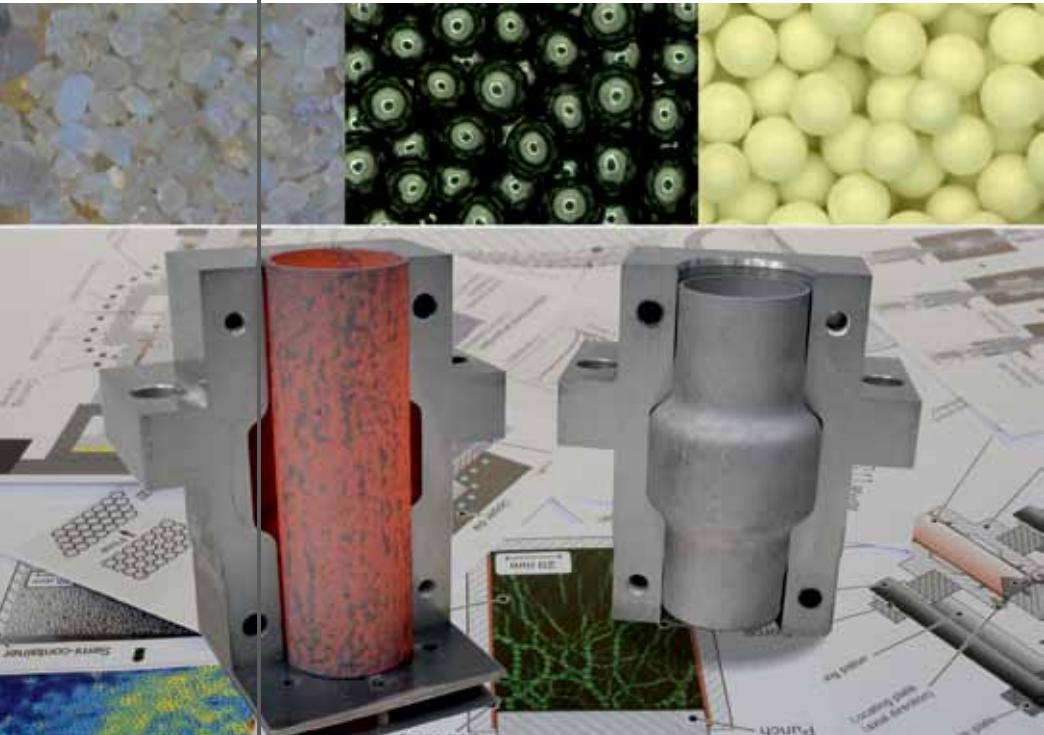


Hui Chen

**Granular medium-based tube  
press hardening**



# **Granular medium-based tube press hardening**

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## Abstract

Using granular materials as forming medium enables the press hardening process for tubes and profiles, which can produce lightweight components with high strength and high stiffness. However, granular material is a conglomeration of macroscopic particles unlike a fluid medium that possesses hydrostatic properties. The aim of this thesis is to investigate the physical concept of this new metal forming process, work out and extend the process limit.

First, the performance of granular material as working medium and the principle of choosing appropriate granular material is identified. A calibration procedure for the material model of granular material (i.e., Drucker-Prager Cap model) is introduced based on the characterization strategy of using instrumented die compaction tests and high-pressure direct shear tests. The accurate flow behavior of 22MnB5 material, which is essential for process numerical modelling, is characterized by a self-designed hot tensile test. The homogeneous induction heating of specimen is ensured by a single-strip face inductor and the precise temperature control is realized by close-loop control. Interaction properties including friction and heat transfer during the forming process are determined by high-pressure shear tests and heat transfer tests, which mimic the press hardening conditions. Inverse parameter identification is used to identify the heat transfer coefficients between the granular material and 22MnB5 blank under different contact pressures.

For a better understanding of the pressure transferring mechanism, an analytical model is developed, which deals with the tube free bulging under non-uniform loading pressures. With the combination of analytical models, the applied loading force for tube free bulging radii is predicted. The model is validated by a tubular free bulging experiment using granular medium.

A fully-coupled thermal-mechanical FE model of granular medium-based tube press hardening is established. Press hardening experiments for a T-shape 22MnB5 tube using granular material as forming medium are carried out. On this basis, the numerical model is validated by experiment measurements. The influence of process factors such as loading conditions, tube thicknesses and granular medium types are identified considering the tube hot bulging height. In order to specify the process limit of using granular materials as forming medium, axisymmetric tube press hardening experiments are designed and conducted as an example to define the process windows by FE simulation and experimental investigations.

This thesis establishes the required fundamental knowledge for an innovative granular medium-based tube press hardening process. Also, an alternative process of passive forming is proposed. The potential of producing high strength and high stiffness components offers the applications of lightweight construction in the automotive industry.

## Zusammenfassung

Die Verwendung von granularem Material als Umformmedium ermöglicht das Presshärten von Rohren und Profilen und damit die Herstellung leichter Bauteile, welche eine hohe Festigkeit und gleichzeitig hohe Steifigkeit aufweisen. Granulate sind Gemenge von makroskopischen Partikeln und besitzen, im Gegensatz zu Fluiden, keine hydrostatischen Eigenschaften. Die während des Umformprozesses entstehende Druckverteilung ist von verschiedenen Einflussfaktoren abhängig und bestimmt maßgeblich die Geometrie des resultierenden Bauteils. Das Ziel dieser Arbeit ist die Untersuchung der physikalischen Grundlagen dieses neuen Umformprozesses, die Bestimmung der Prozessgrenzen und deren Erweiterung.

Zunächst wird das Verhalten von granularem Material als Arbeitsmedium untersucht und das Prinzip der Auswahl geeigneter Granulate erarbeitet. Für die Beschreibung des Verhaltens der Granulate wird als Materialmodell das Drucker-Prager Cap-Modell verwendet und für dieses ein Kalibrierverfahren entwickelt, welches sich auf Hochdruckscherversuche und Kompaktierversuche stützt. Das Fließverhalten von dem verwendeten Presshärtestahl 22MnB5 bei verschiedenen Temperaturen, wurde mit Hilfe eines eigens entwickelten Warmzugversuchs bestimmt. Die homogene Erwärmung der Zugprobe wird durch einen Flächeninduktor realisiert und die entstehende Temperatur durch einen Regelkreis gewährleistet. Die Wechselwirkung zwischen Rohr und Granulat, einschließlich Reibung und Wärmeübertragung während des Umformprozesses, werden durch Hochdruckscherversuche und Wärmeübergangsversuche bestimmt, welche die Bedingungen beim Presshärten nachbilden. Durch inverse Parameteridentifikation werden die Wärmeübergangskoeffizienten zwischen dem granularen Material und dem Stahlrohr bei verschiedenen Kontaktdrücken bestimmt.

Die Ergebnisse werden genutzt um ein analytisches Modell für die freie Rohraufweitung unter ungleichmäßigen Innendräcken zu entwickeln. Hierbei wird die Axialkraft bestimmt, die für die Erzeugung von spezifischen Rohraufweitradien notwendig ist. Das Modell wird experimentell validiert.

Zuletzt wird ein vollständig gekoppeltes thermisch-mechanisches FE-Modell für das Presshärten mittels granularer Medien erstellt. Zur Validierung des Modells werden T-förmige Rohrsegmente in experimentellen Presshärtestests erzeugt. Die Einflüsse von Prozessfaktoren wie die Beladungsbedingung, Rohrdicke und Art des granularen Mediums werden identifiziert. Die Prozessgrenzen werden anhand achssymmetrischer Presshärteexperimente bestimmt.

Diese Arbeit bildet die erforderlichen Grundlagen für das Presshärten von Rohren mittels granularer Medien. Das Verfahren bietet das Potenzial der Herstellung von hochfesten und gleichzeitig hochsteifen Bauteilen und ist damit prädestiniert für Leichtbauanwendungen in der Automobilindustrie.

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