Quantitative Analysis of the Influence of Digital Printing Process Parameters on Leather Printing Quality

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Abstract

Digital printing is a key processing technology in modern packaging and printing, widely used in manufacturing leather products. This study focuses on the impact of digital printing process parameters on leather printing quality. Through literature review and practical operational experience, relevant data were collated and analyzed to explore the effects of technical parameters such as printing speed, workshop temperature, and ink parameters on color reproduction, pattern clarity, and adhesion fastness of leather prints. The results indicate significant correlations between process parameters and printing quality indicators. Additionally, numerous recommendations are proposed to optimize production processes and enhance the quality of digitally printed leather products.

Keywords

Digital Printing; Process Parameters; Leather Products; Printing Quality.

1. Introduction

Printing technology, one of China's Four Great Inventions, has a history spanning thousands of years. With the rapid development of digital technology in recent decades, digital printing has emerged as an advanced printing method alongside traditional printing processes since the early 21st century. Digital printing offers advantages such as high efficiency, flexibility, and personalization, making it widely applicable across industries[1] . For leather products, printing is a critical step to enhance visual appeal by adding patterns and colors to the surface. Many enterprises adopt digital printing for personalized leather processing, creating opportunities for technological advancement[2] . However, due to the diverse types and surface properties of leather materials, precise control of digital printing parameters to achieve high-quality results remains a key challenge. Understanding the influence of process parameters on leather printing quality can guide enterprises in optimizing production, improving product competitiveness, and meeting market demands[3] .

2. Overview of Digital Printing and Leather Printing

2.1 Principles and Characteristics of Digital Printing

Digital printing differs significantly from traditional printing methods, which rely on pre-made printing plates to transfer ink under pressure. Digital printing eliminates the plate-making process, directly transferring digital graphic and text data from computers to printing equipment through inkjet, thermal transfer, or other techniques. Compared to traditional printing, digital printing reduces lead times, enables on-demand production, and supports variable-data printing, driving its rapid adoption in laboratories and manufacturing facilities.

2.2 Applications and Current Status of Leather Printing

Leather is a vital material for producing garments, bags, footwear, and home decor. Printing on leather surfaces enriches product aesthetics but requires careful control of process parameters to ensure quality. While digital printing offers cost-effective and efficient solutions, its quality and consistency may vary compared to traditional methods, necessitating a deeper understanding of influencing factors[4] .

3. Analysis of Printing Process Parameters

Printing quality on leather is influenced by multiple factors, including equipment, substrate properties, ink characteristics, and operational techniques[5] .

3.1 Printing Speed

Printing speed, determined by equipment specifications, typically ranges from several to tens of square meters per hour. Faster speeds may compromise ink transfer and drying, leading to faded or uneven patterns, while slower speeds reduce efficiency and risk thermal damage to leather[6] .

3.2 Influence of Printing Methods on Leather Quality

"The graphic and text transfer effects of different printing methods vary significantly depending on the substrate, thus requiring selection of appropriate processes based on specific printed material types and surface characteristics, as detailed in Table 1.

Table 1. Different printing methods exhibit varying performance on leather substrates

Method	Substrate Range	Ink Layer Thickness	Printing Precision
Relief Printing	Paper, cardboard	Thin (1-2μm)	Moderate (150-300dpi, text/simple patterns)
Gravure Printing	Plastics, metal foil, paper	Medium (5-15μm)	High (600dpi+, gradients/complex graphics)
Screen Printing	Versatile materials	Thick (10-50μm)	Low (50-150dpi, solid colors/simple logos)
Offset Printing	Paper, plastics	Thin (1-3μm)	High (1200-2400dpi, detailed color images)
Digital Printing	Paper, labels, specialty materials	Thin (1-5μm)	Very high (1200-4800dpi, personalized/short-run)

3.3 Drying Characteristics by Printing Method

"Different substrates require distinct printing processes, leading to variations in ink transfer principles and drying mechanisms[7] . Consequently, significant temperature differences are involved in ink transfer and drying. In general, the primary drying methods for ink applied to leather surfaces are as follows, detailed in Table 2.

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Table 2. Ink drying methods vary with printing techniques and ink types

Drying Method	Principle	Ink Types	Key Features	Applications
Natural Drying	Solvent evaporation/oxidation	Water-based, solvent-based	Low cost, slow drying (hours-days)	Handmade leather goods, low-volume production
Hot Air Drying	Forced solvent evaporation	Solvent-based, water-based	Faster drying (minutes), temperature-sensitive	Conveyor-based production (screen/gravure)
Infrared (IR) Drying	Radiation heating	Solvent-based, UV-curable	Deep penetration, high energy consumption	Thick-layer printing (screen/gravure)
Ultraviolet (UV) Curing	Photo-polymerization under UV light	UV-curable	Instant drying, high gloss, equipment-intensive	High-end leather products (footwear, bags)
Electron Beam (EB) Curing	High-energy electron irradiation	EB-curable	No initiators, thorough curing	Industrial applications (non-standard leather)
Solvent Evaporation + Oxidation	Two-stage drying	Traditional solvent-based	Moderate speed, VOC emissions	Low-cost shoe materials

3.4 Ink Parameters

Ink Type: Solvent-based inks offer strong adhesion but environmental risks; water-based inks are eco-friendly but less durable; UV inks provide fast curing and high quality.

Viscosity & Ink Supply: Optimal viscosity ensures smooth nozzle operation (e.g., 8-12 cP for gravure). Inadequate ink supply leads to faded prints, while excess causes smudging.

3.5 Other Parameters

Printing resolution and nozzle distance also affect pattern clarity and color uniformity.

4. Leather Printing Quality Evaluation System

4.1 Color Performance Assessment

"Total color difference (ΔE), lightness difference (ΔL), and hue difference (ΔH) are used to measure discrepancies between printed colors and standard reference colors. Among these, ΔE comprehensively reflects variations in lightness, hue, and saturation. Smaller ΔE values indicate closer approximation of printed colors to the standard, signifying higher color fidelity. Specific parameters are detailed in Table 3.

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Table 3. Leather Printing Color Control Parameters

Category	Parameter	Standard Range	Control Method
Substrate Properties	Leather type	Cowhide, sheepskin, synthetic leather	pH (4.5-6.5), water absorption testing
	Surface treatment	Coating thickness (5-15μm), roughness (Ra 0.5-1.5μm)	Electron microscopy/roughness analyzer
Ink System	Ink type	Solvent-based, water-based, UV-curable	Environmental/equipment compatibility checks
	Pigment concentration	15-30% (mass ratio)	Spectrophotometer analysis, ICC profile creation
	Viscosity (25℃)	Gravure: 8-12 cP; Flexo: 15-25 cP	Viscometer monitoring, additive adjustment
Printing Process	Anilox roller line count	Gravure: 150-300 LPI; Flexo: 100-200 LPI	Pattern precision optimization
	Blade pressure	8-15 bar	Pressure sensor control
	Printing speed	5-20 m/min	Drying system synchronization
	Drying temperature/time	UV: 80-120℃, 0.5-2s; Hot air: 60-80℃, 3-5min	Infrared thermometry, airflow adjustment
Environmental Control	Temperature/humidity	22±2℃, 50±5%	HVAC system regulation
Color Calibration	Standard light source	D65 (6500K)/A (2856K)	Color matching cabinet
	Density values	C:1.0-1.2; M:1.0-1.2; Y:0.8-1.0; K:1.4-1.6	Density meter measurement, formula adjustment
	ΔE color difference	≤2.0 vs. standard	Spectrophotometer correction
Post-treatment	Protective coating	3-5μm thickness, ≥500 abrasion cycles	Uniform spraying/rolling

5. Conclusion and Outlook

This study analyzed the effects of digital printing parameters (speed, method, drying characteristics, ink properties) on leather printing quality, demonstrating significant correlations with color reproduction, clarity, and adhesion. Optimizing these parameters can enhance production efficiency and product quality. Future research should explore emerging technologies and materials to further advance leather printing capabilities.

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