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A Study Focusing on the Advantages and Disadvantages of Using Tungsten Metal in the Medical Field.

[1]Dr.Musbah Kharis Maatgi
Associate Professor,D ept. of Materials Science & Engineering
Faculty of Engineering , Misurata University, Libya

[2] Miss.Fatima Mustafa ALkumeeti
Libyan Academy, Misurata, School of Basic Sciences, Deprt.of Gentic Engineering.

[3] Miss. Souad Alsddeg Abuazom
Libyan Academy, Misurata, School of Basic Sciences, Deprt.of Gentic Engineering.

Abstract *-Tungsten a rare and dense transition metal, is widely acknowledged for its exceptional physical and chemical properties, making it an essential material in various fields, particularly in medical and industrial applications. With the highest melting point of any metal (3422°C) and remarkable resistance to corrosion, tungsten has been successfully utilized in medical implants, radiography, orthopedics, and surgical instruments. Its unique combination of high tensile strength, durability under masticatory stress, and high density contributes to its effectiveness in orthodontics. Despite its beneficial properties, recent research has raised concerns about tungsten's toxicity, particularly regarding its environmental impact and potential health risks. This paper reviews the physical and chemical characteristics of tungsten, its industrial and medical applications, and the emerging issues related to its toxicity and environmental effects. The review emphasizes the need for further research into the safe use of tungsten, considering both its advantages and the potential risks associated with long-term exposure.*

Keywords- *Tungsten, Medical Applications, Toxicity, Environmental Impact, Radiography, Orthopedics, Surgical Instruments, Biocompatibility, Durability, Health Risks, Physical Properties, Chemical Properties.*

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I. INTRODUCTION.

Tungsten (W), a transition metal with the atomic number 74, is renowned for its exceptional properties, including the highest melting point of all metals (3,422°C), remarkable hardness, and a density of 19.3 g/cm³. These characteristics, along with its resistance to corrosion and excellent electrical conductivity, make tungsten indispensable in industries such as aerospace, electronics, energy storage, manufacturing, and implanted medical devices [1].

Tungsten's high melting point and thermal stability make it ideal for high-temperature applications like rocket nozzles and welding electrodes. Its hardness and wear resistance are critical in cutting tools and abrasives, while its electrical conductivity is vital in electronics, such as semiconductors and X-ray tubes. Additionally, tungsten is being explored for emerging technologies, including energy storage devices like lithium-ion batteries and medical applications such as radiation shielding and targeted drug delivery.

Despite its advantages, tungsten faces challenges, including brittleness at low temperatures, difficulty in machining, and potential toxicity of its compounds. Environmental concerns related to mining and processing also highlight the need for sustainable practices like recycling [2].

Tungsten boasts the highest melting point of all metals at 3,422°C making it ideal for applications requiring stability at extreme temperatures, such as in aerospace (e.g., rocket nozzles and turbine blades) and manufacturing (e.g., high-temperature furnaces and welding electrodes) [3].

Additionally, tungsten is one of the hardest metals, ranking high on the Mohs scale of hardness, which grants it exceptional wear resistance. This property makes it invaluable in cutting tools, drill bits, and wear-resistant coatings, with tungsten carbide being particularly prominent in industrial machinery and mining equipment. Its high density of 19.3 g/cm³, comparable to gold and uranium, makes it ideal for applications requiring mass in a compact form, such as counterweights in aerospace, ballast in racing cars, and radiation shielding in medical and nuclear industries. Tungsten is also highly resistant to corrosion, even in harsh chemical environments, making it suitable for chemical processing equipment and marine applications. Although its excellent electrical conductivity and ability to withstand high temperatures make it critical in the electronics industry, where it is used in semiconductors, X-ray tubes, and integrated circuits. Tungsten's low coefficient of thermal expansion ensures dimensional stability under extreme temperature fluctuations, which is crucial for applications like glass-to-metal seals. Its high density and atomic number also make it an excellent material for radiation shielding, widely used in medical imaging devices and nuclear reactors [4].

Tungsten is valued for its biocompatibility and radiopacity, being used in surgical instruments, dental tools, and radiation therapy equipment, with recent advancements exploring tungsten nanoparticles for targeted drug delivery and cancer treatment. Tungsten's versatility in alloy formation, such as tungsten-nickel-iron (W-Ni-Fe) alloys, enhances properties like strength and density, making them suitable for aerospace, defense, radiation shielding, and vibration damping systems. Finally, tungsten is highly recyclable, and the industry's focus on sustainable practices, such as recycling tungsten scrap, reduces the need for mining and minimizes environmental impact, making it an eco-friendly choice for modern applications [5]. There are four types of tungsten Pure tungsten, tungsten carbide, tungsten oxide, and tungsten alloys.

Tungsten offers numerous advantages due to its exceptional physical and chemical properties. Its highest melting point (3,422°C) makes it ideal for high-temperature applications such as rocket nozzles and welding electrodes, ensuring stability and performance under extreme thermal conditions. The metal's remarkable hardness and wear resistance are crucial for cutting tools, drill bits, and wear-resistant coatings, particularly in the form of tungsten carbide, which is widely used in industrial machinery and mining equipment. Its high density (19.3 g/cm^3) is beneficial for applications requiring significant mass in a compact form, including counterweights, ballast, and radiation shielding in medical and nuclear industries. Furthermore, tungsten exhibits high resistance to corrosion, excellent electrical conductivity, and a low coefficient of thermal expansion, contributing to its widespread use in electronics and various industrial settings. Its biocompatibility and radiopacity also make it suitable for surgical instruments, dental tools, and advanced medical treatments, including targeted drug delivery and cancer therapy [6].

Despite these significant advantages, concerns exist regarding tungsten's potential toxicity and environmental impact. Tungsten-based medical devices, while beneficial, may corrode over time, leading to increased concentrations of tungsten in systemic circulation and chronic exposure. This chronic exposure can also occur through contaminated drinking water, raising concerns about potential carcinogenic effects. Studies have indicated that DNA damage induced by tungsten carbide cobalt particles is significantly greater than that caused by cobalt or tungsten carbide particles alone, highlighting a synergistic ability to induce DNA damage. Chronic exposure to tungsten can lead to harmful effects, including increased mutational burden and immunotoxicity, as it adversely affects the growth of B cells. These disadvantages necessitate careful evaluation and ongoing research to ensure the safe and sustainable utilization of tungsten, balancing its benefits with potential risks [3].

This study aims to delineate physical and chemical properties of tungsten, explore its diverse industrial and medical applications, and critically assess the emerging concerns regarding its toxicity and environmental impact.

II. MEDICAL APPLICATIONS OF TUNGSTEN.

The medical applications of Tungsten as follows:

1. Medical Radioisotope Defense

Tungsten is used as a radiation shielding material in various applications, including diagnostic imaging, radiation therapy, and nuclear and industrial shielding. It protects workers in the field of nuclear medicine from gamma rays and X-rays. Previously, lead was commonly used for radiation protection, but it has several disadvantages. Lead is heavy, which can be a burden for medical workers, and it also has toxic effects on both the body and the environment. Tungsten has replaced lead due to its high density and better shielding properties, owing to its higher atomic number. Additionally, radiation shields made from tungsten are lighter than those made from lead, making protective clothing less cumbersome for medical professionals [4].

2. Surgical Tools for Reducing Blood Loss in Tumor Surgery

Extremity tumor resection and reconstruction with tumor end prostheses can lead to significant blood loss, necessitating hemodynamic stabilization and transfusion of blood products. This risk is particularly concerning in tumor surgery, as it may lead to hematogenous dissemination of tumor cells. Therefore, additional surgical measures are required to minimize blood loss in tumor orthopedics.

A promising approach is the use of nonpolar electro surgery to enhance hemostasis during tumor dissection. Needle electrodes made of tungsten are particularly suitable for this purpose, as tungsten has the highest melting point of all metals (3422 °C), which prevents deformation and ensures high abrasion resistance. Using a tungsten needle electrode can reduce blood loss during surgery, and the electrical properties of tungsten result in less tissue damage in laparoscopic tumor resection [7].

3. Transient Biomedical Implants

Electronic devices have proven to be indispensable in today's modern society, especially for monitoring vital parameters such as blood sugar and blood pressure in implantable systems. These devices convert vital data into electrical signals, which can then be sent to external devices for monitoring essential processes. Tungsten has emerged as a promising metal for the fabrication of biodegradable electronic devices, particularly in the field of transient electronics. It is characterized by its ability to dissolve safely and produce non-toxic by-products, making it suitable for various applications, especially in implantable systems.

Tungsten demonstrates predictable and controllable dissolution mechanisms in biological fluids at physiological temperatures, allowing for longer device lifetimes compared to other metals, such as magnesium and zinc. Moreover, tungsten's compatibility with biological tissues minimizes adverse immune responses [8].

4. Dental Instruments

Tungsten has emerged as a critical material in the dental field, particularly in the development of biodegradable dental burs and other surgical instruments. Its unique properties, such as high strength, exceptional hardness, and resistance to wear, make it an ideal choice for cutting hard tissues like bone and teeth. Tungsten carbide burs, specifically, are designed with radial or negative rake angles to enhance their strength and minimize the risk of fracture, which is crucial given the brittleness of carbide. These burs can withstand high speeds of operation without dulling, ensuring efficient and precise cutting during dental procedures. Additionally, the biocompatibility of tungsten allows for its safe use in various implantable medical devices, making it a versatile metal in both restorative dentistry and broader medical applications [9].

5. Prosthetics and Implants

The use of an industrial-grade tungsten carbide drill bit in treating femoral neck fractures in patients with osteoporosis. The drill was utilized to create a medullary canal in a case involving a per-implant fracture, leading to a successful hemi arthroplasty with good functional outcomes. Tungsten carbide is noted for its hardness and high wear resistance, making it an ideal tool for this procedure. It reduces surgical time and may help limit thermal necrosis, a common issue in such surgeries, despite being associated with it. Ramiah et al. highlighted the effectiveness of this drill as a safe and efficient option for treating femoral neck fractures in osteoporosis patients [10].

III. RRESULTS AND DISCUSSIONS.

Tungsten stands out as a unique transition metal, highly valued for its exceptional properties, including the highest melting point among all metals (3422°C), remarkable hardness, and high density (19.3 g/cm^3). These attributes make it indispensable for high-temperature applications like rocket nozzles and welding electrodes, as well as in cutting tools, drill bits, and radiation shielding [1,2,4,]. Additionally, its excellent electrical conductivity, corrosion resistance, and low thermal expansion further contribute to its widespread use in electronics and various industrial settings. Tungsten's biocompatibility and radiopacity also enable its application in surgical instruments, dental tools, and advanced medical treatments, including targeted drug delivery and cancer therapy [1,6].

Tungsten exists in various forms, each tailored for specific uses. Pure tungsten is utilized in filaments and heating elements due to its extreme temperature resistance. Tungsten carbide (WC), known for its diamond-like hardness, is crucial for cutting tools and wear-resistant coatings. Tungsten alloys, such as W-Ni-Fe and W-Ni-Cu, enhance properties like density, strength, and non-magnetic characteristics, making them suitable for aerospace, defense, and medical devices. Tungsten oxides (WO3, WO2) are primarily employed in catalytic and electrochemical applications, including smart windows [1].

In medical applications, tungsten serves as an effective radiation shielding material, offering a safer and lighter alternative to lead for protecting medical personnel from X-rays and gamma rays [4,7]. Its high melting point and abrasion resistance make tungsten needle electrodes ideal for electro surgery, reducing blood loss and tissue damage during tumor resections [7]. Furthermore, tungsten is a promising material for biodegradable electronic implants due to its predictable dissolution and biocompatibility, allowing for safe, transient medical devices [8]. It's also vital in dentistry for durable cutting instruments and in orthopedics, where tungsten carbide drills facilitate complex bone surgeries [9]. Notably, tungsten's high density and radiopacity offer superior performance over traditional materials like lead in radiation shielding, enabling thinner and lighter protective barriers. Similarly, the extreme hardness of tungsten carbide provides a significant advantage in surgical and dental cutting tools, leading to enhanced durability and precision compared to other common materials.

Despite its benefits, concerns regarding tungsten's toxicity and environmental impact persist. Tungsten-based medical devices can corrode, leading to systemic exposure, and contaminated water sources pose carcinogenic risks [3]. Studies indicate that tungsten carbide-cobalt particles can induce significant DNA damage, and chronic exposure may result in increased mutational burden and immunotoxicity by adversely affecting B cell growth [3].

These findings, particularly the synergistic effect of tungsten carbide-cobalt on DNA damage, raise critical questions about the long-term safety of tungsten-containing devices, especially those in contact with biological tissues. This necessitates intensive research into the mechanisms of tungsten corrosion in physiological environments and a comprehensive assessment of the toxicity of all tungsten forms and compounds. Moreover, the development of future tungsten-based materials must prioritize minimizing corrosion and the release of toxic ions to ensure patient and user safety. Further studies are still needed to evaluate the long-term health effects of low-level tungsten exposure and to develop effective strategies for mitigating its toxicity in biomedical applications.

IV. CONCLUSIONS.

Tungsten stands out as a unique transition metal characterized by its exceptionally high melting point, remarkable hardness, and substantial density. These properties make it indispensable across various industries, including aerospace, electronics, energy storage, and medicine. Tungsten's versatility is particularly evident in the medical field, where it's utilized in radiation shielding, surgical instruments, and implantable devices. Its biocompatibility and radiopacity further enhance its suitability for advanced biomedical applications.

However, despite these significant advantages, potential risks associated with tungsten exposure, such as carcinogenicity and immunotoxicity, necessitate careful evaluation and ongoing research to ensure its safe usage in both medical and industrial settings. The tungsten industry is currently witnessing substantial advancements in sustainable practices and recycling methods. As demand for tungsten surges, particularly in emerging technologies, balancing its benefits with environmental and health concerns becomes crucial. Continued research into tungsten's properties and applications is essential for unlocking its full potential while effectively addressing potential risks. Emphasizing sustainability and innovative manufacturing techniques will ensure that tungsten remains a vital component of modern technology and medicine for years to come.

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