Strong and tough 3D-printed ceramics through defect-tolerant materials

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A fast-growing number of scientific and technological studies and patents have been published these past twenty years on additive manufacturing ceramics. Additive manufacturing technologies indeed hold the promise of enabling the achievement of complex or personalized shapes and architectures with less material consumption. On the other side, the full potential of '3D printing' is still not fully reached in practical terms, with few products in the market and a slow industrial progress. There are indeed challenges and questions on additive-manufactured ceramics : (1) CAD-CAM is a very efficient 'benchmark' for personalized pieces (such as dental restoration) and there is no real push towards a decrease of material consumption, (2) The resolutions/dimensional control obtained so far are excellent with state of the art processes (injection, pressing, machining) and the level of precision required is demanding, (3) current advanced "substractive" processes already enable the fabrication of multi-layered and graded materials, which is still debuting by additive manufacturing, (4) additive-manufactured materials yet do not reach mechanical properties of thus processed by conventional technologies.

This presentation summarizes an approach to assess the suitability of additive manufacturing, with examples given in the dental ceramics field. Emphasize is given first on the relations between process parameters - defects population - mechanical strength. In particular, defects that can be found by two major technologies in the field (Stereolithography and Direct Ink Writing) are characterized as well as their effect of final strength. The role of paste rheology during the process (ensuring extrusion or spreading / ensuring self-standing ability, etc.) to control the size of these defects and obtain high-strength materials is then discussed.

We then show that some tough ceramic materials, such as Ceria-doped zirconia composites or yttria-doped zirconia with a low amount of yttria, may lead to ceramic materials with a certain degree of transformation-induced plasticity, translated towards a better defect-tolerance and thus a higher tolerance to process variations than conventional ceramics (e.g. 3Y-TZP). Ce-TZP composites can for example exhibit plasticity before failure, even with defects reaching several dozens of microns. 1.5 Y-TZP (developed by Tosoh under the name 'ZGAYA') can reach a toughness of more than 8 MPa.m1/2 while keeping a strength of more than 1 GPa. Both ceramics can ensure high Weibull moduli, which is generally a challenge when working by additive manufacturing.

Last, we discuss about the accuracy of additively manufactured zirconia four-unit fixed dental prostheses fabricated by stereolithography, digital light processing and material jetting compared with subtractive manufacturing. All additive manufacturing technologies were not yet as accurate as subtractive manufacturing, but stereolithography was the most precise, with a degree of dimensional control considered as sufficient for dental-restoration practice.

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