PhD Thesis Evaluation Report

Name of Candidate: Zhao Shixiang
Title of Thesis: Dynamic plasticity modeling of metallic materials under impact loads: strain-rate effects and thermal softening phenomena
Supervisor: Prof. Petrov Yury Viktorovich, Saint Petersburg State University, D.Sc.
Reviewer: Prof. Gu Yan, Qingdao University, D.Sc.

Introduction

This thesis is dedicated to the investigation of modeling the plastic response of various metallic materials, including aluminum alloys 6082-T6 and 2519A, HSLA-65 steel, a tungsten-based composite 93W–4.9Ni–2.1Fe, and titanium alloy Ti6Al-4V, under different temperatures and high-speed conditions. The chosen thesis topic holds significant relevance in various industries and engineering applications. For instance, in the automotive industry, crashworthiness and occupant safety are paramount concerns, making it essential to study the plastic behavior of metallic materials under impact loads. This research also aims to develop accurate models, i.e. relaxation model of plasticity, that consider strain-rate effects and thermal softening phenomena to predict material response during extreme loading conditions. By incorporating strain-rate effects and thermal softening phenomena in computational models, the research topic can also contribute to designing improved vehicle structures and safety systems, ultimately leading to enhanced passenger protection. Similarly, in the aerospace sector, studying the topic is crucial for aircraft design. Insights into dynamic plasticity under impact loads can lead to improvements in safety, reliability, and efficiency across diverse applications.

Definition of the Research Problem, Scope, and Goals

The thesis addresses the plastic behavior of metals under high-loading rates, focusing on the accompanying adiabatic temperature rise, strain rate effects, and thermal softening phenomenon. Existing models typically introduce rate-dependent and temperature-dependent components into classical empirical models, obtained from direct empirical curve fitting approaches. However, these models often neglect the non-monotonic constitutive response, such as yield drop phenomenon, observed in

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dynamic stress-strain curves. Micromechanism-based models have also been developed but require a detailed understanding of material microstructure and the interaction between dislocations. The thesis introduces the incubation time approach proposed by Petrov and Morozov, which considers strain-rate sensitivity as a manifestation of time sensitivity in materials.

The goals of the thesis are to provide a new perspective on understanding strain rate sensitivity and thermal softening response in metallic materials by developing the incubation time approach. Specifically, the research aims to study the relaxation model of plasticity, incorporating the influence of strain rate effects and thermal softening phenomena while considering negative hardening behavior exhibited by materials subjected to high-rate loads. An original computational scheme for finite element analysis, suitable for the relaxation model of plasticity, is presented.

Review of Relevant Literature

The thesis provides an extensive review of relevant literature, focusing on models and approaches used to understand dynamic plastic behavior in metallic materials. Existing models encompass both empirical formulations derived from direct curve fitting approaches and micromechanism-based models that incorporate physical backgrounds of plastic deformation. The limitations of these models are discussed, such as neglecting the non-monotonic stress-strain behavior and the difficulty in determining parameters experimentally.

Presentation, Language, and Style

The overall presentation of the thesis is appropriate, with few grammatical or spelling errors. The writing style is coherent and appropriate for scientific research work. Citations are correctly provided, and references to concerned literature sufficiently cover the current state of knowledge. The work is well-presented, clearly written, and supplemented with tables and diagrams.

Thesis Structure and Methods Used

The thesis comprises an introduction, 4 chapters, a conclusion, two appendices and a bibliography. Two calculation schemes given in figures 2.2 and 3.2 are well presented. The methods used throughout the thesis, including the finite element method, return mapping algorithm for the time integration of stress, a safe version of Newton–Raphson method for solution of the yield surface equation, etc. are generally adequate and justified. The candidate demonstrates sufficient ability to choose appropriate methods to achieve research goals. The use of finite element analysis techniques in the computational approach is relevant, leading to the validation of the proposed relaxation model.

Contribution to Knowledge and Practice

The thesis makes original contributions through the development of the modified relaxation model of plasticity (RP model) using the incubation time approach. This differs from existing phenomenological models derived from empirical curve fitting approaches. The RP model overcomes limitations observed in other models, particularly in capturing work-hardening response across a wide range of strain rates and temperatures. The examination of temperature-time correspondence and its relationship with the relative stress factor provides valuable insights into the behavior of metallic materials under varying conditions. These contributions are classified as both theoretical and practical.

Recommendations

For future work, it is recommended that the candidate can consider the following points:

1. Provide better and clearer definitions of key terms used in the thesis.
2. Refine titles to make them more informative.
3. Incorporate studies on dynamic fracture into the research work.

Overall Result

The dissertation is an authentic work consisting of original research and a clear author's position. The candidate demonstrates high competence in the field of dynamic plasticity in metallic materials, and the language and style of the dissertation are appropriate for scientific research work.

Questions to the defendant:

1. Is the notation ξ used in formula (3.54) on page 70 only for simplification purposes in formulars, or does it serve other purposes as well?
2. In Chapter 1, the author has introduced the basic idea of artificial neural networks (ANN). The original problem can be transformed into an optimization problem. Here, the loss function is a critical factor in training the artificial neural networks. It serves as a measure of how well the input data match the output data during the training process. I suggest the author make a brief introduction concerning the definition of the loss function.

3. In the finite element analysis, when the materials undergo deformation, it is often necessary to re-mesh the grid to ensure the accuracy of the numerical results. I am wondering whether this study has this problem.

Conclusion

The work meets the requirements for a PhD degree, and the candidate has demonstrated competence in the field of dynamic plasticity in metallic materials. The research findings contribute to the understanding and simulation of material behavior under impact loads, with potential applications in various industries. Based on the evaluation conducted, I recommend the PhD thesis of Zhao Shixiang entitled “Dynamic plasticity modeling of metallic materials under impact loads: strain-rate effects and thermal softening phenomena” for acceptance.

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