

Quality Control in the Apparel Industry: A Printing and Embroidery Perspective

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Introduction

The apparel industry constitutes one of the most critical segments of the textile value chain and holds strategic significance due to its high employment capacity, contribution to foreign trade, and impact on economic growth. Particularly in developing countries, the labor-intensive production structure of the sector provides extensive employment opportunities while also positioning it as a major production hub within global supply chains (Euratex, 2024). The global apparel industry is projected to grow at an average annual rate of approximately 4% by 2025, a trend that is expected to further intensify competition in the sector (Statista, 2024).

Turkey stands out as one of the leading countries in the global market with its production capacity and export strength in the apparel sector. In particular, strong trade relations established with the European Union countries position Turkey as a reliable partner within supply chains (International Trade Centre [ITC], 2024). Moreover, sustainable production practices, fast delivery capability, and flexible manufacturing structure are among the key factors enhancing Turkey's competitiveness. As of 2024, the apparel industry has held a significant share in Turkey's total exports, providing substantial foreign exchange earnings for the national economy (Turkish Exporters Assembly [TİM], 2024).

The concept of quality in the apparel sector is a determinant of a firm's competitiveness and is directly linked to consumer satisfaction, brand reputation, and cost efficiency.

Errors occurring during the production process lead to both product rejections and rework costs. Such quality-related issues increase product return rates, warranty expenses, and brand-associated losses. Therefore, quality control practices are of central importance for production efficiency and financial sustainability (Radmin, 2024).

With the rise of technology and automation, quality control practices are also transforming. Computer vision, machine learning, and artificial intelligence-based methods have the potential to reduce errors stemming from the limitations of human vision, particularly in areas such as early detection of fabric surface defects, monitoring of print alignment, and classification of embroidery flaws. These approaches enable the early identification of defects in production, thereby reducing the need for rework and minimizing waste rates, while simultaneously improving the speed and repeatability of quality control processes. However, when implementing technological solutions, technical challenges such as data infrastructure, standardization of cameras and lighting, determination of classification thresholds, and adaptation to field conditions must also be taken into account (Ozek et al., 2025).

This study aims to examine printing and embroidery processes in the apparel industry in detail and to identify the most common types of defects encountered in these processes in light of both literature and field practices. Issues such as dye bleeding, pattern misalignment, stencil clogging, and stains or creases on the fabric are the focal points in printing processes; while in embroidery, errors such as thread looping, pattern distortion, oil stains, and marking traces are emphasized. In conclusion, this study seeks to highlight the significance of printing and embroidery in terms of quality control within the apparel industry and to systematically present the types of defects observed in these areas.

Overview of the apparel industry

The apparel industry encompasses a wide value chain that includes both design and production processes. The production process typically begins with the procurement of raw materials. The selection of fabrics is determined by the type of product, its intended use, and the required quality standards. Procured fabrics are subjected to quality control tests before production and are stored under appropriate conditions. This stage is critical not only for production efficiency but also for the quality of the final product. Storage conditions necessitate careful management of factors such as humidity, light, and temperature.

Following the proper procurement of fabrics, the cutting process begins. This stage involves cutting the fabric according to the patterns of the product to be manufactured and can be performed manually or with automated machinery. The accuracy and precision of cutting directly influence both labor costs and product quality in subsequent stages. As one of the cornerstones of the production process, cutting must be carried out

meticulously to ensure a defect-free product.

After the cutting stage, printing and embroidery processes are applied to enhance the aesthetic value of the product. Printing is commonly performed using screen printing, digital printing, or transfer printing techniques, while embroidery involves creating patterns with threads. The techniques employed at this stage vary depending on the target market and design specifications of the product. In modern apparel manufacturing, digital printing and computerized embroidery machines not only increase production speed but also support design diversity.

The sewing process ensures the assembly of the cut pieces and gives the product its final form. At this stage, workmanship quality, the machines used, and sewing techniques determine both the durability and the aesthetic appearance of the garment. Following sewing, the ironing process finalizes the shape and appearance of the product, preparing it for the packaging stage. Packaging represents the final step, encompassing the preparation and storage of products in a manner suitable for shipment.

In today's apparel industry, various technologies are employed to improve production processes and enhance efficiency. Automatic cutting machines, digital printing systems, robotic sewing machines, and smart manufacturing systems constitute the core components of modern production approaches. With the advent of Industry 4.0, data analytics, production planning, and quality control processes are becoming increasingly digitalized and optimized. These technological advancements not only strengthen competitiveness in the sector but also shorten production lead times and minimize errors (Sağbaşı & Özdil, 2022).

Nevertheless, the challenges faced by the industry cannot be underestimated. Production costs are influenced by multiple factors such as raw material prices, labor expenses, and energy consumption. Rapidly changing consumer demands require production processes to be both flexible and responsive, which may pose difficulties in terms of production planning and supply chain management. The effectiveness of quality control processes is of critical importance for maintaining brands' competitive advantage and ensuring customer satisfaction. In addition, environmental impacts and sustainable manufacturing practices are becoming increasingly prominent in the sector. Sustainability is evaluated not only as a matter of environmental responsibility but also as a factor that enhances both economic value and brand reputation (Erdem & Doğan, 2020).

The Importance of Quality Control in the Apparel Industry

In the apparel industry, quality refers to the extent to which a product meets customer expectations. Consumers make purchasing decisions not only based on the aesthetic features of the product but also by considering elements such as durability, comfort, and

functionality. Therefore, quality is directly related not only to the physical characteristics of the garment but also to the reliability of the brand and the level of customer satisfaction.

Quality control is a systematic set of activities carried out during the production process to ensure that products comply with predefined quality standards. This process begins with the procurement of raw materials and is applied at every stage of production as well as before the shipment of the final product. By enabling the early detection and correction of defects, quality control ensures the continuity of product quality and enhances customer satisfaction (Vaughn, 2022).

Critical Factors Affecting Quality

Fabric and Material Quality: The quality of fabrics and auxiliary materials used is one of the most fundamental factors determining both the durability and appearance of the apparel product. Key factors affecting the aesthetic value of the product include fabric surface smoothness, color consistency, shrinkage, and pilling tendency. Additionally, the selection of complementary materials such as linings, buttons, zippers, and sewing threads directly impacts the product's longevity. Therefore, careful evaluation of material quality at the initial stages of production is a critical step to ensure the overall quality of the garment.

Workmanship and Operator Skill: Workmanship quality plays a crucial role at every stage of the production process. The skills of operators, their ability to use machinery correctly, and their attention to detail directly influence product quality. A trained and experienced workforce reduces production errors and enhances efficiency.

Production Equipment and Technology: Modern production equipment and technologies increase both the speed and accuracy of the manufacturing process. Computer-aided systems and automated machinery reduce error rates in cutting and sewing operations while enhancing production capacity. These technologies also improve the effectiveness of quality control processes (Kumaş & Duru Baykal, 2023).

Types of Printing and Embroidery in the Apparel Industry

Types of Printing

There are numerous printing techniques used in the textile industry. This section discusses the printing methods commonly employed in the sector, as listed below:

- Water-Based Screen Printing
- Pigment Printing
- High-Relief Printing

- Embossed Printing
- Foil Printing
- Glitter Printing

Water-Based Screen Printing: In water-based printing, water-based inks are used, which possess organic characteristics due to their special compositions. Fabrics printed with water-based inks, which can be washed at 60°C, also offer higher elasticity compared to other printing methods (Keser, 2022). The environmental and human health friendliness of water-based screen-printing materials has made this technique a preferred method for both industrial and artistic applications (Esen & Gündoğdu, 2021).

Pigment Printing: Pigment printing is considered one of the oldest and most important printing techniques in the textile industry. The basic principle involves fixing colored pigments, which are insoluble in water and have no affinity to textile fibers, onto the fabric with the help of a chemical binder. Pigment printing is particularly favored for cotton fabrics (Orhan, 2010).

High-Relief Printing: High-relief printing is a technique in which the design to be printed has raised surfaces. Only the raised areas of the printing plate receive the ink, which penetrates the fabric during the printing process.

Embossed Printing: Embossed printing is a special technique that adds volume and a tactile effect to the fabric. It is achieved by transferring paste mixed with coloring agents onto the fabric using a mold and then fixing it to create a raised surface (Ateks Emprime, 2019). This method produces a pattern that is perceptible both visually and to the touch.

Foil Printing: Foil printing involves transferring metallic foil materials, such as gold, silver, or other metallic-looking foils, onto fabric or other surfaces.

Glitter Printing: Glitter printing is used in the textile industry to create an aesthetic effect. Glitter is added to an adhesive and applied to the fabric using a printing mold. This technique produces a bright and eye-catching visual appearance due to the reflective properties of the glitter.

Types of Embroidery

There are various types of embroidery used in the textile industry. This section addresses the embroidery techniques commonly employed in the sector, as listed below:

- Flat Embroidery
- 3D Embroidery
- Chain Stitch

- Satin Stitch
- Chenille Embroidery
- Goldwork Embroidery
- Cutwork Embroidery

Flat Embroidery: This is the most used machine embroidery type. The design is directly stitched onto the fabric surface, producing a flat and smooth pattern. It is generally preferred for logos, lettering, or simple motifs and is commonly applied on t-shirts, shirts, and jackets (Corbet, 2016).

3D Embroidery: A raised effect is achieved by placing a special foam under the design. This technique is typically used on caps, sweatshirts, and sportswear (Deer, 2025).

Chain Stitch: This type of stitch consists of interlinked loops. While it is common in traditional hand embroidery, it can now be executed with industrial machines. It is especially favored for ethnic patterns and lettering (TRC Leiden, 2017).

Satin Stitch: The interior of the design is filled with closely spaced parallel stitches. Although it resembles flat embroidery, it provides a shinier and more pronounced appearance. It is frequently used for logos and text embroidery (TRC Leiden, 2017).

Chenille Embroidery: This embroidery uses thick, velvety, and fuzzy threads, resulting in a soft and raised texture. It is particularly used for college jackets and sportswear (Wilcom, 2021).

Goldwork Embroidery: This decorative technique employs gold or silver metallic threads. It is typically used in luxury and ceremonial garments, particularly traditional and religious attire. The threads are usually made from metal wires plated with gold, silver, or copper, or from special metallic-looking threads. The metallic threads are not directly stitched onto the fabric; instead, they are laid on the surface and secured with various stitching techniques (Jones & Nabil, 2022).

Cutwork Embroidery: In this type of embroidery, specific sections of the fabric are cut out, and the surrounding areas are finished with embroidery stitches. It is an elegant technique that is particularly preferred in summer women's apparel and children's dresses (Mohapatra et al., 2015).

Factors Affecting Quality in Printing and Embroidery

Printing and embroidery processes are critical not only for the aesthetic appearance of apparel products but also for customer satisfaction and product longevity in the market.

The factors influencing quality in these processes depend on a wide range of variables, including material selection, technology, operator skill, and process parameters. These factors are examined in detail below.

Fabric and auxiliary material properties

The structural characteristics of the fabric—such as knit construction, type of yarn, surface smoothness, and fabric weight—are key variables determining print quality. For instance, a study by Tse and Briggs (1999) tested different knit structures and yarn thicknesses in cotton fabrics; these variables were found to significantly influence quality criteria such as line sharpness, color saturation, and surface texture.

Similarly, the quality of auxiliary materials plays a critical role in embroidery. A study conducted by Emekli and Bahadır Ünal (2019) examined the effects of lining types, upper and lower thread tension, machine settings, and fabric surface on embroidery quality. For example, using thick and heavy linings in large embroidery areas negatively impacted wearer comfort, whereas lighter and water- or heat-soluble linings were preferred for small areas such as logos.

Printing and embroidery process parameters

The type of dye or ink and the application parameters—such as the number of ink layers, fixation temperature, and post-printing treatments—directly affect print quality attributes, including durability and color fastness. For example, in the article “Textile Printing Combined with Embroidery”, it was reported that increasing the number of ink layers in inkjet printing enhances resistance to light and washing; however, excessive layering may negatively affect the hand feel of the fabric and increase production costs (Stümer & Stümer, 2008). Additionally, evaluating prints through both visual and quantitative measurements is crucial. In the study by Tse and Briggs (1999), automated analysis systems were shown to objectively reveal the effects of fabric structure, yarn types, and pre-treatment processes on print quality.

During embroidery, the accuracy of machine settings significantly influences quality. Emekli and Bahadır Ünal (2019) found that improper selection of upper and lower thread tensions can lead to issues such as lower thread protrusion, pattern misalignment, or puffiness. The size and placement of the design are also important. While small logos may require different lining choices, large designs can encounter greater problems with bulk, weight, and surface stiffness. These factors must be considered in terms of both aesthetics and wearer comfort.

Visual perception and objective measurement

Quality assessment in printing and embroidery is often based on visual perception;

however, human factors such as operator fatigue and lighting conditions can compromise consistent evaluation. Therefore, objective measurement techniques are increasingly important. Digital image processing methods, as well as colorimetry assessments of contrast, optical density, and line sharpness, allow for more consistent and reliable analysis of quality (Kumari et al., 2021; Tse et al., 1999).

Causes of Printing and Embroidery Defects in the Apparel Industry

The increasing demand for high-quality products and rapidly changing economic conditions have made it even more critical for apparel manufacturers to produce items at the correct quality standards. Identifying sources of variability in the production process is essential to minimize defects and enhance process performance (Ersöz et al., 2021).

Printing defects

Stencil Defect: In screen printing, a “stencil defect” refers to a problem caused by damage to the stencil used during printing or improper preparation of the stencil. This defect can prevent the print from proceeding correctly and may manifest in various forms.

The primary causes of stencil defects include:

- Uneven application of the emulsion
- Errors in exposure time and incorrect exposure
- Improper placement of the stencil on the printing machine

Figure 1

Example of a “Stencil Defect”



Ink Bleeding: In screen printing, an “ink bleeding” defect occurs when the ink spreads

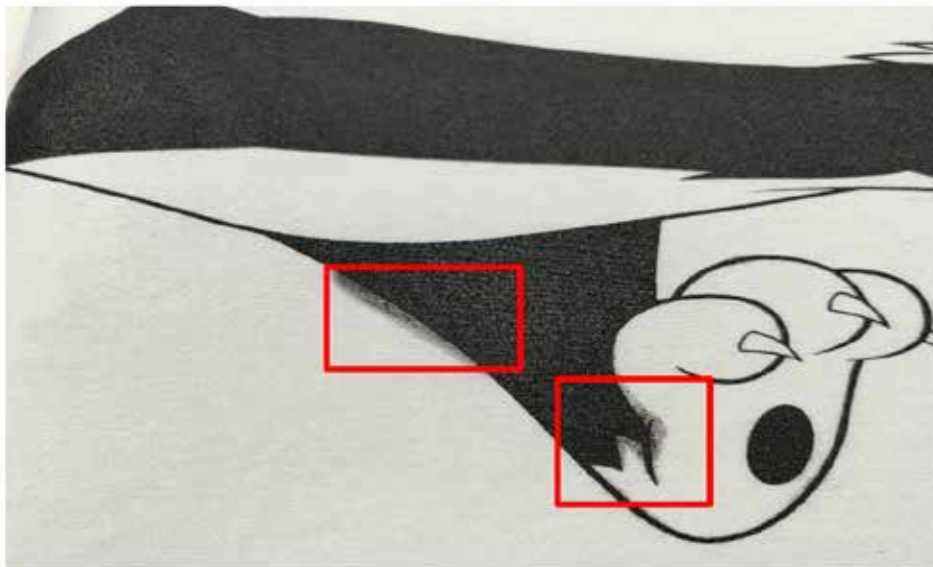
beyond the intended boundaries on the printing surface. This defect results in a blurred, unclear, or smeared appearance of the printed design.

The primary causes of ink bleeding include:

- Excessive use of ink
- Issues with the fabric surface
- Insufficient tension of the stencil

Figure 2

Example of an “Ink Bleeding Defect”



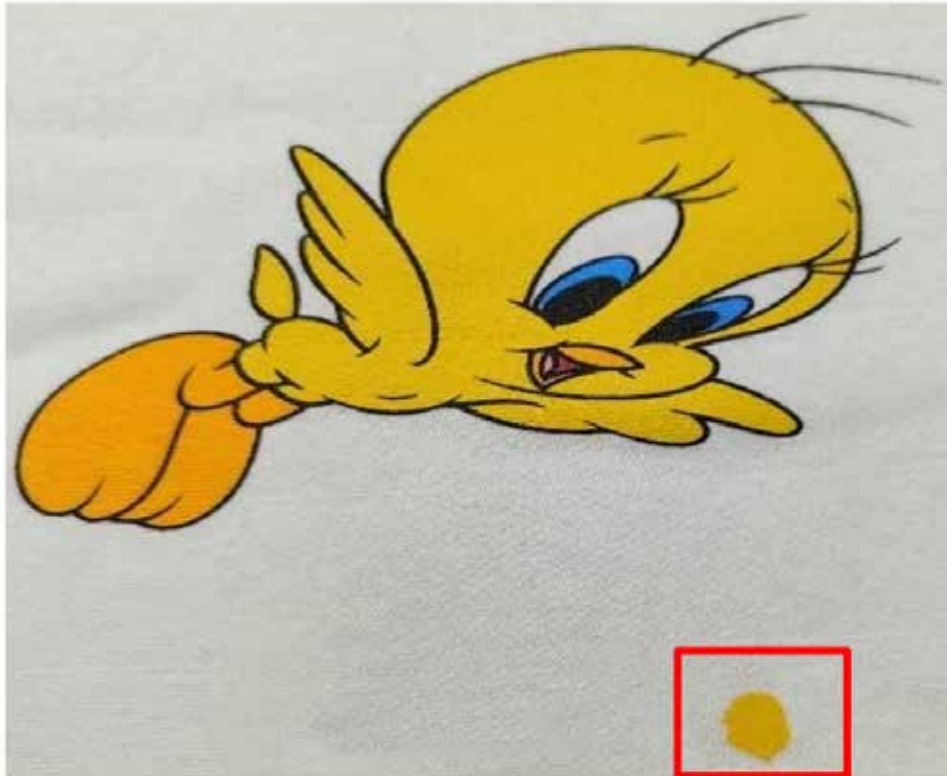
Ink Staining: In screen printing, an “ink staining” defect occurs when ink remains or spreads onto unintended areas of the printing surface, leaving unwanted marks. This defect prevents the print from appearing clean and sharp, negatively affecting print quality.

The primary causes of ink staining include:

- Inadequate cleaning of the stencil
- Excessive use of ink
- Incorrect ink viscosity

Figure 3

Example of an “Ink Staining Defect”



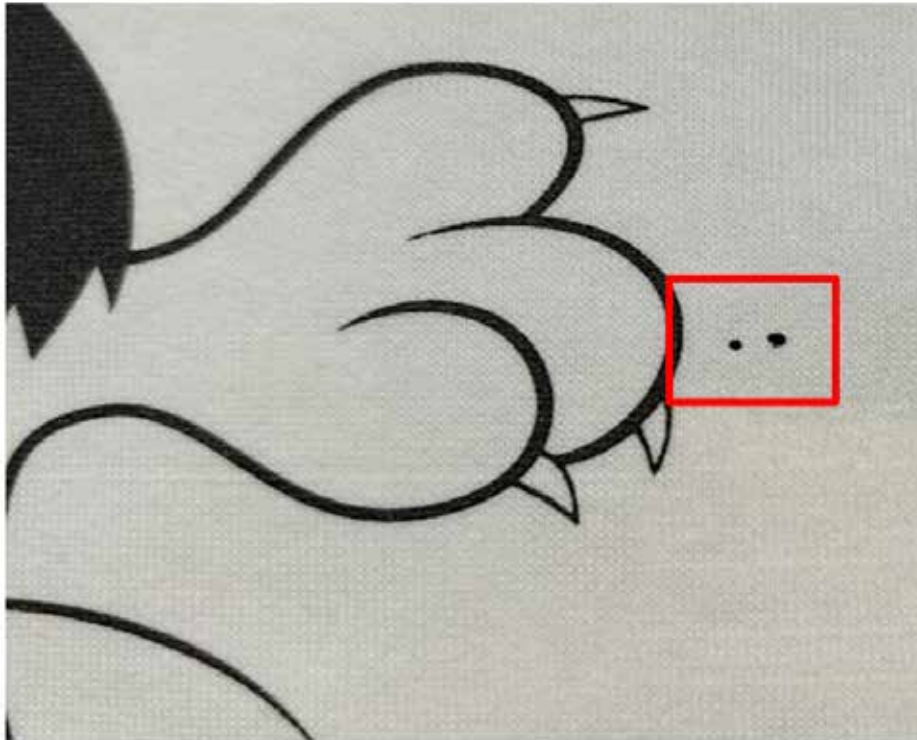
Stencil Leakage: In screen printing, a “stencil leakage” defect occurs when ink seeps outside the intended areas of the stencil during printing. This defect results in prints with blurred or distorted boundaries.

The primary causes of stencil leakage include:

- Damage to the stencil
- Incorrect application of the emulsion
- Improper sealing of stencil edge

Figure 4

Example of a “Stencil Leakage Defect”



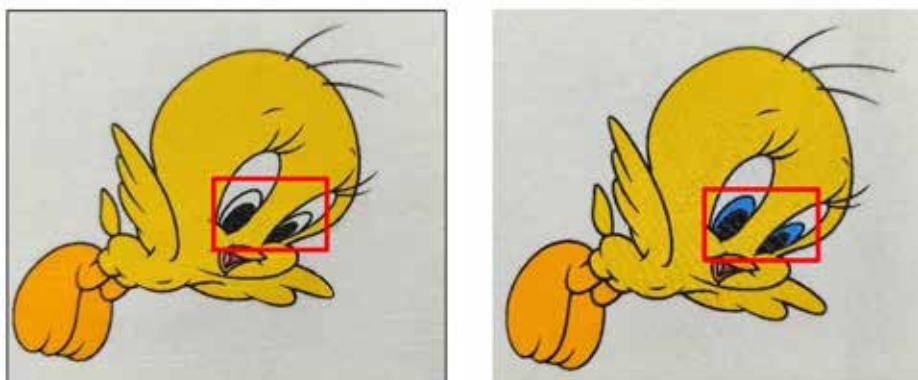
Stencil Clogging: In screen printing, a “stencil clogging” defect occurs when the mesh openings of the stencil become blocked by ink, dust, or other debris. This clogging prevents the ink from transferring properly onto the printing surface.

The primary causes of stencil clogging include:

- Inadequate cleaning
- Excessively thin or thick emulsion layers
- Dried ink residues

Figure 5

Example of a “Stencil Clogging Defect”



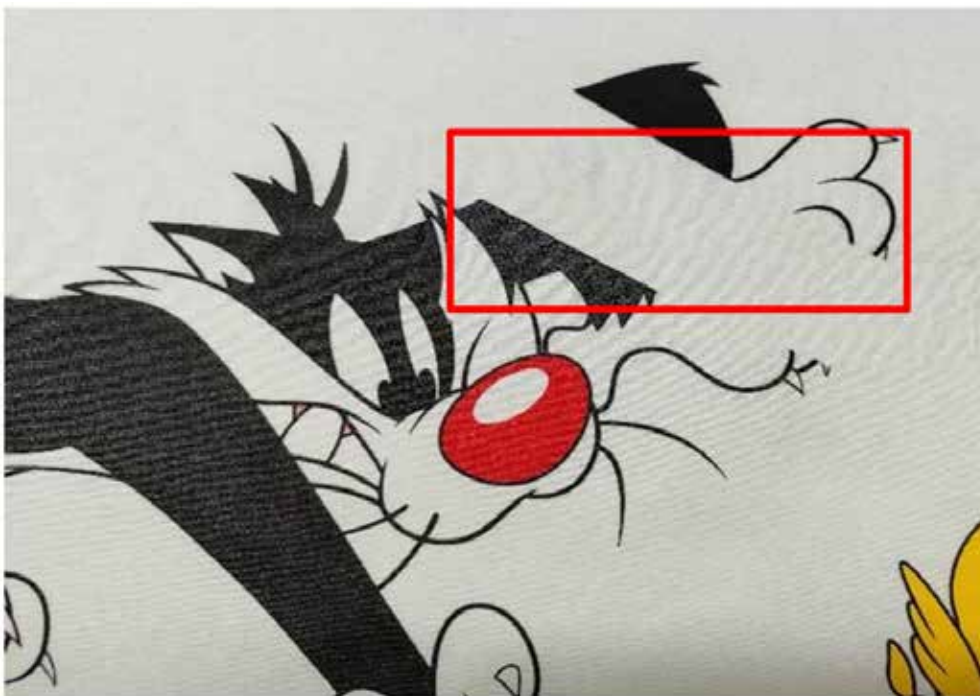
Fabric Folding: In screen printing, a “fabric folding” defect occurs when the fabric is not properly laid out before or during printing, causing folds or creases.

The primary causes of fabric folding include:

- Improper placement of the fabric
- Stretching of the fabric
- Misalignment in the printing machine

Figure 6

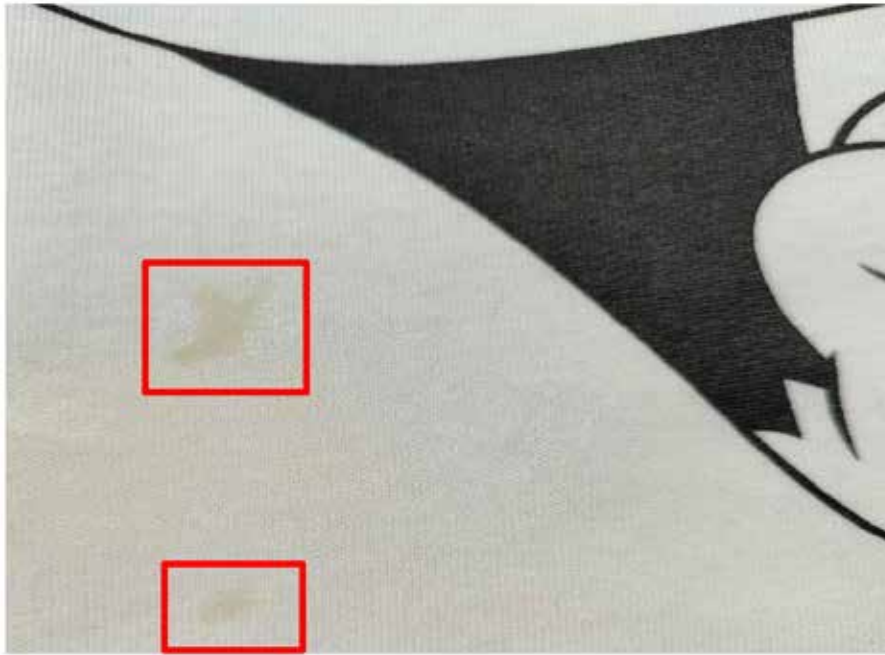
Example of a “Fabric Folding Defect”



Fabric Staining: Stains observed during the printing process are not caused by the printing itself; rather, they are pre-existing defects in the fabric. These stains are not directly related to the printing technique or the type of ink used, but originate from the fabric’s manufacturing process.

Figure 7

Example of a “Fabric Staining Defect”



Embroidery defects

Embroidery Misalignment: In textiles, an “embroidery misalignment” defect occurs when the design produced by embroidery machines shifts or deviates from its intended original position. This defect prevents the embroidery from being executed accurately in the desired area.

The primary causes of embroidery misalignment include:

- Incorrect placement of the hoop
- Insufficient tension of the fabric

Figure 8

Example of an “Embroidery Misalignment Defect”



Embroidery Marking Defect: An “embroidery marking” defect occurs when unwanted marks, lines, or stains remain on the fabric during the embroidery process. These marks typically affect the outcome of the embroidery design or process and negatively impact its aesthetic quality. The primary cause of embroidery marking defects is the pre-marking of the fabric.

Figure 9

Example of an “Embroidery Marking Defect”



Thread Wrapping Defect: In embroidery machine operations, a “thread wrapping” defect occurs when the thread is not properly wrapped or when there are issues with thread tension during embroidery.

The primary causes of thread wrapping defects include:

- Incorrect thread tension
- Poor thread quality

Figure 10

Example of a “Thread Wrapping Defect”



Skipped Stitch: In embroidery machines, a “skipped stitch” defect occurs when threads are missing or entirely skipped in certain areas during the wrapping process. This defect results in unwanted gaps or deficiencies in embroidery design.

The primary causes of skipped stitches in wrapping include:

- Issues with machine settings
- Thread breakage

Figure 11

Example of a “Skipped Stitch Defect”



Embroidery Oil Stain: In embroidery, an “oil stain” defect is defined as a stain on the fabric caused by oil or oily substances during the embroidery process. These stains disrupt the aesthetic appearance of the embroidery and negatively affect the overall quality of the product.

The primary causes of embroidery oil stains include:

- Machine oils
- Improper or insufficient cleaning

Figure 12*Example of an “Oil Stain Defect”***Modern Quality Control Approaches**

Traditional quality control methods have long been an indispensable part of the textile industry. Visual inspection relies on experienced operators examining product surfaces either manually or with the naked eye to detect defects. While this method offers advantages such as low technological requirements and flexibility, it also presents drawbacks, including errors arising from human factors (e.g., operator attention, fatigue, and lighting conditions), reduced efficiency, and inconsistencies. Visual inspection remains widely used, especially in low-budget operations; however, as quality expectations increase and production volumes grow, these methods need to be supplemented with modern quality control approaches.

The rise of automation and digitalization in the textile sector is transforming the quality control process. Technologies such as sensors, high-resolution cameras, automated testing devices, and IoT-based monitoring systems enable continuous data collection on the production line. This allows for both early defect detection and enhanced process traceability. For example, Metin & Bilgin (2024) investigated quality prediction using automatic machine learning models on imbalanced fabric quality datasets, demonstrating that this approach reduces operator dependency while making defects more predictable.

Image processing and AI-based applications constitute another key component that enhances the accuracy and speed of quality control. In a study by Ozek et al. (2025), deep learning models—particularly Convolutional Neural Networks (CNNs)—were

employed for tasks such as identifying surface defects and automatically detecting anomalies during production. These technologies enable the detection of micro-defects that might be overlooked by the human eye, allowing defective products to be removed from the production line earlier and reducing material and cost wastage. Furthermore, the study by G. Nair and Trivedi (2024) demonstrated that adopting machine learning and artificial intelligence in quality control departments significantly improves production efficiency, accuracy, and cost-effectiveness.

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