for Ti-6Al-4V and compared simulation results concerning cutting forces and machining chip morphology to experimental ones. Some representative works regarding the determination of Johnson-Cook parameters from machining experiments can be found in works such as [9, 10].

The purpose of this paper is the determination of parameters of Johnson-Cook constitutive model for 316L stainless steel, using an optimization approach. This is achieved through two major steps; the first step involves the collection of stress-strain curve data and the second involves the fitting of these data to Johnson-Cook material model by using for this reason the Fireworks algorithm, a relatively new and promising stochastic optimization method.

2. Fireworks algorithm

2.1. General aspects

In the current work, the Fireworks optimization algorithm (FWA) is employed for the determination of constitutive material model parameters. This method belongs to the Swarm Intelligence (SI) category of optimization methods, was introduced in 2010 by Tan and Zhu [11] and has found many applications in various fields of science. This method was inspired from actual fireworks displays and contains elements from the observation of tracks of sparks which were produced by the fireworks. Thus, the "sparks" from an initial "explosion" of fireworks fill a region which is considered as the search space for the algorithm and until the optimum is detected, "explosions" from specific regions occur, with a view to approach the optimum point.