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Obtaining mechanical properties of superelastic materials from microindentation data

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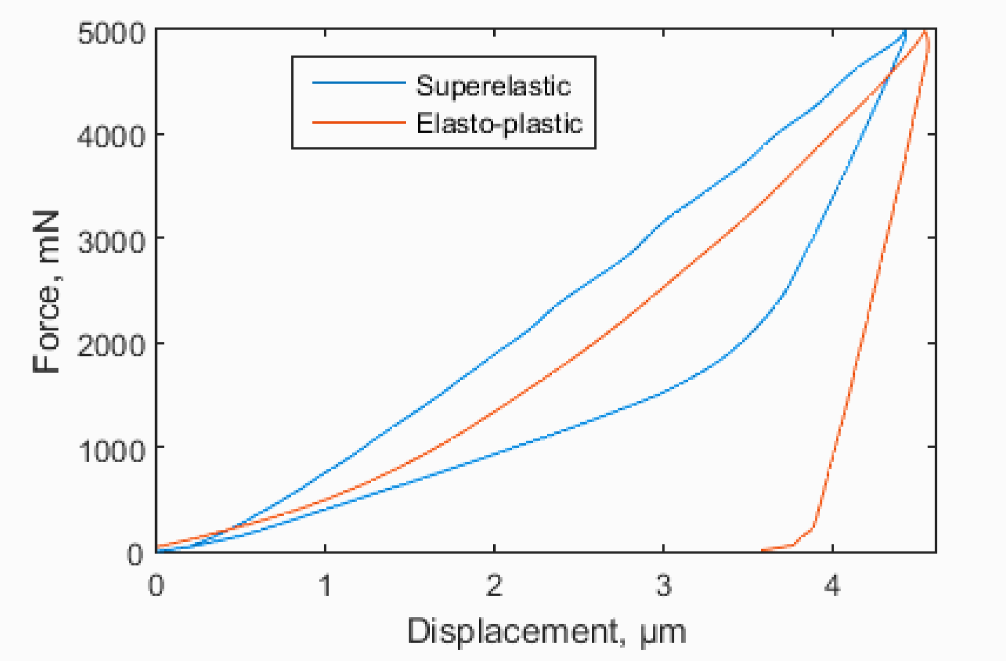
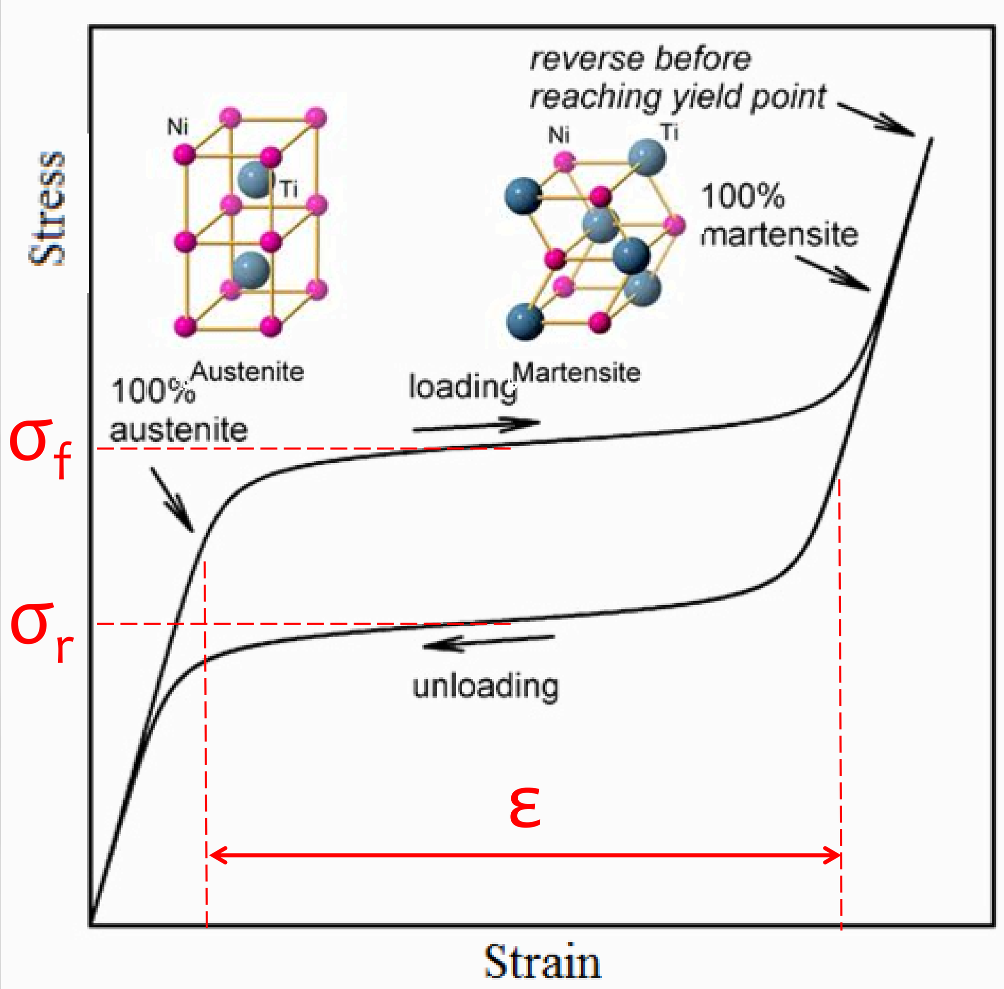
Introduction

This work is focused on indentation of superelastic (SE) materials with austenite - martensite phase transformation and extraction of material properties. Superelasticity includes two stages: (1) elastic deformation by ~0,2% due to interaction of neighboring atoms, (2) recoverable deformation by 2-9% and more due to martensitic transformations (MT). Finite element (FE) modeling was used to model indentation of superelastic alloys with spherical indenter. Several series of simulations were calculated with different elastic modulus of austenite and martensitic phases, stresses of phase transition in both directions. It is possible to create a method for determining mechanical characteristics of superelastic alloys using results of various materials' simulations.



Methods & Materials

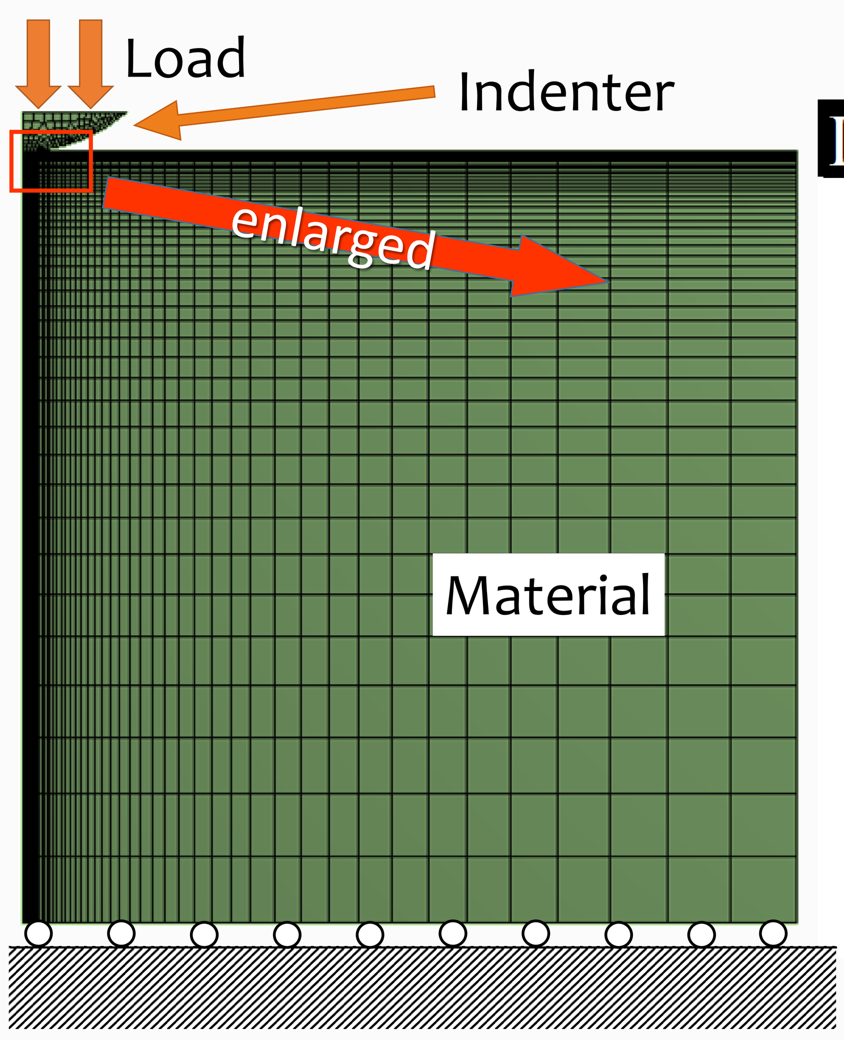
SE materials can deform recoverably to a very high degrees, up to 10%. Phase transformation initiates when stress is higher than the transformation start stress and fully performed after stress is higher transformation finish stress.



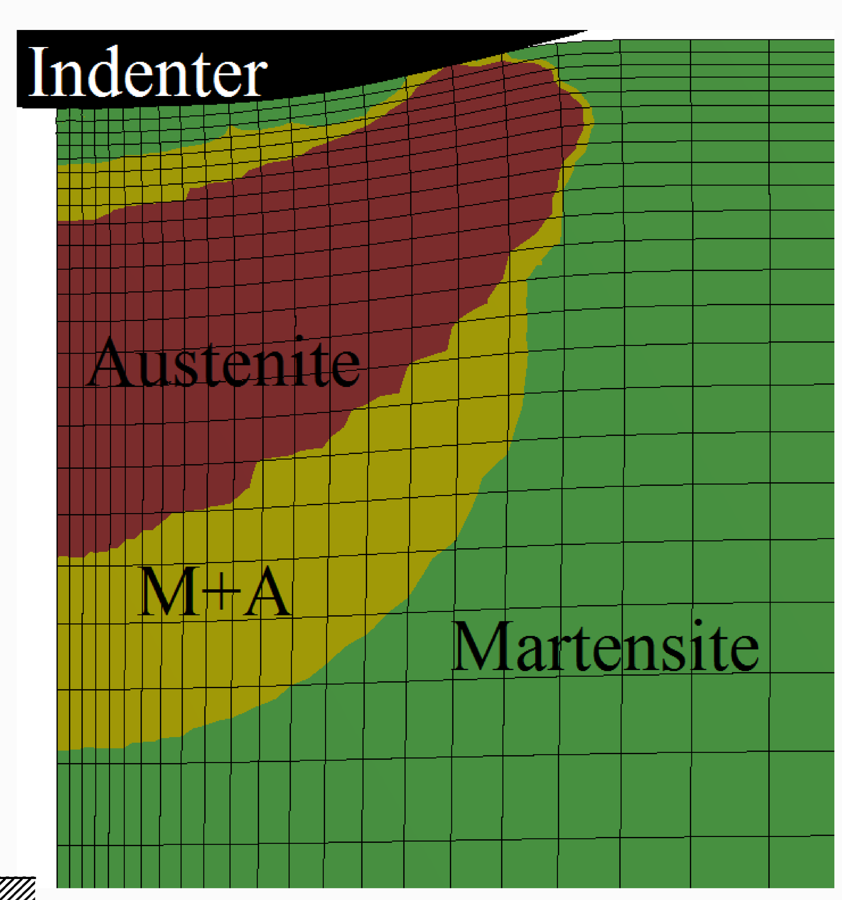
Use of SE materials:

- Medicine (in glasses, stents, dentistry, implants)
- Automotive
- Aerospace
- Sensors and actuators
- Civil structures
- Robotics

Finite element model and boundary conditions

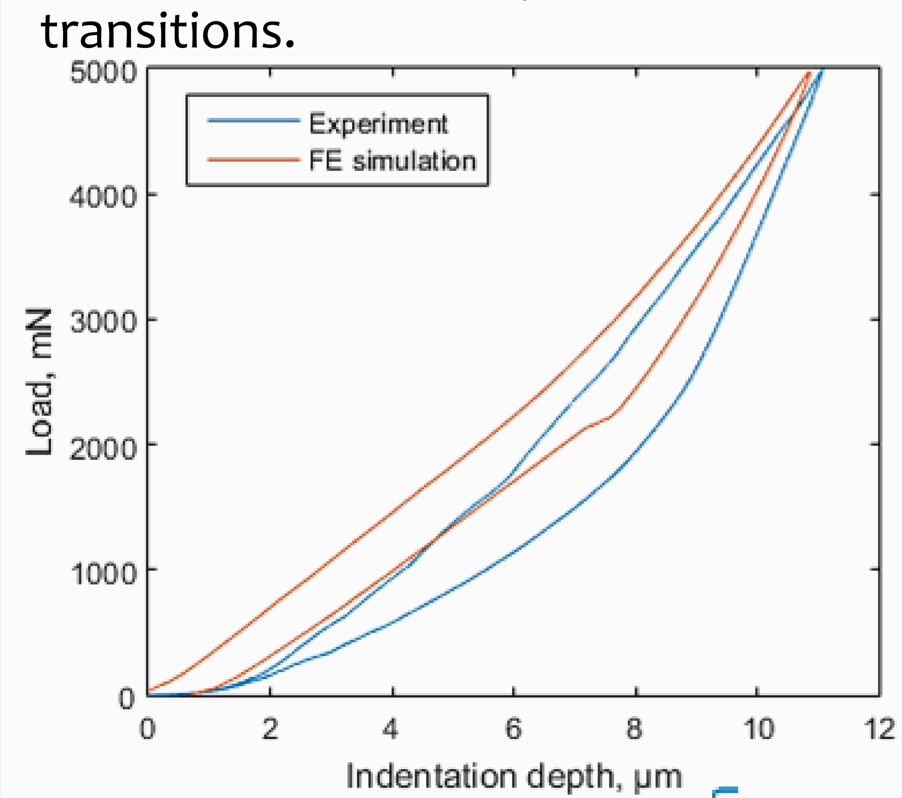


Areas of different phases at maximum load (enlarged view)



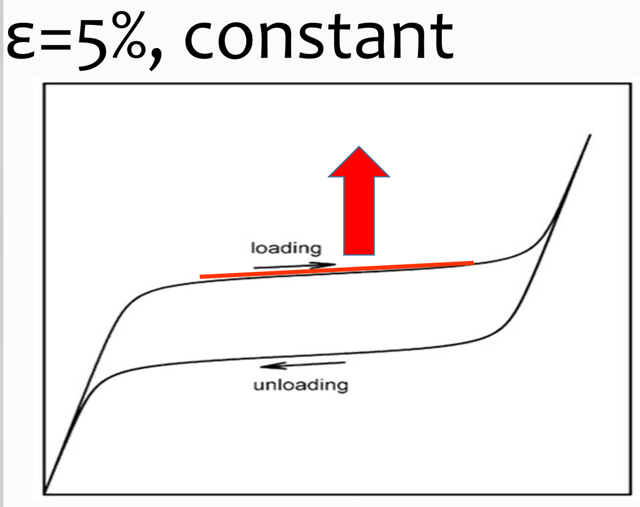
Results

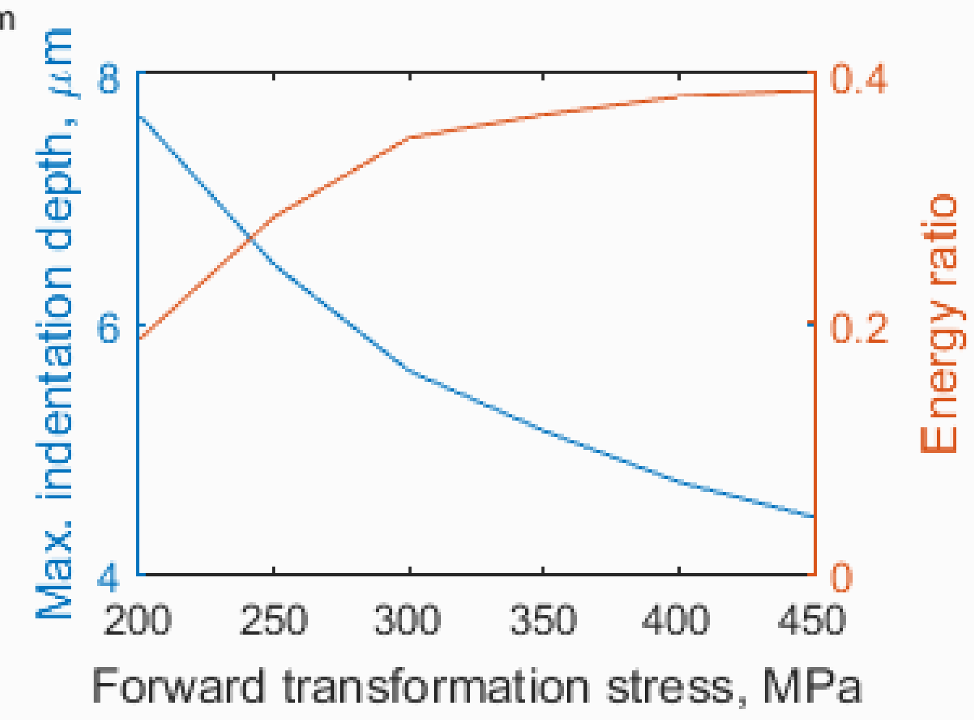
Mechanical properties varied for purpose of understanding the impact they have on results of indentation (force-displacement diagram). Below to the left is quantities what have been varied and to the right is some quantities of simulation results. It includes maximum indentation depth, ration of recovered to thermally dissipated energy. Difference between transformation stress start and finish taken 10 MPa everywhere for both forward and reverse phase transitions.



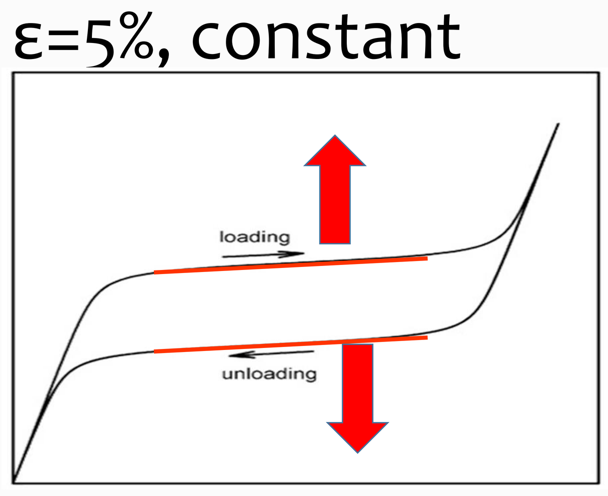
Comparison between FE simulations and indentation experiment for 55.1 Ni 44.9 Ti

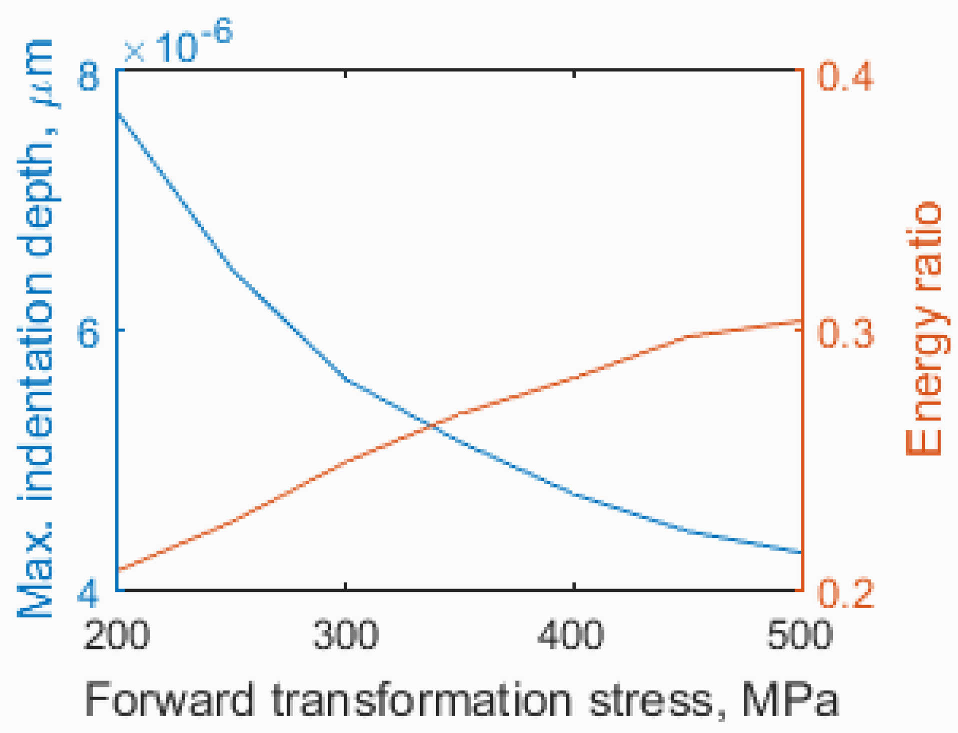
σ_f=200,250…500MPa
σ_r=150MPa, constant
ε=5%, constant

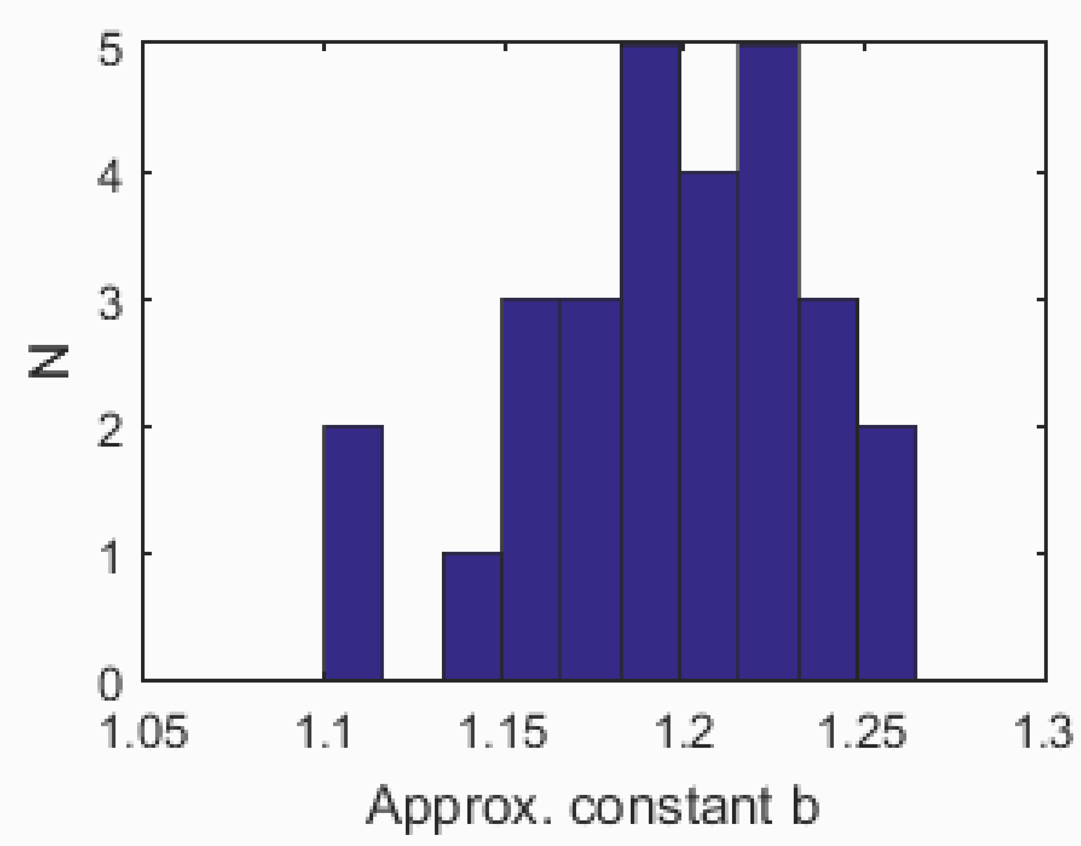




σ_f=350…500MPa
σ_r=300…150MPa
ε=5%, constant







$$P = \cancel{C}h^2$$

$$P = Ch^b$$

$$b \approx 1.22$$

Conclusion

Several series of simulations were conducted with different elastic modulus of austenite and martensitic phases, stresses of phase transition in both directions. It is possible to create a method for determining mechanical characteristics of superelastic alloys using results of various materials' simulations.

Relations between material properties and maximum indentation depth, ration of recovered to thermally dissipated energy and several more is found. Also, discovered that Kick's law (method of approximation of loading curve with square function) is not valid for SE materials.

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