

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
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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 °C / 10^{-3} s^{-1} , where significant twinning-induced dynamic recrystallization (DRX) of the dual-phase ($\alpha + \gamma$) microstructure occurs. In contrast, deformation conditions of 1150-1200 °C /

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 ($7 \mu\text{m}$) Fe-25Al-1.5Ta alloy strengthened by dispersed Laves phase particles using SPS compared to the coarse columnar microstructure obtained by casting ($500 \mu\text{m}$). 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 - $1100 \text{ }^\circ\text{C}$. The optimum processing domain for the Fe-25Al-1.5Ta alloy locates at 1050 - $1100 \text{ }^\circ\text{C}$ / 0.0013 - 0.01 s^{-1} with a 40 - 50% power efficiency, where the material undergoes dynamic recrystallization. However, deformation at $800 \text{ }^\circ\text{C}$ / 1 s^{-1} gives rise to the flow instability resulting from cracking.

Dedication

To my beloved parents

تقدیم به مادرم

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- **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.

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- 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.

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