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SIMULATION DRIVEN DESIGN OF MACHINING FIXTURES IN DENTAL IMPLANT MANUFACTURING

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ABSTRACT

This article deals with the design and functional verification of a clamping fixture intended for the finishing operation of dental implants manufactured using additive manufacturing technology. Given the specific mechanical properties of additively manufactured components and the requirements for dimensional accuracy, it is essential to ensure stable fixation of the workpiece during machining. The proposed solution utilizes a six-point clamping system, which ensures the distribution of clamping forces. The functionality of the fixture was verified through a strength analysis performed in the SimScale simulation environment under defined boundary conditions corresponding to the loads during milling. The analysis results showed that the maximum value of the equivalent stress according to the von Mises criterion reaches 279.1 MPa and is localized in the contact areas between the fixture and the implants. The stress distribution is the same on all implants, confirming the load distribution. Based on the results, a design safety factor was determined, which reaches a value of 2.87, confirming that the designed fixture meets the requirements in terms of mechanical loading and ensures the stability of the system during machining.

Keywords: clamping fixture, dental implants, additive manufacturing, strength analysis, milling.

INTRODUCTION

Dental implants represent one of the most widely used solutions for the replacement of missing teeth due to their high biocompatibility, mechanical strength, and long-term clinical reliability. [1] Recent developments in additive manufacturing technologies have enabled the production of titanium dental implants with complex geometries, customized shapes, and reduced material waste. In particular, powder-bed fusion technologies such as Selective Laser Melting (SLM) have become increasingly adopted in the biomedical industry because they allow the fabrication of patient-specific components while maintaining the mechanical properties required for implant applications. [2]

Despite these advantages, additively manufactured dental implants generally require subsequent post-processing operations. The implants are typically produced as part of a common support platform, which ensures their stability during the additive manufacturing process. After fabrication, the support structures must be removed and the functional surfaces finished to achieve the dimensional accuracy and surface quality required for clinical use. [2][3] Consequently, machining remains an essential stage of the manufacturing process, directly influencing the final quality and functionality of the implant.

In the presented study, the finishing operation is considered as a conventional macro-scale milling process used for the removal of the support platform and the separation of individual dental implants from the additively manufactured base structure. Unlike micromachining processes, where material removal occurs at chip thicknesses comparable to the cutting-edge radius, the investigated operation is characterized by conventional cutting conditions and cutting forces acting on the entire implant assembly. Therefore, the fixture design and subsequent numerical analysis were performed considering macrocutting conditions representative of industrial milling operations.

During machining, cutting forces act on the implant assembly and are transferred through the clamping system to the fixture structure. Insufficient rigidity of the fixture may result in deformation, positioning errors, vibration generation, and reduced machining accuracy. These effects become particularly critical in the case of dental implants, where strict requirements are imposed on dimensional precision, surface integrity, and manufacturing reliability. [3] Consequently, the design of the fixture must ensure not only stable workpiece fixation but also uniform load distribution and sufficient structural stiffness throughout the machining operation.

To reduce development costs and minimize the need for physical prototype testing, numerical simulation methods are increasingly applied during fixture design. Finite element analysis enables the prediction of stress distribution, deformation behaviour, and structural safety under representative machining loads before manufacturing implementation. Such approaches contribute to improved fixture performance and support the development of reliable manufacturing systems for precision biomedical components.

The aim of this article is to design a clamping fixture for the finishing operation of additively manufactured dental implants and to verify its functionality using finite element analysis. Particular attention is devoted to stress distribution, identification of critical regions, deformation behaviour, and evaluation of the structural safety of the proposed solution under defined machining loads.

TEORETICLA REVIEW

Dental implants

Dental implants are medical devices designed to replace missing teeth; they are implanted directly into the jawbone. In terms of materials, they are most commonly made of titanium or its alloys, which are characterized by high biocompatibility, mechanical strength, and corrosion resistance. The surface of the implants is treated to promote osseointegration, i.e., the direct bonding of the implant to the bone tissue. [1]

Currently, additive manufacturing is also used in the production of dental implants, enabling the creation of complex geometric structures and customized solutions. Implants are often manufactured on a shared support platform, which ensures their stability during the printing process. However, after additive manufacturing is complete, it is necessary to perform subsequent technological operations, particularly the removal of this platform. [2]

From a technological standpoint, the machining of dental implants is a specific process that requires high precision and surface quality while eliminating the risk of mechanical damage. Implants are characterized by relatively small dimensions and complex geometry, which increases their susceptibility to deformation during clamping and machining. [3]

Particular emphasis is placed on the cleanliness of the manufacturing process.

Since implants come into direct contact with the biological environment, it is essential to minimize contamination of their surface. This can be caused, for example, by the release of particles from the fixture or an inappropriate choice of material. For this reason, the design of the manufacturing system, including the clamping fixture, takes into account not only mechanical stability but also hygienic and material requirements. [4]

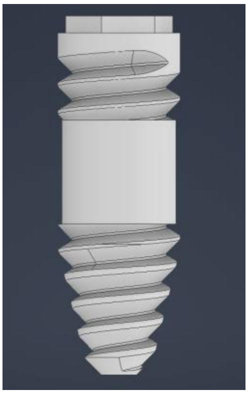

Figure 1. 3D model of a dental implant

Mechanical and dynamic loads in a machining system

During the manufacturing cycle, the clamping fixture is subjected to a system of mechanical and dynamic loads generated by the continuous interaction between the cutting tool, the workpiece, and the fixture body. These forces are primarily caused by the cutting process during material removal, and their nature depends directly on the chosen machining method, the physical and mechanical properties of the workpiece material, and the precise geometry of the tool's cutting edge. At the same time, clamping forces are introduced into the system, the primary function of which is to ensure a stable position of the workpiece, thereby preventing unwanted movement of the platform throughout the entire duration of the machining operation. [5]

The cutting force acting on the workpiece is defined by several vector components. From the perspective of fixture design, its lateral component is the most significant, as it causes a permanent tendency for the workpiece to shift in a direction perpendicular to the machine spindle axis. This factor is identified as critical for the overall stability of the clamping, as it induces a direct load on the clamping elements. These forces are transmitted through the contact interfaces between the workpiece and the fixture, leading to the formation of stress fields that are concentrated primarily in the zones of direct contact and at the points of force transmission. [6]

Contact mechanics and stress distribution in materials

From the perspective of solid mechanics, a fixture is defined as a structural system subjected to a combination of compressive, bending, and, in specific cases, shear stresses. High contact pressures are generated in the clamping zones, which are directly proportional to the magnitude of the applied clamping force and inversely proportional to the size of the contact area. A reduced contact area indicates a nonlinear increase in local stresses, which can lead to micro-deformations or permanent damage to the surface layers of the workpiece. Therefore, during the design process, an in-depth optimization of the contact planes is performed to achieve load distribution across the entire circumference of the platform. [7]

Special attention is paid to the contact mechanics between the individual functional elements of the system. Contact stresses arise at the points of contact, which, if the geometry is improperly selected, can locally exceed the yield strength of the material used. In the case of dental implants, the occurrence of any local surface damage is unacceptable, as these changes could negatively affect the resulting functional properties and aesthetic parameters. The design of the fixture therefore ensures a sufficiently dimensioned and geometrically appropriate contact surface, which effectively minimizes stress concentration at critical nodes. [7]

Static stiffness, accuracy, and dynamic stability of the system

Static stiffness represents one of the key factors affecting machining accuracy and process stability. Insufficient rigidity of the machine tool structure, fixture, or workpiece may result in elastic deformation under cutting loads, leading to dimensional inaccuracies and deterioration of surface quality. Recent studies have shown that topology optimization and finite element modelling can significantly improve the stiffness-to-weight ratio of machine tool structures while maintaining their operational performance. Structural modifications aimed at reinforcing critical load-bearing components contribute to increased rigidity and improved machining accuracy. [8]

Machining accuracy is closely related to the structural behaviour of the machine tool under operational loads. The distribution of deformation throughout the machine structure directly influences the relative position between the tool and the workpiece. Numerical analyses of high-precision machine tools have demonstrated that spindle assemblies, rotary axes, and supporting structures represent the most critical sources of displacement affecting machining precision. Optimisation of these components contributes to reduced positioning errors and improved dimensional accuracy during machining operations. [9]

Dynamic stability represents another essential aspect of machining system performance. During machining operations, cutting forces generate vibrations that affect tool life, surface integrity, and process reliability. Modal analyses and experimental investigations have shown that increasing natural frequencies and reducing structural compliance improve vibration resistance and reduce the likelihood of resonance. The ability to accurately predict the dynamic response of machine structures enables the optimisation of machine tool design and contributes to more stable machining conditions. [9]

The significance of dynamic stability becomes particularly evident during the machining of titanium alloys. Due to their high strength and low thermal conductivity, titanium alloys generate elevated cutting forces and increased thermal loads, which may promote unstable cutting conditions. Recent studies demonstrated that fluctuations in cutting forces, irregular chip formation, and self-excited vibrations may occur under certain cutting conditions, negatively affecting surface quality, dimensional accuracy, and tool wear. Therefore, achieving reliable machining performance requires not only sufficient static stiffness but also adequate dynamic stability of the entire machine–fixture–workpiece system. [10]

Material optimization, durability, and biocompatibility

The material composition of the clamping fixture is a fundamental element in the process of load transfer and distribution. From a mechanical standpoint, the primary parameter is the modulus of elasticity, which defines the material’s ability to resist deformation. The use of materials with a high modulus of elasticity results in minimal elastic deformation, which increases the stability of the system. Strength characteristics, surface hardness, and wear resistance are also taken into account, ensuring the long-term functionality of the fixture without degradation of its technical parameters. [11]

In the specific context of dental implant manufacturing, strict requirements for cleanliness and biocompatibility are integrated into the design. Since these components are intended for implantation into the human body, it is essential to eliminate any form of contamination. Stainless steel is therefore selected as the primary construction material, characterized by exceptional chemical stability and high corrosion resistance. This material selection prevents the risk of releasing metal fragments or oxidation products that could adversely affect the quality of the implants. [11]

The use of stainless steel also contributes to simplifying the maintenance and cleaning processes of the device in accordance with hygiene requirements. The material’s surface is highly resistant to the aggressive effects of chemical cleaning agents and allows for the complete removal of titanium filings and cooling media. This ensures safe repeatability of the device’s use without the risk of undesirable effects between individual production operations. [12]

Specifics of machining additively manufactured titanium components

Additive manufacturing technologies enable the production of complex titanium components with reduced material waste and greater design flexibility. However, components produced by processes such as Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), and Direct Metal Deposition (DMD) generally require subsequent machining operations to achieve the dimensional accuracy and surface quality required for functional applications. Surface roughness, dimensional deviations, partially fused particles, and residual stresses generated during layer-by-layer fabrication represent the primary reasons for applying post-processing operations to additively manufactured Ti6Al4V components. Recent studies have shown that the final quality of additively manufactured parts is strongly dependent on both the additive manufacturing process and the subsequent machining strategy. [13]

The machinability of additively manufactured titanium alloys is strongly influenced by their specific microstructure, mechanical properties, and residual stress distribution. Compared with conventionally manufactured Ti6Al4V alloys, additively manufactured components often exhibit anisotropic behavior, heterogeneous microstructures, and variations in hardness caused by rapid thermal cycling during fabrication. Several studies reported that build orientation, process parameters, and thermal history significantly affect cutting forces, tool wear, and surface integrity during machining operations. Furthermore, additive manufacturing-induced anisotropy has been identified as an important factor influencing tool wear mechanisms and machining performance. [14]

Residual stresses generated during rapid melting and solidification cycles remain one of the major challenges associated with machining additively manufactured titanium alloys. High thermal gradients and cooling rates lead to the accumulation of internal stresses that may affect dimensional stability and contribute to distortion during support removal and finishing operations. In addition, the presence of manufacturing defects, surface irregularities, and microstructural heterogeneity may negatively influence the mechanical performance and long-term reliability of the final component. For this reason, considerable attention has been devoted to optimizing post-processing operations aimed at improving surface integrity and reducing the influence of manufacturing-induced defects. [15]

In the case of dental implant manufacturing, where strict requirements are imposed on dimensional accuracy and surface quality, machining operations represent a critical stage of the production process. The achievement of the required geometric accuracy and surface integrity is essential not only for the functional performance of the implant but also for its long-term clinical reliability. Therefore, the understanding of machining behavior and post-processing requirements of additively manufactured Ti6Al4V components remains an important research topic in advanced biomedical manufacturing. [13]

METHODOLOGY SECTION

The design of the clamping fixture is dictated by the need to ensure the stability and precise positioning of the 3D-printed platform with integrated implants during the milling process. Given the specific mechanical properties of parts produced by additive technologies, particularly their reduced stiffness, it is essential to prevent the occurrence of undesirable deformations.

The design ensures an even distribution of clamping forces to eliminate the risk of mechanical damage to the workpiece. The implementation of this fixture enables machining while achieving the defined geometric accuracy. The high quality of the final product is guaranteed by a clamping method that takes into account the structural integrity of additively manufactured components.

The Figure 2 shows a 3D model of the designed fixture.

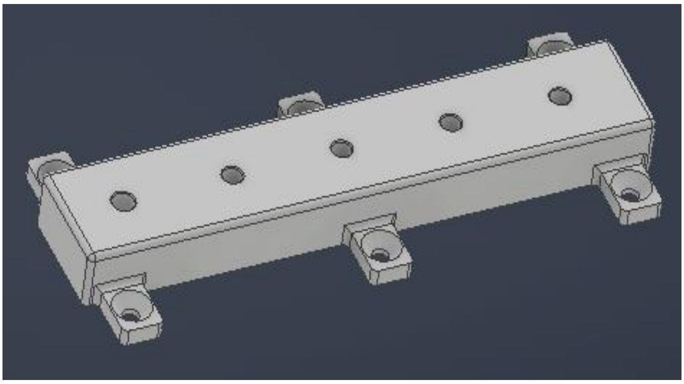

Figure 2. 3D model of the designed clamping fixture

Design characteristics of the clamping mechanism

The main load-bearing part of the structure consists of a section with integrated holes for securing implants. In the design of this body, emphasis is placed on achieving high static rigidity and stability during the machining process. Fixation to the machining center's worktable is achieved via fasteners integrated into the lower part of the body.

The upper surface is defined as a functional clamping plane onto which the workpiece—in the form of a platform with additively manufactured implants—is positioned (see Figure 3). Secure attachment to the worktable is ensured by protrusions with screw holes located on the sides of the fixture. This design prevents vibrations or unwanted movement of the fixture during the cutting process.

The design is focused on functionality and mechanical durability. The fixture enables repeatable and precise positioning of the workpiece, thereby creating conditions for stable machining. The overall solution is optimized to achieve a high degree of operational reliability.

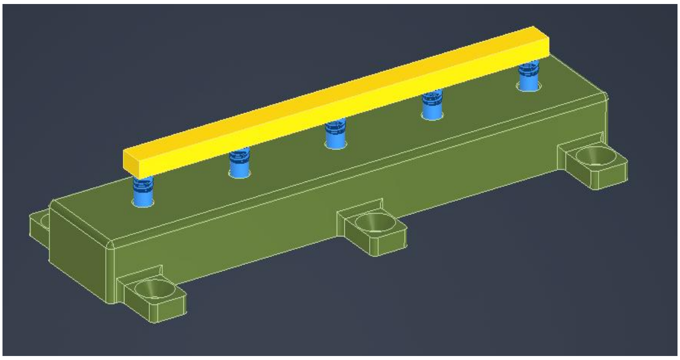

Figure 3. 3D model of a clamped dental implant casting in a clamping fixture

Material Specifications and Manufacturing Processes

The choice of material for the clamping fixture is determined by the need to achieve high tensile strength and static stiffness, while also taking into account the demands arising from the nature of the workpiece and the specific conditions of machining.. The fixture was assumed to be manufactured from precipitation-hardening stainless steel AISI 630 (17-4 PH), which is commonly used in engineering applications requiring high strength and corrosion resistance. The material possesses a yield strength of approximately

800 MPa, which was used as the reference value for the calculation of the safety factor in the finite element analysis. At the same time, this structural material is characterized by high corrosion resistance and chemical stability, which is classified as an essential parameter for applications where emphasis is placed on the sterility and cleanliness of the working environment.

The high surface stability of the selected material ensures that functional surfaces do not degrade during intensive and long-term use, thereby guaranteeing the accuracy and repeatability of the clamping process. In addition, this material allows for subsequent cleaning, decontamination, and sterilization processes without any negative impact on its physical properties.

The workpiece consists of a platform manufactured using additive manufacturing technology, onto which dental implants are integrated. This platform is defined as a temporary support structure that ensures the fixation of the implants during the primary manufacturing process. Due to the nature of selective laser melting, the material may exhibit residual stresses and local structural inhomogeneities that directly affect its mechanical behavior during subsequent subtractive machining. For this reason, it is essential to ensure stable clamping of the entire assembly to prevent deformation during the manufacturing process.

Throughout the entire manufacturing process, the utmost emphasis is placed on eliminating the risk of contamination. Since dental implants are intended for direct contact with the biological structures of the human body, ensuring a high level of cleanliness is a critical parameter. Contamination can be caused not only by direct contact with the body of the device but also by metal microparticles released during the milling process.

The manufacturing operation is primarily focused on removing the abutment platform from the printed dental implants via the milling process. This is a critical phase of production during which the individual components are mechanically separated, and which directly determines the final product quality. During this process, it is essential to ensure the stability of the workpiece and its spatial position relative to the cutting tool. Any form of instability, vibration, or unwanted displacement can lead to irreversible damage to the implants, changes in their geometric specifications, or an unacceptable deterioration of surface roughness.

The design of the clamping mechanism is intended to ensure an even distribution of clamping force across the entire contact surface of the workpiece. This approach eliminates the risk of local overloading and reduces the risk of elastic or plastic deformation. The clamping elements are arranged symmetrically within the assembly, thereby achieving uniform transfer of force flows between the fixture and the platform.

A key aspect of the design is the protection of the functional surface of the implants throughout the entire machining process. Improperly designed clamping could cause microdeformations or damage to the sensitive surface layer, which would ultimately negatively affect the functional properties of the implant after implantation. The fixture therefore ensures a sufficiently secure yet gentle clamping that minimizes mechanical stress in critical areas of dental implants.

The material configuration, in close conjunction with the tool's design, enables the execution of a complex machining process while strictly adhering to requirements for mechanical stability, dimensional accuracy, and technological cleanliness. At the same time, this solution guarantees the preservation of the structural integrity of dental implants and creates suitable conditions for their subsequent processing, including final cleaning and sterilization processes.

Defining the boundary conditions for the simulation

The functional and safety parameters of the proposed clamping mechanism were verified through a comprehensive strength analysis using a simulation method. The simulation was performed using SimScale software. The computational model was created based on the geometric specifications of the fixture. The individual elements included in the analysis are: the fixture's base body, the workpiece defined by a platform with dental implants, and a simplified configuration of screw connections. The model was designed to capture the mechanical responses of the system under force loading and to identify critical zones in terms of local stress concentrations and elastic deformations.

In constructing the computational model, assumptions of linear elasticity and isotropic material behavior were applied, which allows for the evaluation of stress-strain states within the considered operating regime.

The boundary conditions of the simulation calculation were defined to ensure a high degree of agreement with actual operating conditions during the machining process. Fixation was applied to the lower functional surface of the fixture base, thereby simulating a rigid connection to the worktable of the CNC machining center. This methodological approach eliminated all six degrees of freedom of the system, thereby preventing unwanted spatial displacement. The boundary conditions defined in this manner provide a realistic representation of the clamping fixture's behavior during critical phases of the machining operation.

The clamping force is transmitted to the contact interface between the platform and the dental implants, thereby simulating the actual application of clamping pressure to the workpiece. The chosen approach allows for an effective analysis of stress distribution at critical nodes without the need to model microscopic geometric features.

Cutting resistance was expressed in the analysis as a force acting on the workpiece in the direction of tool movement. The magnitude of this force was determined based on milling parameters, with its value accounting for dynamic effects during material removal. The simulation considered a cutting force of 300 N, which represents a conservative load estimate for the given material. The cutting force value of 300 N was selected based on published experimental studies focused on the milling of Ti6Al4V alloys. Petrů et al. reported cutting force components corresponding to a resultant cutting force of approximately 250 N under comparable machining conditions. Considering the variability of machining parameters and to ensure a conservative assessment of fixture performance, a cutting force of 300 N was applied in the finite element analysis. [16]

The modeling accounted for the most unfavorable direction of force application to verify the stability of the clamping even under critical conditions. This approach allows for assessing the fixture's behavior under extreme conditions and verifying that the workpiece remains securely fixed. The fixture is clamped by screw connections at six points. This solution ensures an even distribution of pressure across the entire contact surface and reduces the risk of local deformations. The screw layout is designed symmetrically with respect to the load, thereby increasing the stability of the entire system during machining.

The force acting during machining was concentrated in the model at the point of contact between the tool and the workpiece (see Figure 4). This simplification allows for effective monitoring of how the fixture and workpiece deform under pressure and for identifying the most stressed areas. Despite this simplification, the model provides accurate information on the stress distribution within the structure.

Based on these conditions, it is possible to evaluate whether the designed fixture meets the stiffness and stability requirements necessary for the given machining operation. Part of the analysis involved monitoring deformations caused by clamping and cutting forces. Elastic bending of dental implants was monitored primarily in the section between the fixture and the support platform. The simulation results allow for an assessment of whether the designed structure is sufficiently rigid and stable for precise machining.

The simulation model provides an overall view of the behavior and strength of the designed fixture under real-world operating conditions. Based on the obtained results, the most stressed areas of the structure are identified, which can then be modified to reduce deformations and increase the precision of implant manufacturing.

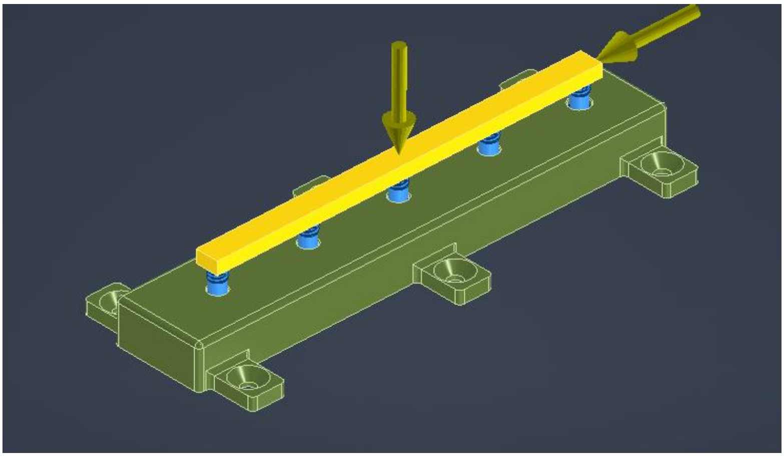

Figure 4. Visualization of simulated machining loads in 3D models

Analysis results

The results of the structural analysis provide a detailed view of the distribution of stresses and strains in the individual segments of the clamping mechanism. Based on the evaluation of the stress state, critical areas of the structure were identified and its overall behavior under operational loads was assessed.

Stress distribution and critical areas

The maximum stress values are concentrated in the contact areas between the fixture and the dental implant platform. This zone represents the primary site of clamping force transmission, which fully corresponds to the expected mechanical behavior of the system. In the visualization of the results, this condition is depicted using a color scale, where increased stress values are indicated by a transition from green to yellow in the immediate vicinity of individual implants. The local increase in stress at these points is a natural consequence of the concentration of forces at the contact points.

Other parts of the mechanism, particularly the massive base body of the fixture, exhibit low stress levels. This confirms the high stiffness of the designed system and the base's ability to effectively absorb and transfer loads without causing undesirable deformations.

Analysis of Deformations and System Stiffness

The deformations observed in the fixture are minimal and do not reach levels that could negatively affect the positioning accuracy of the workpiece. The greatest deviations occur in the area of the plate on which the dental implants are integrated; however, their deformation is negligible compared to the overall dimensions of the system. This result demonstrates that the fixture possesses sufficient rigidity to withstand external loading while maintaining clamping stability.

The stress distribution once again confirms that the load is evenly distributed among all six clamping points. This clamping design eliminates the risk of local overloading, thereby preventing deformation of the platform or damage to the contact surfaces of the dental implants.

RESULTS

The maximum von Mises equivalent stress was measured at 279.1 MPa. This maximum is localized in areas just below the abutment on the dental implant. This is the zone of direct transmission of clamping and shear forces, which is consistent with the expected mechanical behavior of the system.

The stress distribution is shown in Figure 5. The highest values are indicated in red around the contact surfaces and clamping elements.

A detailed view of the stress distribution on a single implant is shown in Figure 6.

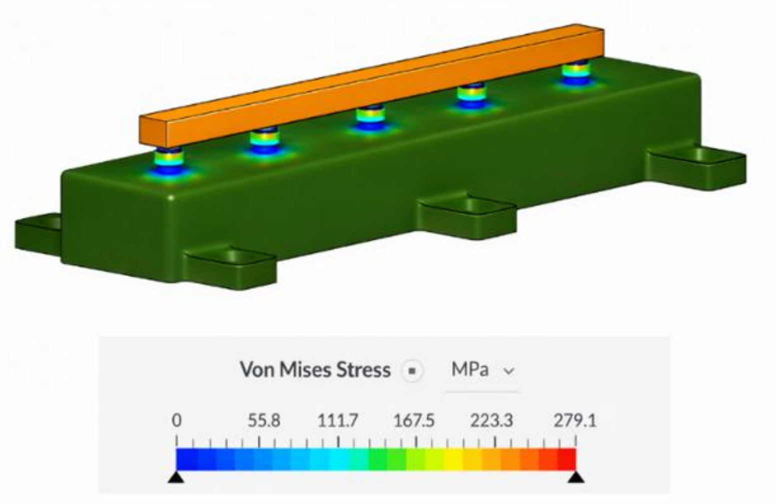

Figure 5. Stress simulation during the machining of dental implants

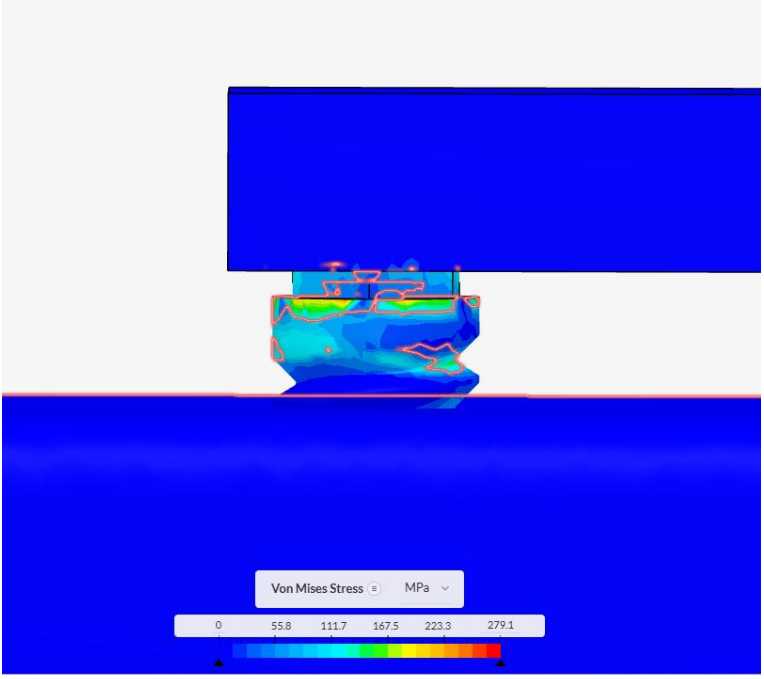

Figure 6. Detailed stress display

The results show that the equivalent stress is distributed evenly across all analyzed implants, confirming the symmetrical load distribution. Significantly lower stress values were recorded in other parts of the structure, confirming the fixture's sufficient stiffness and effective load distribution without the formation of critical stress concentrations.

Based on the results of the numerical analysis, a safety factor for the structure was determined, which expresses the margin of safety against the occurrence of plastic deformation. The safety factor was determined as the ratio of the material's yield strength to the maximum equivalent stress according to von Mises' criterion:

$$FoS = \frac{Re}{\sigma max}$$

FoS – safety factor
Re – yield point of the fixture material
σmax – maximum system load

When considering high-strength stainless steel with a yield strength of approximately 800 MPa and a maximum stress of 279.1 MPa, the safety factor is:

$$FoS = \frac{800\ MPa}{279{,}1\ MPa} = 2{,}87$$

The calculated safety factor is greater than 2, which indicates that the structure has a sufficient strength margin and confirms that the designed fixture is adequate in terms of mechanical loading. The structure is capable of withstanding the applied forces without the risk of plastic deformation.

DISCUSION

The obtained numerical results confirmed that the highest stress concentrations occurred in the contact region between the dental implant and the supporting fixture structure, while the overall deformation of the fixture remained low. Similar findings were reported by Nguyen and Tung, who identified the largest deformations in regions characterized by reduced structural stiffness and increased distance from the clamping locations [17]. These results indicate that the stiffness of the fixture and the arrangement of the clamping elements play a decisive role in maintaining dimensional stability during machining operations. The maximum von Mises stress obtained in the present study reached approximately 279 MPa, which remained below the yield strength of the selected fixture material. This finding confirms the suitability of the proposed fixture design for machining operations involving additively manufactured titanium dental implants. The low deformation values further suggest that the fixture is capable of maintaining the positional accuracy required for precision machining applications. Future research should focus on the experimental validation of the numerical model under real machining conditions. Additional investigations may also evaluate the influence of different clamping configurations, cutting force magnitudes, and fixture materials on stress distribution and deformation behaviour. Furthermore, the integration of real cutting force measurements and process monitoring systems could improve the accuracy of future simulation models and contribute to the development of more robust fixture designs for dental implant manufacturing.

CONCLUSION

This article presented the design and numerical verification of a clamping fixture intended for the finishing operation of additively manufactured dental implants. The proposed fixture was specifically developed for the macro-scale milling process used to remove the support platform and separate individual implants from the additively manufactured structure. A six-point clamping concept was adopted to ensure uniform load transfer and stable fixation of the implant assembly during machining The functionality of the proposed solution was evaluated using finite element analysis under representative machining loads. The simulation results showed that the maximum equivalent stress according to the von Mises criterion reached 279.1 MPa and was localized in the contact regions between the fixture and the implants. The stress distribution was found to be uniform across all analyzed implants, confirming balanced load transfer within the clamping system. Furthermore, the calculated safety factor reached a value of 2.87, indicating that the proposed fixture possesses a sufficient strength reserve and is capable of withstanding the applied machining loads without the risk of plastic deformation. The novelty of the presented research lies in the development and simulation-based verification of a dedicated fixture designed specifically for the post-processing of additively manufactured dental implants produced on a common support platform. Unlike conventional fixture designs, the proposed solution considers the specific geometric arrangement of multiple implants and the load conditions associated with support removal operations. The obtained results demonstrate that the proposed design ensures adequate structural stiffness, stable workpiece positioning, and reliable load distribution throughout the machining process. From a practical perspective, the proposed fixture can contribute to improving machining accuracy, reducing the risk of implant deformation during support removal, and increasing the reliability of manufacturing operations in dental implant production. The use of numerical simulations during the design stage also enables the reduction of development time and costs associated with physical prototype testing. Future research will focus on the experimental validation of the numerical model under real machining conditions. Additional studies will investigate the influence of different cutting force levels, clamping configurations, and fixture materials on stress distribution and deformation behaviour. Furthermore, the integration of measured cutting force data into simulation models will be considered to improve the accuracy of future fixture design methodologies.

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DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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