IdentiTI

Nanostructured titanium alloy for an innovative dental implant

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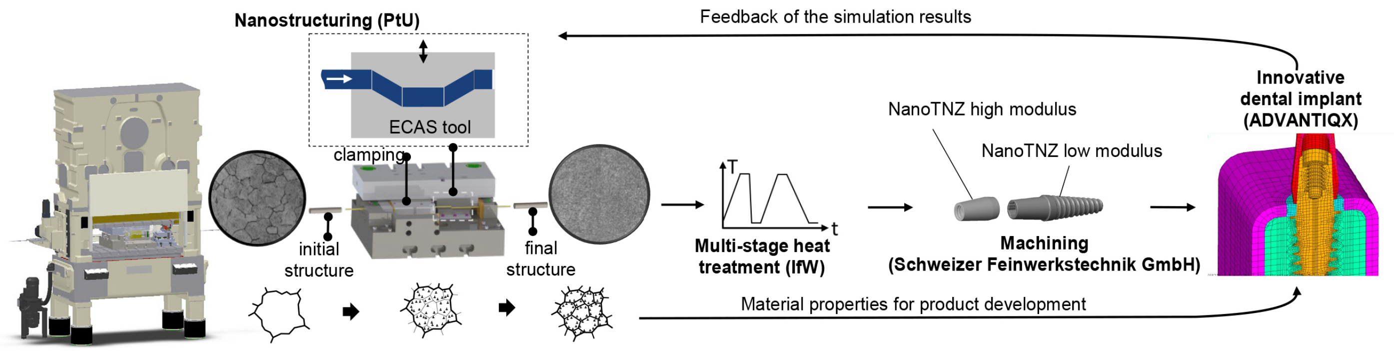
Abstract
The IdentiTI project researched a process chain for the continuous production of the nanostructured titanium alloy Ti-13Nb-13Zr. The aim was to develop an innovative implant system with outstanding properties for health and quality of life.

Project description
Around 1.3 million dental implants are placed in Germany every year. The titanium alloys used for the implant systems (such as Ti-6Al-4V ELI) pose a challenge for the service life of the implants due to their suboptimal chemical, mechanical and biological properties. These can lead to bone resorption, inflammation and loosening of the implant.

A newly developed implant system based on the nanostructured titanium alloy Ti-13Nb-13Zr (NanoTNZ) can overcome these challenges as NanoTNZ has promising chemical, mechanical, and biological properties. In particular, the fine-grained structure of the implant stimulates interactions between the implant and the surrounding body cells. This results in optimized bone healing, as a direct structural bond is created between the surface of the implant and the bone tissue. In addition, it is possible to adapt the modulus of elasticity of the nanostructured implant to the bone to prevent implant loss due to relative movements.

As part of this project, industrial and university project partners from various disciplines (implantology, machining, materials science and forming technology) cooperated with the aim of developing a new, innovative dental implant system. The Institute of Production Technology and Forming Machines (PtU) was responsible for the industrial production of the nanostructured titanium alloy NanoTNZ. The methodology is shown in Figure 1.

The Equal Channel Angular Swaging (ECAS) process developed at PtU enables continuous nanostructuring of materials. As part of this, the formation of fine-grained titanium from the coarse-grained starting material was investigated. Heat treatments were then carried out to adjust the material‘s properties. During nanostructuring, the material TNZ reacts sensitively to a large number of process parameters during heat treatment and forming. It was therefore necessary to have precise knowledge of all influencing variables and their effect on the product to control the nanostructuring in a targeted manner.



[1] Procedure in the development of the innovative implant system

Results

Forming simulation and process parameterization: First, a simulation of the ECAS process was developed to determine the process forces and parameters. The results of the simulations showed an optimal process strategy for multiple forming with a hydrostatic compressive stress state and increased forming temperature.

Design and manufacturing of the tools: An ECAS tool system for processing TNZ was then developed. Temperature and force sensors were integrated to monitor the process.

Adjusting the nanostructure: The relationship between process parameters and material properties was analyzed as part of the numerical and experimental investigation. The process limits resulted from shear bands (see Figure 2A) and wing formation (see Figure 2B). Damage-free production of NanoTNZ (see Figure 2C) was possible if a soft martensitic initial state, a hydrostatic compressive stress state and an increased forming temperature were set.

Design of a continuous route: To produce industrially usable rods for implant applications (see Figure 2D) and to achieve implant-adapted properties, additional operations such as heat treatments, rotary swaging and straightening were performed. The ECAS process was analyzed and optimized in terms of energy consumption. The heating of the process turned out to be the dominant factor, so the process was designed at low temperatures without jeopardizing damage-free forming. The rods have a straight nanostructured structure, are high-strength, simultaneously ductile and have a low modulus of elasticity. A homogeneous hardness distribution with a structure size of 200 nm was determined in the NanoTNZ material state.

Nanostructured dental implant: The results form the basis for the design of a continuous process chain for the economical production of NanoTNZ, which was demonstrated using a dental implant demonstrator (see Figure 3). Customized nanostructures (A, B) were adjusted on this demonstrator and examined regarding their antibacterial properties (C) and their influence on bone growth (D). The nanostructures show an antibacterial effect with simultaneously optimized bone growth compared to standard alloys such as Ti-6Al-4V ELI. The nanostructuring of titanium alloys using ECAS thus demonstrates a promising potential for the social benefit of advanced implants.

Acknowledgement

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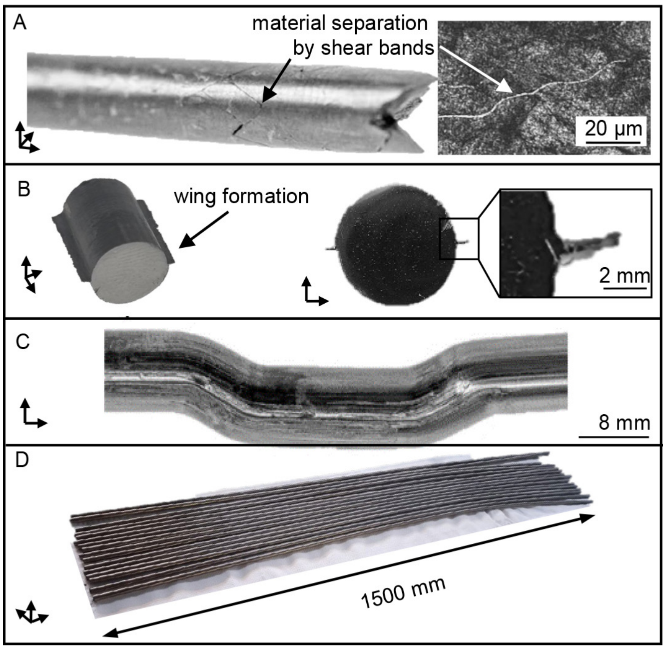
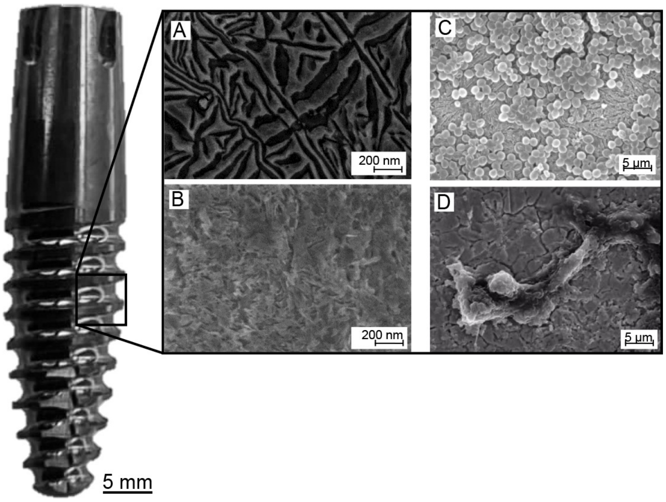


[2] Process limits and results: Material separation by shear bands (A), wing formation (B), successful forming (C) and semi-industrial bars (D)



[3] NanoTNZ dental implant with customized nanostructures (A, B), bacterial colonization (C) and bone growth (D)

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