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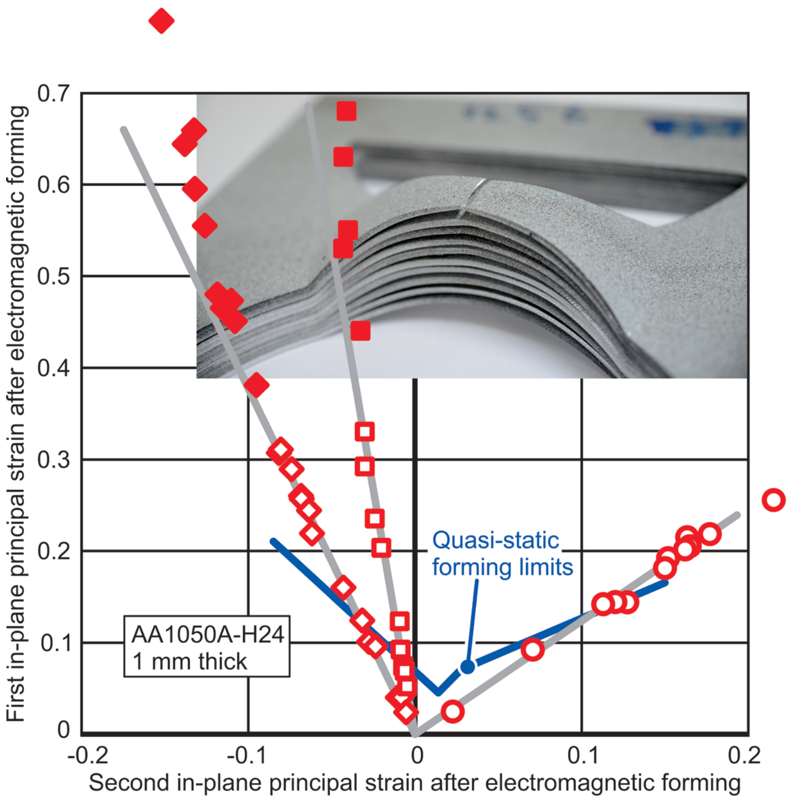
Osman Koray Demir

New test and interpretation of electromagnetic forming limits of sheet metal



Reihe
Dortmunder Umformtechnik

Nr. 106

New Test and Interpretation of Electromagnetic Forming Limits of Sheet Metal

Zur Erlangung des akademischen Grades eines

Dr.-Ing.

von der Fakultät Maschinenbau
der Technischen Universität Dortmund
genehmigte Dissertation

M.Sc. Osman Koray Demir

aus

Uşak / Türkei

Tag der mündlichen Prüfung: 26.08.2019

1. Gutachter: Prof. Dr.-Ing. Dr.-Ing. E.h. A. Erman Tekkaya
2. Gutachter: Prof. Dr. Glenn Daehn

Dortmund, 2019

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Tag der mündlichen Prüfung: 26.08.2019

Dortmunder Umformtechnik

Band 106

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New test and interpretation of electromagnetic forming limits of sheet metal

D 290 (Diss. Technische Universität Dortmund)

Shaker Verlag
Düren 2019

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Dortmund, Technische Univ., Diss., 2019

Printed in Germany.

ISBN 978-3-8440-6986-0
ISSN 1619-6317

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgements

Prof. Dr.-Ing. Dr.-Ing. E.h. A. Erman Tekkaya supervised this study. He supervised not only this study, but also all my studies since I was a bachelor student. I am deeply grateful to him for his supervision, and for all the opportunities and support that he has given to me over the years. Prof. Dr. Glenn Daehn's research was an inspiration for this work. I am therefore extremely thankful to him for participating in my examination committee. I also appreciate the valuable discussions of Prof. Dr.-Ing. habil. Frank Walther and Priv.-Doz. Dr.-Ing. Dipl.-Inform. Andreas Zabel in my oral examination.

This work is a spin-off from the joint project PAK343, funded by the German Research Foundation (DFG). I gratefully acknowledge Prof. Dr.-Ing. Alexander Brosius and Dr.-Ing. Verena Psyk for their contributions to the creation and management of this project. I also appreciate all the researchers of the project for the graceful cooperation. Specifically I thank Dr.-Ing. Yalın Kılıçlar for our harmonious teamwork.

This work was carried out during and after my time as a research assistant at the Institute of Forming Technology and Lightweight Construction (IUL) of TU Dortmund. All my former colleagues at IUL contributed to this work by creating the collaborative working environment there. I benefited mostly from the insightful comments of Dr.-Ing. Alper Güner and Dr.-Ing. Lukas Kwiatkowski. In addition, Dr.-Ing. Christian Weddeling connected me to Dr.-Ing. Lukas Prasol of TU Berlin, who helped me interpret the magnesium results. Marlon Hahn contributed enormously with his feedback. Eike Hoffmann and Ali Guezguez did numerous challenging measurements as student assistants. Alessandro Selvaggio and Heinrich Traphöner helped me reach my data away from IUL. Dr.-Ing. Soeren Gies was always there when I needed his help. I am also in debt to all of our technicians, primarily to Dirk Hoffmann, who milled the tools for my experiments. Furthermore, I thank Nina Hänisch and Jeanette Brandt for their organizational guidance. Special thanks to Jeanette Brandt for her always-smiling face.

All my current colleagues in AutoForm contributed to this work by offering me their invaluable support. Particularly I thank Michael Rembrink and Ralf Schmidt for their encouragement, and Bernd Sann for his help with the abstracts.

Emine and Alper Güner gave me the most vital intellectual and emotional support during the writing. Completion of this work became only possible with their nurturing. I thank them and all my friends, especially Ahmet Güzel, Berat Yoldaş, Kerim Işık, Ogün Heper, Sonja Dockter, Utku Kundakçı, and Yalın Kılıçlar, for being my friends.

My mother Fatma Demir encouraged me to finish my dissertation after my long break. That is why this book is dedicated to her. My father Ramazan Demir designed with me the cover picture. I thank them and all my family, my brother's wife Neslihan Demir, my brother Emre Demir, and lastly, my partner Lara Peters, for their support and love.

Kuşadası, September 2019 O. Koray Demir

Abstract

A new method is proposed to determine the electromagnetic forming limits of sheet metal. The method deforms the specimen apex on a constant strain path, as strain measurements and simulations confirm. The strain path can be varied between uniaxial tension and biaxial tension by changing the specimen and tool shapes. Furthermore, the method breaks the specimen at the apex. In order to ensure an apex failure and avoid bending, a new specimen concept that promotes uniform pressure application is developed.

The proposed method is used to find the electromagnetic forming limit curves for AA1050A, AA5083, and Mg AZ31 sheets. These materials exhibit higher necking limits in the electromagnetic forming, when compared to quasi-static forming. In addition, in the electromagnetic forming, the limits increase with the strain rate. The proposed method is also used to find the fracture limits of these materials under uniaxial tension. The materials exhibit higher fracture limits in the electromagnetic forming. In order to explain the higher forming limits in the electromagnetic forming, fracture surfaces of quasi-static and electromagnetic samples are examined.

Fracture surfaces reveal that the failure in the quasi-static forming is driven by in-plane shear stress, while the failure in the electromagnetic forming is driven by tensile and out-of-plane shear stress. This suggests the existence of out-of-plane shear stress in the electromagnetic forming. Out-of-plane shear stress is shown by Allwood and Shouler (2009) to increase elongation to failure in quasi-static tensile tests. This dissertation proposes out-of-plane shear stress as a reason for the higher limits in the electromagnetic forming. In the electromagnetic forming, out-of-plane shear stresses can arise from the out-of-plane electromagnetic forces. Simulations of the electromagnetic forming limit test shows that they reach considerable magnitudes (about 30% of the initial shear yield stress). Simulations at different velocities show that they increase with the forming rate.

For the reasons of higher forming limits in the electromagnetic forming, previous research has identified inertial stabilization, strain rate hardening, impact with a die, and an increased deformation by twinning. This dissertation demonstrates the positive effect of inertial stabilization, and documents the increase of twinning in the electromagnetic deformation of AZ31. Besides, out-of-plane shear is proposed as a new addition to the list of reasons for higher limits in the electromagnetic forming.

Zusammenfassung

Eine neue Methode wird vorgeschlagen, um elektromagnetische Grenzformänderungskurven für Blech zu bestimmen. Diese Methode verformt Blechproben auf einem konstanten Dehnpfad, wie Dehnungsmessungen und Simulationen bestätigen. Der Dehnpfad kann zwischen einachsigem und zweiachsigem Zug variiert werden, indem die Proben- und Werkzeuggeometrien geändert werden. Außerdem führt die Methode zu einem Riss in der Probenmitte. Um den mittigen Riss zu gewährleisten wird eine neue Probengeometrie entwickelt, die eine gleichmäßige Druckverteilung begünstigt.

Die vorgeschlagene Methode wird verwendet, um Grenzformänderungskurven für Bleche aus AA1050A, AA5083, und Mg AZ31 zu bestimmen. Diese Werkstoffe zeigen in der elektromagnetischen Umformung höhere Einschnürungsgrenzen als in der quasi-statischen Umformung. Außerdem erhöhen sich mit steigender Formänderungsgeschwindigkeit die Einschnürungsgrenzen. Durch die vorgeschlagene Methode werden auch die Bruchgrenzen dieser Werkstoffe unter einachsigem Zug bestimmt. In der elektromagnetischen Umformung liegen die Bruchgrenzen höher als in der quasi-statischen Umformung. Um die höheren Einschnürungs- und Bruchgrenzen zu erklären werden die Versagensmechanismen der Proben anhand von Bruchbildern untersucht.

Die Bruchbilder zeigen, dass das Versagen in der quasi-statischen Umformung durch Schubspannungen *in der* Blechebene, in der elektromagnetischen Umformung dagegen durch Schubspannungen *außerhalb* der Blechebene verursacht wird. Schubspannungen außerhalb der Blechebene erhöhen nach Allwood und Shouler (2009) die Formänderungsgrenzen beim quasi-statischen Zugversuch. Diese Dissertation setzt dieses auch für die elektromagnetische Umformung voraus. Schubspannungen außerhalb der Blechebene können aus elektromagnetischen Prozesskräften entstehen, die außerhalb der Blechebene wirken. Simulationen zeigen, dass sie ungefähr 30% der initialen Fließspannung erreichen und sich geschwindigkeitsabhängig erhöhen.

Bisher wurden als wichtigste Gründe der höheren Formänderungsgrenzen in der elektromagnetischen Umformung die Massenträgheit, die dehnratenabhängige Verfestigung, der Aufprall der Matrize und die erhöhte Zwillingsbildung angenommen. Diese Dissertation zeigt die positive Wirkung der Massenträgheit und beweist die Erhöhung der Zwillingsbildung bei Mg AZ31. Schubspannung außerhalb der Blechebene wird als neuer Grund vorgeschlagen.

Contents