REVIEW ARTICLE

INKJET PRINTING OF CERAMICS - A REVIEW

ABSTRACT

Ceramics have been used to fabricate a wide variety of restorations including inlays, onlays, implants, crowns and fixed partial dentures on account of their biocompatibility, wear resistance and better esthetics. The presently used subtractive manufacturing techniques remove material from raw ceramic blanks to form the restorations which leads to considerable wastage of ceramics. Additive manufacturing (AM) techniques may overcome such deficiencies through bottom-up processing approaches, where 3D objects are built up by adding layer-upon-layer of material. Additive manufacturing techniques that are of special interest to ceramics are stereo-lithography, 3D printing, laser sintering, laser melting and direct inkjet printing. This novel technique has great potential to produce, cost-efficiently, all-ceramic dental restorations at high accuracy and with a minimum of materials consumption.

Key words: Ceramics, additive manufacturing, inkjet printing, piezoelectric.

J Ind Dent Assoc Kochi 2019;1(4):16-9.

Author:

Dr. Manju Mary K.

Senior Lecturer
Department of Prosthodontics
Indira Gandhi Institute of Dental Sciences
Nellikuzhi P.O.
Kothamanagalam, Kerala 686 691

Address for correspondence:
Dr. Manju Mary K.
Mylankal, Greenland gardens
Perumbavoor, Kerala
Email : manjumarypeter@gmail.com

INTRODUCTION

The introduction of CAD-CAM milling revolutionized the dental field by making zirconia a standard material for dental prosthetic restorations. A major disadvantage with the currently used techniques for the manufacture of ceramic restorations is the considerable wastage of raw material from which the restoration is milled out. This method is called subtractive manufacturing because the ceramic restoration is made by cutting sections out of hard sintered ceramic block or by cutting from soft green ceramic and subsequent sintering. The unused portions of the raw ceramic material must be discarded after milling, as the recycling of this excess material is not feasible. This procedure is time consuming and also because of the short milling cycles used, the tools are exposed to heavy abrasion from sintered hard ceramic blocks. Moreover, the surface damage produced by the milling procedure significantly reduce the strength of zirconia which could be further weakened by different surface treatment methods.[1] Even though milling from soft green ceramic saves considerable amount of time, the shrinkage during subsequent sintering can affect the contour and shape of the restorations.

Additive manufacturing of ceramics

The terms "rapid prototyping", "rapid manufacturing", "solid freeform fabrication" and "generative manufacturing processes" are often used as synonyms for "constructive" possibilities. The above-named terms cover various generative manufacturing processes in which 3-dimensional models or components are prepared from computer-aided design data (CAD data)[2]. Examples of typical rapid prototyping processes are stereolithography, 3D printing and inkjet modelling. The principle of rapid prototyping is based on the layered construction of a three-dimensional component. Two-dimensional layers (XY plane) are laid on top of one another. Depending on the thickness of the layers, there is a greater or lesser degree of gradation of the component in the direction of construction (Z direction)[3]. It is expected that this preparation is substantially more cost-effective to implement than processes involving the removal of material. The main potential for savings lies in the use of less material. In addition, constructive processes allow a parallel manufacture which will bring a significant saving in time and increase in productivity.[4]

Additive manufacturing techniques like direct inkjet printing may overcome such deficiencies through bottom-up processing approaches, where 3D objects are built up by adding layer-upon-layer of material.[5] First, a 3D model of the restoration is designed by using Computer Aided Design (CAD). This is sent to a 3D printer which will read the digital data and create the restoration by printing multiple layers using raw materials. The ceramic ink drops ejected through the printer nozzle land on the substrate at the desired position by applying precise digital control where they form drops due to surface tension. These drops are then fused to form three-dimensional ceramic restorative structures. This direct inkjet printing of a ceramic suspension provides the possibility of generating dense green bodies at a high resolution and complex shape.[6]

In comparison with traditional ceramic processing methods, ceramic inkjet printing has a number of advantages. It requires minimum tooling and gives great design and fabrication flexibility[7].

Piezoelectric Inkjet printing of ceramics

Piezoelectric technology is considered to be more feasible for inkjet printing of ceramic restorations[8]. Piezoelectric materials are materials such as certain ceramics that can produce electricity in response to applied mechanical stress, such as compression. Piezo materials can also expand or contract when an electrical charge is applied. The expansion or contraction of the piezo crystal under voltage moves it forward or backward. This slowly pushes or pulls the actuator material that is attached to the piezo crystal. The movement of actuator generates a pressure pulse that ejects the fluid through the nozzle of the printing head. Direct ceramic inkjet printing (DCIJP) uses ceramic powder in a carrier medium which is deposited through a delivery system actuated by a piezoelectric device. Successful printing depends on the preparation of suitable ceramic ink which is essentially a well-dispersed suspension of a fine powder. The dispersion must be stable and free from agglomerates.[9]

J. Ebert et al manufactured a posterior ceramic crown using direct inkjet printing from a tailored zirconia-based ceramic suspension. This ceramic ink consists of approximately 27 vol% of zirconia powder, 55% distilled water, Boehmite sol to prevent agglomeration of the ceramic particles and to increase the green body strength, and dispersants. They injected the ceramic suspension into an empty standard HP cartridge by means of a syringe. The printing device was based on a modified drop-on-demand Deskjet printer (HP DeskJet 930c, Hewlett Packard). The ceramic crown was then 3D-printed and subsequently sintered. They concluded that this novel technique has great potential to produce cost-efficiently, all-ceramic dental restorations at high accuracy and with a minimum of materials consumption.[10]

Drawbacks of current Inkjet printing technology

Typical nozzle diameter of piezoelectric printers ranges from 10-15 µm. So all the particles have to be 50 times smaller than the diameter of the nozzle to avoid clogging of nozzle. A mean ceramic particle size of 90 nm has been achieved during piezoelectric inkjet printing of zirconia ceramic dental components. Sometimes, the drops generated from the print head of an inkjet printer may show the characteristic elongated tail and the formation of satellite drops. The satellite drops may land in a different location from the parent drop, hence compromising the resolution of a printed object.[11] Particle analysis of the powders is necessary to determine ceramic powder particle size and particle distribution is important to prevent agglomeration in the nozzles. Irregular particle size with a wide distribution of particles could possibly increase the chances of agglomeration.[12]

Good contact between ceramic suspension drops is required for homogenous distribution of the material and for the desired characteristics of the resulting restorative material. The distance between the centers of two adjacent drops is called drop spacing. Optimal drop spacing produces a line with smooth edge and uniform thickness. Isolated drops appear on the substrate when drops are printed at a drop spacing larger than twice the drop's radius. If we decrease the drop spacing, the drops partly overlap and merge together, forming a scalloped pattern. Another problem with current technique is the "coffee stain" defect that occurs during drying. It is caused by particle migration from the center to the edge of a drying drop and leading to nonuniform printed structures.[13]

CONCLUSION

Ceramic ink development is now relatively mature and has great potential to produce, cost-efficiently, all-ceramic dental restorations at high accuracy and with a minimum of materials consumption. Though the experiments are in a naïve phase, additive manufacturing technology has potential in terms of cost, productivity and time.[14] With the ability of manufacturing parts directly from a CAD model with adequate accuracy and minimal waste, additive manufacturing holds great potential for the future production of custom dental restoration parts.

There is the important fact that advanced technologies eliminate the risk of dimensional changes of the impressions and casts because they skip these procedures – the prosthetic field can just be scanned and the model directly printed without any disruption of the tissues. The dental laboratory does not need more square meters now because everything is stored simply in the computer hard disk.[15]

REFERENCES

1. Wang H,Aboushelib MN, Feilzer AJ.Strength influencing variables on CAD/CAM zirconia frameworks. Dent Mater 2008;24:633-638.

2. Tay BY, Evans JRG, EdirisingheM. Solid freeform fabrication of ceramics(Review) International Materials Reviews 2013;48(6):341-70

3. Blazdel JF, Evans JRG. Application of a continuous ink jet printer to solid free forming of ceramics, Journal of materials processing technology 2000;99(1):94-102

4. MareikeWätjen A, Gingter P, Kramer M, Telle R. Novel Prospects and Possibilities in Additive Manufacturing of Ceramics by means of Direct Inkjet Printing. Advances in Mechanical Engineering Volume 2014, Article ID 141346

5. Utela B, Anderson RL, Kuhn H. Advanced Ceramic Materials and Processes for Three-Dimensional Printing (3DP). Solid Free FabrSymp. 2006;290-303.

6. Ponnambalam P, Ramakrishnan N, Rajesh PK, Prakasan K. Rheological Behaviour of Ceramic Inks for Direct Ceramic Inkjet Printing. 2006;56(2):279-88.

7. Derby B. Inkjet printing ceramics: From drops to solid. Journal of the European Ceramic Society 2011;31(14):2543-50.

8. Gali S, Sirsi S. 3D printing: the future technology in prosthodontics. Journal of Dental and Oro-facial Research 2015;11(1):37-40.

9. Ebert J, Özkol E, Zeichner A, Uibel K, Weiss O, Koops U, Telle R, Fischer H. Direct Inkjet Printing of Dental Prostheses Made of Zirconia, Journal of Dental Research 2009 Jul;88(7):673-6.

10. Gebhardt A. Vision of Rapid Prototyping, Ber. DGK 2006;83:7-12.

11. Derby B. Additive Manufacture of Ceramics Components by Inkjet Printing. Engineering 2015;1(1): 113–123 .

12. Shen JZ, Kosmac T. Advanced Ceramics for Dentistry. First Edition Elsevier 2014.

13. Yang L, Zhanga S, Oliveira G, StuckerB.Development of a 3D Printing Method for Production of Dental Application. Li Yang. 2011;346-53.

14. Cima MJ, Yoo J, Khanuja S, Rynerson M, Nammour D, Giritlioglu B, Grau J, Sachs EM. Structural Ceramic Components by 3D Printing. Proceedings of the 6th International Solid Freeform Fabrication Symposium. Austin, TX, USA. 1995.

15. Katreva I, Dikova T, Abadzhiev M, Tonchev T. 3D printing in contemporary prosthodontic treatment. Scripta Scientifica Medicinae Dentalis 2016,2(1):7-11.