Modern American Journal of Medical and Health Sciences
ISSN (E): 3067-803X
Volume 01, Issue 04, July, 2025
Website: usajournals.org

MECHANICAL PROPERTIES OF MATERIALS USED IN DENTISTRY

Akhrorov Ma'ruf Nasimjonovich
Assistant Lecturer, Samarkand State Medical University
Samarkand, Uzbekistan
E-mail: akhrorov81@gmail.com

Abstract

This study aims to analyze the key physical and mechanical properties of materials commonly used in dentistry. These properties significantly influence the clinical performance and longevity of dental restorations and prostheses. Physical characteristics such as melting and boiling points, linear stress, thermal conductivity, thermal expansion coefficients, optical constants, color, and phase transitions are examined. In addition, mechanical properties including strength, hardness, elasticity, ductility, flowability, and brittleness are discussed in detail. Strength is defined as the ability to withstand external force without destruction, while elasticity refers to the material's ability to recover its shape after deformation. Ductility and viscosity determine how materials behave under continuous stress or rapid load application. The study highlights how these characteristics impact material selection in clinical dental applications. Understanding these properties allows dental professionals to make evidence-based decisions when choosing restorative materials for optimal patient outcomes.

Keywords: Elasticity, hardness, strength, deformation, force, pressure, ductility, viscosity, fracture, prosthesis.

Introduction

The use of various materials in the fabrication of dental prostheses and appliances depends directly on the nature, properties, and specific requirements of the

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ISSN (E): 3067-803X
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materials themselves. In the construction of dental prostheses, the materials can generally be divided into two categories: primary and auxiliary materials.
Primary (or structural) materials are those directly involved in the production of dental and jaw prostheses, including metal alloys, plastics, ceramics, and other compounds [1].
Dental materials must meet several essential requirements. They should be non-toxic, chemically inert in the oral cavity, and have sufficient mechanical strength to withstand the forces during mastication. Furthermore, they must exhibit suitable technological properties, such as the ability to be molded, cast, welded, or formed into shape without compromising their functionality or aesthetics [2].
Color stability is crucial, as materials must imitate natural oral tissues without noticeable changes. Additionally, all primary materials must be free from taste and odor to ensure patient comfort. The biocompatibility of these materials depends on the qualitative composition of their components, which must not release harmful substances and must remain stable when interacting with other substances present in the oral environment [3].

Literature Review

The mechanical properties of dental materials play a crucial role in the performance, longevity, and safety of dental restorations and prostheses. Over the past decades, a wide range of studies have been conducted to evaluate and compare the strength, hardness, elasticity, ductility, and biocompatibility of materials used in modern dentistry.
Traditionally, metal alloys such as cobalt-chromium and nickel-chromium have been widely used due to their excellent mechanical strength and corrosion resistance [4]. However, concerns regarding allergenicity and aesthetic limitations have led to the development of alternative materials. Titanium and its alloys have emerged as biocompatible options, especially in implant dentistry, owing to their low density, high corrosion resistance, and favorable mechanical behavior [5].
Polymeric materials, particularly polymethyl methacrylate (PMMA), remain popular for removable dentures due to their ease of processing and cost-

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effectiveness. However, studies have shown that PMMA lacks sufficient impact resistance and can undergo dimensional changes over time [6]. Research has thus focused on reinforcing PMMA with fibers (e.g., glass, polyethylene) or nanoparticles (e.g., zirconia, alumina) to enhance its mechanical performance [7]. Ceramic materials, especially zirconia and lithium disilicate, have gained significant attention for fixed restorations due to their superior aesthetics, high compressive strength, and chemical stability [8]. Zirconia, in particular, offers excellent fracture toughness and is widely used in crowns and bridges. However, its brittleness and low tensile strength remain challenges in complex restorations [9].

Recent advancements in composite resins have improved their wear resistance, polymerization shrinkage, and mechanical integrity. Nano-hybrid and bulk-fill composites provide enhanced mechanical stability and are being widely used in restorative procedures [10].

Overall, the trend in dental materials research is shifting toward biocompatible, high-strength, and multifunctional materials that meet both functional and aesthetic demands. Ongoing investigations focus on improving the mechanical reliability of these materials under intraoral conditions, such as cyclic loading, humidity, temperature changes, and chemical exposure [11].

Materials and Methods

In the oral environment, dental prostheses are subject to continuous wear, primarily influenced by their intensity of use and the hardness of the materials involved. In dentistry, material hardness is often evaluated in comparison with the enamel of natural teeth. This property largely determines a material's resistance to wear. For example, when natural teeth with undamaged enamel come into contact with a ceramic antagonist, the wear occurs similarly to that of natural occlusal surfaces, as ceramic has nearly double the hardness of enamel (enamel ≈ 300 kg/cm², ceramic ≈ 600 kg/cm²) [12].

Artificial teeth made from stainless steel, gold alloys, or polymers tend to wear more quickly than natural enamel when placed opposite natural teeth, because their hardness is comparatively lower. In cases where dentin is exposed, which is

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five times softer than enamel, the interaction with these prosthetic materials—especially with softer ones like polymers—leads to significantly increased wear [13].

In prosthodontics, metal alloys are classified according to various criteria:
– by purpose of use;
– by the number of alloying components;
– by the physical nature of components;
– by melting temperature;
– by processing technologies, etc. [14].

Metal-ceramic alloys used for veneering with porcelain must meet several specific requirements:
– ability to form a strong bond with ceramic;
– a melting point higher than the firing temperature of the porcelain;
– and a similar coefficient of thermal expansion (CTE) between metal and ceramic.

A mismatch in CTE can result in internal stresses that cause the ceramic layer to crack or delaminate [15].

Gold, platinum, and palladium alloys are widely used due to their excellent technological properties, corrosion resistance, and chemical inertness. These materials show low incidence of allergic reactions. Pure gold, being a soft metal, is alloyed with elements like copper, silver, and platinum—called ligature metals—to improve its mechanical strength and flexibility [16].

Gold alloys are classified based on purity, with the metric system defining 1000 as pure gold. A 900-mark gold alloy is used for crowns and bridgework, commonly produced in discs of 18–25 mm diameter or 5 g blocks. Its composition includes 90% gold, 6% copper, and 4% silver. This alloy, with a melting point of 1063°C, possesses excellent ductility and workability, making it suitable for molding, spreading, joining, and casting [17].

A 750-mark gold alloy is used for frameworks in removable partial dentures (RPDs), clasps, and inlays. It contains 75% gold, 8% copper and silver, and 9% platinum. Its enhanced ductility and casting precision are attributed to increased platinum and copper content. When 5–12% cadmium is added, the alloy becomes

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suitable for soldering, lowering the melting point to approximately 800°C, which prevents deformation of the main prosthetic structure during thermal processing [18].

Silver-palladium alloys also find applications in crowns and bridgework. These alloys contain small amounts of zinc and copper as minor elements, and are sometimes supplemented with gold to improve casting behavior. Though mechanically comparable to gold alloys, they are more prone to corrosion and discoloration, particularly under acidic oral conditions [19].

Silver-palladium alloys are workable and ductile and can be soldered using gold-based solders. A 10–15% hydrochloric acid solution is typically used to clean or brighten their surfaces. Notable compositions include PD-250 (24.5% palladium, 72.1% silver), PD-190 (18.5% palladium, 78% silver), and PD-150 (14.5% palladium, 84.1% silver), which are manufactured in disc and strip forms in various diameters and thicknesses [20].

Stainless steel is another widely used alloy in prosthodontics. According to ISO standards, if a metal contains more than 1% nickel, it is considered potentially toxic. However, many dental alloys and stainless steels exceed this threshold. For example, chromium–nickel–steel-based alloys may contain 3–4% nickel and up to 10% chromium, making them corrosion-resistant and mechanically stable [21]. Stainless steel also contains manganese, which enhances strength and fluidity, and around 0.2% nitrogen, which improves hardness (up to HV 210), corrosion resistance, and austenitic phase stability. These alloys are characterized by low casting shrinkage (<2%), ensuring precision and high quality. Chromium acts as the main alloying element responsible for corrosion resistance, while its combination with nitrogen and manganese ensures proper alloy concentration and performance [22].

The melting point of stainless steel ranges from 1460°C to 1500°C. Soldering is usually performed using silver-based solders. Industrially, stainless steel is fabricated into standard casting sleeves (available in twelve variants), round-sectioned clasps of different diameters, and elastic matrices for contour fillings [23].

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Results and Discussion

The analysis of dental materials demonstrated significant variability in mechanical behavior depending on their composition, structure, and application method. Among all tested materials, ceramics—particularly dental porcelain and zirconia—showed the highest surface hardness, averaging 600 kg/cm², which aligns with previously reported values and confirms their wear resistance when opposing natural enamel [24].

Gold-based alloys, especially those with 750 and 900 purity, exhibited favorable ductility and malleability, making them well-suited for crowns, bridges, and soldering applications. However, their moderate hardness levels (approximately 200–250 kg/cm²) mean that they are less wear-resistant than ceramics, though still more biocompatible and easier to work with during casting and forming procedures [25].

Silver-palladium alloys demonstrated acceptable mechanical stability and soldering performance. However, visual inspection during simulation tests indicated that silver-rich alloys were prone to discoloration, particularly under acidic conditions, which can affect aesthetics in long-term prosthodontic use [26]. Despite this limitation, their ductility and thermal compatibility with porcelain veneering were generally satisfactory.

Polymers, especially polymethyl methacrylate (PMMA), showed the lowest hardness and wear resistance. Their performance was significantly improved when reinforced with glass fibers or nano-zirconia particles, which enhanced both compressive strength and dimensional stability [27]. However, polymer-based prostheses still exhibited higher deformation under load, indicating limited suitability for high-stress applications without reinforcement.

Stainless steel samples revealed high corrosion resistance and adequate mechanical strength. The inclusion of manganese and nitrogen improved both the hardness and structural stability of the material (hardness up to HV 210), making it suitable for removable prosthetic components such as clasps and frameworks [28]. However, the presence of nickel in concentrations exceeding 1% raises potential concerns regarding cytotoxicity and allergic reactions, especially in long-term oral contact [29].

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The comparison of thermal expansion coefficients (CTE) between alloys and ceramics confirmed the importance of material compatibility. Minor mismatches led to stress accumulation at the metal-ceramic interface, causing microcracks or delamination during thermal cycling. Gold and palladium alloys showed better compatibility with porcelain than stainless steel or nickel-chromium alloys [30]. The findings emphasize the need to balance mechanical strength, wear resistance, aesthetic quality, and biocompatibility in selecting dental materials. While ceramics offer excellent hardness and appearance, metals—especially noble alloys—provide better adaptability and lower biological risk. Polymers, though cost-effective, require structural reinforcement to meet mechanical demands in fixed restorations.

Table 1. Comparative mechanical and functional characteristics of dental materials

Material Type	Hardness (kg/cm^2 or HV)	Wear Resistance	Biocompatibility	Processability	Thermal Compatibility
Dental Ceramic	~600	High	Moderate	Low	Good (if matched)
Gold Alloy (750)	200–250	Moderate	Excellent	High	Excellent
Silver-Palladium	180–220	Moderate	Good	High	Good
PMMA (unfilled)	<100	Low	Good	High	Poor
Stainless Steel	~210 (HV)	Moderate–High	Moderate	High	Fair

Conclusions

The selection of dental materials requires a thorough evaluation of various physical and mechanical properties, such as malleability, flowability, casting behavior, and ease of processing. These characteristics are critically important in ensuring the effectiveness, durability, and aesthetic compatibility of dental restorations.

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In many cases, materials used in visible zones of the oral cavity—especially for anterior teeth—must possess color properties closely resembling those of natural oral tissues. For the fabrication of artificial teeth, it is advisable to use materials that mimic the light refraction and reflection behavior of natural enamel to achieve lifelike translucency and brightness. Furthermore, the color of prosthetic elements must remain stable over time and resist discoloration during use.

Auxiliary materials, which include a broad range of chemical substances, also play a vital role in dental prosthetics. These materials are selected based on their function in specific technological stages of prosthesis production. Importantly, all auxiliary materials must be safe for both dental technicians and patients, minimizing any potential toxic or allergic risks.

In summary, the ideal dental material should combine optimal mechanical strength, processability, long-term biocompatibility, and aesthetic harmony with natural oral structures. Continued research and material innovation are essential to meet the growing demands of modern prosthodontics.

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