The evolution of the microstructure during the austenite/ferrite transformation in medium carbon steel is studied by three-dimensional x-ray diffraction microscopy, which simultaneously provides in-situ information about the ferrite nucleus density, the growth rate of individual ferrite grains, the ferrite volume fraction, and the average austenite grain size prior to the transformation in the bulk of the specimen. Based on the measurements, the classical nucleation theory is extended, taking into account the decrease in potential nucleation site density due to the formation of nuclei, the growth of existing grains, and the decrease in driving force for nucleation due to the overall increase in carbon concentration in the austenite during the transformation. The parameter $\psi$, defined by the activation energy for nucleation being equal to $\psi/\Delta g_V^2$, with $\Delta g_V$ the thermodynamic driving force, contains all the information about the shape of the nucleus and the interfacial energies that are involved in ferrite nucleation. This parameter is determined by comparing the measurements with the model. A single value for $\psi$ is found for three steel grades with different carbon concentration and is at least two orders of magnitude smaller than current models predict. The penetration power of high-energy x-rays in metals has been essential for obtaining these results.