Root Cause Analysis of Textile Defects Using Scanning Electron Microscopy

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Abstract

Textile manufacturers are extensively working on improving the market with qualities, however, textile defects are a great hindrance to them. This article looks at the standard reasons for commonly occurring defects in textiles by employing an SEM analysis. Playing an analytical role, SEM is a tool that allows one to obtain an image that is of a fully enlarged surface of the material. The analysis describes the diagnosis of some microstructural abnormalities such as fiber breakage, contamination of the surface, and irregularities in the spinning and weaving of different textile samples. SEM helps to understand the physical and chemical environments leading to these defects by facilitating the study of these deformities at the micro and nano scales. The investigation performs a defect root cause analysis where the link is made between the defect and a process of manufacture, the quality of raw materials used, or the state of the environment. This article demonstrates how textile manufacturers can use SEM textile defect diagnosis to make improvement recommendations that are actionable to enhance production and reduce the incidence of defects in the future.

Keywords

Root cause analysis of textile defects; Scanning Electron Microscopy

Citation

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1.0 Introduction:

Among the largest and most intricate manufacturing industries in the world is the global textile industry, which has applications in apparel, medical, automotive, and even aerospace textiles [1]. With the increasing popularity of high-end and defectless textiles, maintaining the mass production process has become crucial. Textile defects, which can take place because of a great number of factors, lower not only the mechanical, aesthetic, and functional capabilities of the products but also bring about consumer dissatisfaction, economic loss as well as loss of credibility to the producers [2]. Hence, textile defect analysis becomes one of the essential aspects of quality assurance. Many approaches have been used through the years to detect and minimize textile defects including conventional inspection methods and more sophisticated tools [3].

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1.1 Textile Defects and Their Classification

Textile defects can be divided into structural defects, surface defects, and chemical defects. These defects can occur at different points such as in the production of the fiber, its spinning, weaving, dyeing, finishing, etc. [4].

(i) Structural Defects: These are comprised of fracture of the fiber or the filament, irregular twists of the yarn, and weaving imperfections like the breaking of the warps and wefts. This implies that structural defects are mostly due to mechanical stress factors during the different stages of production, including tension during spinning, weaving, or chemical processes.

(ii) Surface Defects: Pilling, fuzzing, and foreign matter rise to the surface during manufacture or post-manufacturing processes, or due to finishing processes that are incorrectly applied, all of which are referred to as surface defects. Apart from this, they are also associated with low surface tension in synthetic fibers or poor heat setting.

(iii) Chemical Defects: These consist of bad dyeing, chemical leaching leading to fading of fibers, and synthetic textile polymerization defects. It is interesting to indicate that chemical defects are severe in blended textiles where two or three types of fibers are seldom capable of consistent chemical synthesis, leading to wide variation.

1.2 The Significance of Root Cause Analysis in Textiles

Defects may develop at any of the stages in the production process such as fiber, spinning, weaving, dyeing, and finishing and hence it becomes very important to detect them and take corrective actions. So, Root Cause Analysis (RCA) is the systematic process of investigating the reasons behind defects or failures in a given system. In the case of textiles, RCA helps to determine if the materials used were substandard, if the processes were too harsh, or if the defects are caused by outside conditions which we will call the environment. When defects and failures are eliminated through the understanding of the causes of the defects, targeted solutions are provided and hence efficiency increases and wastage is decreased [5].

1.3 Traditional Methods for Defect Detection

Within the field of textile engineering, the characterization of basic sources of defects has traditionally been undertaken through methods such as visual inspection (optical microscopy) and mechanical evaluation.

(i) Optical Microscopy: Optical microscopy is the best-known class of methods for the examination of textile fibers and the evaluation of surface defects. However, such resolution limits, especially at higher magnifications, prevent it from finding finer structural details such as micro-cracks or nano-scale contamination. The technique cannot show defects under that diffraction limit of the light used, approximately 200 nm on average in most optical microscopes.

(ii) Mechanical Testing: Tensile testing and abrasion resistance tests probably are the most common analyses that are used for checking the mechanical properties of fibers. The above tests can indirectly suggest some defects by way of strength and durability evaluation, but they do not give direct visual evidence of the defects themselves. Purely relying on mechanical testing is meager enough to pinpoint or identify precisely the sources of defects and makes source determination quite elusive.

1.4 Limitations of Traditional Methods for Defect Detection

While these techniques are highly sensitive to large defects, they do not have any resolution level for the detection of micro-scale defects. This is why many scientists established the limitations of traditional techniques. They often fail to deliver the required level of resolution and analytical complexity necessary to identify the causes of defects at a microstructural level. For example, this limitation is severely critical in the cases of detecting anomalies at small scales, like micro-cracks, fiber dislocations, surface contamination, and poor bonding of fibre-matrix of composite textiles [3].

1.5 Introduction of Scanning Electron Microscopy Techniques

Advanced microscopy techniques have been developed to bridge the lacuna regarding traditional approaches to textile defect evaluation. The most outstanding tool mainly because it generates micrographs of the surface and the structures of textiles at unprecedented resolutions, is SEM. SEM has various advantages compared to optical microscopy among which include magnification and depth of field. The SEM relies on a focused beam of electrons to offer high-resolution images of the textile surfaces and cross-sections that expose defects invisible to the naked eye. A review has established the utility of SEM in analyzing the microstructural defects of both woven and nonwoven fabrics; fractures along a fiber; surface contamination and areas of incomplete bonding between fibers [6]. Unlike optical microscopy, which has disadvantages including light diffraction and lesser resolution, SEM uses a focused beam of electrons that interact with the surface of a material to produce secondary and backscattered electrons that may reveal the detailed topography and composition of the surface. This would consequently increase the applicability of scanning electron microscopy, particularly because it can function in more than one modality- namely, secondary electron, backscattered electron, and X-ray microanalysis. This makes it possible to gather data on both the surface morphology and chemical composition, essential for identifying root causes of defects. Moreover, SEM enables the morphological observation of textile fibers and surfaces at magnifications ranging from hundreds to hundreds of thousands; therefore, it becomes possible to visually observe such defect structures on a micro and nano level [7]. High magnification makes possible the study of sub-micron features, such as fiber fractures, voids, and contamination that are not easily visible by optical microscopy or even by visual inspection. Hence, SEM has very widely been used in the textile industry over the last decade due to its excellent ability to provide high-resolution images of both surfaces and cross-sections of textiles. Identification and defect analysis through microscopic observation are fast becoming an extremely valuable tool in SEM analysis. Analysis of such defects facilitates diagnosis of the defect and tracing back of the defect to certain stages of the manufacturing process. For example, fiber breakage might be associated with insufficient spinning tension whereas contamination could relate to low environmental controls of the processing course. Thus, the basic focus in this regard would be on the usage of SEM for extensive root-cause analysis of defects in textile samples.

Therefore, the main goals of this article are (i) General defects encountered and documented with different textile materials using SEM imaging techniques. (ii) Fundamentals of defects: correlation of SEM results with manufacturing parameters, material characteristics, and environmental variables. (iii) Suggestions to processing techniques with possible enhancements and corrective actions found from fundamental causes established by SEM examination. By doing so, the outcomes of this analysis will provide manufacturers in the textile industry with actionable

knowledge, which helps reduce defects, increases the efficiency of production processes, and generates higher quality textiles.

In simpler words, placing more emphasis on the root cause analysis of defects would provide practical advice to the textile industry that would help manufacturers solve their problems at the source rather than relying on rectification actions after production. The results will contribute to existing knowledge in the domain of textile defect analysis, showing just how essential SEM can be in identifying those micro-structural defects that the more conventional methodologies often miss. The inclusion of SEM in routine quality control may imply massive improvements in the quality of products entering the market, defect reduction, and observation of industry standards.

1.6 Limitations of SEM in Textile Analysis

Though scanning electron microscopy is useful as a characterization technique to inspect textile defects, there are limitations. An important limitation relates to the lack of preparation of samples in many cases when a thin conductive coating, like gold or platinum, needs to be deposited on non-conductive textile materials to prevent charging effects resulting from the exposure of the electron beam. The problem is, in some cases, this affects the surface properties of the textile; therefore, the defects cannot be observed in their natural form. Moreover, SEM is a surface-sensitive technique and sometimes may not provide a piece of information related to internal defects unless cross-section imaging is performed. However, this gap would be bridged by bringing together SEM with the utilization of secondary techniques such as TEM and AFM because most restraints would be overcome as a much better examination of defects in textiles would be conducted.

2. Methodology

The method describes a procedure to detect and classify the defects associated with the application of Scanning Electron Microscopy on textiles. It encompasses the following: selection of samples, sample preparation, imaging by SEM, classification of defect types, and root cause analysis. The main idea is to utilize SEM for the proper observation and defect diagnosis at the microscopic level and to develop the source of defects during manufacturing.

2.1 Sample Selection

In this regard, the first one was a sample selection of textiles that corresponded to certain manufacturing techniques and kinds of fibers. The choices were made so that both normal and defective portions would be included in the selection process. This was to enable a comprehensive examination of the possible defects existing in the textile industry.

2.2 Sample Preparation

Textile samples are carefully prepared for SEM analysis to ensure accurate imaging and minimize the introduction of artifacts during preparation.

- Cleaning: In some instances, the specimen requires cleaning following compressed air in a manner of attempting to remove the loosely bonded particles and debris. Where surface contamination exists, by way of oils or chemical residues, cleaning using solvents like ethanol or acetone is used followed by air drying in desiccators or ambient air. There is a need to avoid contamination while viewing in the SEM.

- Cutting: Cross-sections by microtome or sharp blade for fibers, yarns, woven, nonwoven, and composite textiles. This proved useful in preparing the samples for SEM study on characteristics of internal structure and surface texture.

- Mounting: Prepared samples are mounted on SEM stubs using carbon adhesive tape. Carbon tape has the advantage of reducing charging effects in non-conductive material and ensuring that the stability of the sample is met during imaging.

- Coating: For SEM, some specific conditions are required, especially for non-conductive materials, such as textiles that require special procedures for coating and mounting. In such a case, the non-conductive textiles undergo a thin layer of a conductive material, such as gold or platinum, to prevent the charging effects due to exposure to an electron beam. A sputter coater is used for this purpose. The coating is carried out at low pressure (~10 mTorr) with a gold/palladium target. The deposition time ranged between 30 and 90 seconds to obtain a deposition thickness of about 10 nm, thereby preserving the native surface properties of the textile while avoiding electron charging.

2.3 Scanning Electron Microscopy Process

The study utilizes a high-resolution scanning electron microscope with a magnification range of 15 to 300,000 times. For analysis of defects in BTRA, the used equipment is the JEOL JSM IT 200 LV of Japan SEM which is equipped with EDAX (USA) EDX detector as they offer good resolution sensitivity and appropriateness for defective samples. Typically, an accelerating voltage of 5 to 10 kV is sufficient to provide maximum resolution without damaging the fibers. The applied voltage is less in surface images and higher for deeper penetration in composite materials. The vacuum is excellent with a high level without admitting moisture and oxygen, which are highly devastating. Several imaging modes are applied to produce sufficient information concerning surface morphology and micro-structural flaws.

- Secondary Electron (SE) Imaging: Used to capture high-resolution surface details, ideal for identifying defects like surface contamination, pilling, and fiber roughness.

- Backscattered Electron (BSE) Imaging: Employed to analyze the composition of the textile materials, especially useful for detecting defects caused by chemical inconsistencies or impurities within composite fibers.

- Energy Dispersive X-ray Spectroscopy (EDS): This technique is coupled with SEM to identify elemental composition and locate chemical defects or contaminants. EDS is critical in analyzing defects caused by chemical residues or additives used during textile processing.

2.4 Imaging Procedure

- Magnification Range: Initial low-magnification (50x to 100x) images are taken to provide an overview of the textile structure. These are followed by higher magnification images for detailed defect analysis.

- Imaging Angle: Tilted views (45° to 70°) are used to capture three-dimensional aspects of the defects, particularly for fibers showing fracture or delaminating.

- Sample Size: Each textile sample is imaged at multiple locations to ensure representative results, especially for heterogeneous materials like composites.

3. Defect Classification and Analysis

The defects observed through SEM are classified based on their morphology, location, and probable causes. This classification helped in systematically identifying the root causes of defects and drawing correlations with specific manufacturing stages.

3.1 Qualitative Analysis

Defects are categorized into the following types based on SEM observations:

- Fiber Breakage/Fracture: A very clear-cut break, but sometimes with a thinning of the fiber on one side to suggest excessive mechanical stress in spinning, weaving, or chemical processing. It occurs in natural and synthetic fibers.

- Surface Contamination: Found to appear as rough layers on the surface or agglomerated particle deposits, contamination arises from either the finishing or dyeing stage. EDS has been applied to detect the chemical composition of the contaminants.

- Pilling and Fuzzing: Common in fabrics like wool and polyester, these surface defects are identified by the formation of small balls of fibers on the surface, often attributed to friction during wear or mechanical processing.

- Delamination and Debonding in Composites: It seemed in composite textiles where poor bonding between the fiber and the matrix resulted in real gaps or fiber pullout. Such defects are typically associated with inadequate resin penetration during composite processing.

3.2 Quantitative Analysis

- Defect Density: Based on the defects per unit area of the textile specimen, for example, defects/mm², defects were calculated. These have been used to assess defects and estimate defect rates in different materials and under varying processing conditions.

- Crack Length and Width Measurement: The length and width of cracks in fractures are measured depending on in-build or external image analysis software, including ImageJ. The scale of fiber fractures is measured. It correlated measurements of crack size with the mechanical stress parameters of the manufacturing process.

4. Root Cause Analysis Framework

Once the defects are identified and classified, a root cause analysis framework is employed to trace each defect back to its origin in the manufacturing process.

4.1 Root Cause Hypotheses:

Based on the critical SEM observations, combined with the classification of defects, the following have been developed as hypotheses for the root causes of these defects: (i) Fiber Fracture: This is generally caused by an over-tension and uneven mechanical stress while spinning, weaving or chemical processing. (ii) Surface Contamination: It may be associated with the handling or exposure at pre and post-processing stages of finishing or packaging. (iii) Composite Delamination: This is caused by poor resin penetration and improper curing during fabrication of composites.

4.2 Process Data Correlation:

All the correlations done on manufacturing process data, including spinning tension, heat treatment temperatures, and chemical additives applied during the dyeing stage, matched defects that were found. Research proved a hypothesis of the root cause and identified various stages where potential improvements may be brought to the manufacturing processes.

4.3 Failure Mode and Effect Analysis (FMEA):

FMEA is used to prioritize the defects based on their severity, occurrence frequency, and detectability. This analysis provides a systematic approach for recommending preventive actions to minimize future defects.

5. Applications of SEM in Textile Defect Analysis

This section includes general conclusions from a few studies based on the analysis of SEM of textile defects using failure mode analysis. The result is categorized very systematically regarding the kind of defects identified in the test sample such as fracture in fibers, surface contamination, delamination of composite, and many more in the structure. Discussions of all these kinds of defects are based on their morphology using SEM, the number of defects occurring, and possible causes in the textile production process. Based on this, various previous studies used SEM for testing defects in textiles with a wide range of materials from natural fibers such as to natural materials like cotton and wool to synthetic polymers such as polyester and nylon. The following subsections will review some of the important studies that

applied SEM to analyze defects and provide insight into their underlying causes as well as possible mitigation.

5.1 Fiber Fractures and Breaks

Among the common defects in fiber materials, fiber breaks are relatively predominant, especially in high-performance fibers, as it is more prone to mechanical stress. A lot of work was performed with the aid of SEM for the investigation of the microstructure of broken fibers and the failure mechanism. For example, tensile fracture in polyester fibers was demonstrated using SEM studies that fractures were initiated from the irregular crystallization of fibers during spinning [8]. Like this, SEM imaging also found that natural fibers like cotton mostly undergo overstretching while spinning, thinning, and breakage of the fibers [9].

5.1.1 Natural Fibers (Cotton and Wool)

SEM imaging of cotton and wool fibers revealed several instances of fiber breakage, with the fractures characterized by sharp, irregular edges. The following observations were made:

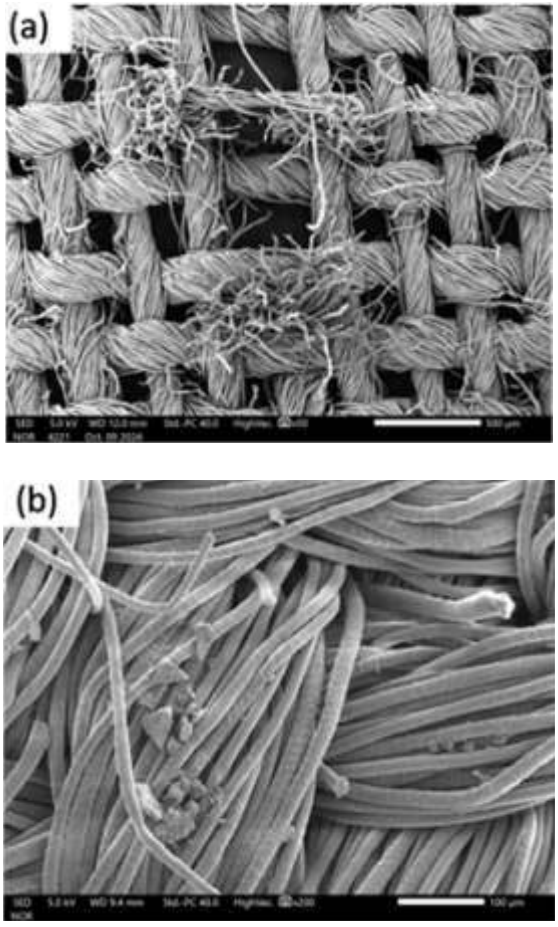

Fig. 1 SEM images of (a) Cotton showing stretched breaking and necking and (b) Wool fibers showing brittle breaking

- Cotton Fibers: The fractures occurred primarily at weak points in the fiber architecture and especially where fibers had been overstretched in spinning. The fractures of all these fibers have a "necking" effect, which indicates high tensile stress. Broken fibers had rough surfaces, indicating a ductile fracture or localized chemical degradation.

- Wool Fibers: Fractures are rougher in wool samples and indicate the breakdown of fibers through splitting at breaking sites. Furthermore, the wool fibers have been evidenced of degradation as their fraying and thinning near breaking points are found. In wool samples, fractures occur with higher concentrations.

Root Cause: The main cause of fiber fractures for both natural fibers was established to be overstressing mechanically, owing to spinning itself. Firstly, twists and tension imparted to fibers in the process of spinning probably happened beyond tensile strength and broke fibers. Further on, at the weaving, the fault in control of tension continued piling up local stresses. The fibers derived from cotton and wool exhibited fractures characterized by brittleness, which are suggestive of mechanical overstress, a phenomenon typically associated with inadequate tension regulation throughout the spinning procedure. The cotton fibers manifested "necking" at their fracture locations, indicating that the applied tensile forces surpassed the fibers' ultimate tensile strength. This observation agrees with the findings since they pointed out that too high twist insertion during spinning may cause fibers to experience concentrated stress at certain points, thus breaking them down prematurely [10].

Mitigation Strategies: To minimize fiber fractures in natural textiles, careful optimization of the spinning parameters, such as reducing twists and controlling tension, is essential. Additionally, the introduction of intermediate relaxation treatments during the yarn formation process could help reduce internal stresses in the fibers. This approach could also be beneficial in reducing long-term fiber damage during weaving and finishing. Proper chemical handling also leads to the elimination of localized fiber damage.

5.1.2 Synthetic Fibers (Polyester and Nylon)

SEM analysis of synthetic fibers such as polyester and nylon provided insight into the different fracture mechanisms:

- Polyester Fibers: The polyester fibers showed brittle fractures with clean, straight breakage points. Some of the fibers had voids and micro-cracks near the breakage points which indicate the existence of internal defects at the time of polymer extrusion, which weakened the fibers.

- Nylon Fibers: The nylon fibers appeared more ductile by fracture characteristics; fracture points looked pulled out and stretched. Moreover, some of the nylon fibers also showed signs of thermal degradation: some had melted and thinned along the fracture boundaries of the fibers indicating high-temperature exposure during the processing or finishing operations.

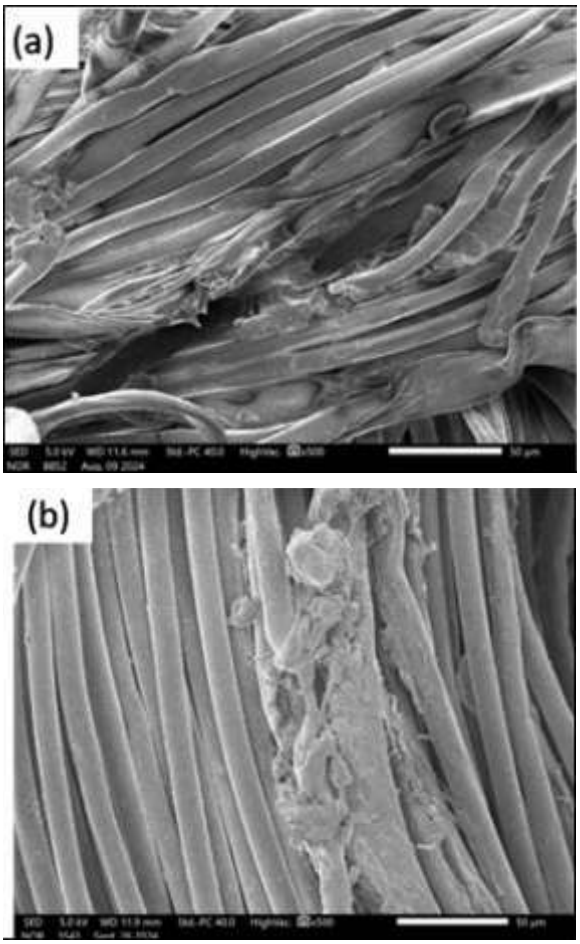

Fig. 2 SEM images of (a) Polyester and (b) Nylon fibers showing breakage and thermal damage respectively.

Root Cause: In contrast to natural fibers, synthetic fibers like polyester and nylon exhibit distinct fracture behaviors that reflect issues in polymer processing. Fiber fractures in synthetic materials are primarily linked to polymer processing defects, such as improper extrusion conditions and insufficient control of fiber cooling rates during the drawing process. High temperatures during manufacturing or finishing could also contribute to the thermal degradation observed in nylon fibers. Polyester fibers, for instance, showed brittle fractures with signs of microvoid formation, which indicates poor molecular orientation during the drawing process. It is also shown that improper drawing temperatures or excessive drawing speeds can lead to uneven molecular chain alignment, resulting in weaker fibers prone to brittle failure. Nylon, on the other hand, demonstrated more ductile fracture characteristics, with signs of thermal degradation, such as melted or thinned sections near the fracture points. This suggests that the fiber is exposed to high temperatures either during polymer extrusion or finishing, weakening the polymer chains. Mitigation Strategies: For synthetic fibers, optimizing the polymer extrusion and drawing process is critical. Ensuring consistent drawing temperatures and controlling the rate of fiber stretching can improve the molecular orientation of the fibers, resulting in improved tensile strength. For nylon, implementing lower temperature limits during finishing could help prevent thermal degradation, especially in performance textiles where strength and durability are critical.

5.2 Surface Contamination and Impurities

Contamination on textile surfaces, such as dust, oils, or residues from processing chemicals, can significantly impact the appearance and performance of fabrics. SEM has proven useful in identifying these contaminants and tracing their origin. A study demonstrated the use of SEM in detecting silicone-based deposition on the surface of polyester [11]. SEM's ability to provide elemental composition data through Energy-Dispersive X-ray Spectroscopy (EDS) further enhances its capability to identify the chemical nature of contaminants, by SEM-EDS to detect the presence of metallic impurities in technical textiles. EDS analysis identified these particles as silicone-based residues, likely originating from the finishing agents used during the fabric treatment process.

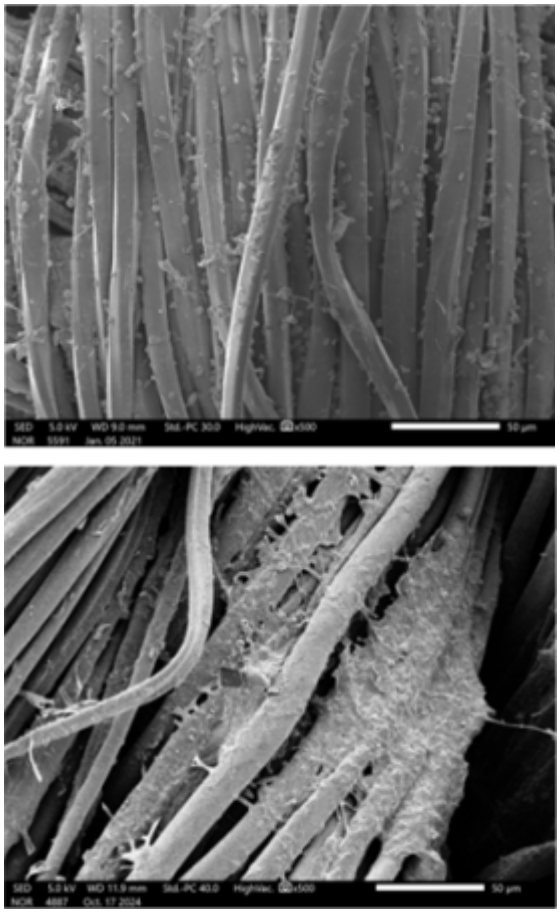

Fig. 3 SEM images of Polyester fibers showing surface contamination and impurities.

Root Cause: Surface contamination was traced back to the post-processing stages of textile manufacturing, specifically during finishing and handling. The silicone residues in polyester fabrics likely resulted from improper rinsing during the finishing process.

Mitigation Strategies: To reduce surface contamination,

especially silicone residues, it is essential to optimize the rinsing process during finishing. Increasing the duration and thoroughness of rinsing can help remove excess finishing agents. Additionally, using alternative, more easily removable agents may further reduce the likelihood of contamination.

5.3 Pilling and Fuzzing: Effects on Textile Wear and Performance

Pilling and fuzzing, the most apparent and damaging defects in textiles to be used as apparel or upholstery are generally found in wool and polyester fabrics [12]. They degrade the appearance and surface smoothness of fabrics and end up resulting in consumer dissatisfaction.

Cotton Fabrics: Pilling is due to the entrapment of free fiber ends at the surface of the fabric. Pills can be sized and it has been noticed that the number of pills differs highly with the density and lengths of fibers. In particular, in the case of cotton fabrics, pilling is distinctly present because of the intertwining of loose fibers existing at the surface. SEM images of the pills revealed that the pills contain an assemblage of short fibers, thus marking the failure mode that leads to the generation of defects under mechanical abrasion during wear.

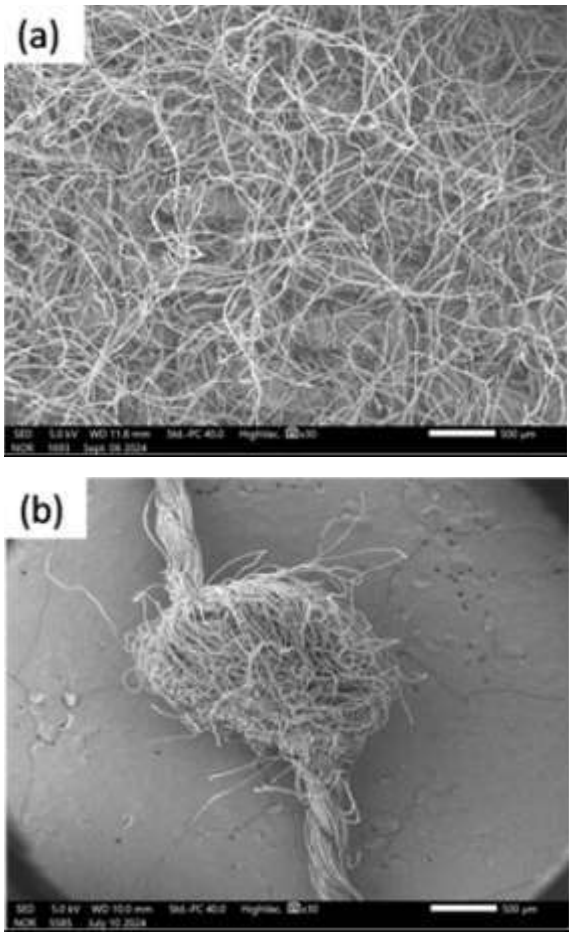

Fig. 4 SEM images of cotton showing (a) fuzzing on the surface of the fabric and (b) pill attached to the surface of the yarn

Root Cause: Pilling and fuzzing were primarily attributed to mechanical abrasion during use or processing. For cotton, the entanglement of fibers resulted from insufficient fiber cohesion during spinning.

Mitigation Strategies: Reducing the tendency of cotton fabrics to pill can be achieved by controlling fiber length and reducing the presence of short fibers during the spinning process. Additionally, chemical treatments that reduce fiber friction, such as enzyme treatments or the application of anti-pilling agents, could be applied to enhance the fabric's resistance to pilling.

Polyester Fabrics: Both pilling and fuzzing were demonstrated by polyester, and characterized by fine fibrils detaching from the main fibers to form small, round pills. The SEM images on polyester exhibit fine fibrils detaching from the main fibers. One of the primary reasons for pills formed upon the surface of polyesters was friction caused by wear or during washing. Polyester falls into the category of possessing a smooth surface with low friction making it even more susceptible to fibril formation.

Root Cause: In polyester fabrics, the low surface friction and elasticity of synthetic fibers made them particularly susceptible to pilling.

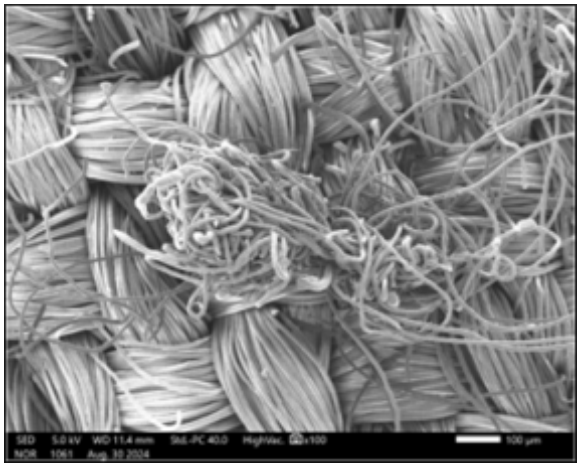

Fig. 5 SEM images of Polyester fibers showing pilling on the surface of the fabric.

Mitigation Strategies: In polyester, both pilling and fuzzing are decreased when the fibers undergo alterations to their surface properties by either a hot setting or an anti-pilling finish. Both treatments raise the possibility that fibrils may form because they increase surface friction and cohesion between the single fibers.

5.4 Defects in Composite Textiles: Delamination and Fiber-Matrix Debonding

For instance, in aerospace and medical applications the bonding at the interface between the fiber and the matrix is critical in maintaining the mechanical performance of the composite textile. Anomalies at the interface related to bonding can cause delamination or pullout of the fibers, those elements that compromise the integrity of the structure.

SEM has been considered as a method to observe bonding defects and their impact on performance. For example, SEM studied delamination in fiber-reinforced polymer composites and thus proved that the defects originated due to an improper resin filling at the production of fiber bundles [13].

Delamination in FR composites was one of the most significant defects observed using SEM. The following features were noted:

- Cross-Sectional Imaging: SEM cross-sections of the composite revealed clear gaps between the polyester fibers and the polymer matrix, indicating poor bonding between the fibers and matrix.
- Fiber Pull-Out: In some areas, polyester fibers were observed to have completely separated from the matrix, with SEM images showing individual fibers protruding from the surface.

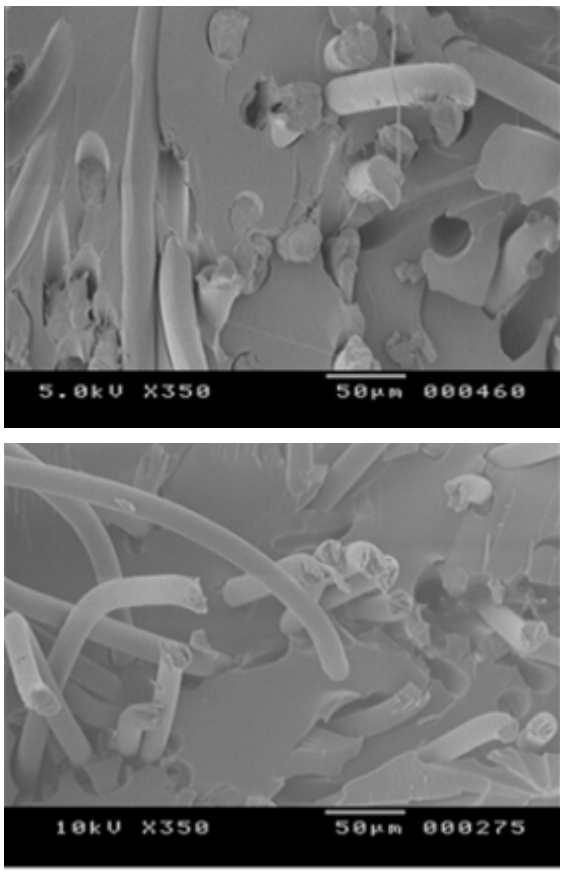

Fig. 6 SEM images of Polyester fibers reinforced epoxy matrix composite showing delamination and fiber-matrix debonding

Root Cause: The following are the reasons for FRC specimen delamination: poor infiltration of resin in making composite, poor curing conditions, and uneven distribution of fibers. Poor application of heat during the curing process may have left the resin cross-linked incompletely. Stress concentrations caused by fiber misalignment weakened the adhesive fiber-matrix interface. Polyester fibers have badly been wetted by the polymer matrix, which has resulted in poor fiber-matrix adhesion; hence, delamination and further fiber pullouts are caused when subjected to load.

Mitigation Strategies: There should also be a resin infusion process that would prevent delamination. Optimum pressure and vacuum conditions can obtain the proper wetting of fibers by the matrix such that the creation of voids may be minimized. Coupling agents or surface treatment of carbon fibers can increase adhesion between the matrix and fibers such that it may reduce delamination. If the fiber alignment in the lay-up procedure is correct, then fiber-matrix debonding can prevent delamination. This can be achieved by using pre-impregnated fibers or through automated fiber placement techniques to minimize the likelihood of misalignment. Optimizing the curing temperature and time also ensures the attainment of full curing of the matrix and a strong bonding with the fibers.

6. Conclusions

The defects in textiles are discussed based on SEM-based root cause analysis, which reveals the mechanisms of various types of defects such as fiber fracture, surface contamination, Pilling and fuzzing, and composite delamination. Knowing the causes might be of benefit to the manufacturer by directed improvement in their processes that should lead to better performance and durability of the textiles. Very helpful to explore the roots of these defects, and analysis findings support suggestions to prevent the same possible faults in the improvements of the process. Analysis, therefore, in its most extensive sense opens up the prospect that SEM can function as a powerful tool in analysis and defect remediation in the textile industry to pave the way for better quality overall quality, durability, performance, and efficient production of textiles can be developed most.

Competing interests

The author(s) declared no potential conflicts of interest concerning this article's authorship, and/ or publication.

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