ONE MILLION INDENTS, A HARDNESS (AND MODULUS) STORY

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Advances in nanomechanical testing have progressed to a point where high-speed mapping and large data sets have become achievable. An Edisonian approach to indentation spacing and rate determines the experimental parameters that are then applied to a modern Damascene steel. One million indents were then performed over a period of less than 6 days thereby mapping out an area of 1mm x 1mm with a spacing of 1µm. To make sense of the data, artificial intelligence algorithms are used to provide an analysis of the hardness and modulus data.

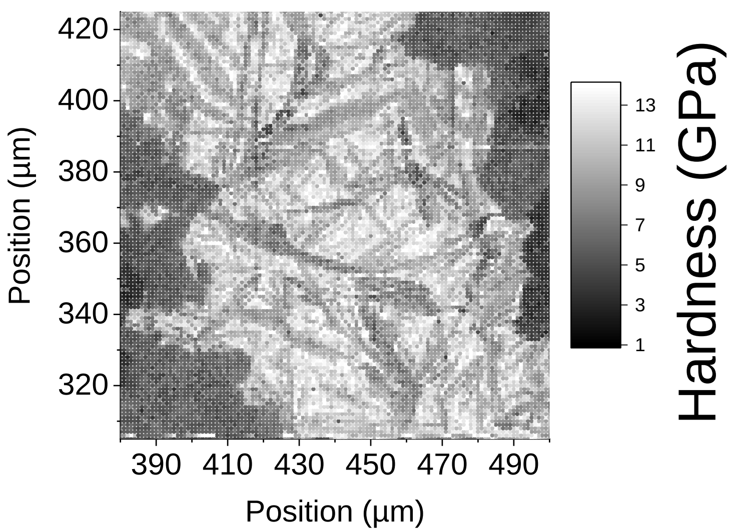

Figure 1 – Detail plot of the 1Mio indentation map; martensitic microstructure found in the layers of steel 1.2842. 90MnCrV8

Mapping a larger area of Damascus Steel reveals that the engineered material shows undulations of hardness at two to three different lengths scales. The largest wave length is formed by the engineered multilayer structure which is a result of the Damascus steel production process. Steel sheets of two kinds are stacked in an alternating way and mechanically held together. Then they are heated and forged in several steps resulting in a steel multilayer structure. Several annealing steps are needed throughout the process to reduce the internal stresses that are building up in the forging process. The steel stack is ultimately becoming a composite steel of high hardness and strength. The steel microstructures found in the two kinds of steel are martensitic for steel 1.2842 and perlitic for steel 1.2767. These microstructures are themselves complex composites of different phases in steel with a periodicity of the microstructure in the range of several 100nm to several µm.

Whether the undulations of mechanical properties are measured at the smallest length scales mentioned above depends on the size of the indentation test performed or the probed volume under the indenter. Modern instruments allow to offset the indenter repeatedly with increments of a few 10^{th} of nanometers to repeatedly perform indentation tests with small probed volumes, with penetration depth as small as single nanometers. The area to be investigated and the pitch between the indents as well as testing time available are related and will determine the resolution, too.
Several questions on how to perform a valid indentation experiment need to be addressed again with the high-speed mapping; namely the effect of strain rate, space between the indentation cup, necessary depth for a valid indentation experiment. But we find ourselves in a different position because the better statistics allows to view at theses aspects differently.

The data analysis of fast hardness maps allows to approach mechanical properties differently – by using artificial intelligence to look at phases , phase amount and spatial distribution. Pitfalls in AI for data clustering are also presented in this talk, but on smaller, less complex data sets.