

# A new all-ceramic crown

## A dense-sintered, high-purity alumina coping with porcelain

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A method of manufacturing an all-ceramic crown composed of a coping of dense-sintered, high-purity alumina with dental porcelain is described. This method takes the sintering shrinkage of alumina into consideration and makes it possible to produce individual dental copings in dense-sintered, high-purity alumina, which is a biocompatible implant material. The alumina used has density, grain size, and flexural strength within the limits of the values required in ISO 6474-1981, 'Implants for surgery, ceramic materials based on alumina'.

□ *Aluminum oxide; ceramics; crowns*

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The increased demand for esthetic restorative treatment in dentistry has made dental ceramics an often-used material for both anterior and posterior restorations. The dental profession is looking for an all-ceramic crown that can be used in molars and premolars. The materials and processes of today for manufacturing all-ceramic crowns include feltspatic dental porcelain or castable glass ceramics (1, 2). ISO 6872, 'Dental ceramic', has requirements of flexural strength of the material used in these all-ceramic crowns (Table 1). The measured flexural strength of the material used in several ceramic crowns on the market is of the same order of magnitude as the requirements in this standard (3, 4). Vita has presented an all-ceramic crown composed of dental porcelain fired on a coping made from pre-sintered alumina infiltrated with colored glass (5, 6). The flexural strength of this coping material is about four times the flexural strength claimed for core powder in ISO 6872.

Alumina-reinforced dental porcelain was developed by McLean & Hughes in 1965 (7). The feltspatic porcelain is strengthened by dispersed crystals of high-strength alumina

in the feltspatic matrix. McLean & Hughes also developed techniques for using preformed alumina reinforcements for dental bridge pontics with enamel veneers. The strength of laminates of alumina and porcelain has been studied by Timoshenco (8), who showed that alumina-enamel porcelain laminates were five times stronger than regular porcelain discs. Pure discs of high alumina were over eight times stronger than regular porcelain.

High-purity alumina is biocompatible and has been in use as implant material since 1964, when Sanhaus used this material for tooth replacements (9). Various clinical applications have since then been proposed for alumina as biomaterial. The commonest has been as socket and ball in hip joint replacement (10). The material for this application is described in the International standard ISO 6474, Implants for surgery—Ceramic material based on alumina (Table 2).

The shrinkage of alumina during sintering to full density is about 15–20%, which has made it impossible to manufacture individual tooth copings of adequate accuracy in pure alumina with the powder technology used today.

Table 1. International standard ISO 6872: flexural strength, MPa

Core powder	100
Dentin/body powder	55
Enamel powder	50

Table 2. International standard ISO 6474: implants for surgery—ceramic material based on alumina

Density	>3.9 g/cm <sup>3</sup>
Al <sub>2</sub> O <sub>3</sub>	≥99.5%
Average grain size	≤7 μm
Flexural strength	≥400 MPa

A technique for manufacturing an individual all-ceramic crown composed of a coping of dense-sintered high-purity alumina with dental porcelain has recently been developed by Nobelpharma AB and AB Sandvik Hard Materials, Sweden. The aim of this paper is to describe the technique of manufacturing this new all-ceramic crown and to examine the ceramic material used in the coping of dense-sintered high-purity alumina.

## Materials and methods

The copings were manufactured by com-

packing high-purity alumina powder with a dry pressing technique against enlarged models of the prepared teeth. The compacted copings were adjusted along the preparation border and sintered unsupported at 1550°C during 1 h. The enlarged preparation models were made with an enlarging Procera copy milling machine, and the enlargement was calculated from the sintering shrinkage of the compacted powder. The principle of the Procera copy milling machine is described in a previous paper (11). By modifying the machine, it has been possible to produce linear expanded copies of stone dies into a suitable material. The actual range of enlargement in this enlarging Procera machine is between 12% and 20%.

The manufacturing of the dense-sintered coping is explained in Fig. 1, which shows the steps of the procedure from a plaster model of a human molar prepared with a deep chamfer to the cemented crown.

The powder used for the manufacturing of the copings was a high-purity alumina (Al<sub>2</sub>O<sub>3</sub> > 99.9%). Sintered copings were prepared for physical characterization in a scanning electron microscope (SEM) by grinding and polishing, using standard techniques. The grain size of the sintered alumina was measured on cross-sections of copings, which were prepared by grinding, polishing, and thermal etching. The phase boundary

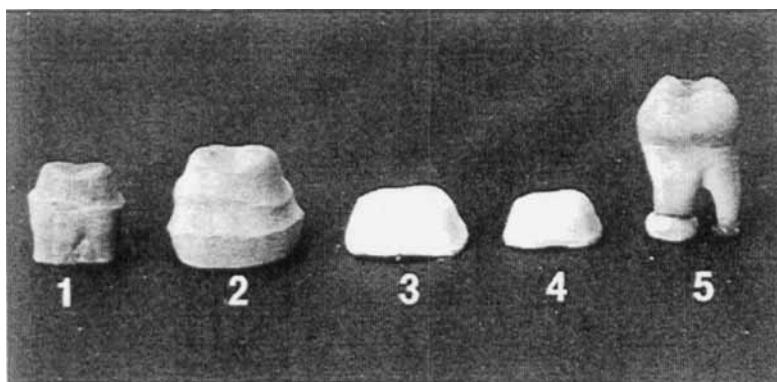


Fig. 1. Manufacturing steps of a dense-sintered, high-purity alumina coping. From the left: 1) a plaster model of a human molar prepared with a deep chamfer; 2) an enlarged model of the preparation model; 3) the coping before sintering; 4) the dense-sintered, high-purity alumina coping; and 5) the final crown built up with a conventional dental ceramic

technique with Vitadur N dental porcelain and cemented with phosphate cement on the prepared human molar.

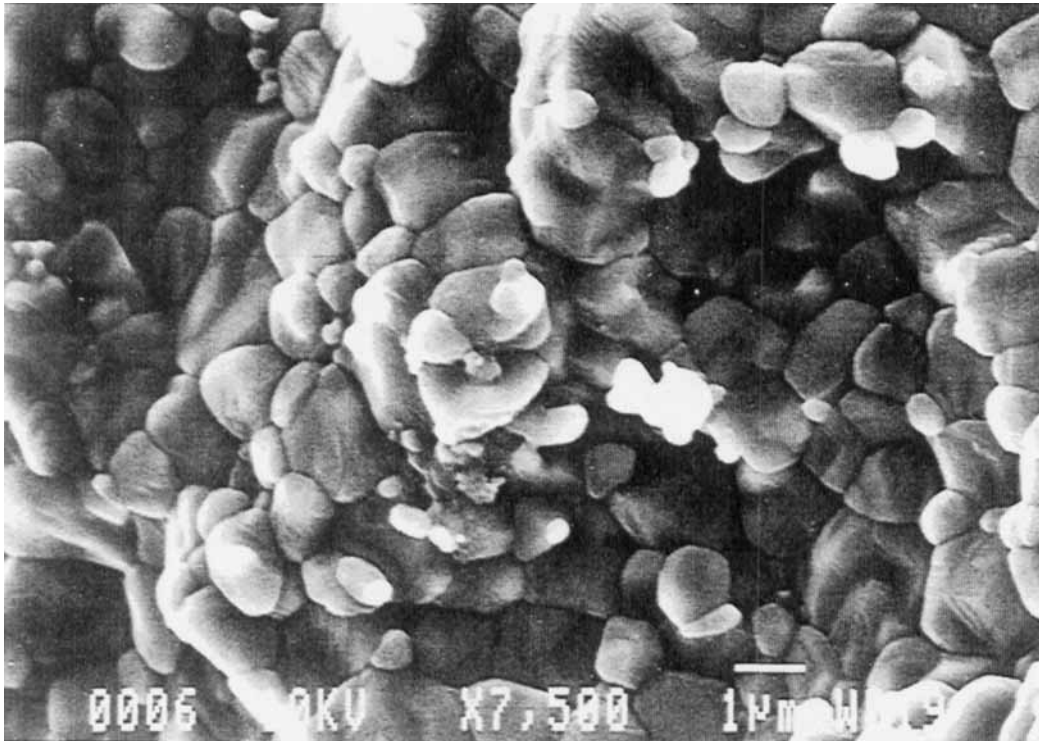


Fig. 2. Scanning electron micrograph of the microstructure of the inner surface of a sintered alumina coping. On the surfaces of the alumina grains the crystalline planes of alumina are clearly seen.

between the porcelain (Vitadur N) and the dense-sintered alumina was studied on polished cross-sections of copings with dental porcelain fired to the external surfaces. The density of the sintered alumina was measured on 10 dense-sintered copings, using the Archimedes principle.

The flexural strength of the dense-sintered high-purity alumina was measured with a three-point bending test on 14 specimens  $5.0 \pm 0.25$  mm wide,  $1.00 \pm 0.05$  mm thick, and  $26.2 \pm 0.1$  mm long. The bending test was performed in a universal testing machine (Model 1361, Instron Corp., High Wycombe, England). The specimens were fractured in a jig as specified in ISO 6872. The span between the center of the bearers was 14.2 mm, and the rate of application of force was 0.498 N/sec.

The overall structural features were viewed by SEM on polished cross-sections and the inner surfaces of the sintered copings.

## Results

A typical microstructure of the inner surface of a sintered coping is shown in Fig. 2. During the sintering the alumina particles grow together to a grain-like structure. On the surfaces of the alumina particles shown in this figure the crystalline planes of alumina are clearly seen.

The thermal etching of the polished alumina surface makes it possible to study both grain boundaries and the crystalline planes of alumina. The mean grain size of the dense-sintered alumina determined from polished and thermal-etched cross-sections of sintered copings was 4  $\mu$ m. Fig. 3 shows a cross-section of this grain structure; within the grains the crystalline planes can be seen.

The phase boundary between the porcelain and the dense-sintered alumina is without any pores or other defects (Fig. 4).

The density of the sintered copings was

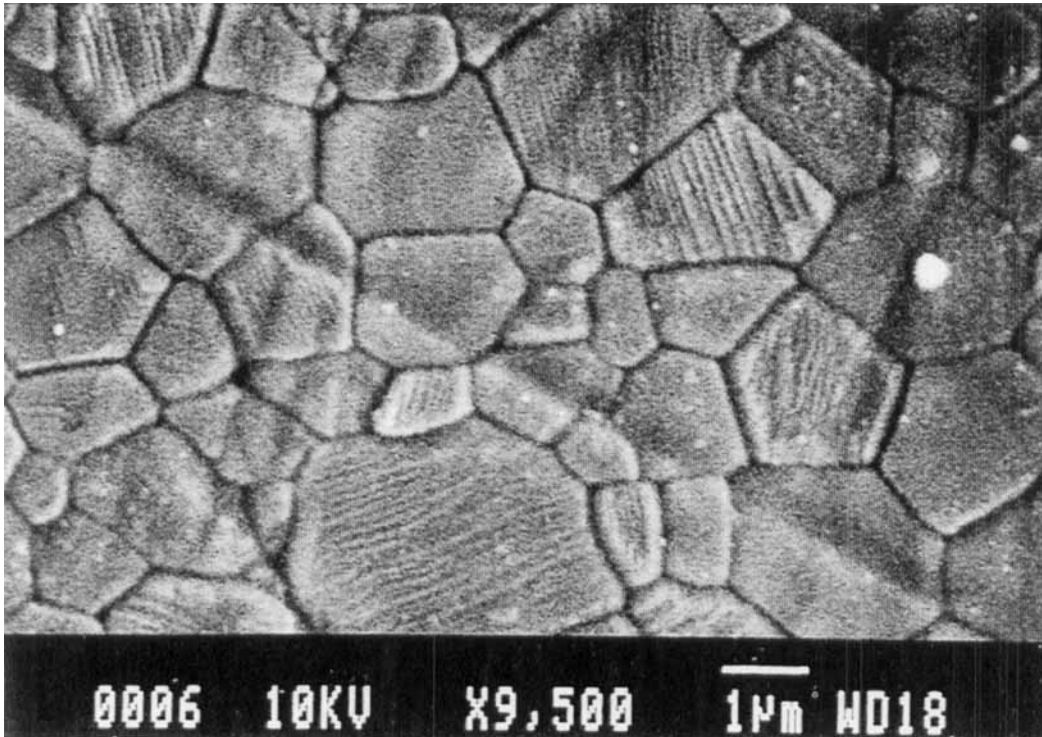


Fig. 3. Scanning electron micrograph of a polished and thermal-etched cross-section of a sintered alumina coping. The grain boundaries and the crystalline planes of the alumina are seen.

$3.94 \pm 0.01$ , and the flexural strength measured was  $601 \pm 73$  MPa.

### Discussion

The sintering of  $\text{Al}_2\text{O}_3$  powder is a solid-state sintering process that involves material transport by diffusion. Volume diffusion, whether along grain boundaries or through lattice dislocations, is followed by shrinkage. The sintering can be explained by the sintering theories of Coble (12, 13), who proposed that sintering of compacted powder can be divided into three stages. The initial stage is characterized by the neck growth between the original powder particles and involves slight increase in density of about 10%. The beginning of the intermediate stage coincides with the beginning of grain growth. During this stage, particles grow to a grain-like structure with pores as channels lying on three-grain

edges. The final stage starts when the cylindrical pores are transformed into spherical voids at about 5% porosity. The pores are lying at four-grain corners. To achieve theoretical density, it is necessary to eliminate discontinuous grain growth. The pores will follow the movement of the grain boundaries and do not become trapped inside the grains. Since the pores remain intersected by the boundaries, the diffusion path is short and facilitates the complete removal of porosity. Cahoon & Christensen (14) found in 1956 that small additions of MgO to alumina prevents discontinuous grain growth and enables the material to be sintered to nearly theoretical density.

The density of the copings of dense-sintered, high-purity alumina was 3.94. This density value is higher than that required by ISO 6474-1981 (Table 2). The average grain size of  $4 \mu\text{m}$  and the flexural strength value of 601 MPa are within the requirements of ISO

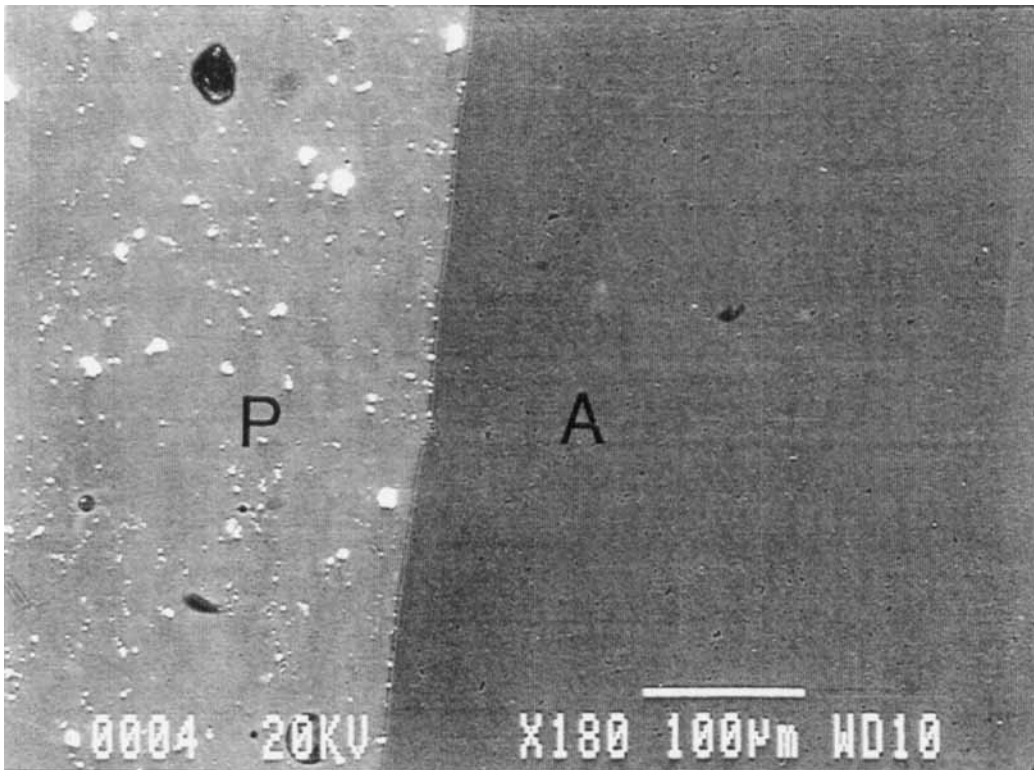


Fig. 4. Scanning electron micrograph of a polished cross-section of an alumina (A) coping with porcelain (P).

6474-1981. The phase boundary between dental porcelain and the dense-sintered alumina did not show pores (Fig. 4). The dental porcelain used had a thermal expansion adapted to alumina, and the bonding of porcelain to alumina is of a chemical nature, probably an ionic bond (7). The melting point of alumina has been determined to be about 2050°C (15). The firing temperature of the porcelain is about 1000°C below this value. As a consequence of the difference between the melting temperature of alumina and the firing temperature, the shape of the alumina copings is unaffected during the firing process. The fit of the crown depends on the gap between the coping and the prepared tooth. This gap can be controlled by enlarging the enlarged preparation model. The fit of the alumina coping to the porcelain will be analyzed in detail in a following paper, but preliminary data indicate that the fit is acceptable according to clinical requirements.

#### Conclusion

The described process for manufacturing an all-ceramic crown composed of dental porcelain fired on a coping of dense-sintered, high-purity alumina takes the sintering shrinkage of alumina into consideration. The method makes it possible to produce individual dental copings in this biocompatible implant material, as well as in other high-strength dense-sintered biocompatible ceramic materials. The alumina used has density, grain size, and flexural strength within the limits of the requirements in ISO 6474-1981 'Implants for surgery, ceramic materials based on alumina'.

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