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Comparison of instrumented Knoop and Vickers hardness measurements on various soft materials and hard ceramics

D. Chicot [a,*], D. Mercier [a], F. Roudet [a], K. Silva [b], M.H. Staia [b], J. Lesage [a]

[a] *Laboratoire de Mécanique de Lille, LML-UMR 8107, U.S.T. Lille, IUT A GMP, Rue de la Recherche, 59653 Villeneuve d'Ascq, France*
[b] *School of Metallurgical Engineering and Materials Science, Central University of Venezuela, Apt 49141, Caracas 1042-A, Venezuela*

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Abstract

Vickers and Knoop hardness measurements performed on various ceramics (hard metals) and light alloy materials (soft metals) are compared. The results show that the Knoop hardness number is, in general, lower than the Vickers hardness number for the highest values of hardness, and this behaviour is reversed when the hardness values are low. This change in values, which occur at 8 GPa, has no real physical meaning and, therefore, it is difficult to interpret such behaviour in terms of the elasto-plastic deformation around the indent such as sinking-in, piling-up, and bulging of the indent faces, phenomena which take place during indentation or after the withdrawal of the indenter.

Prior to interpreting the hardness difference, it is very important to consider the same area in the hardness calculations. That is why we have compared the available hardness data obtained from the literature and recalculated them by considering the projected and true areas of the contact. If the objective is to compare the two hardness numbers, it seems more suitable to consider the true area of contact, procedure which will provide a Vickers hardness number higher than the Knoop hardness number all over the range of the hardness values.

Keywords: Mechanical properties; Hardness; Nitrides; Carbides

1. Introduction

The hardness of a material is defined as the resistance to plastic deformation usually when the indentation test is carried out. The principle of indentation consists in applying a given load and, subsequently, measuring the dimensions of the residual impression left in the material once the indenter has been withdrawn. Hardness of the material is then defined as the ratio between the indentation load and a parameter representative of the area of the residual impression, depending on the shape of the indenter and the method employed for the hardness calculation.

For the Vickers hardness test, the indenter is a square-based pyramid for which the angle, ψ, between the two opposite sides is equal to 136°. The representative area corresponds to the true area of contact between the pyramid and the material at the maximum load of indentation. By means of simple geometrical considerations, the contact area may be expressed as a function of the diagonal of the indent. The Vickers hardness number (VHN) generally used is then calculated using the following formula:

$$\mathrm{VHN} = \frac{P}{A_{\mathrm{TAC}}} = \frac{P}{d^2/2 \cdot \sin(\psi/2)} \left(= 1.8544\frac{P}{d^2}\right) \quad (1)$$

where VHN is expressed in MPa, if P the applied load is in N and d is the diagonal of the indent in mm. A_{TAC} represents the true area of contact.

The Knoop hardness test used a lozenge-based pyramid with the angle θ between the two opposite faces being 172°5 and the angle φ between the other two being 130°. Calculation of the Knoop hardness number considers the projected area of contact in the plane of the material. The projected area is calculated using the length of the indent by knowing the theoretical relationship between the length and the width of the impression. The Knoop hardness number (KHN) is calculated as follows:

$$\mathrm{KHN} = \frac{P}{A_{\mathrm{PAC}}} = \frac{P}{L^2\,\mathrm{tg}(\varphi/2)/2\,\mathrm{tg}(\theta/2)} \left(= 14.229\frac{P}{L^2}\right) \quad (2)$$

where KHN is expressed in MPa, if P the applied load is in N and L is the large diagonal of the indent in mm. A_{PAC} represents the projected area of contact.

* Corresponding author. Tel.: +33 320 677320; fax: +33 320 677321.
E-mail address: didier.chicot@univ-lille1.fr (D. Chicot).

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In the majority of the hardness studies, different authors compare the Vickers and Knoop hardness measurements by using these two forms of calculations for the hardness numbers. We will show above that this approach leads to a wrong result, which is characterized by an inexplicable change of behaviour at a given value of the hardness.

2. Analysis of hardness data obtained from literature

Prior to the discussion related to various hardness measurements performed on hard ceramics, previous comments should be made on the validity of the experimental data. With the aim to normalize the hardness measurements, some rules and procedures were set and listed in several international standards such as the European draft standard ENV 843-4,[3] the National Institute for Standards and Technology[4] and the Fraunhofer-Institute for Ceramic Technologies and Sintered Materials.[5] Since these standards allow to perform appropriate measurement routines, the hardness values that were carefully measured under these recommendations could provide a valuable data base which could be used in order to compare the influence of the two indenter's geometries on the hardness numbers. Moreover, since each laboratory carried out the hardness measurements by employing the two indenter's geometries on the same sample, the comparison between the two hardness numbers, HV1 and HK2, is rendered possible and the discussion is then consistent for all data available from different laboratories.

Therefore, in the present work, we used the data provided by Ullner et al.,[1,2] which have tested several typical commercial ceramics, mainly silicon nitride, silicon carbide and aluminium oxide, by employing ENV 843-4 standard. However, Ullner et al.[1,2] raised the problem of the reproducibility between hardness measurements carried out in different laboratories and have concluded that the magnitude of standard deviations are independent of both hardness technique employed and laboratory were the measurements were carried out, and are, probably, associated with the variation of the microstructural characteristics of the material, i.e. porosity, grain orientation and grain size.

All the hardness values, HV1 and HK2, obtained from Ullner et al.[1] are summarised in Table 1. In order to complete a series of examples for hard metals, we have added the results presented by Gong et al.[6] on various ceramics based on silicon nitrides containing a different amounts of yttrium and lanthanum oxides. All the specimens were subjected to Vickers and Knoop indentations under the same applied load of 2.45 N, which was sufficiently high to avoid indentation size effect (ISE).[7] Additional general information of ISE allowing the hypothesis mentioned above are given, for example, in the extended review published by Cheng and Cheng.[8]

The hardness values obtained by Gong et al.[6] are the average results from of 10 indentations tests for each type of indenter and the reported error related to the diagonal measurement was of $\pm 0.5\ \mu m$. Additionally, these authors have also published part of the experimental data obtained by Mukhopadhyay et al.[9] for seven sintered silicon nitride ceramics and five liquid-phase sintered SiAlON. Fig. 1 presents these two sets of experimental data reported by Gong et al.[6] which follow nearly the same trend.

To take into consideration much lower hardness values, we are considering the hardness results reported by Shaw et al.[10] for four metallic alloys. The average hardness values are in the range of 1–2 GPa and have been obtained by applying loads ranging between 0.1 and 10 N. Table 2 presents these results, which are the average of at least 10 indentations/applied load. Taking into account the hardness values obtained as a function of the applied load, we could consider that this material does not present an ISE. Fig. 2 represents all the hardness data as a function of the applied load indicating the correspondence between the two hardness numbers. In this figure, it is shown without ambiguity that the KHN values are lower than VHN values for those materials, which exhibited high hardness (Fig. 2a). At the contrary, for the materials that have low hardness, the KHN values are superior to VHN values (Fig. 2b). In a first

Table 1
Data related to the hardness numbers for some ceramic materials reported by Ullner et al.[1]

Code	Source/material code	Type	HV1[a]	HK2[a]
A	NIST/SRM 2830	HPSN	15.80	14.30
C	IKTS	GPSN	14.70	13.50
D	IKTS	GPSN	14.80	13.80
E	Tenmat/Nitrasil R	RBSN	10.20	9.40
F	Lucas-Cookson/Syalon 201	SiAlON	16.00	14.10
G	IKTS	LPS-SiC	25.60	19.60
H	CERAMTEC/CD	SiC	26.50	17.20
I	CERAMTEC/RK	Al_2O_3	18.90	16.10
J	IKTS	Al_2O_3	21.20	17.30
K	Morgan Matroc/VITOX (white)	Al_2O_3	19.90	17.10
M	Morgan Matroc/VITOX (white) + tempered	Al_2O_3	18.00	15.70
R	IKTS	GPSN	15.00	13.80
S	IKTS	LPS-SiC	24.90	20.20
T	IKTS	Al_2O_3	20.70	17.40
U = E	Tenmat/Nitrasil R	RBSN	10.20	9.30
V	IKTS	SiC	25.10	21.60
W = I	CERAMTEC/RK	Al_2O_3	18.90	16.10
X4, X5, X6, X7	IKTS	HPSN	14.60–17.70	13.50–15.30

[a] Hardness values are given in GPa.