The scientific goal of the project consists in fundamental research on the behavior of metastable materials produced using additive methods and strained at cryogenic temperatures (liquid nitrogen 77K and liquid helium 4.2K). A constitutive model of the plastic strain-induced fcc-bcc phase transformation will be developed, comprising new kinetics including nucleation, growth and coalescence of the secondary phase. Moreover, the constitutive model will describe multiphase material, consisting of the austenitic matrix and type Eshelby ellipsoidal inclusions, corresponding to both martensite variants: ε and α′. Also, based on the in-house experimental data, the phase transformation tensor will be introduced into the constitutive model, taking into account both the volumetric and the shear components. Finally, impact of the heat treatment on the mechanical properties and the phenomena occurring at extremely low temperatures will be examined. Among the phenomena, the intermittent plastic flow, the diffusionless martensitic transformation and the development of micro-damage in the metastable materials manufactured by using additive methods will be analyzed.

Among the typical materials used at cryogenic temperatures (including temperatures close to absolute zero), the austenitic steels from the TRIP group are very popular due to their good physical and mechanical properties. Additive AM technologies, i.e. additive manufacturing using 3D printing, enable the production of ready-made elements with complex geometry from austenitic stainless steels such as 304L and 316L. A representative of additive technologies is the selective laser sintering (SLM) method, popular in research and development departments of enterprises and scientific centers. The selective laser sintering process is a heat-activated process. Melting of the material is achieved by heating it with a high-power laser beam, followed by rapid melting due to heat conduction. This leads to the formation of a high temperature gradient between the remelted material and its surroundings, which causes thermal deformations and residual stresses, which translates into the mechanical and physical properties. This may be particularly important for the processes that austenitic steels undergo at cryogenic temperatures, such as the intermittent plastic flow, the diffusionless phase transformation and the development of microdamage. In order to adequately eliminate residual stresses caused by the manufacturing process, austenitic stainless steels will be annealed in various temperature ranges.

The next stage includes experimental tests under the influence of uniaxial loads in a wide range of temperatures (293K, 77K, 4,2K). The tests will be carried out using a unique set consisting of a vacuum-insulated cryostat placed in a testing machine. The cryogenic medium in the form of liquid helium or nitrogen is supplied via a dedicated transfer line from the dewar to the cryostat. The set is equipped with acoustic sensors to identify material degradation mechanisms, as well as a ferritoscope used to analyze the degree of phase transformation. The evolution of the microstructure will be examined using a scanning electron microscope equipped with crystallographic (EBSD) and chemical composition (EDS) detectors, as well as using synchrotron radiation.

An important stage of research includes constitutive modelling of the plastic strain-induced fcc-bcc phase transformation, containing new kinetics comprising decomposition into three stages, i.e. nucleation, growth and coalescence of the newly formed phase. The model is based on the classical rate independent plasticity, including the nonlinear hardening resulting from two mechanisms:
1) interaction of dislocation with the inclusions of secondary phase,
2) change of proportions between the primary and the secondary phase, resulting in the evolution of the tangent stiffness operator.

The importance of the obtained results is related to the development of new directions of research, such as understanding the phenomena occurring in the crystal lattice, developing the theory of plasticity and developing additive technologies. The obtained results have great material significance related to the microstructural analysis and constitutive modelling, which provides opportunities to design new materials. The research results are used in such fields as superconducting magnets in accelerator and magnetic resonance techniques, vacuum and pressure vessels operating at low temperatures, heat exchangers operating in liquid or superfluid helium, cryogenic lines for transporting liquefied gases, superconducting energy transport lines over long distances, structures operating in space and exposed to deformation at low temperatures, liquid hydrogen and oxygen transport systems in space technology.