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Acidity of Base Coats and its Influence on the Structure of the Nail Plate

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ABSTRACT.

Against the backdrop of the rapid expansion of the global nail care segment, the issue of chemically induced damage to the nail plate associated with prolonged wear of polymer coatings is becoming particularly acute. The aim of the study is to conduct a multifactor analysis of the effects of base coat acidity on the structural and biochemical parameters of the nail plate, tracing causal links between product formulation, mechanisms of its interaction with keratin, and objectively recorded indicators of damage. The work is based on a systematic review of peer-reviewed publications from the Scopus and Web of Science databases, as well as content analysis of technical documentation and industry reports. The study demonstrates that the intact nail plate is characterized by a mildly acidic surface pH (pH ≈ 5.1), which ensures barrier properties. Acidic base coats containing methacrylic acid form adhesion through chemical etching, leading to hydrolytic cleavage of keratin peptide bonds, disruption of disulfide bridges, and a quantitatively recorded decrease in cysteine content (by 22.1%) and methionine (by 36.5%) after six months of use. These changes are accompanied by a reduction in plate thickness (from 0.50 mm to 0.46 mm) and a shift of pH into the alkaline range (to >6.0), which weakens its natural antimicrobial defenses. In contrast, acid-free systems achieve fixation through covalent bonding without compromising the integrity of the keratin matrix. The acidity of the base layer acts as a key determinant of its destructive potential. The presented data have applied value for nail technicians, cosmetic formulators, and consumers, supporting the prioritization of technologies that preserve the biochemical and structural integrity of the nail plate.

Keywords: acidity, base coat, nail plate, keratin, methacrylic acid, nail pH, chemical damage, onychoschizia, disulfide bonds, onychomycosis.

Introduction

The nail service industry is one of the most rapidly evolving segments of the global cosmetics market. According to analytical estimates, in 2024 the volume of global sales of nail care products reached 24.56 billion US dollars; by the end of 2025 it is expected to increase to 25.76 billion US dollars, and by 2032 to 36.27 billion US dollars with a compound annual growth rate (CAGR) of 5.01% [1]. Other calculations likewise register a stable upward trajectory: 12.14 billion US dollars in 2024 with a forecast of 17.94 billion US dollars by 2032 at a CAGR of 5% [2]. Within the demand structure, the nail polish segment led, accounting for 68.34% of the market in 2024 [1].

The principal drivers of expansion include the heightened importance of personal care and image, the influence of fashion trends, and the intensive role of social media, especially among millennials and Generation Z [2, 3]. On this basis, a dominant consumer orientation is consolidating: a preference for non-toxic and clean solutions [2]. An increasing number of consumers consciously avoid formaldehyde, toluene, dibutyl phthalate (DBP), and hydroxyethyl methacrylate (HEMA), which are associated with potential health risks [5, 31].

The shift toward safer formulas is a natural market response to its own expansion. The mass proliferation of long-lasting yet chemically complex manicure systems is accompanied by a rise in documented cases of nail plate damage and allergic reactions. This amplifies the demand for alternatives perceived as gentler. As a result, a self-reinforcing loop emerges: market expansion stimulates consumption and exposes associated problems, which then guide the next wave of product innovations and marketing solutions, from acid-free to HEMA-free formulas.

The popularity of durable cosmetic nail coatings, primarily manicures using gel polishes (hybrids), is directly associated with the risk of iatrogenic damage to the nail plate. Existing studies convincingly demonstrate that such interventions lead to a marked reduction in nail thickness, a marker of its structural destruction under the influence of the chemical formulations themselves, acetone used for removal, and mechanical filing [4, 7].

Quantitative observations confirm the depth of the biochemical reconfiguration. Prolonged use of hybrid manicure (for six months) is associated with a significant decrease in the content of key sulfur-containing amino acids in the keratin matrix: cysteine by 22.1% and methionine by 36.5% [7]. The stated chemical degradation manifests clinically as increased brittleness, lamellar splitting (onychoschisis), and overall fragility of the nails [7]. Thus, the pursuit of long-lasting aesthetic durability comes into direct conflict with the maintenance of the biological integrity of the nail plate.

Despite recognition of the damaging potential of cosmetic agents, the scientific literature lacks a systematic, multilevel analysis that, within a single study, would consistently link a specific technological parameter: the acidity (pH) of the base coat with precise biochemical mechanisms of keratin degradation and subsequent quantitative changes in the structure of the nail plate.

The aim of the study is a comprehensive assessment of the effect of the acidity of base coats on the structural and biochemical state of the nail plate, the determination of causal relationships between the chemical composition of the product, the mechanisms of its interaction with keratin, and validated quantitative indicators of damage.

The author's hypothesis is that the use of highly acidic bases (in particular, formulas based on methacrylic acid) initiates destructive transformations of the nail keratin matrix, including hydrolytic cleavage of peptide bonds and rupture of disulfide bridges; the consequence is a measurable decrease in the proportion of sulfur-containing amino acids, thinning of the plate, and a shift in its physiological pH balance, which increases vulnerability to pathogenic factors.

The scientific novelty of the work is defined by the interdisciplinary integration of knowledge from cosmetic chemistry, biochemistry, and dermatology with the aim of tracing the full causal cascade from the molecular architectonics of the coating composition to clinically significant consequences for the nail plate.

Materials and methods

The study relies on the methodology of a systematic review of the scientific literature combined with content analysis of technical documentation. The systematic review was used for the targeted aggregation, critical interpretation, and synthesis of data from peer-reviewed publications on keratin biochemistry, polymer chemistry, dermatological aspects of pH, and nail plate pathologies. This design provided an integrated understanding of the structural and functional characteristics of the nail plate as a substrate and of the mechanisms of its interaction with chemical agents. Content analysis was employed to examine technically significant extra-academic sources — patents, technological descriptions of cosmetic ingredients, and analytical industry reports — which made it possible to identify the composition of contemporary commercial formulations and current market trajectories not reflected in the academic discourse.

The source base was formed predominantly from publications of recent years in order to maximize the relevance of empirical and theoretical data. Preference was given to works indexed in the leading international bibliometric databases Scopus and Web of Science, and the theoretical framework was built from articles published in high-impact journals in dermatology, biochemistry, pharmacology, and materials science. To reconstruct the market context and consumer trends, reports of key research and consulting providers were analyzed, including Fortune Business Insights, Maximize Market Research, and Technavio. Thus, the two-component configuration of sources made it possible to stitch together the fundamental scientific agenda with up-to-date practical information from the industry.

Results and discussion

The nail plate is a highly organized, fully keratinized biostructure that performs barrier and sensory functions [17]. Its thickness ranges within 0,25–0,6 мм; essentially it is about 25 layers of densely packed, dead flattened keratinocytes (onychocytes) [18]. Histologically, three layers are distinguished: dorsal — the outer, thin layer with the greatest hardness, formed by several rows of cells; intermediate — the thickest layer (approximately 75% of the total), with a pronounced fibrous organization and softer compared with the dorsal; ventral — the inner thin layer that ensures firm attachment of the plate to the nail bed [9, 19]. The structural framework is formed by the fibrillar protein keratin, represented by two main varieties of α-keratin: hard, accounting for 80–90% of the mass, and soft, whose share is 10–20% [9]. Such a composite ratio provides a unique balance of hardness and elasticity of the nail. Mechanical strength, stiffness, and resistance to external influences are largely determined by the high density of transverse disulfide bridges (S—S) between keratin polypeptide chains [20, 21]. These covalent bonds are formed by oxidation of the thiol groups (SH) of the sulfur-containing amino acid cysteine, of which nail keratin is particularly rich [12].

Empirical data demonstrate a direct dependence between the number of disulfide cross-links in keratin and the mechanical stiffness of the nail plate. In particular, in women with osteoporosis, for whom increased nail brittleness is characteristic, a statistically significant decrease in the number of S–S bonds relative to healthy peers is recorded [12]. Thus, disulfide bridges act as a critical molecular target for chemical impacts capable of initiating their reduction or hydrolysis. Destabilization of this cross-linked network inevitably translates into a loss of structural integrity and a decrease in the mechanical strength of the entire nail.

The common notion of the nail as an inert structure lacking a measurable pH does not withstand experimental verification: contact pH-metry demonstrates that the surface of intact fingernails maintains a stable mildly acidic reaction with a mean pH of 5,1 ± 0,4 [15]. After handwashing with soap, the value transiently rises to 5,3 ± 0,5; however, within ~20 minutes it returns to the baseline physiological level, indicating the presence of an intrinsic buffering capacity of the plate. Notably, the internal thickness of the nail plate is characterized by even lower (more acidic) pH values compared with its surface [15].

The physiological consequences of this acidity are fundamental. By analogy with the skin's acid mantle, which maintains pH 4,5–5,5 and provides antipathogenic protection [10], the mildly acidic reaction of the nail surface performs barrier and antimicrobial functions, creating unfavorable conditions for adhesion and colonization by potential pathogens. It is noteworthy that a higher, that is, less acidic, nail pH promotes germination of

Trichophyton rubrum spores, the leading etiological agent of onychomycosis [22]. Consequently, the natural nail pH is not a passive chemical parameter but an active component of innate defense. Any cosmetic intervention that substantially and persistently shifts pH in the alkaline direction undermines this barrier mechanism, effectively forming an entry gate for infection.

Base coats for nails are complex, multicomponent polymer systems engineered to form an adhesive, flexible, and uniform interfacial barrier between the nail plate and the decorative layer [25, 26].

Film formers — the key structural matrix that, after solvent removal, creates a continuous and mechanically robust film; most typically nitrocellulose as well as acrylate copolymers and vinyl polymers are used.

Solvents — volatile organic compounds (for example, butyl acetate, ethyl acetate, acetone) that dissolve polymers and accompanying ingredients; they provide application-friendly flow and define drying kinetics.

Plasticizers — low-molecular-weight additives (for example, camphor, dibutyl phthalate, citrate derivatives) that intercalate between polymer chains and increase their mobility, whereby the dried film retains the required flexibility and resistance to cracking.

Adhesive polymers — specialized resins (for example, toluenesulfonamide/formaldehyde resin) that enhance the adhesion of the coating to the keratin surface of the nail plate and stabilize the base–nail interface [26, 27].

Traditional acidic primers and base coats optimized for acrylic and gel systems contain high fractions of methacrylic acid (MAA), often 50–88% [13]. Their action is chemically aggressive: MAA acts as a corrosive agent that, upon application to the nail plate, removes surface lipids and moisture and, most notably, initiates micro-etching of the keratin structure with pore formation. The resulting microrelief increases the effective contact area and creates mechanical anchors for subsequent layers of polymer material. At the molecular level, the components of an acidic primer form predominantly weak, short-lived hydrogen bonds with keratin.

In contrast, acid-free primers and base coats do not contain methacrylic acid, although they may include other chemical agents (for example, ethyl acetate) [29]. Their mechanism is fundamentally different and not related to destruction of the nail surface: such systems operate on the principle of double-sided tape. Primer molecules have two reactive ends: one covalently binds to functional groups of keratin in the nail plate, and the other binds just as strongly and covalently to the monomers of the applied gel or acrylic, forming a stable chemical bridge between the nail and the coating. Additionally, acid-free primers temporarily shift the surface pH into the alkaline range, which also enhances the adhesion of polymeric materials [30].

For clarity, a comparative characterization of both types of systems is presented in Table 1.

Table 1. Comparative characteristics of the composition and mechanisms of action of acidic and acid-free base coatings (compiled by the author based on [6, 14, 24, 29, 30]).

Parameter	**Acid systems**	**Acid-free systems**
Primary active component	Methacrylic acid (MAA)	Esters, acrylates (e.g., ethyl acetate)
Mechanism of action	Physicochemical etching, micropore formation, dehydration	Formation of a chemical bridge, temporary pH alteration
Type of bonding with keratin	Hydrogen bonds	Covalent bonds
Effect on nail structure	Destructive, leads to thinning and mass loss	Non-destructive, preserves surface integrity

Methacrylic acid, possessing pronounced acidic and corrosive properties [13], upon contact with the keratin of the nail plate initiates a cascade of destructive biochemical reactions. Etching in this case is not a simple mechanical roughening of the surface but a deep chemical attack on the protein matrix.

First, in an acidic medium, acid-catalyzed hydrolysis of peptide bonds (−CO−NH−) linking amino acid residues in the polypeptide chains of keratin proceeds; similar to the action of acids on other proteins, including collagen, this leads to chain fragmentation and a decrease in the molecular mass of the protein [11]. Second, the acid disrupts the system of hydrogen bonds that stabilize the secondary structure (α-helices and β-sheets), which causes denaturation — unfolding of the protein globule, loss of the native conformation, and subsequent deterioration of mechanical properties [11]. The micropores formed on the surface represent zones of chemically degraded and structurally compromised keratin. Each repeated application of an acid primer results in chemical removal of another microscale layer of functional protein, which explains the cumulative nature of the damage and the progressive thinning of the nail plate with regular use. The schematic distinction of the mechanisms is shown in Fig. 1.

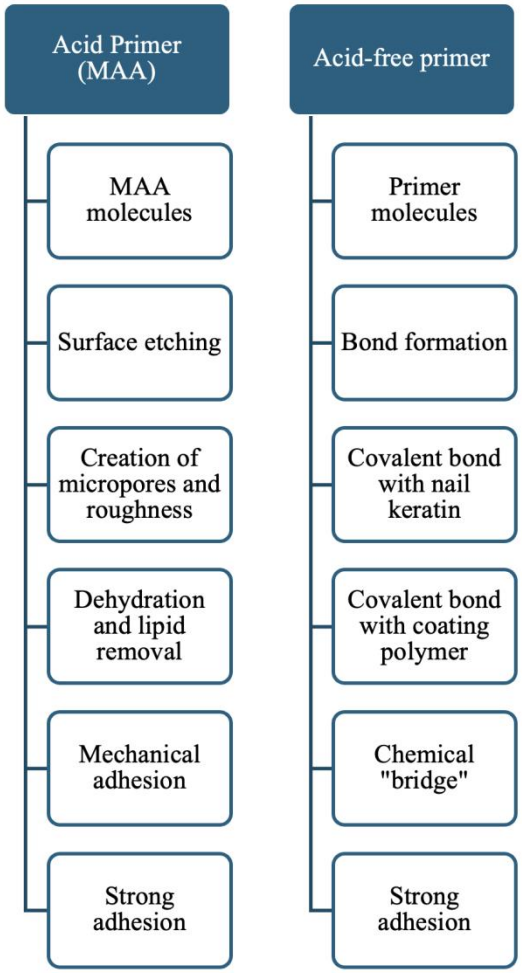

Fig. 1. Schematic representation of the mechanisms of action of acidic and non-acidic primers (compiled by the author based on [11, 13, 17, 20]).

An acidic primer provides adhesion through destructive etching of the surface of the nail plate, whereas an acid-free primer creates a robust chemical bridge between the nail and the coating without compromising its integrity. A quantitatively verifiable marker of chemical destruction of keratin is the loss of key amino acids that determine its architecture and mechanical stability. In the study by Batory M. [7] these changes were measured: after six months of regular application of hybrid manicure, the concentration of cysteine — the principal former of disulfide cross-links — in the nail plate decreased by 22.1%, whereas the content of methionine decreased even more markedly — by 36.5% [7]. Such a deficiency profile directly indicates the degradation of both transverse S–S bonds and the polypeptide backbone of the protein. Visualization of the percentage reduction in the concentrations of cysteine and methionine after six months of regular application of hybrid manicure is presented in Figure 2.

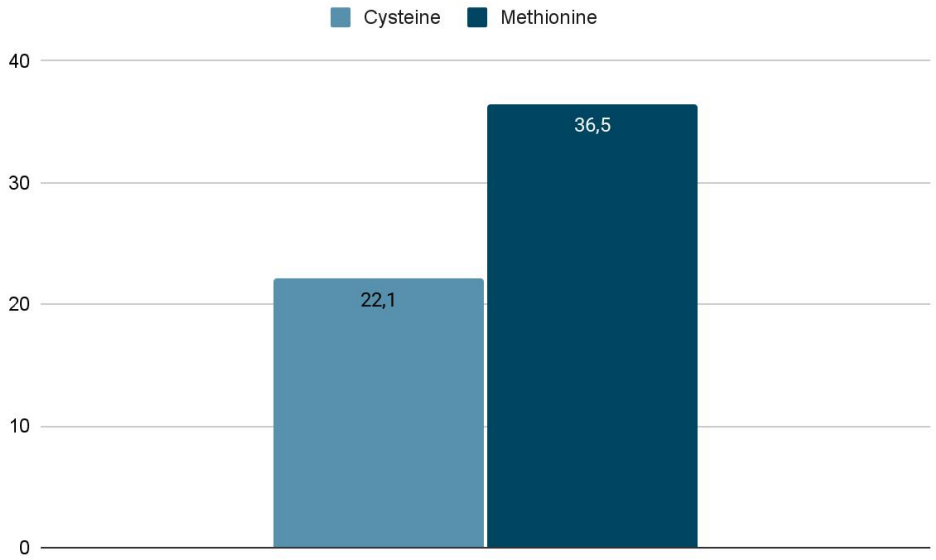

Fig. 2. Diagram of the decrease in the content of sulfur-containing amino acids in the nail plate (compiled by the author based on [7]).

These biochemical shifts are coupled with a macroscopically recordable transformation of the nail. In the same work a statistically significant thinning of the nail plate was recorded: the mean thickness decreased from 0.50 ± 0.12 mm to 0.46 ± 0.12 mm upon completion of the six-month period [7]. This confirms that chemical exposure leads not only to functional weakening but also to a loss of mass of the nail plate. Figure 3 will present a comparison of nail plate thickness before initiation and after six months of using hybrid manicure.

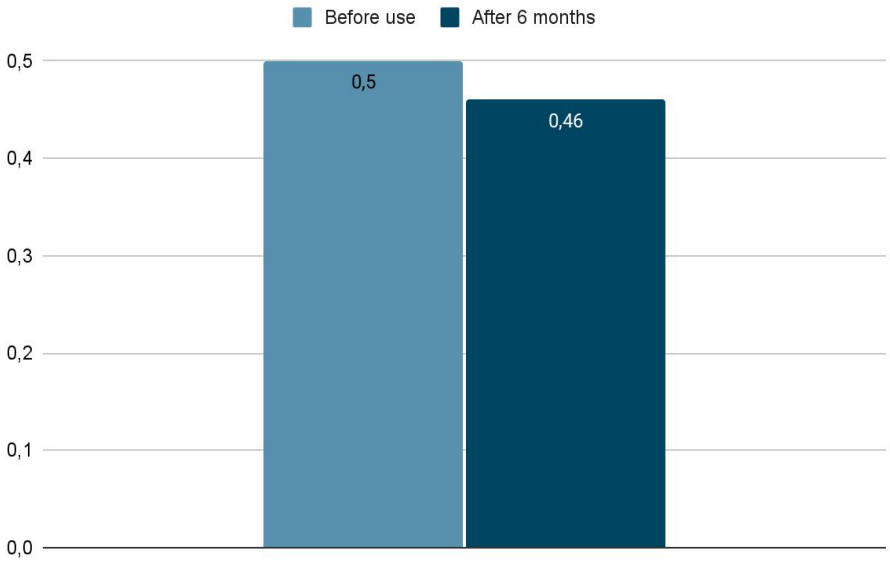

Fig. 3. Change in the average thickness of the nail plate (compiled by the author based on [7]).

The application of decorative coatings markedly disrupts the natural acid–base balance of the nail plate. The magnitude and direction of the pH shift depend on the formulation type: the most pronounced alkalinizing effect is exerted by gel and acrylic systems, as well as gel polishes, in which pH rises above 6.0. Conventional nail polish has a weaker effect, raising pH on average to 5.8. Summary indicators are presented in Table 2.

Table 2. Summary data on changes in the pH of the nail plate after applying various decorative coatings (compiled by the author based on [15, 31]).

Condition/Type of coating	**Mean pH value**
Healthy nail (control)	≈ 5.1
Conventional nail polish	≈ 5.8
Gel polish (hybrid)	> 6.0
Gel/Acrylic	> 6.0

A shift of pH from its natural mildly acidic level (≈5.1) to the neutral or mildly alkaline range (>6.0) is of fundamental importance for the physiology of the nail plate. As noted earlier, the acidic perisurface milieu is a key component of innate antimicrobial defense. Neutralization of this acidic mantle creates a favorable niche for colonization by pathogenic microbiota, primarily fungi, which are the principal etiologic agents of onychomycosis [22, 23]. Thus, long-term coatings not only cause mechanical and chemical depletion of the nail but also compromise its biological defense.

Microscopic disruptions in the biochemical architecture of keratin are inevitably translated into macroscopic clinical manifestations. Attenuation of intercellular adhesion and degradation of the keratin matrix underlie the development of onychoschizia (horizontal lamellar splitting of the plate, especially from the distal edge) and onychorrhexis (the appearance of longitudinal ridges and fissures) [20, 21]. These phenotypes vividly reflect the loss of structural integrity of the nail and are often observed in patients who regularly resort to aggressive cosmetic procedures [7].

Furthermore, with regard to impairment of barrier function and increased risk of onychomycosis, an intact nail plate functions as an effective physicochemical barrier. Chemical insults that increase porosity, generate microfissures and, critically, neutralize the protective acidic pH sharply reduce barrier properties. Damaged, porous nails become more susceptible to invasion by pathogenic fungi [8]. Onychomycosis, predominantly caused by dermatophytes (Trichophyton rubrum and T. mentagrophytes), remains the most prevalent infectious disease of the nails, affecting a substantial proportion of the population [16].

A peculiar vicious circle arises: chemical components of cosmetic coatings initiate damage to the nail plate, creating a gateway for microbial ingress; subsequently, the supervening fungal infection amplifies nail destruction through the production of keratolytic enzymes [8]. In this regard, the use of aggressive base coats should be considered a significant predisposing factor in the development of onychomycosis.

Along with direct structural traumatization of the nail, a number of ingredients in modern polymer systems are associated with a risk of immunological reactions. Acrylates and methacrylates (including methyl methacrylate, ethyl acrylate, HEMA), which serve as key monomers of gel and acrylic materials, are well-known and highly active contact sensitizers. Contact of incompletely polymerized material with the skin of the periungual fold (perionychium) can provoke allergic contact dermatitis, clinically presenting with erythema, edema, pruritus, and scaling. The problem affects both clients and nail service professionals who are regularly exposed occupationally to these substances. This underscores the multidimensionality of risks inherent in modern nail technologies, encompassing not only structural nail damage but also immunological reactions to coating components.

Conclusion

The conducted analysis demonstrated that the acidity of base coatings is the determining parameter governing their impact on the biochemical architecture and structural integrity of the nail plate. The study results are formulated as follows.

Acidic systems based on methacrylic acid provide adhesion via destructive-type chemical etching. This mechanism initiates hydrolysis of peptide bonds and keratin denaturation, which is evidenced by a quantitatively recorded decrease in the content of key sulfur-containing amino acids (cysteine and methionine) and progressive thinning of the nail plate with regular use.

Acid-free systems function as a more atraumatic technology: by forming covalent bonds between the nail and the polymer coating, they ensure reliable adhesion without compromising the integrity of the keratin matrix.

Prolonged use of long-wear coatings, especially gel and acrylic, induces a pronounced shift of the physiological pH of the nail plate (≈5.1) toward the alkaline range (up to >6.0). This leads not only to degradation of the protein structure but also to weakening of innate antimicrobial defense mechanisms, increasing the likelihood of fungal infections, including onychomycosis.

Thus, the author’s hypothesis that high acidity of base formulations initiates a cascade of destructive changes in the nail plate is fully confirmed. The aim of the study has been achieved: the full pathogenetic continuum has been traced — from the molecular characteristics of the product (presence of methacrylic acid) through the interaction mechanism (chemical etching) to biochemical (loss of amino acids, pH shift) and structural (thinning) disturbances, which translate into clinical manifestations — brittleness, splitting, and an increased risk of infection.

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