Optimization of a Porous Graded Ti-HAP Osteosynthesis Plate for Tibia Fracture Fixation

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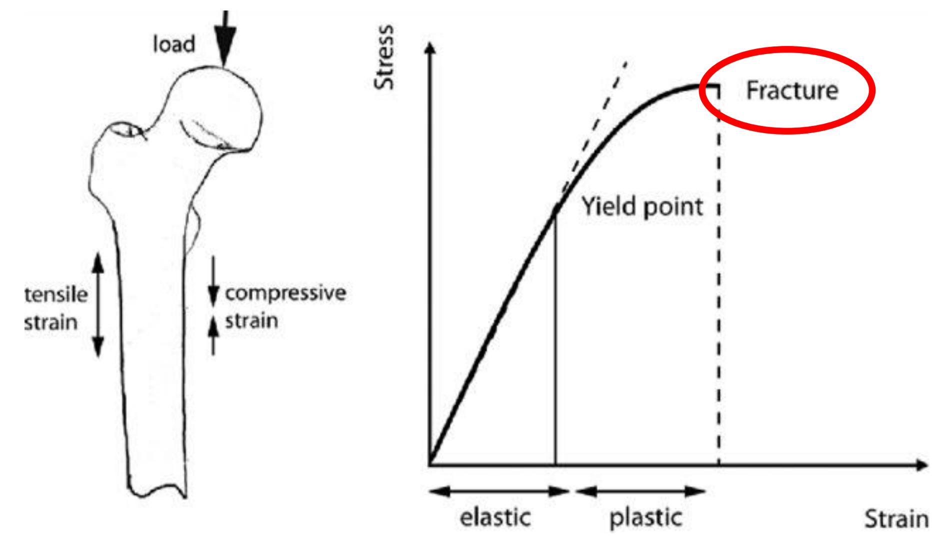
Introduction

Exceeding the strength of the bone can lead to its fracture.



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Bone healing using osteosynthesis plates

Titanium or steel plates:

- ✓ High strength
- ✓ High hardness
- ✓ Good biocompatibility
- ✓ Corrosion resistance

YOUNG'S MODULUS

HIGH vs. LOW

Stress shielding

Bone healing process

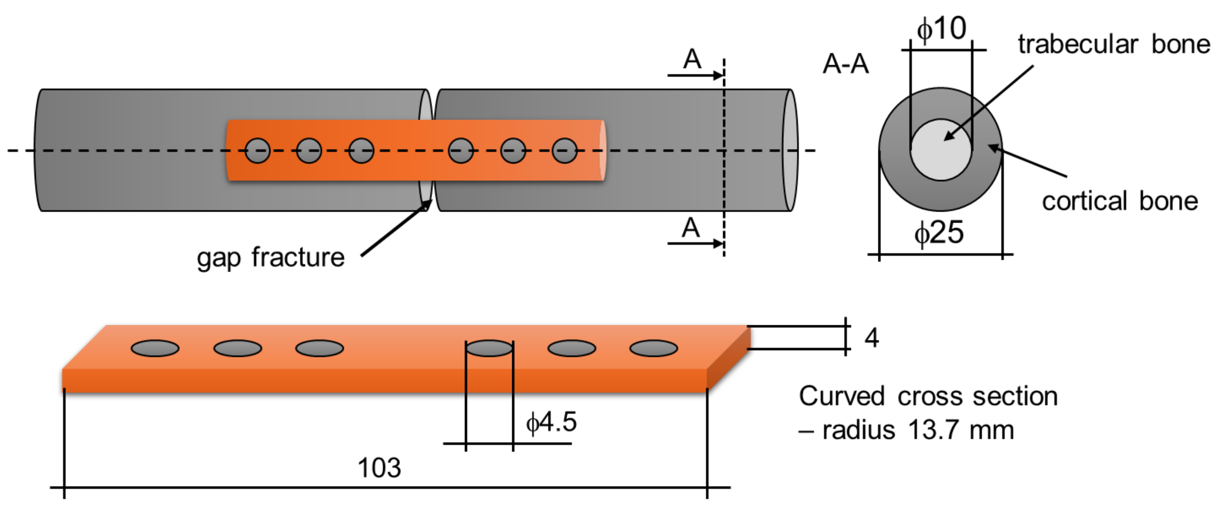
Functionally Graded Materials (FGM)

- ✓ Variable mechanical properties along a given direction
- ✓ Enhanced biocompatibility and tissue healing (porous od bioactive materials)
- ✓ Reduced stress concentgration (lowering stress shielding effect)
- ✓ Higher durability and reliability of implant

GOOD CANDIDATE: Titanium-hydroxyapatite FGM material

Hydroxyapatite – biocompatibility and mechanical properties close to bone tissue

Methods



Fractured conditions (angle):

- 0° (transverse fracture)
- 15°
- 30°

Material	Density [g/cm³]	Young modulus [MPa]	Poisson's coefficient [-]
Titanium Ti	4.5	116000	0.34
HAP	3.15	73000	0.28
Cortical bone	1.8	Ex-7000 Ey-18400 Ez-8500	Vxy-0.099 Vyz-0.065 Vxz-0.141
Trabecular bone	0.37	1020	0.225
Callus (1 week)	1.1	0.1	0.45
Callus (7 week)	1.434	10000	0.3
Callus (12 week)	2	15000	0.3

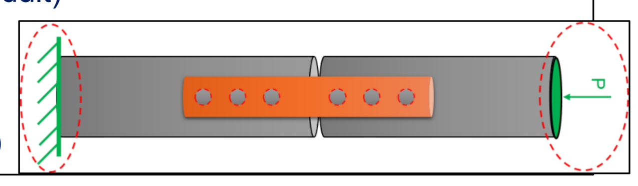
Effective FGM material properties

- *non-porous plate:* $P = (Pt - Pb)\, Vf + Pb$
- *porous plate:* $P = (Pt - Pb)\, Vf + Pb - \alpha/2(Pt+Pb)$
- $Vf = (z/h + 0.5)^n$

where: Pt and Pb – materials properties of top and bottom FGM layer
Vf – volume fraction of the plate
α – porosity parameter (0 for non porous plate, 0.1 and 0.3)
n – material distribution parameter in the layer (n={0.2; 0.5; 1})

Boundary conditions

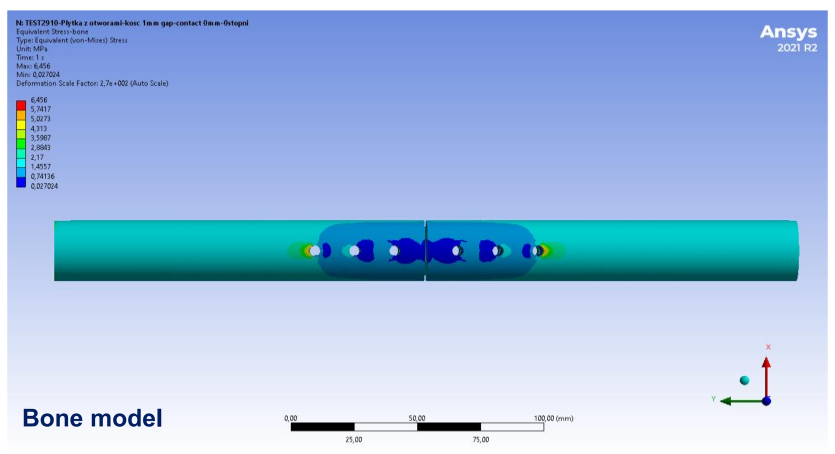
- Compression test
- Force F= 800 N (80 kg weight of adult)
- Gap fracture: 1 mm
- Ti-HAP FGM osteosynthesis plate
- Titanium screws
- No plate-bone contact (1 mm gap)



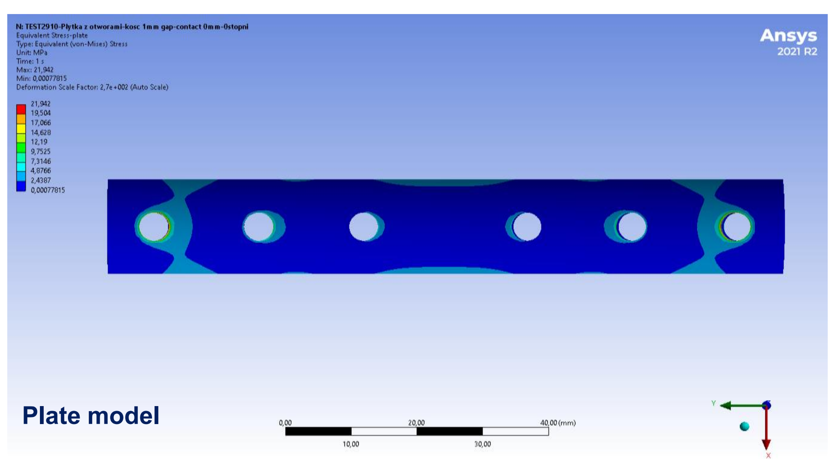
Results

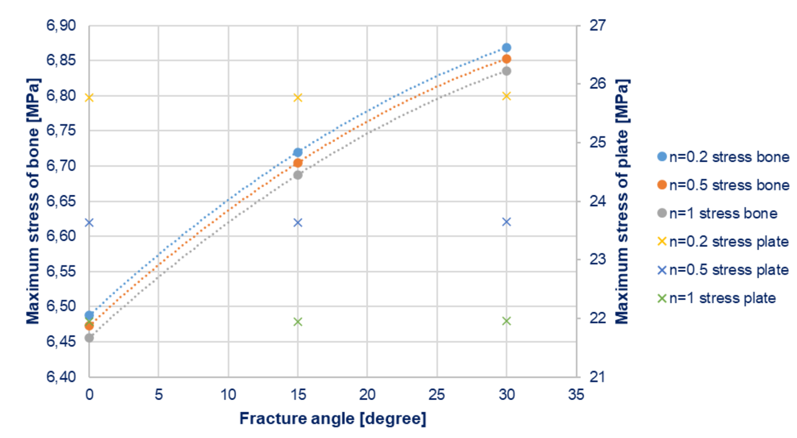
Parameter N of FGM material vs. Mechanical response

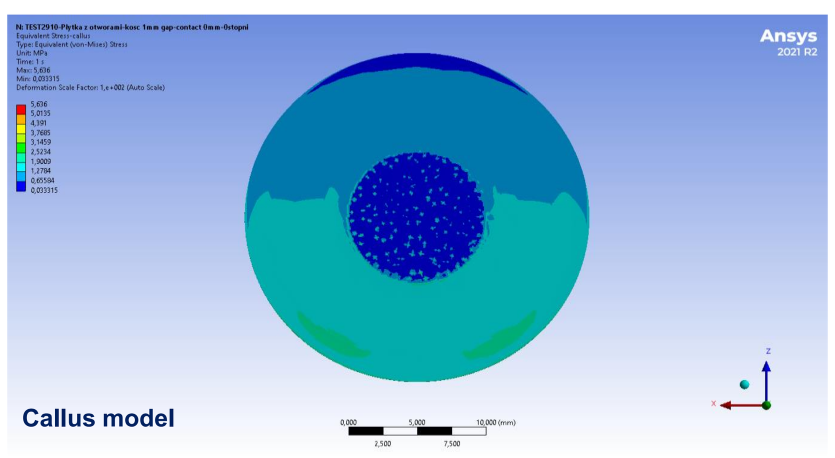
Maps distribution for model with FGM plate (N=1, non-porous)



Model with non-porous plate	Transverse fracture		
	n=0.2	n=0.5	n=1
Total deformation [mm]	0,067	0,067	0,066
Max. stress bone [MPa]	6,49	6,47	6,46
Max. stress plate [MPa]	25,77	23,63	21,94
Max. stress callus [MPa]	5,61	5,62	5,64



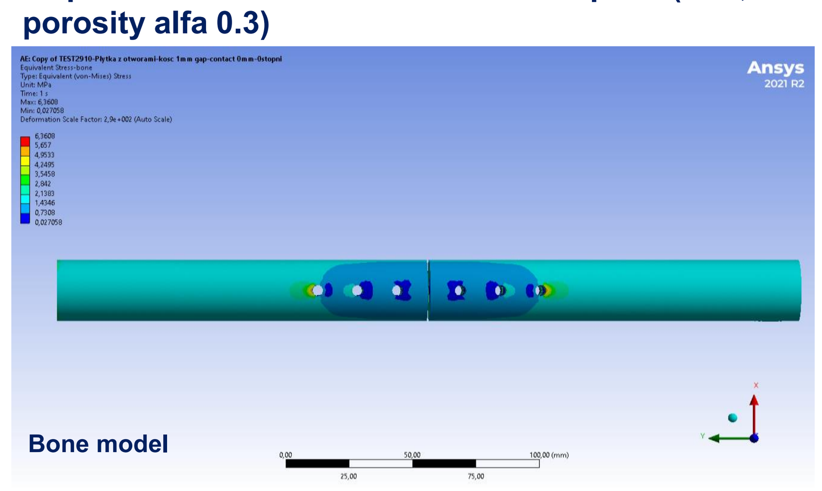


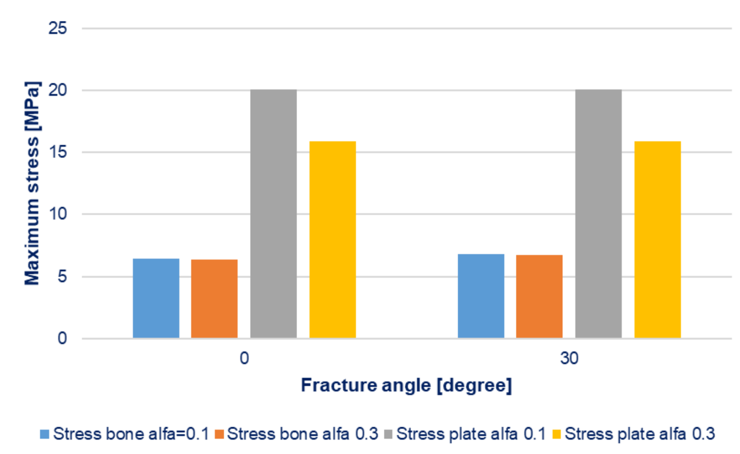


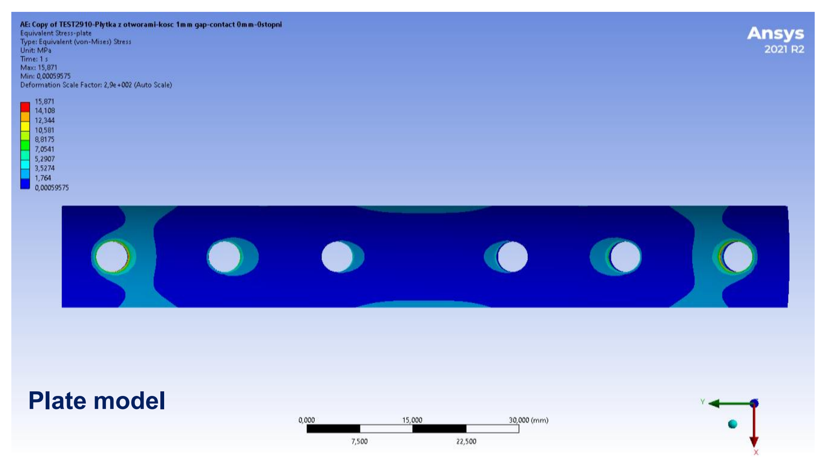
Porosity of FGM material vs. Mechanical response

Maps distribution for model with FGM plate (N=1, porosity alfa 0.3)

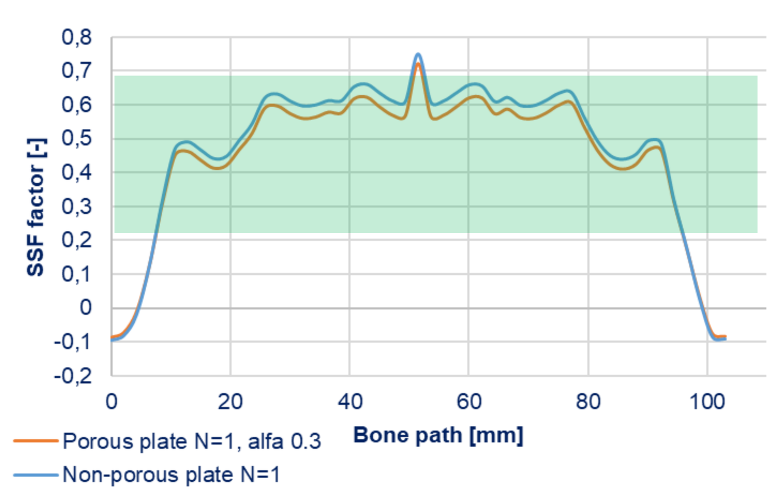
Model with porous plate	Transverse fracture	
	porosity α=0.1	porosity α=0.3
Total deformation [mm]	0,066	0,064
Max. stress bone [MPa]	6,43	6,36
Max. stress plate [MPa]	20,09	15,87
Max. stress callus [MPa]	5,65	5,68

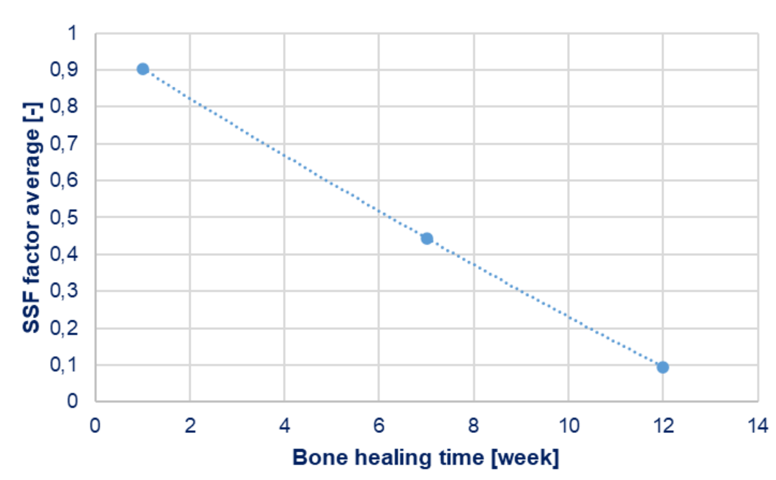


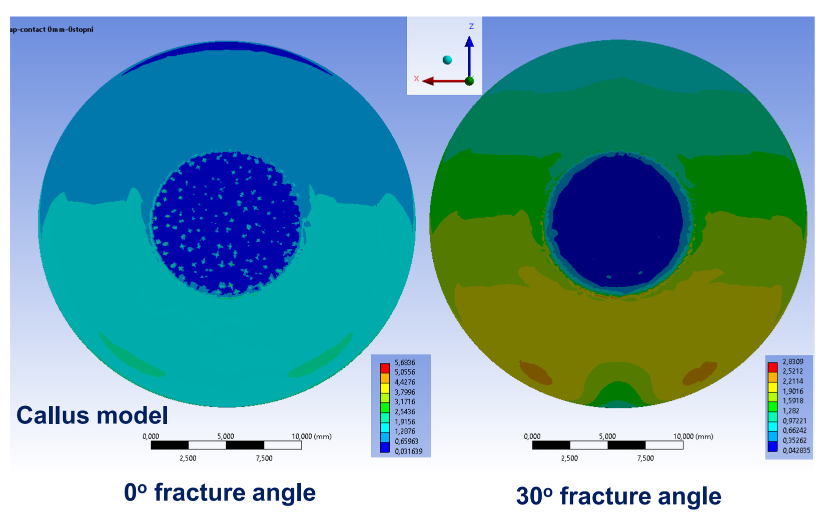




Analysis of stress shielding factor SSF







Conclusions

The performed numerical studies allowed the following final conclusions to be drawn:

1. Osteosynthesis plates made of the metal-ceramic Ti-HAP material with a gradient structure seems to be a good solution compared to commonly used implants.
2. A non-porous FGM plate with a gradient coefficient of N=1 contributes to low stresses and deformations in the bone–implant model.
3. The bone fracture angle does not significantly affect the deformations and stresses of the bone–plate system.
4. Introducing porosity into the Ti-HAP FGM plate leads to relatively similar stress values in the bone while significantly reducing plate stresses by 10% and 30% for porosity coefficients of 0.1 and 0.3, respectively.
5. A porous plate for bone fractures reduces the stress shielding effect, achieving acceptable coefficient values that decrease over the course of bone healing.

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