

## Review of the Doctoral Thesis

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Affiliation of the reviewer: Institute of Structural Analysis of Poznan University of Technology

Author: M.Sc. Eng. Ved Prakash Dubey

Title: Yield Surface Identification of Functional Materials and Its Evolution Reflecting Deformation History under Complex Loadings

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### 1. General Assessment

The doctoral dissertation by Mr. Ved Prakash Dubey addresses a challenging and timely research problem in experimental mechanics and materials engineering: the identification of yield surfaces for functional metallic materials, and the study of their evolution under complex loading conditions with prior deformation histories.

The work focuses on four classes of materials:

- commercially pure titanium (CP-Ti, HCP structure),
- commercially pure copper (CP-Cu, FCC structure),
- Ti–Cu bimetal (HCP–FCC combination), and
- SS316L stainless steel in both wrought and additively manufactured (LPBF) forms.

The novelty of the thesis lies in its integrated experimental–analytical approach: advanced biaxial testing, systematic pre-deformation under controlled multiaxial stress states, and yield surface characterisation using Szczepiński’s anisotropic yield criterion. This is coupled with microstructural investigations (EBSD analysis) to link mechanical behaviour with crystallographic texture and grain morphology.

The research contributes both to fundamental understanding of anisotropic plasticity and to applied engineering practice in metal forming, additive manufacturing, and structural design.

### 2. Relevance and Scientific Context

The yield surface is a central concept in plasticity theory, representing the limit beyond which irreversible deformation occurs. While extensively studied in isotropic materials under simple loading, the combined effects of manufacturing-induced anisotropy and complex pre-deformation histories remain insufficiently documented, especially in functional engineering alloys and composites.

Engineering components in aerospace, automotive, energy, and biomedical sectors often operate under variable, multiaxial loadings and may undergo pre-straining during manufacturing (e.g., rolling, extrusion, forming) or service. These pre-strains alter the yield surface in ways that can significantly affect fatigue resistance, failure modes, and service life.

Mr. Dubey's work addresses this gap by:

- testing materials with different crystallographic structures and processing routes,
- quantifying anisotropy before and after controlled pre-deformation, and
- providing quantitative curves for use in constitutive modelling.

### **3. Original Contributions**

The dissertation contains several original elements that, to my knowledge, have not been reported in this combined form:

1. Application of Szczepiński's yield criterion for systematic yield surface identification in multiple materials, including additively manufactured alloys, under controlled pre-strain conditions.
2. Design of bespoke experimental methodologies, including thin-walled tubular specimens enabling combined axial–torsional loading in a single specimen, and sequential probing to identify yield loci with minimal material use.
3. Comparative study of manufacturing methods—conventional wrought processing vs. LPBF additive manufacturing—with respect to yield anisotropy and its evolution.
4. Microstructural–mechanical correlation using EBSD, revealing links between grain orientation, slip system activation, recrystallisation, and yield surface shape.
5. Parametric quantification of yield surface evolution, including ellipse parameters (centre shift, axis lengths, rotation angle), enabling direct integration into computational constitutive models.

### **4. Methodology Assessment**

The methodological section of the thesis is particularly strong. Key strengths include:

- Comprehensive mechanical testing programme:
  - Uniaxial tensile tests for baseline properties.
  - Complex axial–torsional loading paths for biaxial states.
  - Controlled pre-deformation via monotonic tension and combined tension–cyclic torsion at defined amplitudes and frequencies.
- Precision in yield point determination: Multiple offset strain values are considered, and methods such as least-squares fitting are applied to yield points, ensuring reproducibility.
- Microstructural characterisation: EBSD mapping before and after pre-deformation captures texture changes and grain evolution. This is especially important in explaining anisotropy in CP-Ti and the Ti–Cu bimetal.

- Material diversity: The inclusion of HCP, FCC, and mixed-structure materials, as well as AM vs. wrought processing, allows generalisation of findings and cross-comparison.
- Integration with theoretical models: The thesis does not merely present experimental results but directly fits them to Szczepiński's criterion, demonstrating its applicability and limitations.

The methodology is well justified, clearly described, and supported by schematic diagrams, specimen drawings, and test setups.

## 5. Main Findings

The key scientific findings can be summarised as follows:

- Commercially Pure Titanium (CP-Ti):
  - Exhibits initial anisotropy due to manufacturing-induced texture.
  - Pre-deformation generally reduces yield surface size except in the pure tension direction.
  - EBSD confirms reorientation of grains and activation of specific slip systems.
- Commercially Pure Copper (CP-Cu):
  - Monotonic tension causes kinematic hardening (yield surface translation).
  - Combined tension–cyclic torsion causes either anisotropic hardening or softening, depending on torsion amplitude—low amplitude strengthens certain directions, high amplitude softens.
- Ti–Cu Bimetal:
  - Behaviour reflects combined properties of Ti and Cu layers.
  - Pre-deformation by monotonic tension causes kinematic hardening; combined loading leads to softening.
  - EBSD reveals recrystallisation at higher shear strain levels, altering anisotropy.
- SS316L Stainless Steel:
  - LPBF manufacturing introduces strong build-orientation-dependent anisotropy.
  - Z-oriented specimens show the lowest yield strength and stiffness.
  - Pre-deformation softening depends on microstructural morphology and pre-strain magnitude.

These findings are presented quantitatively via fitted ellipse parameters, allowing numerical comparison between states.

## 6. Critical Remarks and Suggestions

While the dissertation is of high quality, a few points could further enhance its impact:

### 1. Analysis:

The doctoral thesis surveys a wide range of materials, but this breadth comes at the expense of a thorough investigation into each material's behaviour under complex stress states. The work focuses on initial plastic surfaces, documenting their changes under harmonic torsion or initial stretching. A more impactful contribution would be the development and implementation of a dedicated model that accounts for potential anisotropic elastic properties and quantifies the Szczepiński criterion parameters for a specific material. Strain hardening effects should also be incorporated; at present, Figures 4.36 and 4.37 present only stress values, without the plastic strain function  $f(\sigma_{ij})$ . The reported tests involve strains not exceeding 1%, leaving the material's subsequent behaviour unaddressed. In the doctoral thesis, the coefficients A, B, C, D, and F are reported as having been determined using the least squares method to fit the experimental data; however, the values are not explicitly presented in any tables or figures in the thesis.

### 2. Conciseness:

The literature review (Chapter 2) and yield criteria overview (Chapter 4) could be more concise, as some classical model descriptions are well known to the intended audience.

### 3. Comparative summary tables:

A consolidated table summarising the effect of each pre-deformation path on all materials' yield surface parameters would make cross-material trends easier to identify.

### 4. Implementation discussion:

The conclusions could further elaborate on direct implementation of obtained parameters into finite element software for predictive simulations.

### 5. Statistical analysis:

While repeatability appears good, more explicit reporting of statistical scatter in yield point determination could strengthen robustness claims.

### 6. Editorial and editorial notes:

It would be advisable for all figures in the Literature Review chapter that are directly taken from source publications to include clear bibliographic references in their captions. This would help maintain good academic practice, ensure proper acknowledgment of the original sources, and guide readers to the original context of the material.

These remarks, however, are minor in the context of the overall quality of the work.

## 7. Candidate's Scientific Output

Mr. Dubey has published his findings in high-impact journals (*International Journal of Plasticity*, *Manufacturing Letters*), demonstrating both the novelty and the relevance of the research. His participation in the NCN-funded project and international collaboration (Erasmus+ exchange) highlights his active role in the broader scientific community. The work reflects research independence and the ability to lead complex experimental campaigns.

## 8. Overall Evaluation

This doctoral thesis is methodologically rigorous, experimentally rich, and scientifically significant. It provides new insight into the evolution of yield surfaces in functional metallic materials and validates a less commonly applied but powerful yield criterion for anisotropic materials. The research bridges experimental mechanics, materials science, and computational modelling.

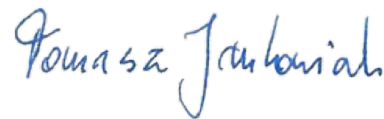
The results will be of interest to:

- researchers in plasticity and constitutive modelling,
- engineers in additive manufacturing and forming technology,
- designers of high-performance structural components in aerospace, automotive, and biomedical fields.

## **9. Final Recommendation**

In my opinion, the dissertation by M.Sc. Eng. Ved Prakash Dubey meets and exceeds the criteria set by Polish and international regulations for the award of the doctoral degree.

I recommend without reservation that the Candidate be admitted to the public defence and awarded the title of Doctor of Engineering and Technical Sciences in the discipline of Mechanical Engineering.

A handwritten signature in blue ink that reads "Tomasz Jankowiak". The signature is written in a cursive, flowing style.

dr hab. inż. Tomasz Jankowiak, prof. PP