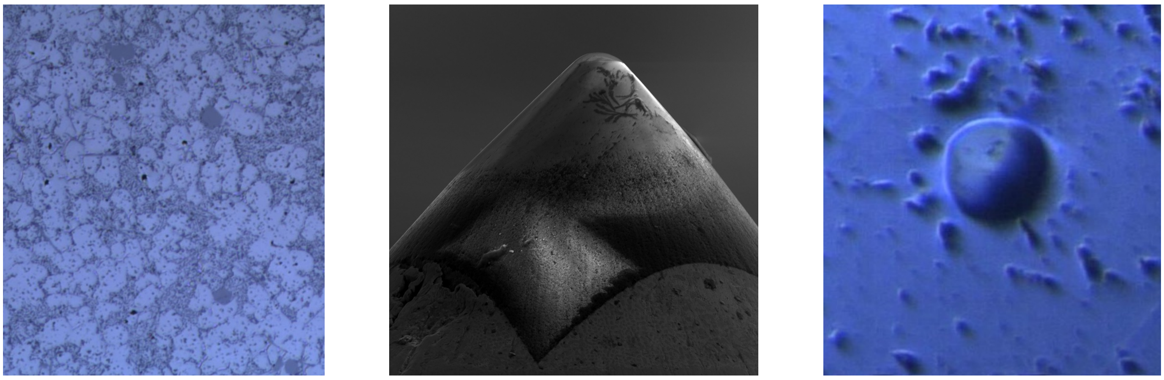
Material science:

Using Nanoindentation to draw big conclusions

When streamlining material models in the production industry there is a need to achieve energy efficiency and reduce carbon dioxide emissions, achievable partly by optimising component production. Implementing current research of Nanoindentation at BorgWarner makes it possible to try new techniques of determining material properties directly on components used in the industry today.



From left to right: The microstructure of an aluminium alloy, a nanoindenter with a tip radius of 25 µm, and the residual imprint after a nanoindentation.

The standard procedure for determining the strength of a material, is by performing a tensile test. A tensile test is when a sample of a material is pulled until breaking, and results in a stress-strain curve showing the strength of the material. However, a tensile test can only provide the average material behaviour, which is enough for most materials. But not all materials are properly represented by the average strength. For instance, if a material has been partially heat treated to make it stronger in certain segments, as is the case with this project, a tensile test would still only provide the average properties of the material. To be able to provide accurate data of the different regions, the thesis[1] aims to estimate the varying strengths by using nanoindentations.

A nanoindentation is performed with a small indenter, usually in the shape of a cone, sphere or a pyramid. This indenter is used to perform a small dent in the material. The indentation is typically performed up to a depth of approximately 1 µm. The output from a nanoindentation is a load-depth curve showing the force needed to reach certain depths and provide useful information about the elasticity of the material. It is then possible to estimate the strength of the material using various methods for relating the load-depth curve to the stress-strain curve.

The method used in the thesis[1] to translate the data from indentation to a larger material perspective, is an analytical method based on the works by Xu and Chen.[2] It is a mathematical method derived from classical contact mechanics and geometrical relationships. Analytical methods are, because of them being based in these basic relationships, desirable to use, but also problematic because of their inherent inability to compensate for deviations in experimental settings.

The experimental environments sensitive nature, acting on a nanoscale and thereby trying to circumvent the significant microstructural influences, led to inconclusive results. But the method showed great promise in being able to compare the strengths of distinct regions of material as well as different materials to one another, which can be used by the company today.

For the future, the thesis[1] recommends BorgWarner to also look into an exciting possibility to incorporate Machine Learning Algorithms into the handling of experimental data. MIT recently published an article[3] about converting nanoindentation data into material properties with the help of a neural network, showing great potential in combining an analytical approach with the capacity of fine-tuning the system to understand experimental environments.

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[1] Lindsjö & Linander: A method for developing stress-strain relationships using Nanoindentations, Lund, Dec. 2020.

[2] Baoxing Xu/Xi Chen: Determining engineering stress–strain curve directly from the load–depth curve of spherical indentation test, in: Journal of Materials Research 25.12 (2010), DOI: 10.1557/jmr.2010.0310, pp. 2297–2307.

[3] Lu et al.: Extraction of mechanical properties of materials through deep learning from instrumented indentation, in: Proceedings of the National Academy of Sciences 117.13 (2020), pp. 7052–7062, URL: https://www.pnas.org/content/117/13/7052.