Cold sintering of bioceramics for embedded conductive lines

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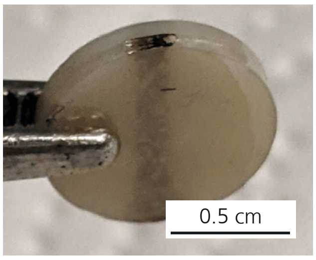

Fig. 1: Bioceramics with embedded gold line produced by cold sintering and inkjet printing.

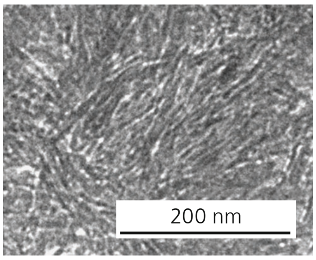

Fig. 2: Nanostructure of cold-sintered bioceramics.

Sintering of bioceramics at low temperatures

Cold sintering significantly expands the potential applications and functionalities of ceramics and ceramic-based composites. While conventional sintering often requires temperatures above 1000 °C, the processing temperatures of cold sintering are typically below 300 °C. This is made possible by a high consolidating pressure. Due to the much lower temperatures, energy consumption is reduced by a factor of 10, processing times are shortened, and CO_2 emissions are decreased – this makes cold sintering a promising option for developing novel materials.

Additionally, cold sintering enables simultaneous sintering of diverse material combinations, which would not be possible with conventional sintering technology. This includes a range of ceramics, metals and, in particular, polymers. By combining these different material groups in a cohesive way, new possibilities of functionality with significant advantages for biomaterials development are available. Among them is the integration of temperature-sensitive biological additives or pharmaceuticals into dense bioceramics or biometals without compromising their structural integrity or effectiveness. Another example is the incorporation of biocompatible metals, such as gold or platinum, directly into the bioceramic matrix, for example in the form of electrodes or electronic conductive lines.

Bioceramics with embedded conductive lines

One method that could be demonstrated is the production of a hydroxyapatite (HAp)-based bioceramic with embedded conductive lines through cold sintering and inkjet printing (Fig. 1). The initial material is a custom-developed hydroxyapatite composite powder that consists of very fine nanocrystals of hydroxyapatite interwoven with a gelatin matrix. When cold-sintered, this bioceramic achieves a density close to 99 % (Fig. 2).

Thanks to the unique combination of gelatin (denatured collagen) and synthesized HAp, along with low-temperature processing conditions, a bioceramic with mechanical properties similar to bone was obtained, exhibiting a compressive strength of nearly 200 MPa and ductile behavior (Fig. 3).

To embed conductive lines into the developed bioceramic, a custom gold nano-ink, developed at Fraunhofer IKTS, was used. This ink is printable via inkjet technology and gets electrically conductive even at temperatures below 200 °C, resulting in verifiably biocompatible conductive lines. This combination of materials would not be possible with conventional thick-film pastes of multilayer ceramics (LTCC, HTCC), as these only sinter at high temperatures above 700 °C. A further advantage of cold sintering is that there is no need for thermal debinding as required of paste or tape-casting binders.

Cold sintering can be carried out at temperatures as low as 50 °C, thereby offering opportunities for the incorporation of temperature-sensitive bioactive substances. This approach allows for the development of novel functional implants, which, for example, enable the transmission and control of electrical muscle signals through multilayer bioceramic implants.

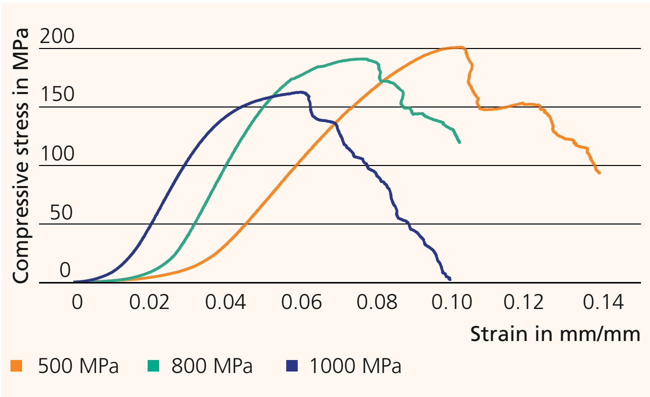

Fig. 3: Mechanical properties of the bioceramics.