Biomechanic and Design of Hip Implant
Kalça İmplantının Biyomekaniği ve Tasarımı

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***Abstract*—This study aims to model the suitability of hip implant materials according to age and patient characteristics, focusing on a comprehensive evaluation of the materials used in hip implants. The increasing prevalence of hip-related disorders due to factors such as aging, reduced physical activity, and weight issues has intensified the demand for hip implants. The primary objective of this study is to conduct a comparative analysis of mechanically and biocompatibility-tested materials to identify the most suitable material for enhancing patients' quality of life while maintaining cost-effectiveness. The study evaluates the appropriateness of materials such as ceramics, stainless steel, chrome-cobalt alloys, titanium, and polyethylene for hip implants, considering their mechanical properties, durability, corrosion resistance, and biocompatibility through extensive laboratory testing. The lack of detailed studies specific to hip implants in the existing literature underscores the contribution of this research to the field. Utilizing models derived from computed tomography images and designed with Solidworks 3D modeling software, finite element analysis was conducted on the implants. The findings will be compared with existing literature, and an assessment report will be prepared. Developing a personalized and cost-effective implant with optimal characteristics is crucial for broad accessibility. Determining the most suitable material for implant durability and longevity is a primary goal. Additionally, selecting materials tailored to the patient's age, weight, physical activity level, and budget will contribute to creating customized hip implants. The results of this study will elucidate the advantages and disadvantages of different materials used in hip implants, providing valuable insights for material selection and application in the literature. The findings will serve as a foundational basis for future research in hip implants, guiding informed decision-making in material selection for surgeons, engineers, and patients alike. The ultimate aim is to contribute to our nation by fostering indigenous implant research and implementation through collaborative efforts and industry support.**

Keywords*—*hip implant; biomechanic; finite element analysis

***Özetçe*—Bu çalışmada, kalça implantlarında kullanılan malzemelerin kapsamlı bir şekilde değerlendirilmesine odaklanarak, kalça implantı malzemelerinin yaş ve hasta özelliklerine göre uygunluğunu modellemeyi amaçlamaktadır. Yaşlanma, fiziksel aktivitenin azalması ve kilo sorunları gibi faktörler nedeniyle kalçayla ilgili rahatsızlıkların yaygınlığının artması, kalça implantlarına olan talebi yoğunlaştırmıştır. Bu çalışmanın birincil amacı, maliyet etkinliğini korurken hastaların yaşam kalitesini artırmak için en uygun malzemeyi belirlemek üzere mekanik ve biyouyumluluk açısından test edilmiş malzemelerin karşılaştırmalı bir analizini yapmaktır. Çalışmada seramik, paslanmaz çelik, krom-kobalt alaşımları, titanyum ve polietilen gibi malzemelerin mekanik özellikleri, dayanıklılıkları, korozyon direnci ve biyouyumlulukları göz önünde bulundurularak kalça implantları için uygunluğu kapsamlı laboratuvar testleriyle değerlendirilmektedir. Mevcut literatürde kalça implantlarına özgü detaylı çalışmaların eksikliği, bu araştırmanın alana katkısının altını çizmektedir. Bilgisayarlı tomografi görüntülerinden elde edilen ve Solidworks 3D modelleme yazılımı ile tasarlanan modeller kullanılarak implantlar üzerinde sonlu eleman analizi yapılacaktır. Optimum özelliklere sahip kişiselleştirilmiş ve uygun maliyetli bir implantın geliştirilmesi, geniş erişilebilirlik için çok önemlidir. İmplant dayanıklılığı ve uzun ömürlülüğü için en uygun malzemenin belirlenmesi birincil hedeftir. Ayrıca, hastanın yaşına, kilosuna, fiziksel aktivite düzeyine ve bütçesine göre uyarlanmış malzemelerin seçilmesi, kişiye özel kalça implantlarının oluşturulmasına katkıda bulunacaktır. Bu çalışmanın sonuçları, kalça implantlarında kullanılan farklı malzemelerin avantaj ve dezavantajlarını aydınlatacak ve literatürde malzeme seçimi ve uygulaması için değerli bilgiler sağlayacaktır. Bulgular, kalça implantları alanında gelecekte yapılacak araştırmalar için temel bir dayanak oluşturacak ve cerrahlar, mühendisler ve hastalar için malzeme seçiminde bilinçli karar vermeye rehberlik edecektir. Nihai amaç, işbirliği çabaları ve endüstri desteği yoluyla yerli implant araştırmalarını ve uygulamalarını teşvik ederek ülkemize katkıda bulunmaktır.**

Anahtar Kelimeler*—*kalça implantı; biyomekanik; sonlu eleman analizi

I. Introduction

Hip implants are essential for managing hip joint disorders by alleviating pain, restoring mobility, and improving the overall quality of life. The increasing occurrence of hip disorders due to factors such as an aging population decreased physical activity, and rising weight-related concerns has led to rising demand for effective hip implants. This study aims to create models for hip implant materials, taking into account age and specific patient attributes. It involves a thorough comparison of materials through mechanical and biocompatibility testing. The objective is to pinpoint materials that offer the best combination of performance and affordability, ultimately contributing to the enhancement of patient well-being [1].

A. Problem Statement

This study centers on evaluating the appropriateness of diverse materials, including ceramics, stainless steel, chrome-cobalt alloy, titanium and its alloys, and polyethylene, for hip implants. Through comprehensive laboratory tests, the research aims to assess mechanical properties, durability, corrosion resistance, and biocompatibility, addressing a gap in the existing literature that lacks a detailed investigation specifically focused on hip implants [2]. Using finite element analysis, implant designs will be created based on models derived from computed tomography images and Solidworks 3D solid modeling [3]. Mechanical and sterilization tests will follow to explore material compatibility with patient age and other factors, employing various mechanical and biological tests to evaluate durability and biocompatibility.

B. Motivation

The primary objective is to create a cost-effective and customized hip implant that addresses individual factors such as age, weight, activity levels, and financial considerations. This research aims to identify the most suitable material for optimal implant longevity and durability, laying the groundwork for personalized implant design and material choices tailored to each patient. The study's results will offer valuable insights into the pros and cons of various hip implant materials, supporting informed decision-making in the healthcare sector. Surgeons, engineers, and patients will find guidance in selecting the most fitting hip implants based on these findings. Additionally, the study aspires to bring enhanced value to the country through local and national research and application of implants, contributing to progress in the field and inspiring future research initiatives.

II. Related Studies

Worldwide, there is a significant rise in the number of hip implant surgeries, paralleling the global increase in life expectancy. Each year, millions of individuals undergo hip implant procedures, a surge attributed to the aging demographics and advancements in healthcare services [4]. The longevity of hip implants can be extended through the application of precise surgical techniques and contemporary implant designs. Currently, successful hip implants boast a lifespan ranging from 15 to 20 years, with this duration contingent on various factors. Key elements affecting implant life include surgical precision, implant-person compatibility, patient lifestyle frequency and orientation, material wear resistance, corrosion resistance, manufacturing-related form errors, and the biocompatibility of the chosen material [5]. Deliberate attention to these factors and precautionary measures can significantly enhance the long-term success of hip implant procedures. In terms of innovation, the scope for change is somewhat limited. The construction phase of a manufactured implant encompasses three primary components: design, material selection, and manufacturing. Material selection, aimed at enhancing compatibility with the human body, is particularly crucial. This project's primary objective is to develop implants tailored to individual patients, considering parameters such as age, weight, activity levels, and budget constraints in addition to material specifications. Titanium, renowned for its high biocompatibility, chemical inertness, and strength, proves durable over time. Its low modulus of elasticity and suitability as an alternative to hard tissue make it biomechanically advantageous, especially in applications like hip implants. Innovations in microstructure design, considering its correlation with corrosion fatigue strength, and modifications to the implant surface, such as film layers impacting protein absorption and bone cell differentiation, can enhance biocompatibility [6].

Stainless steel's durability and connectivity when integrated into the body make it a preferred choice. Its high durability and corrosion resistance contribute to the implants' longevity when exposed to bodily fluids and tissues. However, attention must be paid to application requirements, as stainless steel implants may not meet specific needs. For instance, they might create more stress in force distribution, potentially increasing the risk of fractures [7]. Additionally, the heavier nature of stainless steel implants could lead to undesirable load increases in certain applications, necessitating a focus on lighter materials [6].

Gessner et al.'s work (2019) [8] on cobalt-chromium alloy has influenced subsequent implant studies. Cobalt-chromium's mechanical suitability for loading and high wear resistance make it a preferred choice in implant applications. However, the low bioactivity of these materials poses challenges for full integration with natural tissues, potentially resulting in long-term biocompatibility issues. Consequently, meticulous material selection, considering the specific needs of the patient, becomes imperative. Recent advancements, such as the widespread use of bioactive coatings and surface modifications, aim to enhance biocompatibility and promote better tolerance by the body.

Mohamed N. Rahaman et al. (2007) [9] discussed the use of Ceramics in Hip and Knee Joint Replacement Implants. Hip implants manufactured with ceramics and ceramic nanocomposites offer advantages such as high durability, extended service life, low wear, and biocompatibility. However, drawbacks include fragility, high costs, production complexities, and the need for overhaul. Selecting the most suitable implant material depends on the patient's specific needs and surgical requirements. To enhance ceramic materials, incorporating nanoscale ceramic materials in hip implant construction and utilizing ceramic nanocomposites with different layers or phases can improve durability and mechanical properties.

Adnan Sevencan et al.'s studies [10] on biodegradable polymers have paved the way for further research. Polymers, known for their ability to dissolve in the body over time, are extensively used as biomaterials. However, their susceptibility to breakage due to weak force poses risks. Polymers that dissolve in the body aid in tissue healing, eliminating the need for implant removal. While polymers like polylactic acid (PLA), polyglycolic acid (PGA), polydioxanone (PDS), and polycaprolactone (PCL) are commonly used in orthopedics, their careful handling is crucial to prevent breakage. High molecular weight polyethylene (UHMWPE) is prevalent in hip and knee implants. Despite its chemical inertness, challenges may arise, such as the difficulty of absorbing and removing particles left in the body due to wear.

In this study, the selected materials from the aforementioned studies were considered, and among all biomaterials examined, five materials were chosen. Evaluating the mechanical and biological properties of these materials in a specially designed hip implant model offers a unique approach to data assessment. The primary aim of this research is to assess hip implant materials suitable for age and patient-specific needs while investigating the most effective treatment methods. The study strives to enhance patients' quality of life and accessibility to treatment. In pursuing a cost-effective and customizable implant, the research aims to optimize treatment processes. The results will contribute to informed decisions regarding material selection in surgical applications, shedding light on the advantages and disadvantages of different hip implant materials. This study aspires to guide future hip implant research, adding value to the country through domestic and national implant research and application. Ultimately, the project seeks answers to questions such as "Which methods are effective in hip implant manufacturing?" "What mechanical and biological tests should be conducted on hip implants?" "Is it feasible to select materials for patient-specific implants?" "Which biomaterials can be used most affordably in hip implant manufacturing?" and "Is it possible to design and manufacture personalized implants with optimal properties and a balanced price-to-performance ratio?" Solutions will be explored in response to these questions after the study.

III. Materials & Methods

The project consists of 5 main phases in total. These stages are:

- Mechanical design and Finite element analysis,
- Material analysis,
- Implant production,
- Mechanical Tests,
- Biocompatibility Tests,
- Result analysis,

At the end of each stage, the work done will be checked, deficiencies will be identified, these will be reconsidered, alternative solutions and solutions will be developed and tested again.

A. Mechanical Design and Finite Element Analysis

Our study focuses on developing a hip implant, and after conducting thorough research, it is evident that similar implants are commonly crafted from titanium and titanium alloys. In our endeavor, we aim to streamline the creation of a patient-specific implant by incorporating materials such as titanium and its alloys, chromium-cobalt alloys, polyethylene, ceramic, and stainless steel, ensuring compatibility with the original design. The mechanical design phase will utilize the SolidWorks program for solid modeling in both 2D and 3D dimensions. Part drawings will be created separately, emphasizing producibility and ease of assembly.

Following the completion of the general design in SolidWorks, the finite element method will be employed to analyze stress distributions and accumulations. Any identified issues will prompt adjustments in the design or the selection of materials, with the ultimate goal of minimizing stress-related concerns [11], [12].

B. Material Analysis

Following comprehensive mechanical calculations and examinations, we meticulously selected five biomaterials out of the 15 researched, considering their price-performance quality as highlighted by ref. [13]–[15]. The chosen biomaterials include:

- Stainless Steel
- Titanium and Titanium Alloys
- Polyethylene
- Ceramics
- Chromium-Cobalt Alloys

1) Stainless Steel: Comprising iron, chromium, nickel, and other alloys, stainless steels, particularly grades 316L and 316LVM, stand out for their extensive use in medical implants. Noteworthy mechanical properties include high strength, good toughness, corrosion resistance, impact resistance, and fatigue resistance. Key properties are as follows:

- Strength: 500-900 MPa (Tensile Strength)
- Yield Strength: 200-450 MPa
- Elongation: Between 40% and 60%
- Hardness: Typically expressed as Rockwell C hardness (HRC).
- Thermal Conductivity: Intermediate
- Low-Temperature Performance: Ability to maintain strength even at low temperatures

2) Titanium and Titanium Alloys: Known for its lightweight and high strength, titanium and its alloys resist high temperatures and corrosion. Titanium, widely used in medical implants, adheres well to the body, offering durability without adding significant weight. The selected Ti-6Al-4V (Titanium-Aluminum-4 Vanadium) type boasts properties such as:

- Strength: 240-550 MPa
- Density: 4.5 g/cm^3
- Modulus of Elasticity: 110 GPa
- Thermal Conductivity: 21 W/(m.K)
- Corrosion Resistance: High (Comparable to Stainless Steel)

3) Polyethylene: Characterized by softness and toughness, polyethylene is a plastic material with a low friction coefficient. Its application in artificial joints is attributed to its soft and flexible nature, contributing to wear resistance and long-term durability. Key properties include:

- Strength: 10-30 MPa
- Density: 0.91 g/cm^3
- Modulus of Elasticity: 0.1-1 GPa
- Thermal Conductivity: Low
- Corrosion Resistance: Good

4) Ceramics: Boasting high-temperature resistance, hardness, and corrosion resistance, ceramics are, however, prone to brittleness. Notable properties encompass:

- High Hardness: Usually 5-10 GPa
- Low Elasticity: Modulus About 50-300 GPa
- High Breaking Strength: Usually 100-1000 MPa
- Low Coefficient of Thermal Expansion: 2-10 x 10≐6 /°C
- High Thermal Conductivity: 1-30 W/(m·K)
- Low Density Generally: 2-6 g/cm^3
- Corrosion Resistance: Chemically inert with high corrosion resistance

5) Chromium-Cobalt Alloys: Renowned for high strength, wear resistance, and corrosion resistance, chromium-cobalt alloys exhibit durability and resistance to impact and fatigue. Mechanical properties include:

- Durability: 600-1100 MPa
- Hardness: 400-500 HV
- Fatigue Strength: 350-500 MPa
- Modulus of Elasticity: 200-240 GPa
- Density: 8-9 g/cm^3

The importance of comparing these materials' mechanical properties with test results cannot be overstated [16], [17]. This comparative analysis is crucial for assessing design correctness and ensuring the appropriateness of material choices. The success of the project hinges on the outcomes of specific tests and experiments, underscoring their critical role in project advancement.

IV. Results and Discussion

The comprehensive assessment of materials used in hip implants, as outlined in this research study, represents a pivotal step towards enhancing patient outcomes and addressing the growing demand for effective solutions in the face of increasing hip-related disorders. The primary goal of this study is to conduct a thorough comparative analysis of mechanically and biocompatibility-tested materials, with a focus on modeling which was shown in Figure 1, the suitability of hip implant materials based on age and patient characteristics.

The applied forces are as shown in the Figure 2. Von Mises stress was evaluated with forces applied from three different points.

The von Mises stress, also known as the equivalent stress or equivalent von Mises stress, is a scalar value that represents the combined effect of normal and shear stresses on a material. It is derived from the principal stresses, which are the three orthogonal stresses acting on a point within a material. The von Mises stress is a commonly used criterion for assessing the yielding or failure of materials under complex stress states.

A. Ceramics

In the context of ceramics, which are known for their high strength and brittleness, the von Mises stress provides valuable information about the material's ability to withstand applied loads without fracturing. When the von Mises stress exceeds the material's strength limit, it indicates that the material is under significant stress and may be susceptible to failure or fracture. The minimum and maximum values of the von Mises stress provided in the analysis shown in Figure 3, $4.818e+04N/m \wedge 2$ and $9.906e+09N/m \wedge 2$ respectively, represent the range of stress levels experienced by the ceramic material. The maximum value suggests that the material can withstand very high stresses before reaching its failure limit, while the minimum value indicates the lowest stress level at which the material may exhibit significant deformation or other mechanical responses.

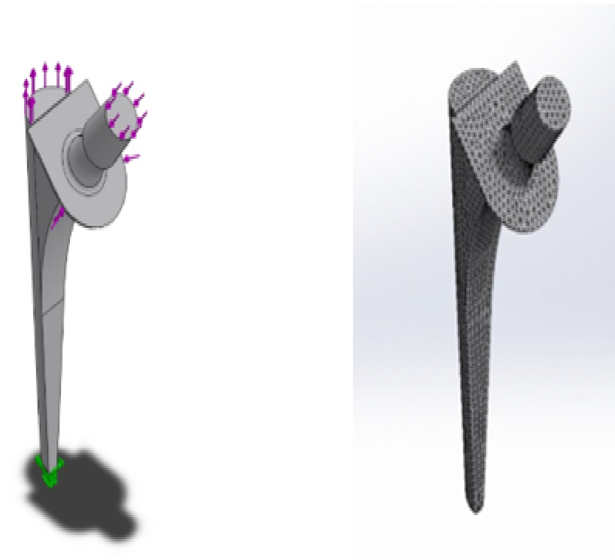


Figure 1: Load directions of the product and Meshed version

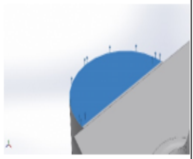
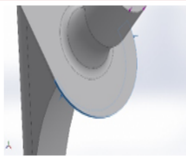
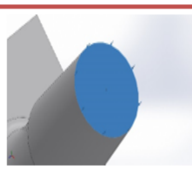
Load name	Upload Image	Load Details
Force-1		Objects: 1 faces Type: Apply normal force Value: -1.900 N
Force-2		Objects: 1 faces Type: Apply normal force Value: 700 N
Force-3		Objects: 1 faces Type: Apply normal force Value: 1.300 N

Figure 2: Forces applied to the scratched implant

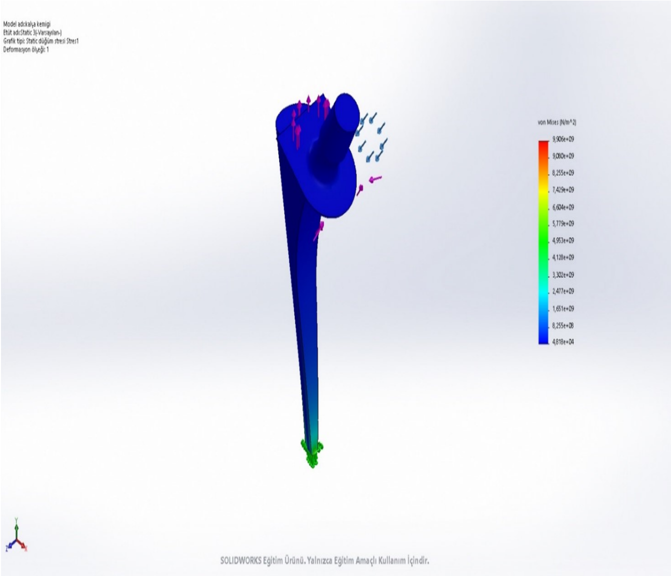


Figure 3: Von Mises Stress results caused by applying force to the ceramic in the range of 700-1900N

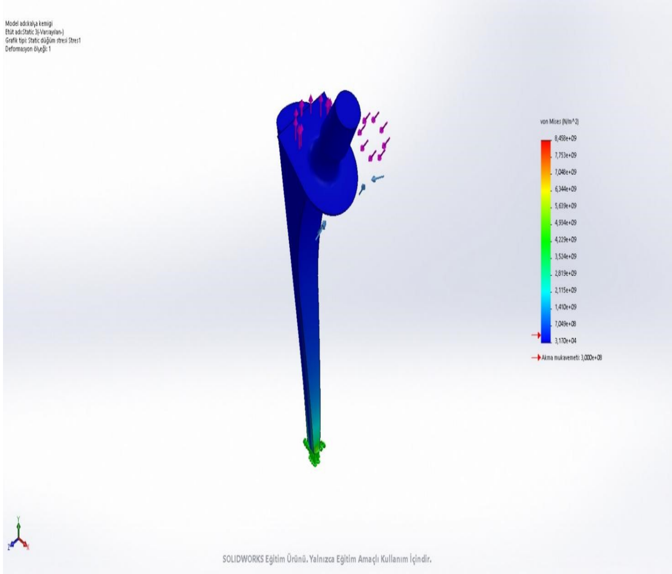


Figure 4: Von Mises Stress results caused by giving strength to Chromium-Cobalt alloys in the range of 700-1900N

B. Chromium-Cobalt Alloys

In the case of chrome cobalt, the von Mises stress values mentioned in the analysis indicate the range of stress that the material can withstand displayed in Figure 4.

The minimum von Mises stress value of "$3,170e{+}04N/m^2$" suggests the lowest stress level at which the material may experience yielding or deformation. This value indicates the material's resistance to deformation under various loading conditions.

On the other hand, the maximum von Mises stress value of "$8,458e+09N/m^2$" represents the highest stress level that the material can withstand before potential failure or fracture. It is essential to ensure that the applied stress on the material remains below this maximum value to maintain its structural integrity.

C. Titanium and Titanium Alloys

In the case of titanium and titanium alloys, the analysis (Figure 5) indicates that the von Mises stress values range from $6.539e+04N/m^2$ to $6.439e+09N/m^2$.

The analysis specifies the maximum von Mises stress criterion, which is a measure of the maximum stress level that the material can sustain before failure occurs. The maximum von Mises stress values mentioned in the analysis are $6.439e+09N/m^2$.

Titanium and titanium alloys are known for their excellent strength-to-weight ratio, corrosion resistance, and high-temperature stability. The specific von Mises stress values mentioned in the analysis can provide insights into the material's performance under different loading conditions.

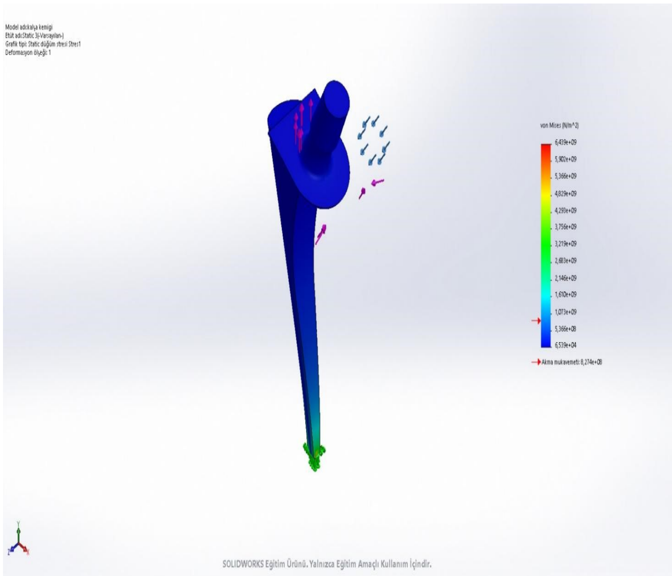


Figure 5: Von Mises Stress results caused by giving strength to titanium and titanium alloys in the range of 700-1900N

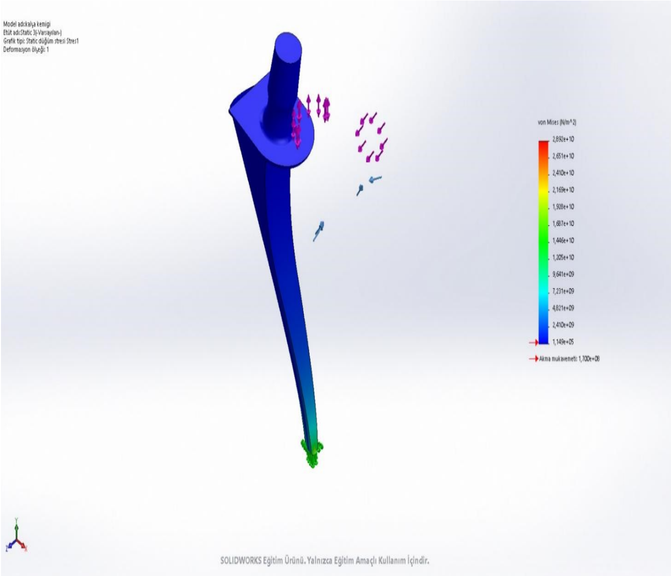


Figure 6: Von Mises Stress results caused by giving strength to Stainless Steel in the range of 700-1900N

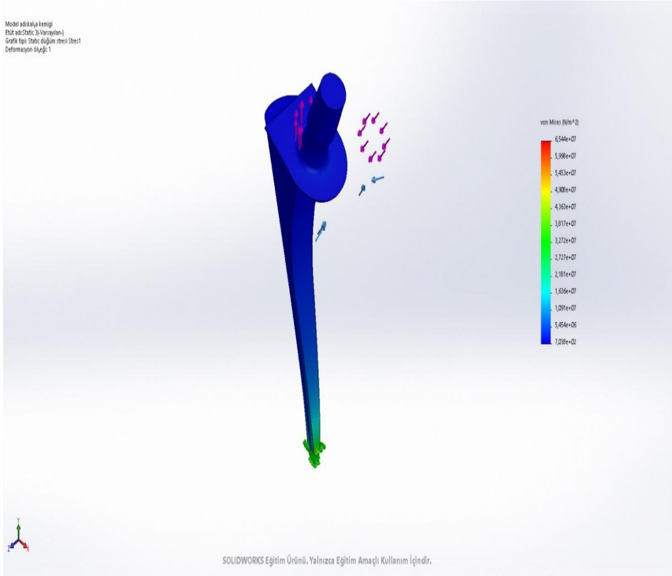


Figure 7: Von Mises Stress results caused by applying for each area 10N to high-density polyethylene

D. Stainless Steel

For Stainless Steel, the minimum von Mises stress value of $1.149e + 05N/m^2$ indicates the lowest equivalent stress experienced by the material (in Figure 6). Similarly, the maximum von Mises stress value of $2.892e + 10N/m^2$ represents the highest equivalent stress. These values provide an understanding of the stress levels the Stainless Steel material can withstand under the given loading conditions.

E. High Density Polyethylene

High-density polyethylene (HDPE) is a type of thermoplastic polymer known for its high strength and excellent impact resistance shown in Figure 7.

In the case of HDPE, the von Mises stress values provided in the analysis indicate the range of stress experienced by the material. The minimum value of $7,038e+02N/m^2$ represents the lower end of the stress range, while the maximum value of $6,544e + 07N/m^2$ represents the upper end. It's important to note that the specific conditions under which these stresses are obtained, such as loading conditions, temperature, and geometry, can significantly affect the von Mises stress values.

F. Low Density Polyethylene

Von mises stress is particularly useful for materials that exhibit isotropic and ductile behavior, such as low-density polyethylene (LDPE).

In the case of LDPE, the von Mises stress provides a measure of the equivalent stress experienced by the material, taking into account both normal and shear stresses [22]. This is important because materials can fail or deform plastically when the von Mises stress exceeds a certain threshold.

The analysis specifies the von Mises stress range for LDPE as $4,352e + 02N/m$ (minimum) and $2,382e + 08N/m$ (maximum). These values indicate the stress levels that LDPE can experience under the given conditions. The minimum value represents the lower bound of stress, while the maximum value represents the upper bound. It's important to note that these values may vary depending on the specific loading conditions and geometry of the LDPE component being analyzed.

Overall, the von Mises stress information provided in the analysis (in Figure 8)gives insights into the stress levels that LDPE can withstand or experience.

Comparing the two materials behaviors, we can see that the Von Mises stress values for low-density Polyethylene are lower than those for high-density Polyethylene. The minimum Von Mises stress is lower in the low-density Polyethylene

$$(4.352e + 02N/m^2)$$

compared to the high-density Polyethylene

$$(7.038e + 02N/m^2)$$

. Similarly, the maximum Von Mises stress is also lower in the low-density Polyethylene

$$(2.382e + 08N/m^2)$$

compared to the high-density Polyethylene

$$(6.544e + 07N/m^2)$$

. This suggests that low-density Polyethylene can withstand lower stress levels compared to high-density Polyethylene. Even though these two materials are the same, due to the difference in density, low-density polyethylene is displaced more when a 10N force is applied, while high-density polyethylene

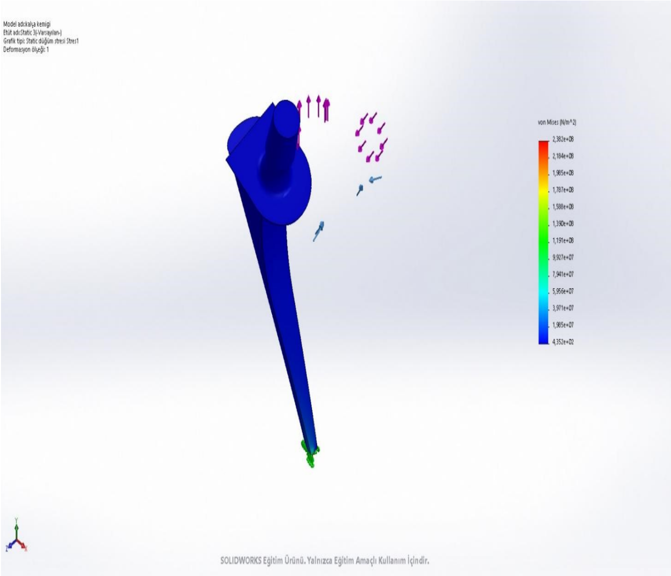


Figure 8: Von Mises Stress results caused by applying for each area 10N to low density polyethylene

is displaced less. In addition, it would not be right to compare this material with others because the product does not lift when we apply more force to polyethylene.

G. Comparison of the remaining four materials

1) Ceramics vs. Chromium-Cobalt Alloys: Performance: Ceramics generally have lower von Mises stress values compared to chromium-cobalt alloys. This suggests that ceramics are more brittle and have a lower load-bearing capacity, while chromium-cobalt alloys exhibit higher strength and better load-bearing capabilities. Durability: Ceramics are susceptible to cracking or fracturing under tensile stress, while chromium-cobalt alloys are more resistant to fatigue and deformation. Therefore, chromium-cobalt alloys tend to have higher durability compared to ceramics.

2) Ceramics vs. Stainless Steel: Performance: Ceramics typically have lower von Mises stress values compared to stainless steel. This indicates that ceramics are more brittle and have lower load-bearing capabilities, while stainless steel exhibits higher strength and better load-bearing capacity. Durability: Stainless steel has higher durability compared to ceramics due to its better resistance to fatigue, corrosion, and deformation. Stainless steel can withstand higher stress levels without failure, making it more durable in various applications.

3) Ceramics vs. Titanium and Titanium Alloys: Performance: Ceramics generally have lower von Mises stress values compared to titanium and its alloys. This suggests that ceramics are more brittle and have lower load-bearing capabilities, while titanium and its alloys exhibit higher strength and better load-bearing capacity. Durability: Titanium and its alloys have higher durability compared to ceramics due to their excellent fatigue resistance and corrosion resistance. They can withstand higher stress levels, making them more durable in demanding applications.

4) Chromium-Cobalt Alloys vs. Stainless Steel: Performance: Chromium-cobalt alloys and stainless steel can have comparable von Mises stress values, depending on the specific alloys and grades. Both materials exhibit good load-bearing capabilities and mechanical strength. Durability: Both chromium-cobalt alloys and stainless steel have good durability due to their resistance to fatigue and corrosion. The specific durability will depend on the alloy composition, surface finish, and environmental conditions.

5) Chromium-Cobalt Alloys vs. Titanium and Titanium Alloys: Performance: Titanium and its alloys generally have higher von Mises stress values compared to chromium-cobalt alloys. This suggests that titanium alloys exhibit higher strength and load-bearing capabilities, while chromium-cobalt alloys have good mechanical properties as well. Durability: Both chromium-cobalt alloys and titanium alloys have good durability. Chromium-cobalt alloys are known for their excellent wear resistance, while titanium alloys offer exceptional corrosion resistance and fatigue strength.

6) Stainless Steel vs. Titanium and Titanium Alloys: Performance: Titanium and its alloys generally have higher von Mises stress values compared to stainless steel. This indicates that titanium alloys exhibit higher strength and load-bearing capabilities, while stainless steel has good mechanical properties as well. Durability: Both stainless steel and titanium alloys have good durability. Stainless steel is known for its corrosion resistance, while titanium alloys offer excellent corrosion resistance, fatigue strength, and biocompatibility.

In summary, von Mises stress ranges reflect each material's ability to resist stress. Titanium offers a good balance between strength and lightness, Stainless Steel provides excellent corrosion resistance and mechanical properties, Chromium-cobalt improves the properties of stainless steel, and Ceramics exhibit exceptional strength and thermal stability. Apart from the von Mises force, the other thing we evaluated was the displacement of each material against the applied forces. While we had the chance to apply the same force to four different materials, the durability of the material did not allow this in the polyethylene group. According to the equal forces in the other four materials we applied, the material with the most displacement was stainless steel, while the material with the least displacement was ceramic. The displacement of a material with applied force is of critical importance in understanding the behavior and performance of the material. This provides important information to evaluate the strength properties, elastic behavior and overall durability of the material. The specific von Mises stress range for each material gives us information about the applicability of the materials.

V. FUTURE WORKS

As stated in the methodology section, a detailed finite element analysis of the implant was conducted comparatively on five different materials. When proceeding to the production of the implant, it is crucial to perform specific tests. As the material selection and sizing are customized to the patient, these values are not publicly available on the internet because they are treated with utmost care due to being personal information. For this reason, measurements have been taken from a well-known company. When designing an implant using the SolidWorks program, we utilized these values. Adhering to specific dimensions within reference ranges is commonly employed in the drafting process of an average implant and consistent with industry standards. Although the values obtained through finite element analysis were extracted using SolidWorks, mechanical tests will also be conducted for error-free production. These tests, conducted following international standards and regulations, encompass Stress-Strain, Uniaxial Tensile, Yield Strength, Elongation, Fatigue, and Hardness tests. Additionally, other planned tests, including mechanical tests and biocompatibility tests, will be implemented during the production phase of the implant. Biocompatibility tests hold critical importance during the material selection phase [18]–[21]. Evaluating their effects on surrounding tissues contributes to a comprehensive understanding of potential health risks. These tests also determine the material's potential degradation over time by microorganisms or enzymes. This comprehensive testing process is a crucial step to ensure that the developed implant is both biocompatible and mechanically reliable. Actual stress levels experienced in real-world applications may vary depending on factors such as specific alloy composition, manufacturing processes, applied loads, and environmental conditions.

VI. CONCLUSIONS

In conclusion, our research has delved into the mechanical intricacies of five distinct materials—ceramics, chromium-cobalt alloys, titanium and titanium alloys, stainless steel, and high-low density polyethylene—used in hip implant applications. The comparative analysis of these materials against established standards has unveiled valuable insights into their stress-resistance capabilities.

Our study emphasizes the significance of tailoring material choices to the specific needs of patients, considering factors such as long-term health, durability, cost, and biocompatibility. The mechanical tests conducted on these materials provide a foundation for informed decision-making, guiding clinicians and researchers in selecting the most suitable material for patients.

In essence, the culmination of our findings reinforces the pivotal role of material selection in shaping the future of hip implant designs and refining surgical practices. As we conclude, the insights gained from this research offer valuable guidance for clinicians, researchers, and the broader medical community, fostering advancements in hip implant technology and ultimately enhancing the overall quality of life for patients.

ACKNOWLEDGEMENTS

This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under Grant Number 1919B012328356. The authors thank TUBITAK for their support.

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