Технічні науки

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USE OF ENVIRONMENTALLY FRIENDLY MATERIALS IN MODERN JEWELRY PRODUCTION

Summary. *This article considers the problem of traditional use of nickel in jewelry production, associated with the risk of allergic reactions, and presents a comprehensive solution based on the development of an innovative nickel-free alloy with gold plating. A review of the literature demonstrates that nickel, used to provide luster and strength to products, can release ions upon skin contact, leading to allergic contact dermatitis. The present study is devoted to the development of a new composition that excludes nickel, while maintaining the necessary mechanical and aesthetic properties, as well as the technology of gold plating with the formation of a protective barrier layer, which ensures the hypoallergenicity of the product. The obtained results, confirmed by X-ray fluorescence analysis (XRF) and certification from "UKRCHIMANALIZ" LLC (2020), indicate the complete absence of nickel and the coating resistance to corrosion, which meets modern regulatory requirements (EN 1811, REACH). The scientific novelty lies in the integration of environmentally friendly materials into jewelry production through the creation of a unique nickel-free alloy capable of meeting the requirements of safety, aesthetics and functionality.*

Key words: *Nickel-free, hypoallergenic, gilding, jewelry production, environmentally friendly materials, XRF analysis, regulatory standards.*

Introduction. Modern jewelry manufacturing faces the challenge of identifying environmentally friendly materials that ensure not only high aesthetic quality and durability but also safety for end consumers. For decades, the use of

nickel in alloys for gold plating has contributed to enhanced strength and brilliance of jewelry; however, its presence is associated with a high risk of allergic reactions, such as contact dermatitis, as confirmed by numerous studies [1; 2]. Additionally, the growing focus on environmental sustainability and material safety necessitates a transition to innovative solutions that exclude harmful elements.

Several studies have thoroughly described the mechanisms of nickel ion release from conventional alloys and their effects on the skin during prolonged contact. Research by Whittington K.M. and Lo W.Y. [3] demonstrates that even a small amount of nickel in decorative coatings can lead to excessive ion release, ultimately triggering allergic reactions. Gabe D.R. and Larson S. [2] further highlight the necessity of employing barrier technologies and alternative compositions that can mitigate the risk of allergization while preserving the aesthetic and functional characteristics of jewelry. A review of existing literature indicates that despite technological advancements, the issue of safe nickel replacement remains unresolved, as most developments focus either on reducing nickel release or creating protective coatings rather than entirely eliminating nickel from alloy compositions.

Thus, a significant scientific gap is evident: the absence of a comprehensive solution that enables the substitution of nickel-based alloys in jewelry manufacturing without compromising mechanical strength and aesthetic appeal. The development of a new material that meets the criteria of environmental sustainability, hypoallergenicity, and high technological performance is a priority for contemporary science and industry.

This study aims to examine and comprehensively evaluate a novel nickel-free alloy with gold plating, characterized by hypoallergenic and environmentally safe properties for use in modern jewelry production. The study will compare its operational and aesthetic characteristics with those of conventional nickel-based alloys currently used in the industry.

The scientific novelty of this research lies in the exploration of an innovative alloy composition that is entirely free of nickel, thereby eliminating the risk of allergic reactions while maintaining the necessary physical properties and visual appeal of jewelry. The development of this material has been validated through X-ray fluorescence (XRF) analysis [4], providing an objective assessment of the chemical composition and quality of the resulting alloy.

The research hypothesis suggests that the use of the new nickel-free alloy, combined with modern gold-plating technologies, will achieve an optimal balance of mechanical, aesthetic, and hypoallergenic properties. Ultimately, this is expected to reduce the incidence of allergic reactions among consumers and enhance the market competitiveness of jewelry products.

1. The issue of nickel usage in jewelry manufacturing

For many decades, nickel has been an integral part of traditional gold-plating technologies. In jewelry manufacturing, it has been used as an intermediate coating (commonly referred to as "bright nickel plating") to ensure surface smoothness, gloss, and corrosion resistance of the base material [1, 5]. Due to its physicochemical properties, nickel enhances the adhesion of the upper decorative layer, evenly distributes mechanical stress, and increases the wear resistance of the product. The economic efficiency and technological reliability of nickel coatings have contributed to their widespread use despite well-known drawbacks associated with the potential release of nickel ions.

However, prolonged contact of jewelry with the skin leads to nickel corrosion under the influence of sweat, which contains chlorides and has a mildly acidic environment. These conditions promote the release of nickel ions from the coating, particularly if the deposited nickel layer is porous or contains impurities such as sulfur, which is added to enhance brightness [2]. The penetration of nickel ions into the epidermal layers can induce immunological sensitization in predisposed individuals, leading to the development of allergic contact dermatitis. The clinical manifestations of this condition include redness, itching, and

localized inflammation, with symptoms often worsening upon repeated exposure to the allergen [3].

In response to identified health risks for consumers, the European Union has implemented regulatory limits on the release of nickel from items that come into direct skin contact. The Nickel Directive and relevant standards, such as EN 1811:2011 (+A1:2015) and EN 12472:2005 (+A1:2009), set a maximum permissible nickel ion release level of 0.5 μg/cm² per week [3]. Additionally, the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) regulation mandates strict compliance with hazardous substance content limits in consumer products, further emphasizing the need for a transition to environmentally friendly materials [6].

Epidemiological studies indicate that nickel allergy is one of the most common forms of contact dermatitis. Among women, who traditionally wear more jewelry, the risk of developing nickel allergy ranges from 10% to 20%, whereas in men, this figure is significantly lower, at approximately 2–5% [7]. These data underscore not only the medical but also the socio-economic significance of the issue, as the high prevalence of nickel allergy influences consumer choices regarding jewelry and drives the demand for higher product quality and safety standards.

Below, Table 1 summarizes the key regulatory documents and testing methodologies used to monitor nickel release from jewelry items.

Table 1

Overview of Regulatory Requirements for Nickel Release Levels in Jewelry

Regulatory Document	Testing Method	Permissible Nickel Release Limit (μg/cm²/week)
EN 1811:2011 + A1:2015	Wear and corrosion simulation (after 2 years of use)	< 0.5
EN 12472:2005 + A1:2009	Wear and corrosion simulation under controlled conditions	< 0.5

REACH (Annex XV)	Application of standardized methodologies (considering EN 1811 results)	< 0.88* (depending on specific usage conditions)

Note: The permissible limit under REACH may vary based on the application conditions and product specifications

The long-established practice of using nickel in gold-plating alloys, driven by its technological advantages, is now associated with significant health risks for consumers. The occurrence of allergic reactions and stringent regulatory requirements are driving the scientific community and industry toward the development of alternative, environmentally friendly materials that can provide the necessary functionality and aesthetic quality of jewelry without harmful effects on the skin.

2. Development and characterization of a new nickel-free alloy with gold plating

As part of this study, an innovative nickel-free alloy was developed, eliminating the use of nickel at all stages of production, thereby preventing the release of nickel ions and the subsequent risk of allergic reactions. The chemical composition of the alloy was determined using X-ray fluorescence (XRF) spectral analysis, with data certified by LLC "UKRKhimAnaliz" [4]. According to the analysis results, the alloy composition is as follows:

- Aluminum (Al): 2.19%
- Silicon (Si): 0.8%
- Copper (Cu): 64.22%
- Iron (Fe): 4.85%
- Zinc (Zn): 14.55%
- Tin (Sn): 13.39%

This composition results in a material with optimal mechanical and aesthetic properties, comparable to traditional nickel-based coatings but entirely free of nickel. The alloy is primarily composed of a copper-zinc base with the addition of tin, providing high corrosion resistance, sufficient strength, and

improved plasticity. Additional elements (Al, Si, and Fe) contribute to optimizing technological properties such as weldability and surface treatment, which are particularly important for subsequent decorative coating applications.

Compared to traditional alloys, where nickel is used as a primary component—either as a base layer or in bright nickel plating to enhance gloss and wear resistance [1; 2]—the new composition demonstrates the following advantages:

- Nickel-free composition: The absence of this element eliminates the risk of nickel ion release, as confirmed by certified data.
- Comparable mechanical properties: The high strength characteristics are preserved through the use of tin and zinc, while corrosion resistance is enhanced due to the copper matrix.

For a visual comparison of the characteristics of the new alloy and traditional nickel-based coatings, Table 2 is presented below.

Table 2

Comparative Analysis of the New Nickel-Free Alloy and Traditional Nickel Coating [3; 5]

Parameter	New Nickel-Free Alloy	Traditional Nickel Coating
Chemical Composition	Cu: 64.22%; Zn: 14.55%; Sn: 13.39%; Fe: 4.85%; Al: 2.19%; Si: 0.8%; Ni: 0%	Primarily nickel (>90%) with added impurities (e.g., sulfur for brightness)
Nickel Content	Absent	Present (ranging from 6% in some alloys to >90% in electroplated deposits)
Mechanical and Corrosion Properties	High strength and corrosion resistance provided by the copper-zinc matrix with tin addition	Provides gloss and durability but requires an additional barrier coating to minimize nickel release
Nickel Ion Release (μg/cm²/week)	0 (nickel-free composition ensures complete elimination of nickel ion release)	8–10 without a barrier layer; 37–50 with a thin gold layer (due to porosity and accelerated corrosion)

Following the formation of the base alloy, a decorative gold coating is applied, serving both aesthetic and protective functions. The gold-plating

technology is designed to create a continuous barrier layer that prevents corrosion and the potential release of ions from within the alloy. The key stages of the process are as follows:

- Surface Preparation: Mechanical and chemical treatment of the new alloy removes oxide layers and contaminants, creating optimal conditions for subsequent coating deposition.
- Gold Deposition: The electrolytic gold-plating method is employed, ensuring uniform material distribution and strong adhesion. In this case, the use of an intermediate barrier layer, traditionally required in bright nickel plating, is unnecessary, simplifying the technology and reducing the risk of allergic reactions.
- Barrier Layer Formation: Modern gold-plating techniques may include additional steps, such as the application of UV-curable electrophoretic coatings, which enhance the integrity of the gold layer and improve its corrosion resistance [2, 3].

The absence of nickel in the base alloy significantly reduces the risk of allergic reactions. Studies have shown that the primary factor triggering contact dermatitis is the release of nickel ions, particularly with prolonged skin contact [3]. The new alloy, being completely nickel-free, ensures that even with extended use, there is no risk of allergenic substance release, positively impacting the biocompatibility of the material.

To confirm the safety and compliance of the new material with established standards, comprehensive testing was conducted, demonstrating the high quality of the alloy. XRF analysis data confirm the complete absence of nickel, aligning with regulatory requirements (EN 1811, EN 12472, and the Nickel Directive) [3, 5]. Additionally, a comparative analysis with traditional nickel coatings indicates that the nickel ion release level for the new alloy is zero, whereas for conventional coatings, this parameter ranges from 8 to 10 μg/cm²/week (without a barrier layer) and reaches 37–50 μg/cm²/week when a thin gold layer is applied [3].

Thus, certified data confirm that the new nickel-free gold-plated alloy meets modern safety standards and possesses hypoallergenic properties. The use of this material not only eliminates the risk of allergic contact dermatitis but also maintains the high aesthetic and mechanical characteristics required in jewelry manufacturing. This represents a significant competitive advantage over traditional technologies, where nickel use remains a substantial health risk for consumers.

3. Environmental and market significance of implementing nickel-free technologies

The implementation of nickel-free technologies in jewelry manufacturing significantly reduces product toxicity and minimizes negative environmental impact. Traditional alloys containing nickel contribute to the release of nickel ions during use, leading not only to allergic reactions in consumers but also to the accumulation of toxic substances in ecosystems [3]. The new nickel-free alloy minimizes the risk of soil and water contamination while simplifying waste disposal and recycling processes. According to recent reports by the European Commission and the OECD, reducing the use of toxic metals is one of the key directions for sustainable industrial development, significantly lowering the environmental burden [6; 8].

From a consumer perspective, the "nickel-free" label serves as a strategic indicator of product safety and high quality. The absence of nickel entirely eliminates the risk of allergic reactions, which is particularly relevant for vulnerable groups such as allergy sufferers, children, and pregnant women [7]. Increased awareness of health and environmental responsibility is driving demand for hypoallergenic and eco-friendly products. Modern consumers increasingly prioritize products that meet both aesthetic and environmental standards, strengthening trust in brands that adopt innovative nickel-free technologies.

From an economic standpoint, the adoption of nickel-free technologies presents new market opportunities for product differentiation and competitive advantage. Eliminating nickel not only ensures compliance with strict regulatory standards (such as EN 1811, REACH, and others) but also expands the target audience by attracting consumers focused on environmental safety and health.

The innovative nickel-free alloy, which maintains high aesthetic and mechanical properties, not only meets modern safety standards but also enhances the manufacturer's reputation as a socially responsible company. Long-term reductions in production costs, achieved through process optimization and lower compliance expenses, position this solution as a strategically advantageous investment in the future of the jewelry industry.

The following Table 3 is presented to illustrate the benefits of adopting nickel-free technologies.

Table 3

Comparative analysis of environmental and market advantages of traditional nickel-based and nickel-free technologies

Criterion	Traditional Nickel-Based Technologies	Nickel-Free Technologies
Environmental Toxicity	High risk of nickel ion release, contributing to environmental pollution [Whittington, 2018, pp. 63–70]	Absence of nickel eliminates toxic element accumulation; reduced chemical impact on ecosystems [OECD, 2023, pp. 45–50]
Waste Disposal and Recycling	Complex disposal processes requiring additional costs for purification and waste treatment [Smith et al., 2021, pp. 34–38]	Simplified and more environmentally friendly disposal processes due to the absence of toxic components [OECD, 2023]
Consumer Safety	Limited audience due to allergy risks (allergy sufferers, children, pregnant women) [Thyssen & Menné, 2007, pp. 286–290]	Expanded target audience due to complete hypoallergenicity; increased consumer trust [Euromonitor International, 2023, pp. 60–65]
Market Prospects	Limited segment growth due to negative health effects and the need for additional protective	Sustained growth of the hypoallergenic jewelry market, enhanced competitiveness, and opportunities for

	layers [Whittington, 2018, pp. 63–70]	brand differentiation [Euromonitor International, 2023, pp. 60–65]
Production Costs	Additional expenses for regulatory compliance and nickel release control [McKinsey & Company, 2024, pp. 28–32]	Cost reduction through optimized technological processes and elimination of the need for additional barrier coatings [McKinsey & Company, 2024, pp. 28–32]

The implementation of nickel-free technologies not only addresses the issue of environmental toxicity associated with traditional coatings but also creates significant market opportunities for jewelry manufacturers. The integration of environmentally friendly materials strengthens competitive advantages, expands the target audience, and meets the growing consumer demand for product safety and sustainability.

Conclusion. The conducted study demonstrates that the development and application of a nickel-free gold-plated alloy represent a significant breakthrough in jewelry manufacturing. The elimination of nickel from the base material completely removes the risk of allergenic ion release, significantly reducing the likelihood of allergic contact dermatitis in consumers. The gold-plating technology, incorporating a protective barrier layer, ensures not only high corrosion resistance but also the aesthetic appeal of jewelry that meets modern industry standards.

The results, confirmed by XRF analysis and certification (LLC "UKRKhimAnaliz," 2020), indicate that the new material complies with strict regulatory requirements (EN 1811, REACH) and has the potential for widespread use in the production of hypoallergenic jewelry. This study paves the way for further research on optimizing alloy composition and protective coating technologies, as well as integrating environmentally sustainable solutions into the production of high-quality jewelry, contributing to the development of a safer and more sustainable industry.

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