Publishable Summary for 22RPT01 TracInd BVK-H
Traceability for indentation measurements in Brinell-Vickers-Knoop hardness

Overview

Hardness is an important material property determined by measuring an indentation size realised on the tested material surface in the Brinell, Vickers and Knoop (BVK) scales. This project will investigate the indentation measurement phenomena to provide a better defined, more consistent, unified and reliable measurement and traceability methodology to overcome the inconsistency between NMIs and lower levels of indentation (hardness) measurements as well as between NMIs. The project outcomes will be used in the next generation of hardness definitions, instrumentation and standardisation to improve the accuracy of material testing in all engineering fields, including aerospace, automotive, health, industry, and research and development.

Need

Material properties are crucial factors in construction, design and engineering. Knowledge of the critical mechanical properties of materials used in production and construction is essential to prevent health and safety hazards, control the costs of production, and create better designed, healthy and consumer friendly products. This knowledge is obtained through the establishment of accurate, reliable and consistent reference standards for material properties at NMIs and a link to end-user measurements for the lowest level test in a workshop through a continuous traceability chain. Brinell, Vickers and Knoop testing methods are three of the most important ones used for testing the hardness of metallic materials. Hardness is determined in these scales by measurement of the size of an indentation made with an implement of known geometry and properties on the surface of the material with a known force. There are many types of indentation measurement systems and methodologies. The indentation size measurement is completely dependent on the image magnification and processing instrument, the operator, and software if any. There are significant hardness measurement inconsistencies among NMIs, as well as between NMI and testing laboratories due to a lack of a well-defined methodology and specifications for the variety of indentation measurement instruments used. For example, optical microscopes with different numerical apertures (NAs) and software give different measurement results. This issue was demonstrated in 2005 at the NMI level in the CIPM Brinell Key Comparison, CCM.H-K2. At the lower levels of the measurement chain, the problem is much more evident. Traceable propagation of the reference value from NMIs to testing laboratories is not achieved due to the variety of simple devices used for testing without controlling all parameters. This project aims to overcome these critical problems by establishing the necessary methodologies and references for consistent, unified, reliable and traceable hardness indentation measurements from the NMI level to testing laboratories.

Objectives

The overall objective of this project is to establish a traceable, consistent, and reliable indentation measurement methodology, considering the influence of measurement parameters and instrument specifications, for Brinell, Vickers and Knoop hardness scales. The specific objectives are as follows.

1. To establish universal definitions for indentation boundaries for Brinell, Vickers and Knoop hardness scales and to determine the required measurement parameters to be used with the highest accuracy and most commonly used instruments at the NMI level (scanning and optical) for the detection and measurement of indentation dimensions in line with relevant ISO standards.

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2. To develop and validate stable reference indentation artefacts representative of the full Brinell, Vickers and Knoop hardness scales for propagation of traceability from NMI level to end users and to ensure inter-NMI comparability and consistency of indentation measurements.
3. To develop a methodology to ensure robust traceability for Brinell, Vickers and Knoop hardness measurements, from NMI to user level, through determination of the effect of influence factors on measurement results, and the development and validation of uncertainty models considering the most commonly used instrumentation at all levels and the applicable documentary standards. Additionally, to produce recommended technical specifications for manufacturers of hardness calibration and testing instruments.
4. To develop the software of an existing indentation measurement system (IMS) to automatise the determination of indentation locations and their measurements where possible and to determine the types of indentations that are suitable for such measurements and classify them.
5. To facilitate the take up and long term operation of the capabilities, technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs/DIs, calibration and testing laboratories), standards developing organisations (ISO), and end users (e.g. industry, regulators, manufacturers). The approach should be discussed within the consortium and with other EURAMET NMIs/DIs e.g. EURAMET TCs or EMNs, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

Progress beyond the state of the art and results

Development of methodology for Brinell-Vickers-Knoop indentation measurement:

Indentation measurement is generally realised with optical measurement devices, such as an optical microscope, with which two perpendicular diameters for Brinell, two diagonal length of Vickers and one diagonal length of Knoop indentations are measured. After inconsistent results were found in indentation measurements performed in the CIPM Brinell Key Comparison, CCM.H-K2, in 2005, the reason was found to be a significant effect caused by the use of lenses with different numerical apertures (NAs). It is now advised to use NAs equal to or larger than 0.4 and measurement traceability is established via a certified stage micrometer (line scale). Yet, there is still no firm definition for the borders of indentations in all three scales (BVK) needed to determine the start and end points of the dimensional indentation measurements, which continues to be a source of measurement inconsistencies.

This project will establish a definition for the border of the circular shaped indents in the Brinell scale for different sizes and shapes (sink-in vs pile-up), for the corners of the square shaped indent in Vickers and the equilateral indent in the Knoop scale for different shapes (hard and soft). Then, specification will be determined for recognising the borders and corners the indentations. At the conclusion of this project, end-users will have precise definitions of the measurands in the Brinell, Vickers and Knoop scales, and a standardised method for identifying their boundaries.

Development Brinell-Vickers-Knoop reference indentations:

The traceability in indentation measurement is established by calibration of the IMS via a certified stage micrometer and a reference indentation on a hardness reference blocks, but these indentations are certified only by the NMI or calibration laboratory with their own IMS. The traceability in 2D (via stage micrometer) is easy to manage because the marking on the stage micrometer is more obvious and the imaging system and operator effect is much less. However, in actual indentation measurements, results vary according to system performance and imaging parameters due to the 3D characteristic of the indentations.

This project will design and develop a set of long-term stable reference indentations for representative scales and hardness levels to serve as transfer standards which will ensure accurate dissemination of the scales and traceability of measurement results.

Development of traceability chain from NMI to user level:

Hardness testing machines are produced without regard to considerations of traceability or correlation between the highest measurement systems and the simpler ones used in industry. There is lack of understanding of relevant definitions and traceability requirements in the applicable ISO and ASTM hardness standards which causes very significant deviations in implementation.

This work will develop a methodology to unify propagation of traceable and consistent indentation measurements from NMI and DI level to calibration and testing laboratories. Furthermore, recommendations will be drafted for producers of hardness calibration and testing machines to ensure the compatibility of the machines they produce with higher level systems and the consistency of measurement results throughout the measurement chain.

Automatisation of indentation measurements:

Indentation measurement systems at NMIs and DIs operate either manually or semi-automatically. Semi-automatic measurement enables measurement of the size of an indent in one direction after which the indentation must be manually rotated by 90º to make the second diameter or diagonal length measurement. This can be done only for one indentation although there have been trials to measure more than one indentation by specifying the location manually by the operator before their realisation. In entirely manual measurement systems, the border of indentations is decided by the operator which means there may be significant inconsistency between measurements performed by different operators.

In this project, the indentation measurement system present at TUBITAK will be revised to improve its software and mechanical components to demonstrate full automatisation of indentation measurements. After the revisions, the locations of indents will be selected through the software and marked on a hardness block by the indentation measurement system (IMS) automatically, the indents will then be realised on the block by primary standard machines, and then the block will be placed in the IMS in its first position where the indentation locations were marked and saved by the software and indentation measurements will be realised automatically. This will be done for indentations for which edge detection with image processing are possible. Differently sized and shaped indentations will be analysed to determine the characteristics of those suitable for automatic measurements.

Outcomes and impact

Outcomes for industrial and other user communities:

This project aims to improve the reliability of hardness tests at the industrial level by providing a better defined hardness (indentation) measurement methodology and sets of reference indentations agreed upon by the NMIs to provide traceability in BVK hardness scales. More importantly a methodology for traceability from the NMI level to the end user will be developed and based on this a set of recommendations for hardness testing instrument producers will be produced and disseminated. Uptake of the recommendations will enable a new generation of instrumentation for BVK hardness tests that produce results that are more consistent with the higher level machines. On a wider scale, more accurate, reliable and consistent hardness measurements will benefit all industries in which such measurements are central to producing higher quality, durable and safer products.

Outcomes for the metrology and scientific communities:

The problem at the core of this project is the source of the traceability in hardness measurements, which is the definition of the indentation and the methodology for its measurement. The first outcome of the project will rely on a scientific approach to indentation phenomena to arrive at a universally applicable and clear definition of its borders, and accordingly, a uniform method for its measurement. This will enable more accurate and consistent measurement results, and consequently, improved hardness calibration and measurement capabilities (CMCs) at NMIs and DIs and a significant advancement in hardness metrology. Automatisation of hardness measurements, which will be demonstrated at an NMI in this project, also brings the prospect of faster and more cost-efficient measurements which are less affected by operator related errors.

Outcomes for relevant standards:

The main outputs of the project, including BVK indentation definitions, uncertainty models and methodology for establishment of traceability for BVK hardness measurements will be used as input to improve ISO 6506-1, ISO 6506-2, and ISO 6506-3 for Brinell, ISO 6507-1, ISO 6507-2, and ISO 6507-3 for Vickers, and ISO 4545-1, ISO 4545-2, and ISO 4545-3 for Knoop hardness tests, which currently have significant deficiencies. ASTM standards ASTM E92, ASTM E384 and ASTM E10 may also be improved as a consequence. Standardisation is envisioned to be one of the main conduits for widespread uptake of project outputs by industry and other end-users.

Longer-term economic, social and environmental impacts:

More consistent, reliable and traceable measurements of material properties will enable better, safer product design and manufacturing at a lower cost. Hardness tests are widely used material testing methods to obtain preliminary information about abrasion and strength properties of a material easily and quickly. The durability of a selected material is critical to the proper, predictable and safe functioning of manufactured products and components and the safety of the built environment.

Europe is one of the largest producers and exporters of highly engineered products, including aircraft, automobiles and other vehicles, defence systems, durable households' goods, etc, for which accurate and reliable knowledge of constituent materials is key to quality, and by extension, product marketability and demand. Having access to reliable and traceable hardness measurements will thus benefit European industry and its competitive position on global markets. More directly, the uptake of the recommended technical specifications for hardness testing machines by manufacturers will ensure that European producers will have an edge over their rivals in this field.

Failures of material in wastewater and waste disposal infrastructure and in systems for storage and transportation of toxic and hazardous substances are an instance of a source of environmental damage that could be ameliorated through better measurement of material properties so that their critical failure points are known with greater accuracy and reliability. Inconsistent and incomparable measurements, as is currently prevalent in hardness testing, introduce an unacceptably high level of risk of failure in systems needed for the safe handling of toxic substances. With better testing of hardness, and therefore of material durability, the infrastructure, systems and products that are relied upon to protect the environment can be expected to be more suitable for purpose, longer lasting and less likely to unpredictably fail.

Finally, safer and more reliable products, a reduction in the likelihood of hazards and accidents caused by product failure, and an appreciable improvement in the quality of the built environment will serve to enhance societal health and wellbeing.

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		01 September 2023, 36 months
Coordinator: Cihan Kuzu, TUBITAK Project website address: -	Tel: +90 552 6961028	E-mail: cihan.kuzu@tubitak.gov.tr
Internal Beneficiaries: 1. TUBITAK, Türkiye 2. BEV-PTP, Austria 3. CMI, Czechia 4. GUM, Poland 5. IMBiH, Bosnia and Herzegovina 6. INRIM, Italy 7. PTB, Germany	External Beneficiaries: 8. INM, Moldova 9. POLITO, Italy 10. UNZE, Bosnia and Herzegovina 11. ZAG, Slovenia	Unfunded Beneficiaries: 12. EASYDUR, Italy 13. LTF, Italy 14. MPA NRW, Germany