Forschungsberichte LEICHTBAU

Lehrstuhl Konstruktion und Fertigung
Prof. Dr.-Ing. habil. Markus Bambach

Brandenburgische
Technische Universität
Cottbus - Senftenberg

Aliakbar Emdadi

High-Temperature Deformation Behavior of Intermetallic Titanium and Iron Aluminides Produced by Spark Plasma Sintering

Band 1

High-Temperature Deformation Behavior of Intermetallic Titanium and Iron Aluminides Produced by Spark Plasma Sintering

Von der Fakultät für Maschinenbau, Elektro- und Energiesysteme
der Brandenburgischen Technischen Universität Cottbus–Senftenberg
zur Erlangung des akademischen Grades eines Grades eines

Doktors der Ingenieurwissenshaften

genehmigte Dissertation

vorgelegt von

M. Sc.

Aliakbar Emdadi

geboren am 18.07.1986 in Tabriz, Islamic Republic of Iran

Vorsitzender: Prof. Dr. Florian Pyczak

Gutachter: Prof. Dr.-Ing. habil. Markus Bambach

Gutachter: Prof. Dr.-Ing. habil. Sabine Wieß

Tag der mündlichen Prüfung: 19.11.2020

Forschungsberichte Leichtbau

Band 1

Aliakbar Emdadi

High-Temperature Deformation Behavior of Intermetallic Titanium and Iron Aluminides Produced by Spark Plasma Sintering

Shaker Verlag
Düren 2021

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.: Cottbus-Senftenberg, BTU, Diss., 2020

Printed in Germany.

ISBN 978-3-8440-7933-3
ISSN 2747-9064

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

Abstract

Field-assisted sintering technology/spark plasma sintering (FAST/SPS) is a rapid sintering technique with great potential for achieving fast densification with minimal grain growth in a short sintering time. Presently the industrial applications of FAST/SPS processing are mainly in areas where it is complex or challenging to process high-performance materials by conventional processes where usually hot isostatic pressure (HIP) processes are applied.

In general, the components produced by the forging of preforms fabricated by ingot metallurgy do not exhibit optimal mechanical properties due to a coarse-grained microstructure inherited from the as-cast precursor. In this context, employing a hybrid processing route comprised of FAST/SPS and hot forging could consolidate powder materials into near-net-shaped forged components with a refined microstructure and improved hot deformability. Furthermore, this process chain shows advantages over the conventional multi-step process by eliminating the ingot casting step and most of the ingot's thermomechanical treatment to achieve the desired microstructure and shape.

In this research, a new processing route consisting of SPS and hot forging was investigated in terms of microstructure evolution and hot workability for titanium aluminide (TNB-V5, Ti-45Al-5Nb-0.2B-0.2C, at.%[1]) and iron aluminide (Fe-25Al-1.5Ta) alloys. Processing maps were constructed based on the dynamic materials model (DMM) and used as a process design tool to identify the deformation mechanisms and optimum processing windows that will render defect-free parts during industrial-scale manufacturing.

The alloy powder materials were produced by gas atomization. The microstructures of the initial powders, as-built (as-cast or SPSed), and deformed specimens were characterized via light-optical microscopy (LM), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), electron backscatter diffraction (EBSD), and differential scanning calorimetry (DSC). Compression tests were performed using a deformation dilatometer in an argon atmosphere to a true strain of 0.8 at different temperature and strain rate ranges.

Although the TNB-V5 alloy was not designed for forging operations, results demonstrate that the SPS process can create a homogeneous equiaxed microstructure consisting of globular α_2- and γ-grains. The α_2-grains decorate the interfaces and triple junctions between former powder particles leading to a relatively high degree of deformability. The current research offers a new process design strategy by opening up the possibility of using local non-equilibrium conditions in the material during the forging process, which could stabilize the ductile phases locally and excludes the necessity for the presence of ductile β-phase to achieve a high degree of hot workability. The optimum processing window for the studied TNB-V5 alloy locates at 1200 ºC / 10^{-3} s^{-1}, where significant twinning-induced dynamic recrystallization (DRX) of the dual-phase (α + γ) microstructure occurs. In contrast, deformation conditions of 1150-1200 ºC /

[1] All compositions are given in at.% throughout the text unless otherwise stated.

10^{-2}-10^{-1} s^{-1} should be inhibited during deformation processing due to the formation of porosities.

The current research also offers a possibility to produce a homogeneous fine-grained (7 µm) Fe-25Al-1.5Ta alloy strengthened by dispersed Laves phase particles using SPS compared to the coarse columnar microstructure obtained by casting (500 µm). Such a refined microstructure renders high strength with the retention of sufficient ductility for the material at elevated temperatures and leads to a high degree of hot forgeability at 800-1100 ºC. The optimum processing domain for the Fe-25Al-1.5Ta alloy locates at 1050-1100 ºC / 0.0013-0.01 s^{-1} with a 40-50 % power efficiency, where the material undergoes dynamic recrystallization. However, deformation at 800 ºC / 1 s^{-1} gives rise to the flow instability resulting from cracking.

Dedication

To my beloved parents

تقدیم به مادرم

Acknowledgments

The work detailed in this dissertation is the result of my engagement as a researcher at "Lehrstuhl Konstruktion und Fertigung" (KUF) at Brandenburg University of Technology, Cottbus-Senftenberg (BTU).

Prof. Dr.-Ing. habil. Markus Bambach has sparked my interest in the field of manufacturing. My admiration for his enthusiasm for the subject and his ability to convey that excitement to people around him cannot be overstated. This research work would not have been possible if not for his trust, guidance, patience, and insight throughout my research.

The work in this thesis was greatly influenced and motivated by Dr. Ulrike Hecht (Access e. V. Institute, Aachen) through many discussions and publishing joint papers. I am thankful for her time and efforts.

I appreciate Access e. V. Institute and Access TechCenter, Aachen, for allowing me to visit them. Discussions with the researchers of the Materials Research Department directly or indirectly helped me in my research. I wish to thank Mr. V. T. Witusiewicz for running Thermo-Calc computations. I owe special thanks to Mr. Oleg Stryzhyboroda (Access e. V., Aachen) for conducting the scanning electron microscopy and electron backscatter diffraction.

I would also like to thank Professor Dr.-Ing. habil. Sabine Weiß for the suggestions and comments about my candidacy, and I am greatly honored that she agreed to be the co-referee for this dissertation.

I am grateful to Prof. Dr. Florian Pyczak, who directly helped me with TiAl alloys through discussions and publishing a joint paper.

I am thankful to Dr. Jiwoon Lee from the Korea Institute of Industrial Technology for his help with the processing maps, which I used as a tool for optimizing hot deformation parameters.

I would also like to express my gratitude to all my colleagues at KUF-BTU. Plenty of my experiment results would not have been available without the hard work of Mrs. Irian Sizova and Dr. Sebastian Bolz.

The research resulting in this dissertation was supported mainly by funding from the German Research Foundation (DFG) through project no. BA 4253/4-1, in which the methods for analyzing the forming behavior depicted in the present work were developed. I also appreciate the Graduate Research School "LokPro" at BTU Cottbus-Senftenberg for the material and process development.

Last but not least, I want to thank my parents for their continued support, patience, and a constant source of encouragement during my graduate studies.

Publications

The findings of this thesis were published in the following peer-reviewed journals:

- **A. Emdadi**, I. Sizova, O. Stryzhyboroda, U. Hecht, J. Buhl, M. Bambach, Hot workability of a spark plasma sintered intermetallic iron aluminide alloy above and below the order-disorder transition temperature, *Procedia Manufacturing*, 47C (2020) 1281-1287.

- **A. Emdadi**, M. Bambach, I. Sizova, U. Hecht, Hot deformation behavior of a spark plasma sintered Fe-25Al-1.5Ta alloy with strengthening Laves phase, *Intermetallics*, 109 (2019) 123-134.

- M. Bambach, **A. Emdadi**, I. Sizova, U. Hecht, F. Pyczak, Isothermal forging of titanium aluminides without beta-phase — Using nonequilibrium phases produced by spark plasma sintering for improved hot working behavior, *Intermetallics*, 101 (2018) 44-55.

Besides, the author contributed to the following peer-reviewed publications:

- M. Bambach, I. Sizova, **A. Emdadi**, Development of a processing route for Ti-6Al-4V forgings based on preforms made by selective laser melting, *Journal of Manufacturing Processes,* 37 (2019) 150-158.

- M. Bambach, I. Sizova, **A. Emdadi**, Towards Damage Controlled Hot Forming, *Applied Mechanics and Materials,* 885 (2018) 56-63.

- J. A. Stendal, **A. Emdadi**, I. Sizova, M. Bambach, Using neural networks to predict the low curves and processing maps of TNM-B1, *Computer Methods in Materials Science*, 18 (2018) 134-142.

A part of the results was presented as a contribution to the following conference:

- **2020**. The 23rd International Conference on Metal Forming (ESAFORM), Cottbus, Germany. Oral presentation: Hot workability of a spark plasma sintered intermetallic iron aluminide alloy above and below the order-disorder transition temperature.

Contents