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Short Communication

Metal Additive Manufacturing Technology for Digital Dentistry

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DESCRIPTION

Additive manufacturing creates objects by building materials layer by layer using Computer-Aided Design (CAD) models. Additive manufacturing techniques include binder jetting, powder bed fusion, sheet lamination, directed energy deposition, material extrusion, and VAT photo polymerization. In dentistry, Selective Laser Melting (SLM), a powder bed fusion technique, is widely used to fabricate metallic dental prostheses [1,2]. SLM uses a fiber laser to realize layer-by-layer metal powder melting according to CAD data to enable the creation of complex geometries, simplified production processes, and reduced material waste [3]. SLM can ensure uniform quality, regardless of the dental technician's skill. Thus, SLM has replaced conventional casting methods and is used to fabricate implants, Porcelain-Fused-To-Metal (PFM) restorations, and Removable Partial Denture (RPD) frameworks [4,5]. Co-Cr-Mo powder is primarily used for PFM restoration and RPD frameworks, whereas Ti-6Al-4V and pure Ti are used as implants. This review discusses Co-Cr-Mo alloys fabricated *via* SLM in terms of their microstructure, mechanical properties, accuracy, fit, and biocompatibility [6].

Microstructures and mechanical properties

A well-known drawback of SLM is that residual stress accumulates during fabrication because of the repeated rapid heating and cooling solidification process, which induces delamination, collapse, and deformation. Thus, SLM builds normally require heat treatments to relieve residual stress. However, the microstructures and mechanical properties are influenced by the heat treatment conditions.

In the as-built state, SLM-fabricated microstructures exhibit specific fine cellular or columnar dendritic structures [3]. Compared with conventional casting, finer grains were obtained, which contributed to excellent mechanical properties [7]. In previous studies, the results of tensile tests revealed that the Ultimate Tensile Strength (UTS) and 0.2% Proof Strength (PS) were significantly superior to those obtained by using the conventional casting method [3]. In the case of heat treatment, there are two approaches: one involving heat treatment at 750°C-900°C to release residual stress and induce martensitic transformation ($\gamma \rightarrow \varepsilon$), and another involving heat treatment at 1150°C-1200°C to release residual stress and induce recrystallization. When heated within the range of 750°C-900°C, specific fine dendritic structures have been shown to disappear and grain boundaries became decorated with precipitates [8]. Regarding the mechanical properties, an increase in the proportion of the ε phase relative to the γ phase has led to improvements in 0.2% PS, UTS, and hardness, whereas ductility decreased [9]. Because of these characteristics, they are commonly used in the production of PFM where ductility is not a primary requirement. Recrystallization has been shown to occur in response to an 1150°C-1200°C heat treatment, resulting in a microstructure that is predominantly composed of the γ phase, which corresponded to a significant improvement in ductility [8]. However, the UTS and 0.2% PS have been shown to be lower than those of the as-built material, although they significantly exceeded those of the samples produced by using the conventional casting method [10,11]. Therefore, this method is used for the production of RPD frameworks that require high ductility.

CoCrMo alloys produced *via* an additive manufacturing method meet the requirements of the International Organization for Standardization (ISO 22674:2022) and possess significantly superior mechanical strength compared to samples produced *via* a conventional casting method, making them suitable for use in dental prosthetic devices [12].

Biocompatibility

Dental materials regulate the local oral microenvironment *via* contact with surrounding tissues, and the release of metallic ions from alloys can lead to various adverse tissue reactions and/or hypersensitivity in individuals [13]. Therefore, alloys introduced into the oral environment should have a lower rate of release of metallic ions to reduce the risk to patient health [13]. Several studies have reported considerably lower rates of metal ion release in SLM samples than in conventional cast samples, indicating that the corrosion resistance of SLM-processed Co-Cr-Mo alloy samples is superior to that of conventional cast samples [13,14]. This has been attributed to the specific fine cellular dendritic microstructures and formation of relatively small carbides in the SLM-processed Co-Cr-Mo alloy samples, as well as in the protective passive film [14,15]. Another study reported that the SLM group exhibited higher rates of cell proliferation than the traditional cast-treated

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cells, indicating the higher biocompatibility of the SLM-prepared alloy [16]. Thus, SLM technology yields more biocompatible builds than conventional casting techniques.

Accuracy and fitness

Accuracy and fitness are the two primary criteria used to assess the functionality and durability of dental prostheses. Because SLM builds objects layer by layer, the production of samples with inclined surfaces may lead to the occurrence of a stair-step effect [17]. This effect occurs as a result of the small gaps between the vertical layers of a material during the manufacturing process, as they can potentially influence the surface quality and geometric precision. The influence of the stair-step effect varies according to the orientation of the structure, and the impact of the stair-step effect diminishes as the angle (α) between the sample's building orientation and its inclined surface decreases [17]. Additionally, when fabricating an overhang surface with an angle exceeding 45°C, a support structure is necessary to prevent deformation, warping, collapse, and crack formation [18]. The design of the support structure varies based on the orientation of the samples. When a large number of support structures are attached to the fabricated object, manual removal of these supports is required post-fabrication, which can negatively impact accuracy. Currently, in relatively small dental prostheses such as single crowns, the SLM method demonstrates a superior marginal fit compared to the conventional casting method [19]. However, reports have indicated that complex and large prostheses, such as RPD frameworks, may have lower fit accuracy and precision than those obtained *via* existing methods [20,21]. Therefore, it is necessary to optimize the angulation of the specific shapes of large dental prosthetic devices, as well as the design of the support structures. In addition, due to the limited number of clinical studies, further evaluation through clinical research is also necessary in the future.

CONCLUSION

Manufacturing dental prostheses *via* SLM offers several advantages, including simplification of the production process, uniform quality, and relatively higher efficiency. It also provides superior mechanical strength and biocompatibility compared with conventional methods. Regarding fit and accuracy, favorable data have been obtained for relatively small dental prostheses such as single crowns. To extend the application to more complex and larger prostheses, it is necessary to optimize the design of the support structures and orientation of the samples during fabrication.

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