Most naturally occurring and manufactured materials are polycrystalline materials. Particularly widespread and used for many years in many industries are metals that also have a polycrystalline structure. Such wide use of metals is associated with their high mechanical strength, good conductivity and good formability in various technological processes. The properties of metals and other polycrystalline bodies are closely related to their microstructure. Polycrystalline materials are made of small crystallites (grains) with dimensions usually from fractions of μm up to 100 μm, separated by grain boundaries. These crystallites have different orientations of the crystal lattice in relation to the system associated with the material, and the statistical description of the orientation distribution characterizes the so-called crystallographic texture.

The mechanical properties of single grains depend on the local forces acting on them and their orientation. When the local stress reaches a certain value and is properly oriented in relation to the crystal lattice, permanent plastic deformation of the grain occurs through sliding on the crystallographic plane. However, such deformation occurs much more easily in planes most densely packed by atoms and in directions where the positions of atoms are densest. That is, plastic deformation due to slips can occur only on certain planes and in certain directions, which are the so-called slip systems. This process depends directly on the shear stress for given system and whether it exceeds the so-called critical shear stress for that system. Moreover, when for a particular crystal lattice (e.g. hexagonal close packed lattice) there are few available slip systems, the phenomenon of twinning may occur. In this case slips occur simultaneously for adjacent planes, causing the transformation of part of the grain into the so-called twin grain with the same crystal lattice, but with orientation symmetric with respect to the common habitus plane. It is also a plastic deformation and can be described by twinning system.

From the description above, it follows that the macroscopic plastic deformation, under the externally applied load must depend on the deformation of individual grains, as well as on the crystallographic texture (i.e. grain orientation distribution) and the interaction between these grains. On the other hand, grain strains depend on the shear stresses on the slip and twinning systems, and thus on the state of local stresses for the grains. Therefore, there is a significant relationship between the plastic behavior of grains and the macroscopic behavior of the material, its mechanical strength and plastic formability.

To describe the plastic deformation of a polycrystalline material, a multi-scale model can be used, linking the grain behavior with the macroscopic behavior of the material (self-consistent models). In these models, it is possible to take into account the crystallographic texture, describe the slip and twinning phenomena, but it is difficult to unambiguously determine the interactions between grains. Therefore, there is a great need to find methods for direct determination of stresses on polycrystalline grains from the experiment. The diffraction method is an invaluable technique, thanks to which we are able to examine the stresses for groups of grains with specific orientations or belonging to individual phases. In our earlier works, we proposed original methodologies to determine the stresses for the grains inside the material (neutron and synchrotron diffraction) and close to the surface of the sample (low-energy X-rays). However, these methods were only tested for a simple single-phase material (magnesium alloy) and for simple strain modes (tension and compression).

The main aim of this project is the step forward and the application of our new original methodologies to study more complex materials, such as textured two-phase materials and composites, as well as to study the behavior of materials under complex deformations. The next stage of the research will be the verification of multi-scale models, using experimentally determined quantities as input data. It should be emphasized that the main goal of this work is to obtain as much information as possible about the plastic behavior of grains by means of experimental methods. With this information, the model can be validated. Previously, this was not possible because the assumptions of the model had to be introduced a priori.

The results obtained in this work will allow to describe the mechanisms of plastic deformation such as crystallographic slip and twinning (determination of the critical shear stress values) and directly relate them to the behavior of the material. Linking the phenomena at different scales will also enable to predict, using verified models, complex elastic-plastic deformations for polycrystalline materials with different degrees of crystallographic texture.