DIAMOND

Development of Intelligent and Advanced Implants made of Nanostructured Ti13Nb113Zr Alloy

Coordinator	Dr.-Ing. Lukas Kluy | Stefan Kraus M. Sc.
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Department	Functional and Composite Structures
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Abstract

In the DIAMOND project, medical technology products are being developed using the alloy Ti-13Nb-13Zr, a second-generation titanium alloy that does not contain the critical alloying elements aluminum and vanadium and allows a wide range of mechanical, physical and biological properties to be set.

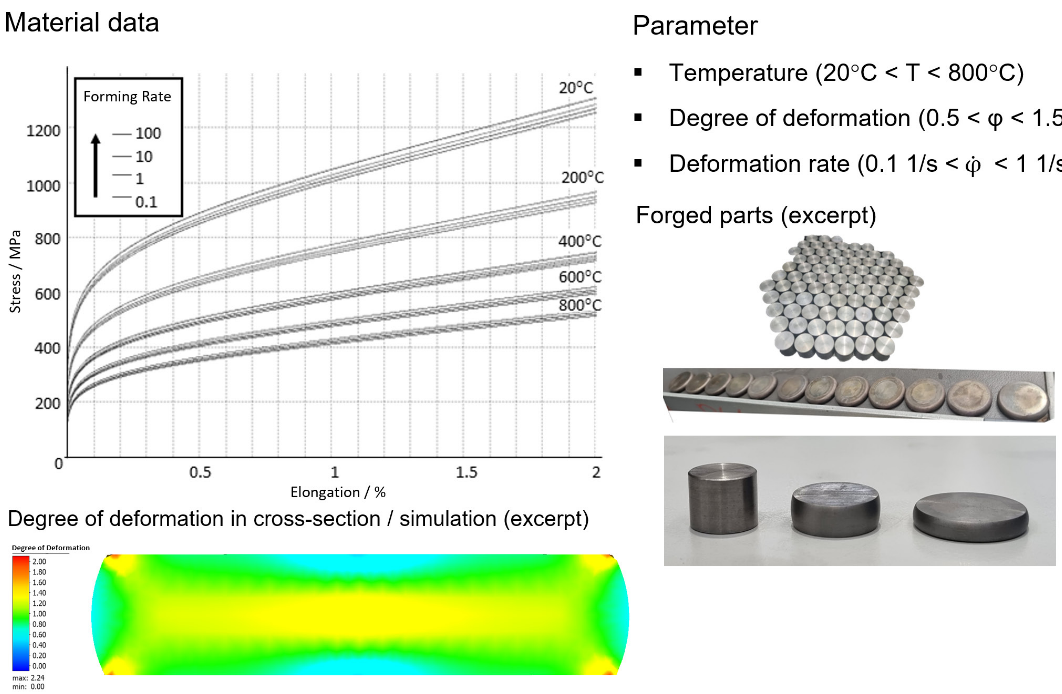
Project description

In the DIAMOND project, medical technology products were developed from the alloy Ti-13Nb-13Zr (TNZ), a second-generation titanium alloy that does not require the critical alloying elements aluminium and vanadium and allows the adjustment of a wide range of mechanical, physical and biological properties. The aim was to adjust a new generation of implants and osteosynthesis products made of TNZ in a multidisciplinary approach with a nanoscale surface structure. In this sub-project, a continuous moulding process (continuous multidirectional swaging) was developed to produce the nanostructure. The nanostructuring proved to be particularly sensitive to parameters such as temperature, forming speed and degree of forming. The optimum process conditions were first determined by forging-like tests. A NanoTNZ bone plate was then produced, which demonstrates the stable production of a homogeneous nanostructure using the novel process chain and at the same time fulfils the biological and orthopaedic requirements (homogeneous nanostructure, high strength and thin design).

Results

Simulation structure

The forming simulation software Simufact Forming 2021 with an implicit solver was used for the virtual process design. The thermomechanically coupled three-dimensional finite element simulations enabled a detailed assessment of the acting stress and the homogeneity of the workpieces in the longitudinal and transverse directions. The material models and process parameters were adapted to the specific application on the basis of the material parameters determined at the IfW. The parameters were varied depending on the temperature, the degree of forming and the forming rate (Figure 1). In addition, the tribological conditions were mapped by modelling the material-lubricant pairings used, whereby tangential, isotropic kinematic contact models were used. The tools of the continuous multidirectional swaging process (CMDS) were designed as rigid bodies with thermal conduction. Forming lengths of



[1] Forging-like cylinder crush tests for the recrystallisation tests

Institute for Production Engineering and Forming Machines – PtU
Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. Peter Groche | info@ptu.tu-darmstadt.de

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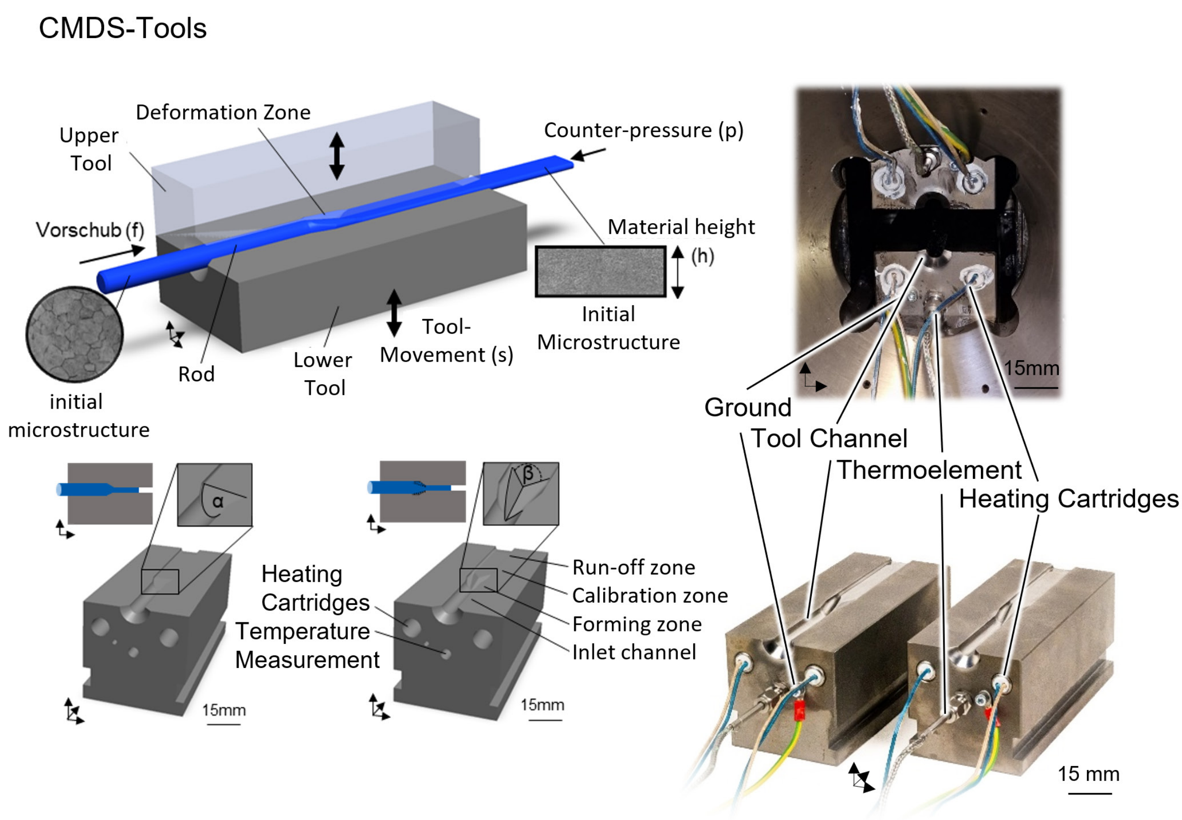


[2] The developed CMDS tools

50 mm were simulated to simulate a continuous process. The simulation results were checked for convergence and validated geometrically and analytically (Figure 3, see also WP4). The GOM ATOS 5 device was used for the geometric validation, with which the real samples were scanned in three dimensions. The deviations between simulation and experiment remained below 3 %, which demonstrates a high level of agreement. In the simulation, various tool geometries were initially analysed in order to derive promising tools for further investigations. This was followed by a systematic variation of the back pressure, the material thickness (reduction) and the number of forming passes in order to develop an optimum process route for a uniform strain distribution.

Tool geometry

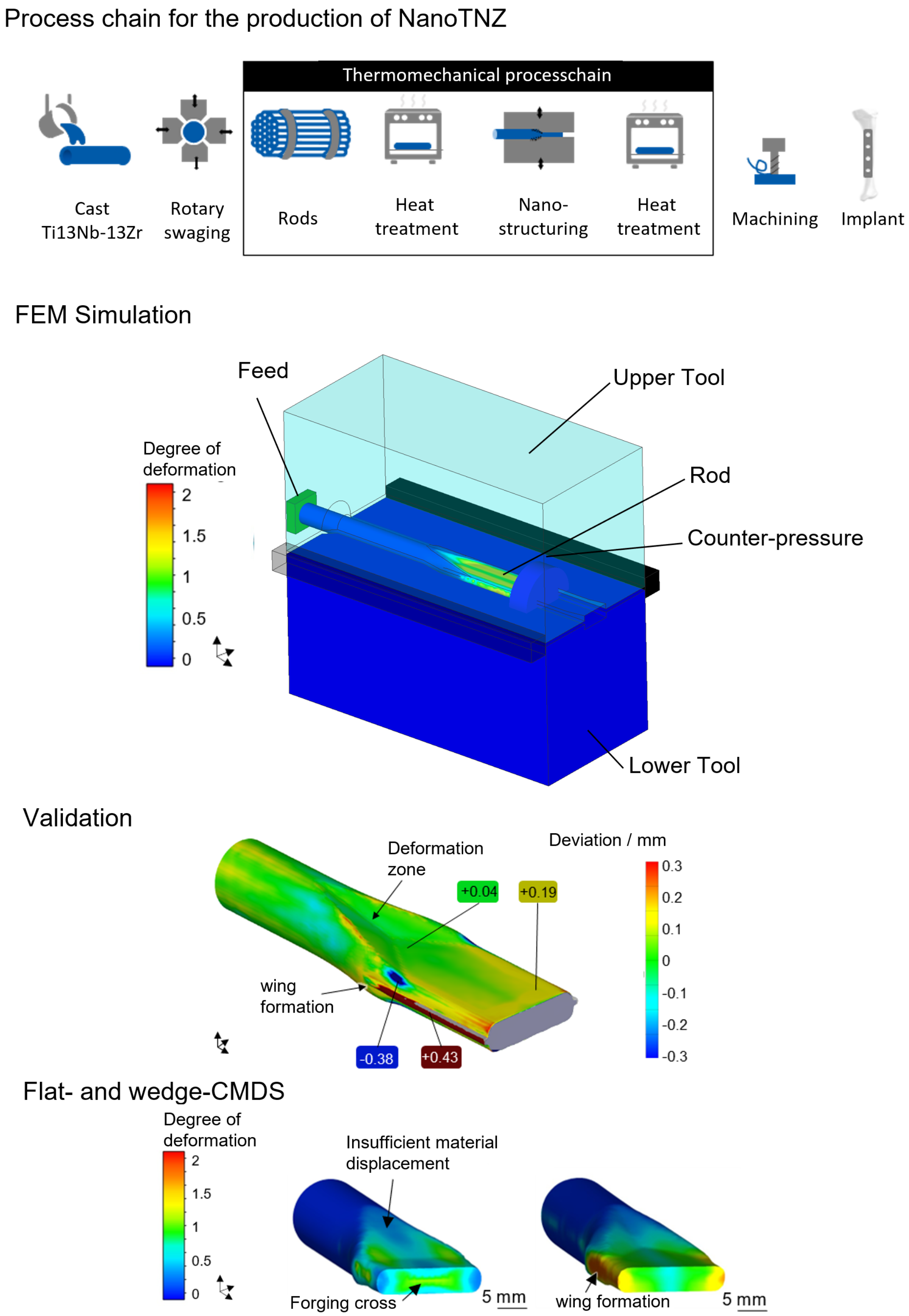
Figure 2 shows the tool geometries of the flat and wedge CMDS. The flat CMDS specimen is characterised by an inhomogeneous degree of deformation (inhomogeneous material displacement) and the formation of a forging cross. In particular, the degree of deformation distribution on the surfaces is inhomogeneous, whereas a homogeneous degree of deformation distribution on the surfaces is desired to form the nanostructure for the osteosynthesis plates. If a wedge geometry is introduced into the forming zone, this leads to homogeneous material displacement. The wedge CMDS geometry is therefore used for further investigations.

Counter pressure

The influence of the back pressure on the strain distribution can be seen in Figure 4. Without back pressure, the strain distribution in the cross-section is inhomogeneous, which is due to insufficient mould filling. With increasing back pressure, better mould filling is achieved. At a back pressure of 12 MPa and 24 MPa, the homogeneity of the strain distribution increases. In addition to the homogenisation of the strain distribution, a state of compressive stress is induced in the forming zone, which enables damage-free forming. A back pressure of 36 MPa leads to complete mould filling and a comparatively homogeneous strain distribution, even at the edges. However, the simulation shows buckling of the bar in front of the CMDS moulds, which would lead to a damaged bar in the real process. For the following tests, a counterpressure of 24 MPa is selected, which represents a compromise between homogeneity and formability.

Reduction and number of passes

In order to increase the homogeneity of the strain distribution, a different reduction (variation of the material height due to the infeed of the tools) and number of passes (1 to 2 passes) at 24 MPa back pressure are investigated as parameters for the degree of forming and the strain distribution. The strain distribution for the reduction of 50 % shows an inhomogeneous strain distribution with low total strain. If the infeed is increased and thus the material height reduced, the strain also increases. At a reduction of 60 %, the simulation shows a homogeneous strain distribution. At 65 % reduction, the material flows into the mould halves and wings are formed, which is why this method is not pursued further. If the rod is passed through the mould several times, the total strain increases according to the super-

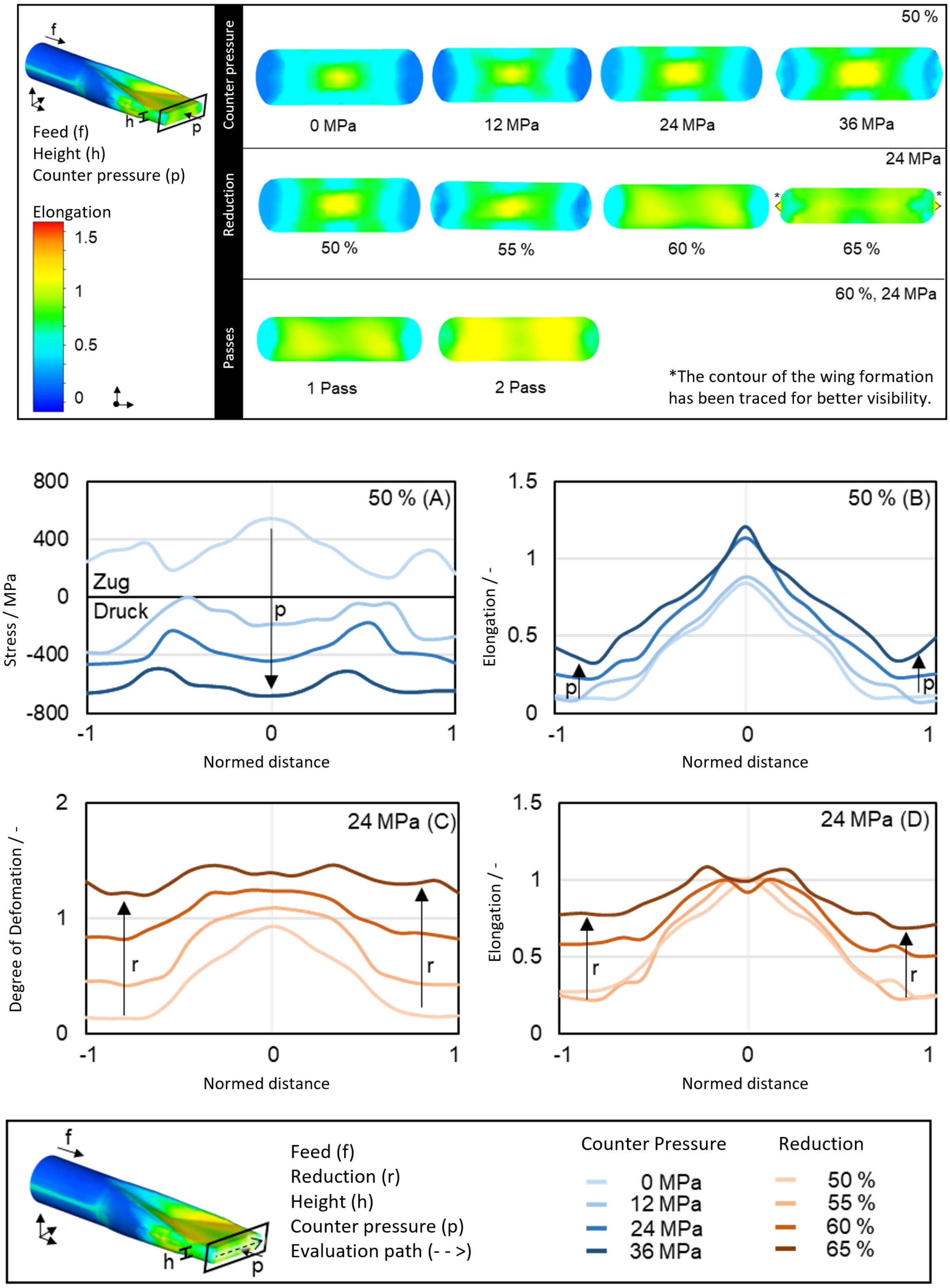


[3] Process chain and FEM with validation, geometry comparison between real sample and simulated sample

position principle. In particular, 2-pass CMDS shows a more homogeneous strain distribution than 1-pass CMDS.

Conclusion

The simulation results led to the identification of an optimal process strategy for 1-pass CMDS. With a back pressure of 24 MPa and a reduction of 60 % in order to achieve both a homogeneous strain distribution and a high degree of forming.



[4] Influence of the parameters back pressure, reduction and passes on the homogeneity of the strain distribution and on the degree of deformation

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Institute for Production Engineering and Forming Machines – PtU
Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. Peter Groche | info@ptu.tu-darmstadt.de

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