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PHD THESIS Summary

ASPECTS OF METAL-TO-METAL AND METAL-TO-CERAMIC INTERACTION FOLLOWING THE APPLICATION OF MODERN TECHNOLOGICAL PROCEDURES

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INTRODUCTION

The field of prosthetic dentistry has seen remarkable evolution in materials, equipment, and techniques in recent decades, with both traditional and modern methods finding synergy. While outdated techniques have resurfaced in association with contemporary ones, continuous improvement remains the norm. Biocompatibility is a key concern for practitioners, and the combination of various materials offers both mechanical strength and natural aesthetics in prosthetic restorations.

Metals, including noble and base-metal alloys, have undergone significant evolution, not only in composition but also due to advancements in technology. Gold and its alloys were once prevalent in fixed prosthodontics but have been gradually replaced by alloys with reduced gold content and base-metal alloys, largely due to economic considerations. Titanium, introduced in dentistry in 1968, boasts exceptional properties such as biocompatibility, corrosion resistance, low density, and excellent mechanical strength. It finds extensive use in fixed and removable prostheses, implantological prosthetics, odontology, orthodontics, and oral surgery.

The traditional process of creating prostheses with metallic infrastructure involves time-consuming melting and casting, which is prone to errors. However, new technologies like galvanization, electroerosion, sintering, CAD/CAM/CAE, and SLS-SLM processes have emerged as alternatives, reducing work stages and minimizing technological errors.

Challenges in adapting titanium prostheses, especially regarding axis modification on abutments, can be addressed using laser correction techniques, significantly reducing correction time. Fabricating fixed prosthetic restorations from multiple pieces requires obtaining aggregation elements separately through melting-casting processes and subsequent consolidation. Solidarity processes have evolved from batch bonding to modern techniques like laser welding, microplasma welding, and electric pressure welding with the syncrystallization system.

These modern bonding procedures require additional equipment and expertise. Experimentation focuses on optimizing welding parameters for specific alloys and designs. Evaluation of welding quality through experimental methods, both destructive and non-destructive, is essential to understand the behavior of joined parts in vitro and in vivo.

In summary, the evolution of materials, equipment, and techniques in prosthetic dentistry has been remarkable. While modern technologies have streamlined processes, some traditional methods have found renewed relevance. Biocompatibility remains a priority, and the combination of materials offers both mechanical strength and natural aesthetics in prosthetic restorations. Ongoing experimentation aims to optimize welding parameters and evaluate the quality of welds for enhanced performance and longevity of prosthetic devices.

GENERAL PART

1. SLS/SLM Backround

Over a century, casting alloys have played a vital role in prosthodontic treatments, facilitated by Taggart's invention of the centrifugal casting machine in 1907, alongside the lost-wax technique. Initially, gold alloys were favored for their biocompatibility and ease of use, but as gold prices rose, attention shifted to more affordable alternatives like Au-Ag-Pd and Pd-Ag alloys. The subsequent emergence of non-precious dental alloys, including Fe-Cr-Ni, Ni-Cr, Co-Cr, and Ti alloys, addressed cost concerns. Presently, Co-Cr alloys, due to their biocompatibility, high strength, wear resistance, and corrosion resistance, are widely used in various dental applications.

However, the high hardness of Co-Cr alloys poses challenges in traditional casting techniques, leading to exploration of alternative manufacturing methods. The demand for faster and more predictable treatments has driven the adoption of computer-aided design and computer-aided manufacturing (CAD/CAM) techniques, both subtractive and additive. These techniques enable the fabrication of prosthetic appliances with greater efficiency and precision.

Subtractive CAD/CAM involves mechanically milling material blanks to obtain desired geometries, while additive CAD/CAM, or 3D printing, builds prosthetic appliances layer by layer. Among the additive techniques, powder bed fusion (PBF) methods like selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM) are commonly used for dental applications.

SLS utilizes a high-power laser to fuse small particles of powder-form material, allowing for the creation of objects with approximately 70% density. On the other hand, SLM involves fully melting the raw powder material to achieve fully dense parts (>99% density). EBM, similar to SLM, uses a focused electron beam to melt the metal powder in a vacuum environment.

Although SLM is the most widely used 3D printing technique for metal processing in dentistry, it has drawbacks such as poor surface quality and porosity. Post-processing treatments like polishing and heat-treatment are often required to overcome these issues. Despite these drawbacks, SLM offers advantages over traditional methods, including faster production times, lower costs, and superior mechanical properties.

Studies comparing SLM-produced substructures with those from traditional casting methods have shown that SLM specimens exhibit fine grains and homogeneously dispersed intermetallic compounds, leading to better mechanical properties and comparable bond strength with ceramic layers. However, further research is needed to fully understand the effects of the SLM technique on various properties of dental alloys.

Moreover, the effects of repetitive firing during ceramic veneering on SLM-produced metallic substructures are not extensively studied. While some studies suggest a negative impact on passive fit, others report comparable marginal and internal accuracy to conventional production procedures.

The aim of this work is to assess the crystalline structure modification of the metallic substructure of a SLM Co-Cr-W dental alloy veneered with ceramics, subsequent repeated firings of the ceramic layers, carried out at temperatures exceeding 900°C, by means of the X-ray diffraction (XRD) technique. Two different veneering ceramics, with similar firing parameters were used, in order to determine if there is any influence on the alloy’s behavior.

1.1 SLS Technology in dental medicine

Selective Laser Sintering (SLS) is an additive manufacturing technique that utilizes high-powered lasers to selectively fuse powdered materials, layer by layer, to create three-dimensional (3D) objects. Originally developed for rapid prototyping and industrial manufacturing applications, SLS technology has gained significant traction in dental medicine due to its ability to produce highly accurate, customized dental prostheses and appliances. This comprehensive overview aims to delve into the principles, applications, advantages, limitations, and advancements of SLS technology in dental medicine, highlighting its transformative impact on modern dental practice.

SLS technology operates on the principles of additive manufacturing, where digital design data is converted into physical objects layer by layer. The process involves several key steps:

- Powder Bed Preparation: A thin layer of powdered material, typically a biocompatible polymer or metal alloy, is spread evenly across a build platform within the SLS machine.
- Laser Sintering: A high-powered laser selectively fuses the powdered material in the desired areas, based on the digital design data provided by computer-aided design (CAD) software.
- Layer-by-Layer Build: After sintering a single layer, the build platform is lowered, and a new layer of powder is spread over the previously sintered layer. The process is repeated iteratively until the entire object is fabricated.
- Post-Processing: Once the printing process is complete, the fabricated object undergoes post-processing steps such as cooling, cleaning, and surface finishing to achieve the desired final properties.

The precision, speed, and versatility of SLS technology make it well-suited for producing complex, patient-specific dental prostheses and appliances with high accuracy and reproducibility.

2. Metal Ceramics

Metal ceramics, also known as ceramo-metal or ceramo-metallic restorations, are widely used in dentistry to restore teeth damaged by decay, trauma, or other factors. These restorations offer a combination of strength and aesthetics, making them a popular choice for both functional and cosmetic purposes.

Composed of two main components, metal ceramics consist of a metal substructure and a layer of ceramic material. The metal substructure, typically made from high noble metal alloys containing gold, platinum, or palladium, provides strength and support for the restoration. Meanwhile, the ceramic layer, often composed of porcelain or glass-ceramic material, is applied over the metal to mimic the natural appearance of teeth.

The strength and durability of metal ceramics make them suitable for restoring teeth in areas of the mouth subjected to high biting forces. This durability allows them to withstand chewing and biting forces over an extended period, ensuring long-term functionality.

In terms of aesthetics, the ceramic layer of metal ceramics is customized to match the color, translucency, and texture of natural teeth. Skilled dental technicians carefully layer and shape the ceramic material to achieve a lifelike appearance, blending seamlessly with the surrounding dentition.

Metal ceramics are versatile and can be used to restore various dental defects, including large cavities, fractures, and extensive tooth damage. They are commonly utilized for fabricating crowns, bridges, inlays, onlays, and dental implant restorations.

The metals used in metal ceramics are biocompatible, meaning they are well-tolerated by the body and do not typically cause adverse reactions in most patients. However, allergic reactions to certain metals may occur in some individuals, necessitating careful consideration by dentists during material selection.

Cost-effectiveness is another advantage of metal ceramics compared to all-ceramic restorations like zirconia or lithium disilicate crowns. While they may not offer the same level of translucency or aesthetic perfection, metal ceramics strike a balance between strength, aesthetics, and affordability.

Despite their advantages, metal ceramics have limitations. They may require more tooth preparation compared to all-ceramic restorations, and the metal substructure may become visible at the gumline, especially with gum recession. Additionally, the ceramic layer can be prone to chipping or fracturing under extreme biting forces.

In conclusion, metal ceramics remain a popular choice for dental restorations, particularly when strength, durability, and affordability are key considerations. However, advancements in dental materials and technology continue to expand treatment options, offering patients and dentists more customized and aesthetic outcomes.

3. Welding technologies

3.1 Electric arch welding.

Electric arc welding is a fundamental technique in dental prosthetics, allowing for the fusion of metal components to create durable and aesthetically pleasing dental appliances. Noble metals like gold, silver, and platinum, valued for their biocompatibility and corrosion resistance, are commonly used in these applications. Additionally, non-noble metals such as cobalt-chromium and nickel-chromium alloys offer favorable mechanical properties and cost-effectiveness.

Specialized welding electrodes, often made of tungsten, and shielding gases like argon or helium, are crucial for precise control and protection of the welding process, preventing oxidation and contamination. Biocompatibility is a paramount concern, necessitating rigorous testing and adherence to regulatory standards to ensure patient safety.

Recent advancements in materials science and welding technologies have further enhanced the field of dental prosthetics. Innovations in alloy design and welding equipment, coupled with digital workflows and 3D printing technologies, have improved efficiency, consistency, and quality in dental laboratories. These advancements continue to drive innovation, offering new possibilities for enhancing patient care and treatment outcomes in dental medicine.

3.2 Laser Welding in Dental Medicine

Laser welding in dental medicine utilizes focused laser beams to fuse dental materials precisely, offering advantages like minimal heat input and dissimilar material welding capability. Various lasers, including Nd:YAG, CO_2, and diode lasers, are employed based on their unique characteristics and applications. Laser welding finds extensive use in fabricating, repairing, and customizing dental prostheses, orthodontic appliances, and endodontic instruments. Its precision enables intricate assembly, adjustments, and modifications with minimal distortion, contributing to minimally invasive dentistry principles. Laser welding supports versatile applications across dental specialties, ensuring optimal fit, durability, and aesthetic outcomes in restorative and prosthetic treatments, thereby enhancing patient care and treatment efficacy in modern dental practice.

3.2 Plasma welding in dental medicine

Plasma welding, a sophisticated joining technique in dental medicine, utilizes high-energy plasma to fuse dental materials precisely, revolutionizing various aspects of dental treatment and prosthetic fabrication. Its applications span from fabricating dental prostheses to repairing orthodontic appliances, offering precise control over welding parameters and minimal heat damage to surrounding tissues. Plasma welders, including microplasma, micro-TIG, plasma arc, pulse arc, and laser welders, cater to diverse welding tasks, each with unique advantages and applications. These welders contribute to enhancing treatment outcomes, streamlining procedures, and prioritizing patient safety and comfort in modern dental practice. Plasma welding continues to evolve, integrating with digital workflows and advancing regenerative therapies, promising further improvements in patient care and treatment efficacy.

SPECIAL PART

4. Crystalline structure assessment of ceramic veneered Co-Cr-W dental alloy substructures obtained by selective laser melting-a pilot study

The aim of this study was to comprehensively evaluate the impact of ceramic veneering on the crystalline structure of a selective laser melted (SLM) Co-Cr-W dental alloy. This investigation was conducted using a combination of analytical techniques including X-ray diffraction (XRD), atomic force microscopy (AFM), and scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM-EDS). By employing these methodologies, the researchers sought to gain a nuanced understanding of the alterations occurring within the alloy's crystalline structure as a consequence of the ceramic veneering process.

To achieve this objective, ten identical plates fabricated using SLM were selected for the study. These plates were subsequently veneered with two different types of ceramics. The researchers subjected the plates to multiple firing cycles, each exceeding temperatures of 900°C, simulating the ceramic veneering process. Through XRD analysis, the study aimed to identify any newly formed crystalline phases within the Co-Cr-W alloy and to discern variations in crystallite sizes. This technique provided valuable insights into how the repeated firing of ceramic layers influenced the alloy's crystalline structure.

Moreover, AFM was employed to examine the surface morphology of the alloy following the firing cycles. By generating micrographs and histograms, the researchers aimed to visualize and quantify the impact of repeated firings on the surface topography of the Co-Cr-W alloy. This allowed for a detailed assessment of how the alloy's surface was affected by the ceramic firing process, corroborating the findings obtained from XRD analysis.

In addition, SEM-EDS analysis was conducted to investigate the impact of different firing parameters on both the alloy and the ceramic microstructure. By examining the surface quality and chemical composition of the ceramics, this technique provided further insights into the behavior of the veneering materials. The disparities in chemical composition identified by EDS were expected to correlate with variations in the behavior of the ceramics during the firing process.

The overarching aim of this study was to elucidate how the repeated firings of ceramic layers influence the crystalline structure of the SLM Co-Cr-W dental alloy. By employing a multi-technique approach encompassing XRD, AFM, SEM, and EDS, the researchers aimed to provide a comprehensive understanding of the complex interactions between the alloy and the veneering ceramics, thereby informing future developments in dental prosthetic materials and fabrication techniques.

5. Mechanical assessment of Metal Structures of Dental Prostheses Welded via Various Technologies

The primary aim of this study was to evaluate the mechanical strength of metal frameworks intended for fixed partial prostheses, specifically focusing on those constructed from a Co-Cr alloy. Fixed partial prostheses, commonly known as dental bridges, are critical components in restorative dentistry, serving to replace missing teeth and restore oral function and aesthetics. Given their integral role in dental rehabilitation, it is imperative to assess the mechanical integrity of the materials used in their fabrication to ensure long-term clinical success.

To address this aim, the researchers employed a systematic approach. Initially, metal frameworks were fabricated using Co-Cr alloy, a material known for its favorable mechanical properties and biocompatibility. These frameworks served as the basis for subsequent mechanical testing. The study then proceeded to investigate the impact of two distinct welding techniques—laser and plasma—on the mechanical performance of the frameworks.

The decision to utilize laser and plasma welding processes stemmed from their widespread use in dental prosthetics and their potential to influence the mechanical properties of the welded joints. By subjecting the frameworks to these welding methods, the researchers aimed to discern any differences in mechanical strength between the welded and non-welded specimens, thereby elucidating the efficacy of each welding technique in reinforcing the structural integrity of the prosthetic frameworks.

Mechanical testing was conducted using the Mecmesin MultiTest 5-i device, a specialized apparatus capable of applying controlled forces to assess material strength and behavior. The results of these tests provided valuable insights into the response of the metal frameworks to mechanical loading, enabling the researchers to draw conclusions regarding their overall robustness and resistance to deformation and fracture.

Upon analysis of the mechanical test data, several key findings emerged. Firstly, the control samples, which had not undergone welding, exhibited yielding behavior under applied loads, indicating their ability to deform without fracturing—a desirable characteristic for dental prosthetic materials. In contrast, the samples welded using laser and plasma techniques displayed differing fracture behaviors. While laser-welded samples exhibited fracture under high mechanical loads, plasma-welded samples fractured at substantially lower values.

Furthermore, the study identified several factors influencing the success of welding processes and the mechanical strength of the welded joints. These included the quality of the joint surface, the presence of sharp angles, surface preparation techniques, and the avoidance of inclusions and discontinuities—all of which are critical considerations in ensuring durable and reliable prosthetic restorations.

The overarching aim of this study was to evaluate the mechanical strength of metal frameworks for fixed partial prostheses, with a specific focus on assessing the efficacy of laser and plasma welding techniques in reinforcing these structures. By elucidating the influence of welding processes on the mechanical properties of the frameworks, the study contributes valuable insights to the field of dental prosthetics, guiding the selection of optimal fabrication and repair methods to enhance the longevity and performance of fixed prosthetic restorations.

6. Comparative Analysis of Microstructural Alterations in Metallic Substructures Welded via Electric Arc, Plasma, and Laser Methods

The research findings indicate that while current practices offer potential for rectifying defects in the metal components of fixed dental prosthesses, not all methods lead to optimal outcomes.

The comparative analysis of welding methods, as evidenced by intensity graphs and microstructural characteristics, provides valuable insights into their respective performance and implications for material integrity. Firstly, the observed decrease in crystallinity in the arc weld compared to laser and plasma welding suggests differing thermal effects and solidification behaviors. Laser welding, despite minimal alterations in the intensity graph, exhibits the highest lattice strain, indicating significant internal stress within the welded structure. This phenomenon can potentially affect the mechanical properties and long-term stability of the weld joint.

On the other hand, plasma welding, characterized by the smallest lattice strain and preservation of crystallite sizes akin to benchmark samples, highlights its efficacy in maintaining material integrity and minimizing structural alterations. The absence of visible changes in the intensity graph further underscores its stability and reliability in welding applications. These findings suggest that plasma welding may offer a favorable balance between structural integrity and microstructural refinement.

Furthermore, the discussion delves into the underlying mechanisms driving the observed differences among welding methods. Laser welding's ability to produce finer and more uniform microstructures can be attributed to its precise control over heat input and localized heating, facilitating the formation of refined grain structures. Similarly, plasma welding, with its advantages in heat control and finer microstructure generation, presents a promising alternative to traditional electric arc welding processes.

In contrast, electric arc welding, while widely employed, is characterized by broader heat-affected zones and less precise heat control, potentially leading to greater variability in microstructure and mechanical properties. The discussion highlights the trade-offs between process simplicity and microstructural refinement, emphasizing the importance of selecting appropriate welding methods based on specific performance requirements and material considerations.

Overall, the findings underscore the importance of comprehensive assessment and selection of welding methods to ensure optimal performance and material integrity in welded structures.