ON THE MICROHARDNESS AND YOUNG'S MODULUS OF HUMAN TEETH

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AIM OF THE WORK

•Determination of material hardness (H), and elastic properties such as Young's modulus (E).

• Acquire knowledge of the physical properties of teeth and tissues : Important aid for understanding their mechanical behavior under clinical loading conditions

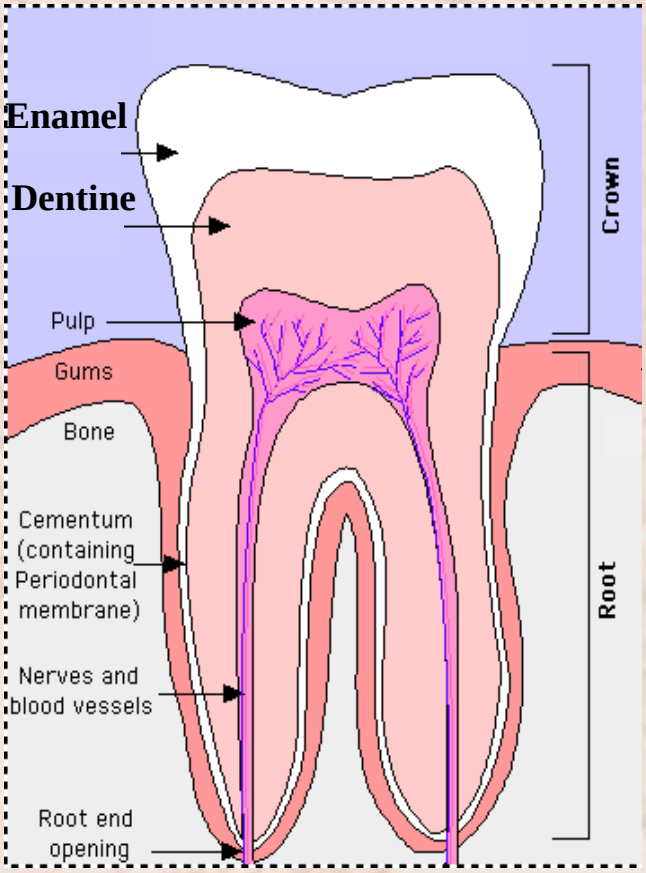
•Knoop indentation test enables the E value of human teeth to be obtained in a simple fashion and has potential to be used as a quality control tool in the development of dental implants or prosthetic teeth.

•Biomimetic aspects in mechanical engineering: design better coatings

OUTLINE

- Introduction – Teeth structure
- Theoretical Background – Determination of E from H
- Experimental Procedure – Sectioning teeth and measuring hardness
- Results & Discussion – Correlation between hardness and modulus
- Conclusions

Human Tooth, Structure



Enamel:

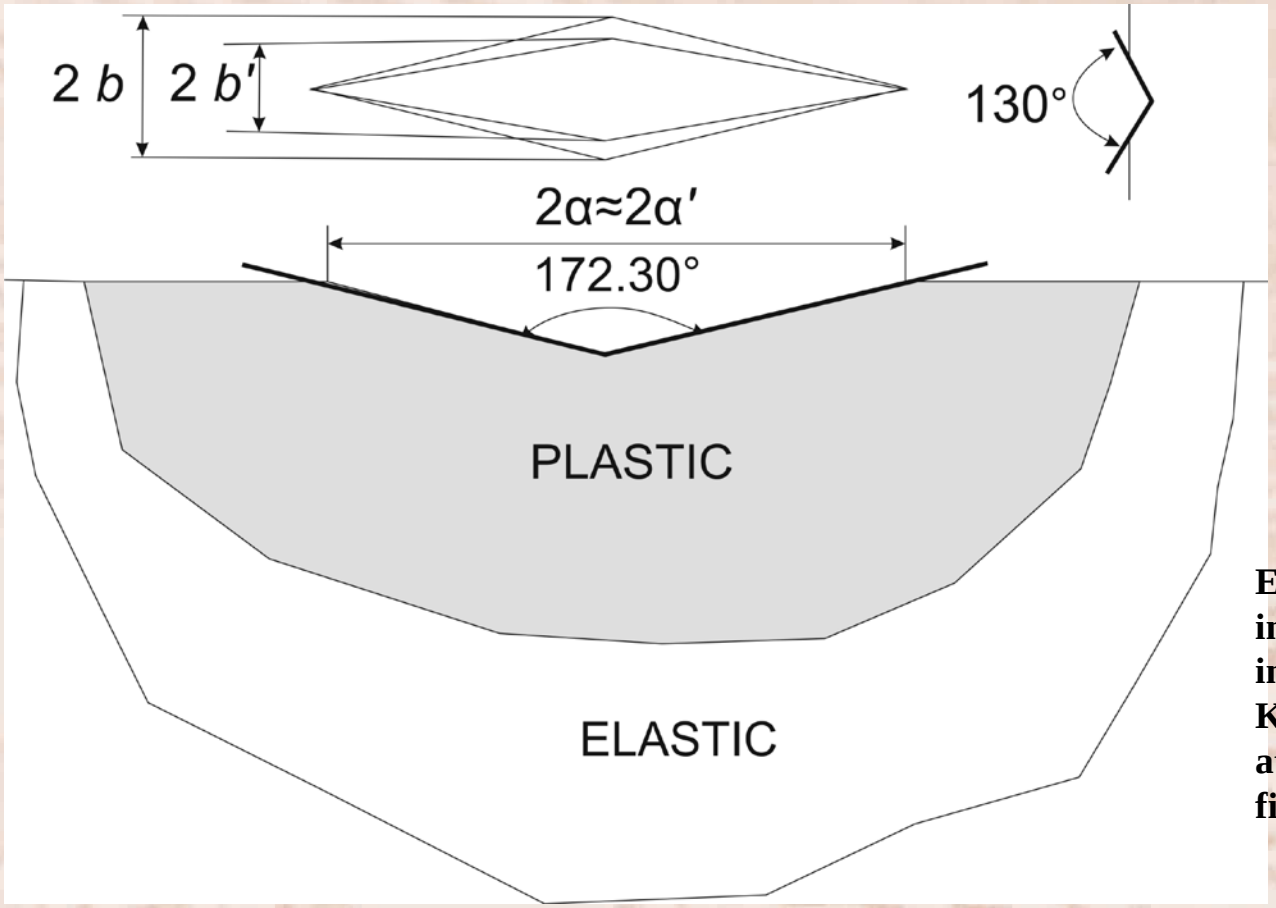
The hardest and most highly mineralized substance of the body. It consists of 96 % of hydroxyapatite, with water and organic material composing the rest.

Dentine:

Hydrated composite of mineralized collagen fibers and nanocrystalline hydroxyapatite, with ~ 45% hydroxyapatite, 35 % collagen, 20% water (by volume). Dentine consists of microscopic channels (dentinal tubules) which radiate outward through the dentine and contain fluid and cellular structures.

Recovery of Knoop indentation

• **Material Properties including hardness *(H)*, Young's modulus *(E)* and fracture toughness can be calculated from measurements taken from Knoop & Vickers indentations.**



Elastic recovery of Knoop indentation (elastic-plastic indentation). Geometry of Knoop indenter is also given at the upper part of the figure.

Methods of obtaining E

Marshall's method

based on the measurement of elastic recovery of the in-surface dimensions of Knoop indentations

$$\frac{b'}{a'} = \frac{b}{a} - \frac{\alpha_1 H}{E}$$

$\frac{b}{a}$ *ratio of the diagonal dimensions a and b in the fully loaded state = 0.140646*

$\frac{b'}{a'}$ *ratio of the altered dimensions after unloading*

a_1 *proportionality constant*

Marshall et al, Comm. American Cer. Soc. 65(10), (1982), p. 175-176

Conway's method

relates *H/E* to the residual length of a minor diagonal *(b)* of Knoop indentations

$$\left(\frac{b'}{b}\right)^2 = 1 - 2\left[(1-\nu^2)\tan\gamma\right]\left(\frac{H}{E}\right)$$

ν *Poisson's ratio*

γ *average half angle of a Knoop indenter 75°*

Conway, J. Mat. Sci., 21 (1986) p.2525-2527

Experimental Procedure

Specimen Preparation

- Dental extraction
- Longitudinal sectioning using a low speed diamond wheel
- Mounting in an epoxy resin
- Grinding with SiC papers 120, 320, 500, 800 and 1000 grit
- Polishing with diamond paste of 3 and 1 μm diameter

Specimen Examination, Microhardnes Measurements

Optical Metallography

Microhardness testing (Vickers and Knoop indenters)

Instrument reliability was verified by using calibrated test blocks

Hardness and Modulus

Values of Knoop hardness for enamel and dentine were calculated as follows

$$H = \frac{1450 \cdot F \cdot 10^3}{a^2}$$

H: **Knoop hardness number**

F**: Force in Nt (0.98)**

α**: length of the longer diagonal in μm.**

Values of Young's modulus (*E*) for enamel and dentine at different indentation distances were calculated by rearranging Marshal's equation in terms of *E*:

$$E = \frac{\alpha_1 H}{\left(\frac{b}{\alpha} - \frac{b'}{\alpha'}\right)}$$

where:

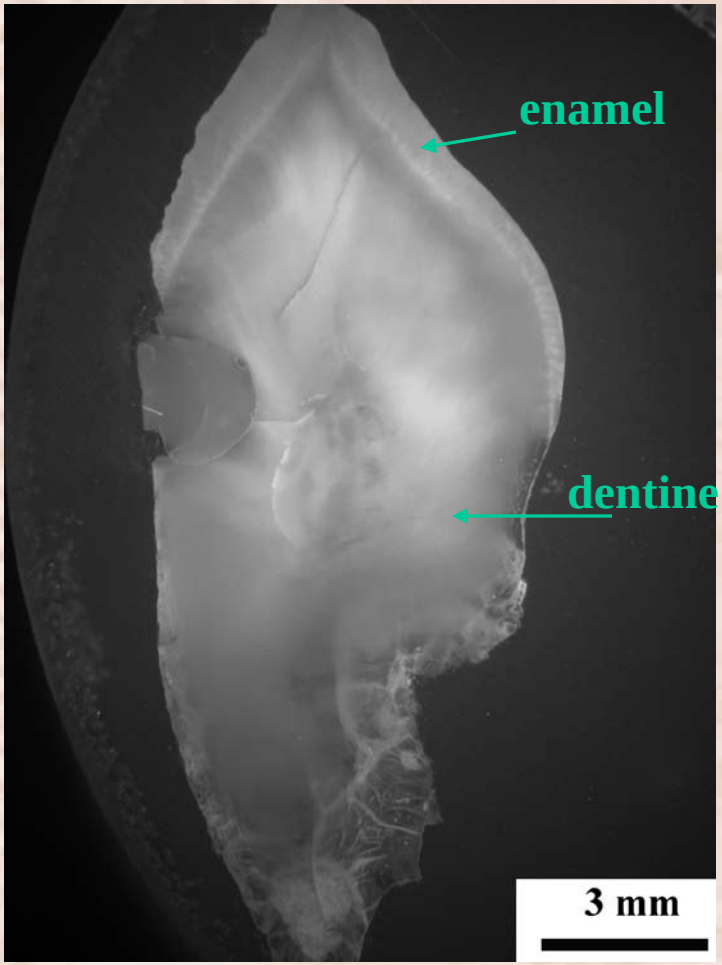
$\frac{b}{a}$ *ratio of the diagonal dimensions a and b in the fully loaded state =* ***0.140646***

$\frac{b'}{a'}$ *ratio of the altered dimensions after unloading*

a_1 *constant*

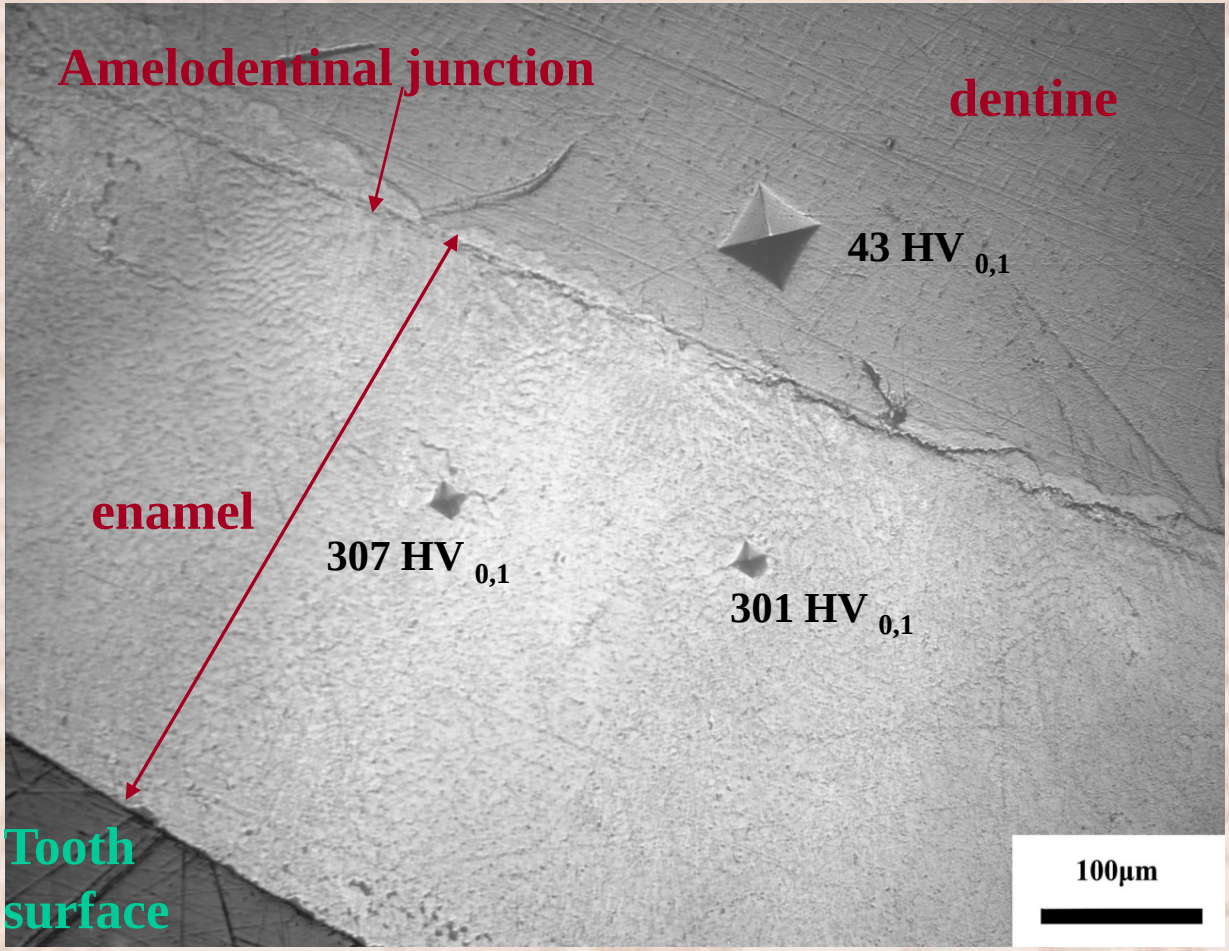
- ***1.5*** *Marshall's theoretical calculation using elliptical indenter*
- ***0.45*** *Marshall's experimentally derived value*
- ***0.34*** *Meredith's proposed value*

Results



Macroscopic appearance of a human tooth subjected to the specimen preparation described previously

Results

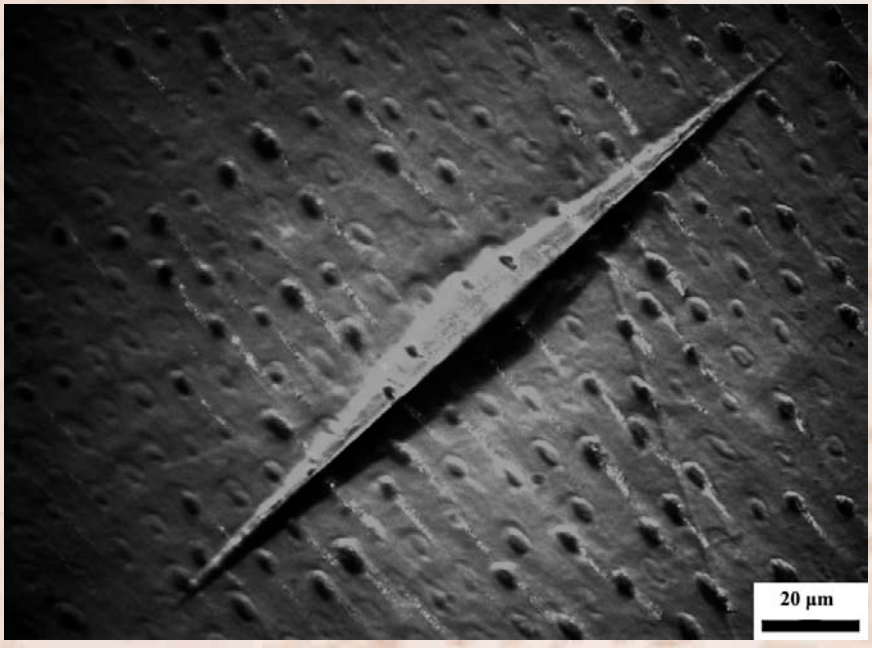


Typical Vickers Microhardness measurements in enamel and dentine

Typical Knoop Indentations

enamel

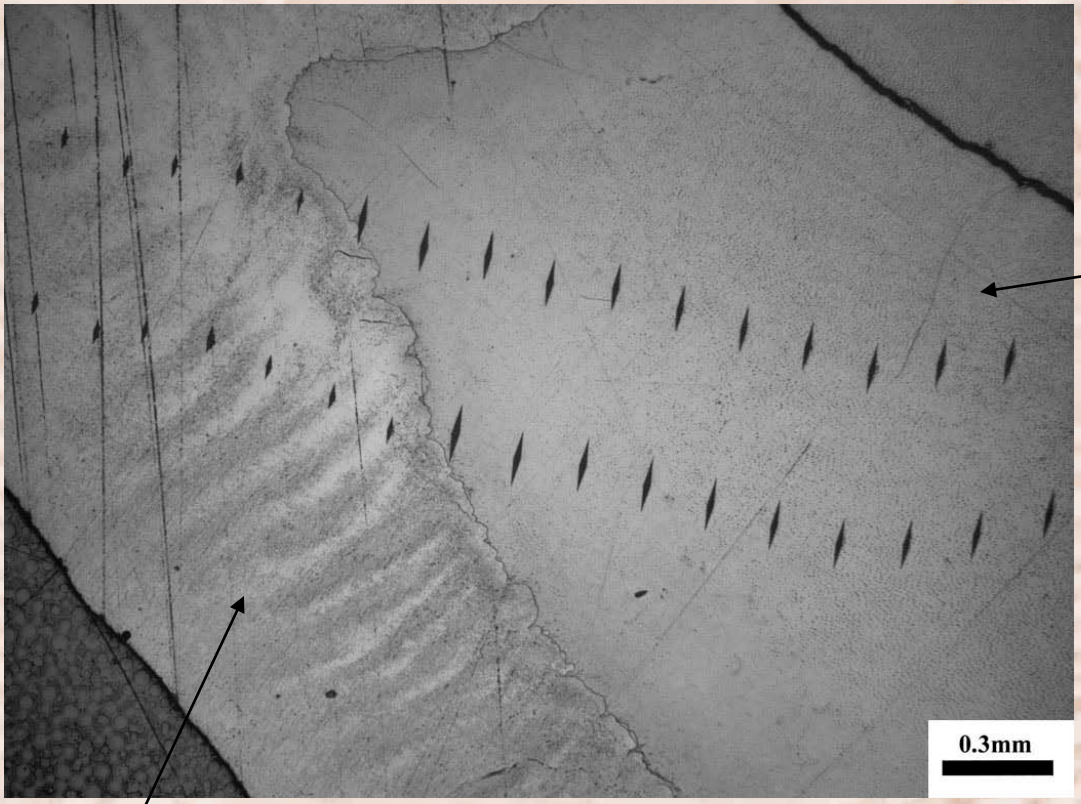
Load: 100gr



dentine

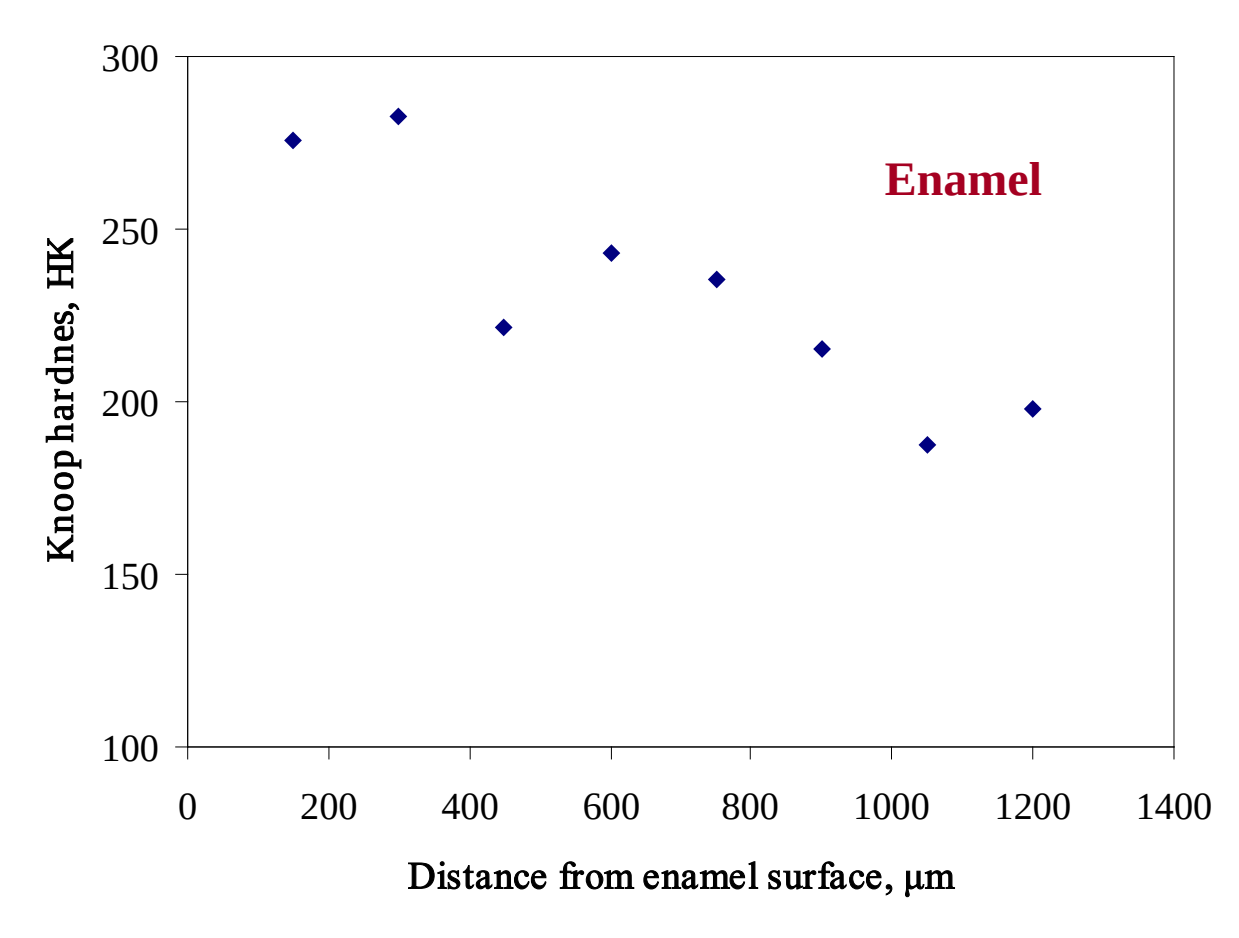
Residual Surface impressions after Knoop microhardness measurements in enamel and dentine

Results & Discussion



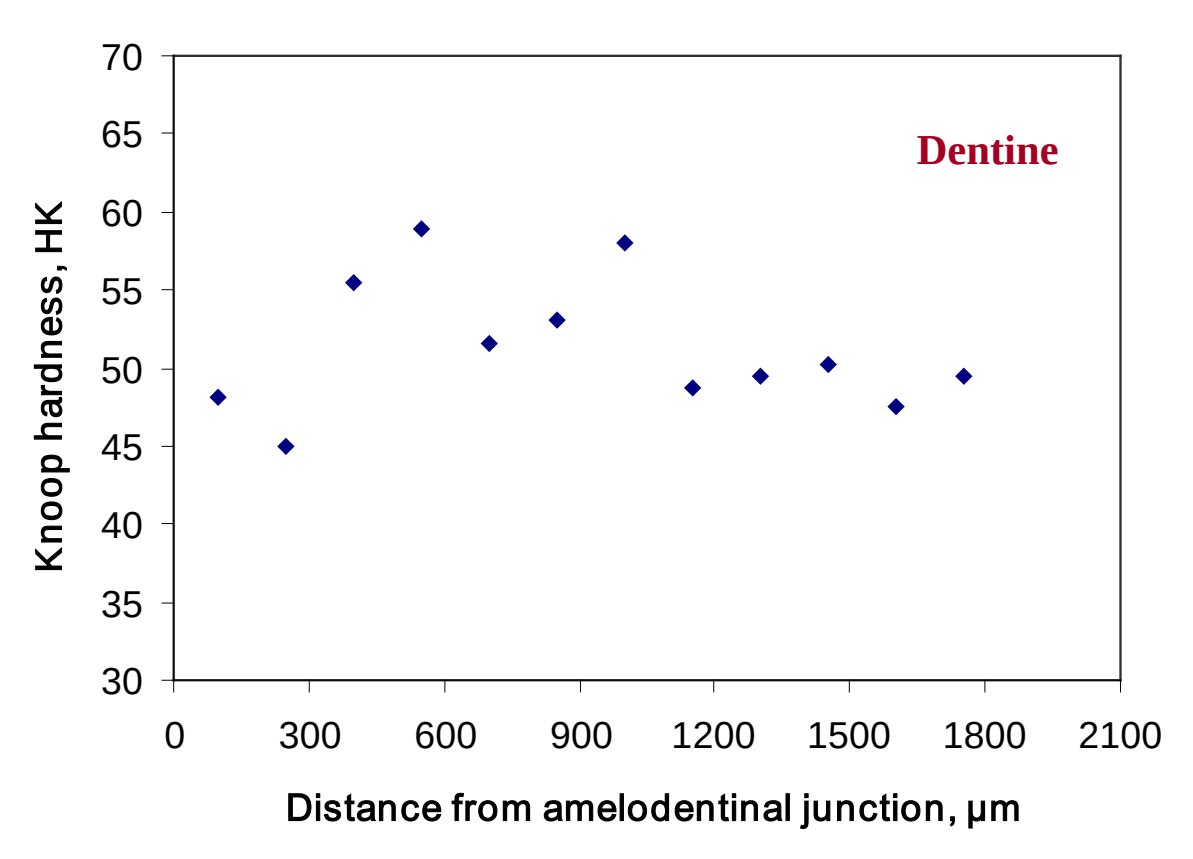
Microhardness profile. Measurements were taken at distances of 150 μm.

Microhardness - Enamel



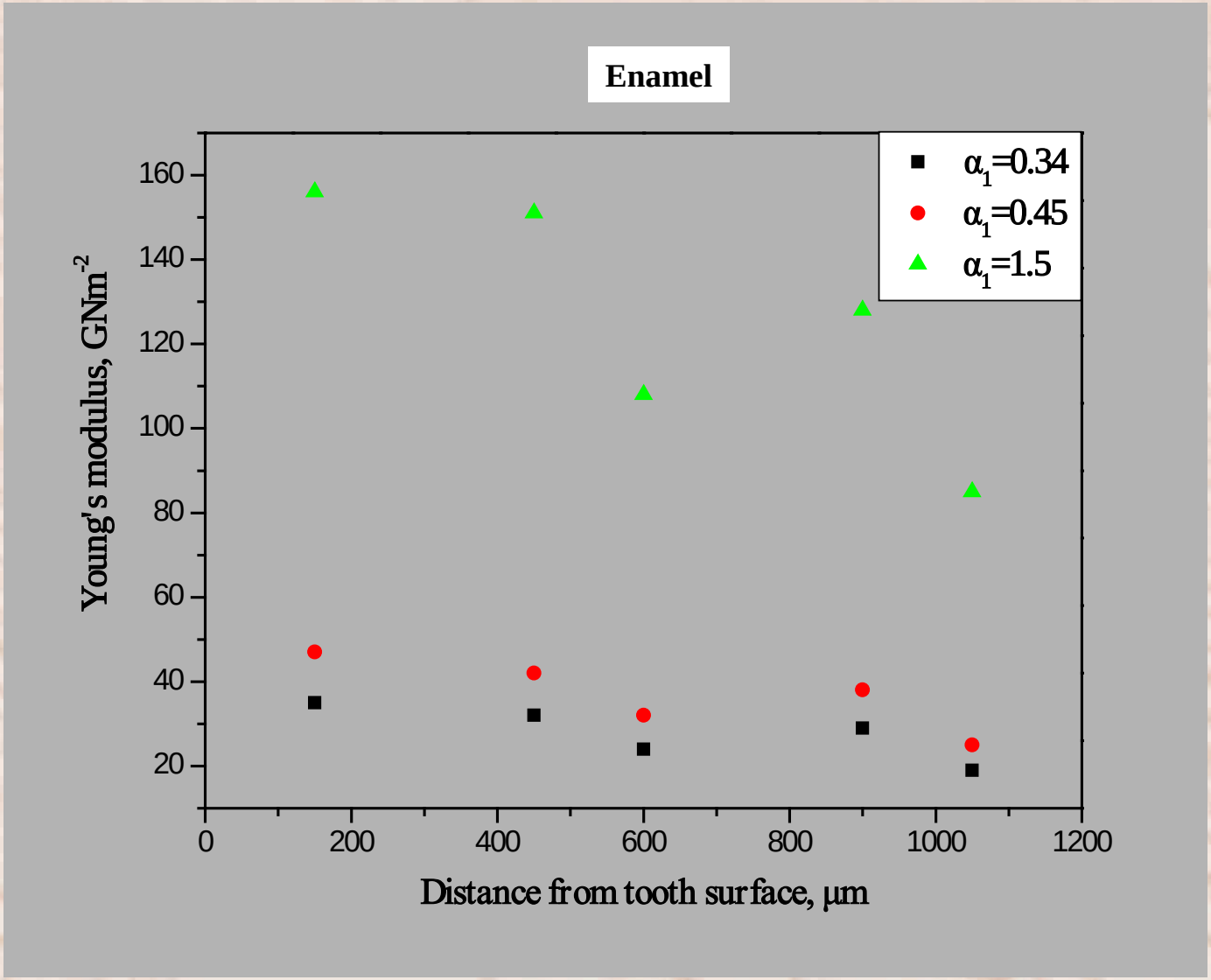
Knoop microhardness in enamel with distance from the tooth surface

Microhardness - Dentine



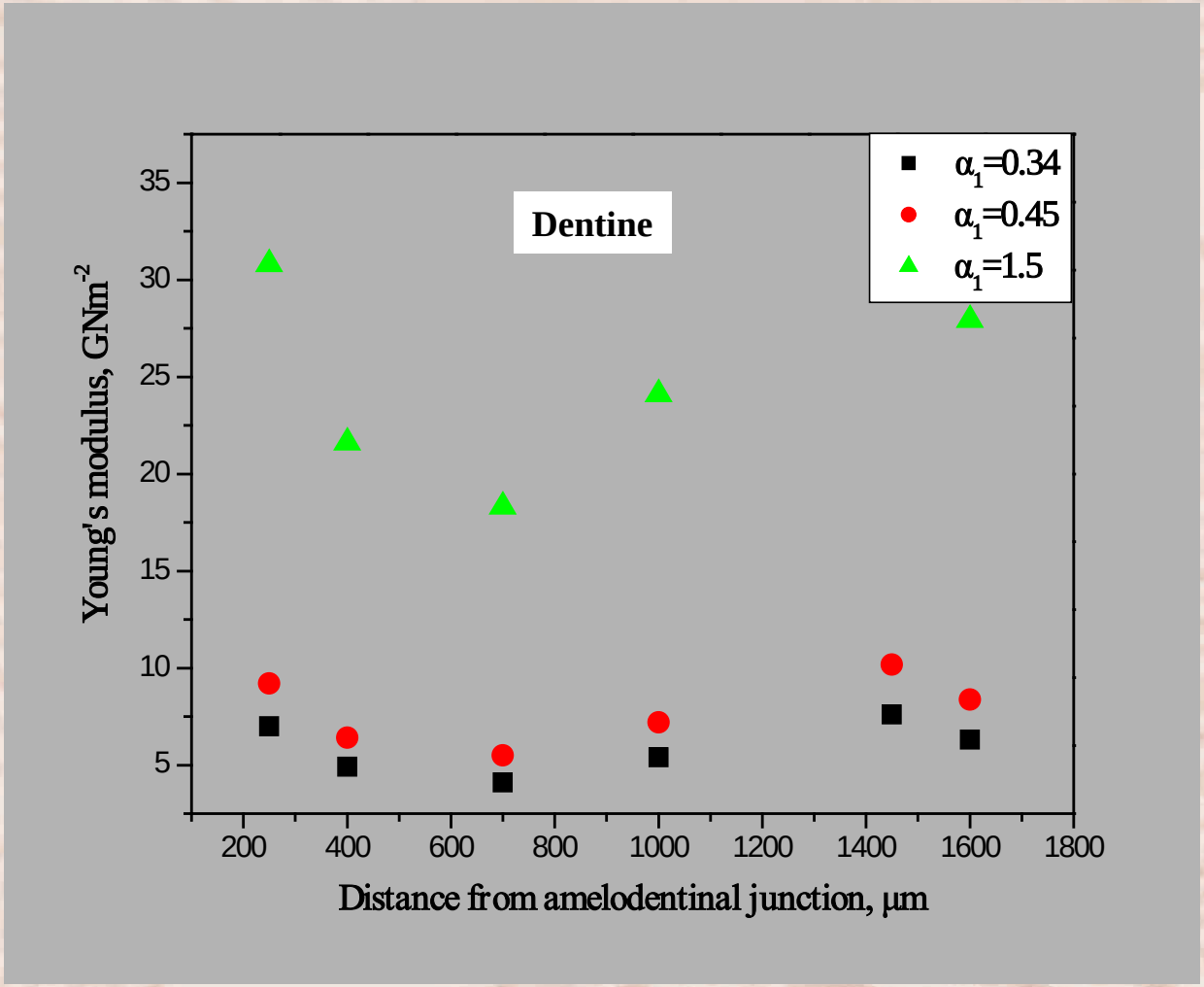
Knoop microhardness in dentine with distance from the amelodentinal junction

Young's modulus - Enamel



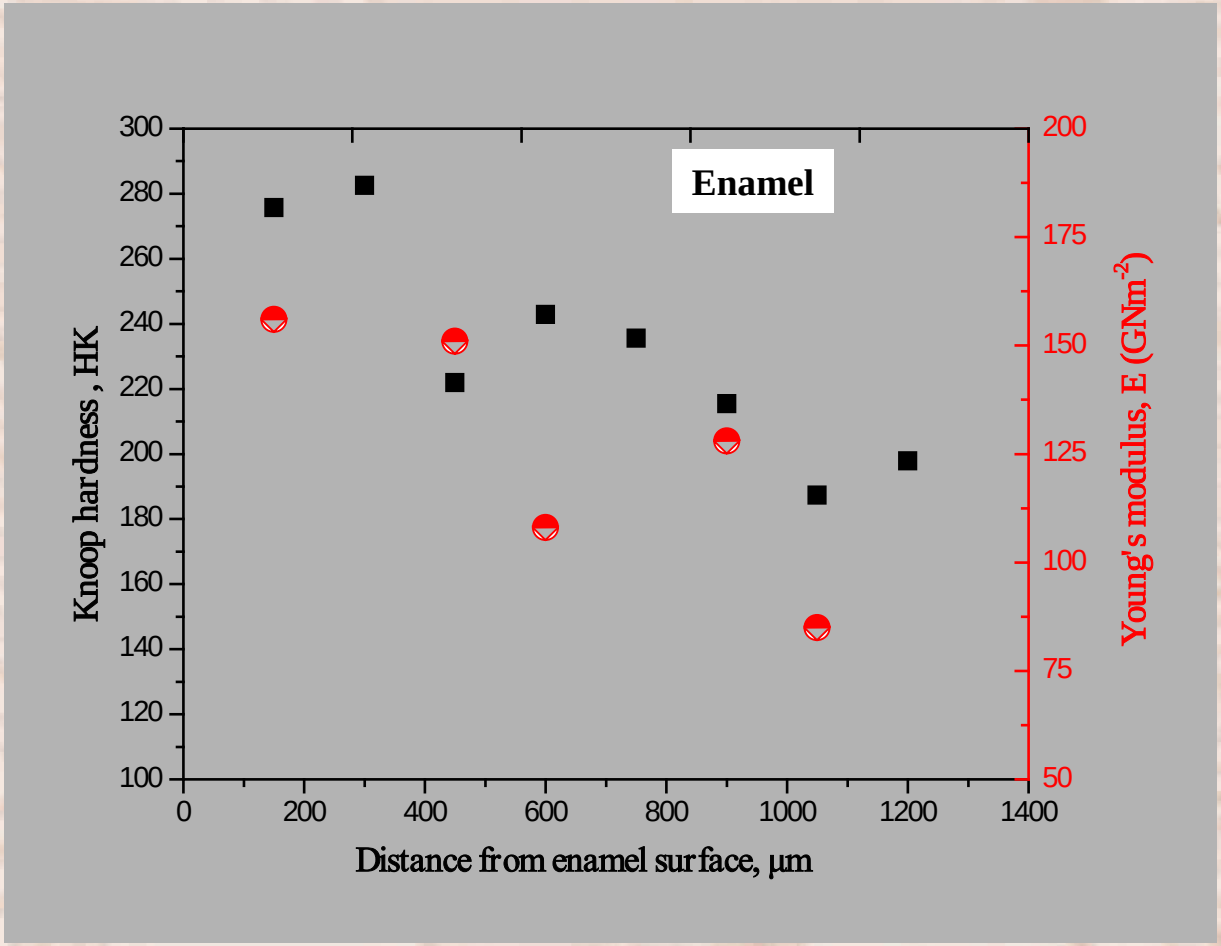
Calculated Values for Young's Modulus of Enamel with distance from tooth surface

Young's modulus - Dentine

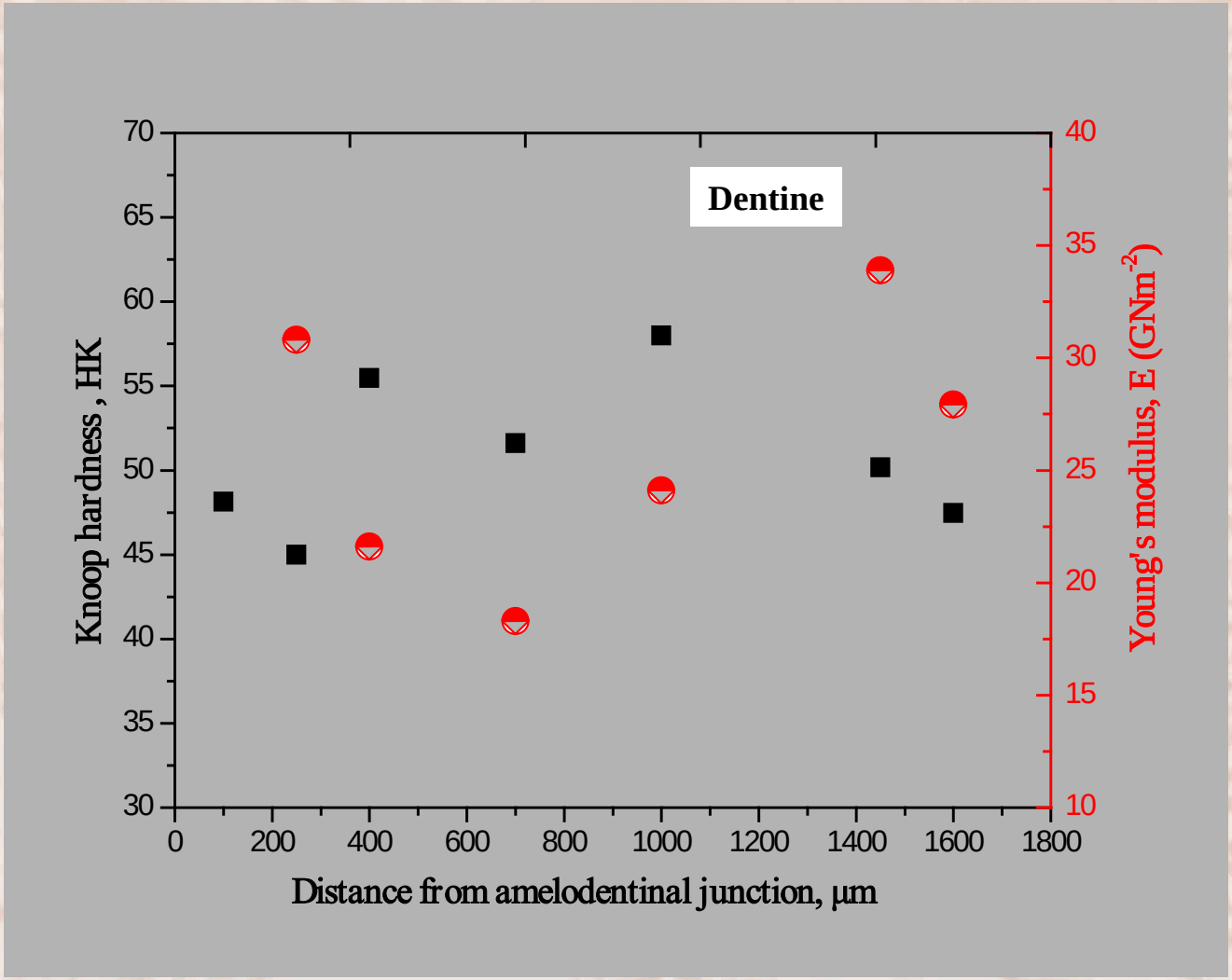


Calculated Values for Young's Modulus of Dentine with distance from amelodentinal junction

H-E correlation in Enamel



H-E correlation Dentine



Conclusions

- **Knoop, as well as, Vickers microhardness were determined for enamel and dentine and are in good agreement with other results reported in the literature.**
- **Microhardness of both enamel and dentine varied with depth**
- **Young's modulus was determined by utilizing the method described by Marsall et all. Our values are in good agreement with those of other researchers.**
- **The variation of E with distance from the tooth surface and from the amelodentinal junction correlates with the variation of microhardness.**