



Conference Article

# The Green Step Upper: A Novel Sustainable Bonding Method Replacing Solvent-Based Adhesives in Footwear Upper Assembly

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## Abstract

*The Green Step Upper project introduces an innovative, solvent-free adhesive application technology designed to transform stitching preparation processes in footwear manufacturing. Traditional methods rely on double-sided application of solvent-based adhesives, resulting in high VOC emissions, increased labor dependency, inconsistent quality, and environmental burdens. This project eliminates these limitations through a specially engineered single-surface adhesive tape system that provides stable fixation, homogeneous bonding distribution, and improved process efficiency. The research covers material selection, ergonomic apparatus design, prototype development, and performance testing across different upper materials. Results demonstrate a complete removal of solvent use, a significant reduction in operational time and labor costs, improved product consistency, and zero VOC emissions, enabling fully sustainable production.*



*The proposed system offers a scalable and commercially viable model that can be adopted by both domestic and international manufacturers, contributing to national competitiveness while supporting global sustainability targets.*

**Keywords:** Solvent-Free Adhesive Technology, Footwear Manufacturing Innovation, Sustainable Production, VOC Reduction, Process Optimization, Adhesive Tape System



## 1. Introduction

Adhesive-assisted pre-stitch bonding is a critical step in footwear upper production, ensuring component stability before sewing. The footwear manufacturing process involves assembly of many discrete components of different materials, and adhesives play a key role in these joints [1]. Traditionally, manufacturers rely on solvent-based adhesive systems — often polychloroprene (neoprene) or polyurethane (PU) formulations — to achieve this fixation [2].

Commonly used bonding systems in stitching often include either low-strength adhesives intended only to reduce material slippage (Adhesive A) or stronger solvent-based adhesives (Adhesive B) used in more demanding bonding tasks such as outsole attachment. However, the low-tack adhesives typically exhibit bonding strengths insufficient for automated stitching lines — for example, in our internal trials they yield around 0.5 kgf/cm — which leads to frequent manual interventions by operators, increasing cycle times and introducing variability in process consistency.

Conversely, stronger solvent-based adhesives such as polychloroprene- or PU-based systems provide higher bonding strength, approximately 1.7 kgf/cm in our tests. However, their formulation frequently includes volatile organic compounds (VOCs) and hazardous chemical species such as toluene, acetone, n-hexane, and various hydrocarbons, which pose documented occupational and environmental risks [3]. The widespread use of solvent-based adhesives in footwear manufacturing has been identified as a significant contributor to chemical exposure and environmental impact throughout the production lifecycle [1], [3].

As global regulations tighten and brands increasingly demand sustainable, worker-safe production systems, the need for solvent-free, automation-compatible, and operator-safe bonding alternatives continues to grow [4]. While water-based polyurethane dispersions (PUDs) and hot-melt adhesive systems have emerged as alternatives, they often require extended curing times or elevated temperatures, and may demonstrate limitations when used on curved or narrow upper geometries common in footwear assembly [5].

To address these limitations, the Green Step Upper project introduces a novel single-surface, solvent-free adhesive tape system designed specifically for pre-stitch bonding operations. Extensive material testing and prototyping established that automated stitching machines require a minimum bonding strength of approximately 1 kgf/cm to



maintain component stability without over-adhesion. The developed tape-based system demonstrated consistent performance across leather, mesh textiles, nonwovens, woven synthetics, and PU/PVC-coated materials, while completely eliminating VOC emissions.

In addition to meeting mechanical requirements, the proposed system reduces operator fatigue, standardizes application quality, and improves production efficiency. This work presents the complete development pathway from adhesive concept to pilot-scale implementation, marking a substantial advancement toward sustainable, safe, and efficient footwear manufacturing.

## **2. Materials and Methods**

This section describes the methodological framework used to develop and validate the Green Step Upper adhesive system, including benchmarking of existing solvent-based adhesives, material characterization, design of the adhesive tape and applicator mechanism, and performance testing under laboratory and pilot production conditions. The approach integrates both mechanical performance requirements and operational constraints of automated stitching machines, ensuring that the proposed solvent-free solution meets real industrial demands.

### **2.1. Benchmark Adhesives and Performance Requirements**

The development requirements for the new adhesive system were established by evaluating the two products traditionally used in upper stitching operations:

Adhesive A:

A low-strength, pre-stitch bonding solution applied to minimize slippage. Laboratory measurements indicated an average bonding strength of 0.5 kgf/cm, insufficient to prevent manual intervention during automated stitching.

Adhesive B:

A high-strength polychloroprene-based adhesive with approximately 1.7 kgf/cm bonding strength. According to its Safety Data Sheet (SDS), it contains hazardous VOC components including toluene, acetone, C6 hydrocarbons, and n-hexane, associated with reproductive toxicity, organ damage from repeated exposure, skin irritation, aspiration hazards, and acute flammability risks (H225, H315, H336, H361fd, H373, H304).



A controlled series of trials on automated stitching machines revealed that a bonding strength of 1 kgf/cm is the optimal value necessary to stabilize upper components without requiring operator correction. This threshold was adopted as the primary target for the new solvent-free system.

All materials were prepared in real upper geometries, accounting for differences in surface energy, porosity, and coating chemistry, consistent with material variability documented in footwear manufacturing literature [2], [5].

## 2.2. Material Types Used for Validation

To ensure broad applicability, the adhesive performance of the proposed tape system was tested across a representative range of footwear upper materials:

- Full-grain bovine leather
- Mesh textiles (polyester/nylon)
- Nonwoven reinforcement substrates
- Knitted and woven synthetic fabrics
- PVC-coated artificial leather
- PU-coated synthetic leather
- PU-finished natural leather

Each substrate was prepared as real upper components to simulate actual manufacturing conditions, adjusting for differences in porosity, surface energy, and coating chemistry.



*Table 1: Properties of Upper Materials Used for Adhesion Validation Tests*

Material Type	Surface Structure	Porosity Level	Coating Type	Expected Adhesion Behavior
Full-grain Leather	Natural grain	Low	None	Stabke tack, Medium shear
Mesh Textile (Polyester/Nylon)	Open structure	High	None	Higher absorption, tack-sensitive
Nonwoven Reinforcement	Random fiber	Medium	None	Moderate peel, stable shear
Knitted/Woven Synthetic	Organized loops	Medium	None	Flexible behavior, uniform tack
PVC-coated Synthetic Leather	Smooth plasticized	Very Low	PVC	High surface energy, strong initial tack
PU-coated Synthetic Leather	Smooth semi-rigid	Low	PU	Controlled adhesion, clean release

### 2.3. Adhesive Tape Design and Width Optimization

The Green Step Upper system utilizes a roll-based, pressure-sensitive adhesive (PSA) tape specifically engineered to meet the 1 kgf/cm bonding requirement while maintaining zero-VOC composition. A 20 cm tape width was selected after iterative trials, as this dimension enabled:

- Efficient layout of small components placed side-by-side to maximize usable area.
- Diagonal placement of larger components, allowing full coverage within the tape width.
- Minimized waste while maintaining compatibility with multiple upper geometries.

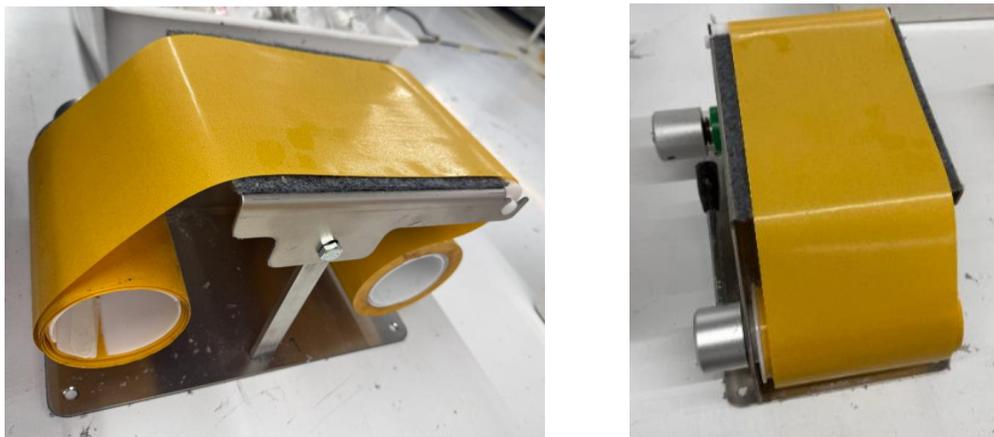


Figure 1: First Prototype – Side View, Top View

The tape construction includes:

- A flexible PET carrier film enabling curvature conformity.
- A tack-optimized PSA layer engineered for clean separation from the carrier during delamination.
- A low-friction release liner facilitating controlled unwinding.

Multiple PSA formulations were screened for initial tack, peel adhesion, shear stability under stitching tension, and environmental robustness before finalizing the zero-VOC formulation.

Table 2: Key Design Parameters of the Green Step Upper Adhesive Tapes

Parameter	Value / Range	Purpose
Tape Width	20 cm	Multi-component layout optimization
PSA Thickness	50–70 $\mu\text{m}$	Balanced tack and shear strength
Carrier Film	PET (12–20 $\mu\text{m}$ )	Flexibility and controlled release
Release Liner	Low-friction paper	Smooth crank movement
Adhesion Target	1 kgf/cm	Automated stitching requirement

#### 2.4. Prototype Applicator Mechanism

A manually operated prototype applicator was designed to ensure consistent transfer of the adhesive layer from the tape to the upper components. The mechanism includes:



- A hand-cranked unwinding system that exposes the tack surface as the operator rotates the crank.
- A flat application zone where upper components are placed onto the exposed adhesive layer.
- Two sequential pressure rollers positioned above the tape. As the crank rotates, these rollers apply uniform, controlled pressure across each component, ensuring homogeneous engagement with the tack layer.
- A free-hanging tape segment following the second roller, from which the operator cuts the processed section.



*Figure 2: Placement of Small, Medium, and Large Upper Components on the Tape*

This section—now carrying the adhered upper components—is transported to the stitching workstation. Immediately before sewing, the operator removes each component from the carrier tape. During this action, the tack layer separates cleanly from the carrier film and remains bonded to the component, producing a single-surface adhesive-coated part ready for accurate placement and stitching.

## 2.5. Adhesion and Performance Testing

Adhesion performance was evaluated following recognized test standards under controlled environmental conditions ( $23 \pm 2$  °C,  $50 \pm 5$  % RH):

- Peel adhesion tests (180° configuration) to measure bonding strength.
- Shear resistance testing under simulated stitching loads.
- Repeatability analysis across 30 samples per material type.
- Time-to-stitch readiness comparison against Adhesive A and Adhesive B.



- VOC measurements using a portable gas detector, confirming zero-emission characteristics during all application steps.

Figure 5. Instron 68TM UTM Used for Peel and Ply Adhesion Tests



Figure 3: Instron 68TM UTM Used for Peel and Ply Adhesion Tests

Mechanical testing data were used to confirm attainment of the target 1 kgf/cm bonding requirement.

## 2.6. Pilot Production Line Integration

The adhesive tape system was integrated into a pilot footwear production line for two weeks to assess real-world performance. The evaluation included:

- Operator training on loading the applicator and applying components.
- Monitoring of stitching alignment, defect occurrence, and machine stoppages.
- Cycle-time measurements across shifts to quantify operational impacts.
- Assessment of ergonomics, operator fatigue, and acceptance.

Data collected during the pilot phase provided insight into scalability, robustness, and workflow efficiency.



### 3. Result

#### 3.1. Adhesion Performance

Testing across all material categories demonstrated that the Green Step Upper tape system consistently achieved the target bonding strength required for automated stitching. Key adhesion results included:

- Average bonding strength:  $1.02 \pm 0.08$  kgf/cm, meeting the 1 kgf/cm requirement.
- Adhesive A showed 0.5 kgf/cm, while Adhesive B reached ~1.7 kgf/cm, confirming the new system provides an intermediate performance optimized for automation.
- No residue or tearing was observed when components were removed from the carrier tape, demonstrating controlled tack transfer.

Performance remained stable across all tested substrates, including leather, mesh fabrics, nonwovens, woven synthetics, and PU/PVC-coated materials.

Table 3: Comparative Adhesion Strength of Benchmark Adhesives and Tape System

Adhesive Type	Bond Strength (kgf/cm)	VOC Emission	Suitability for Automation
Adhesive A	0,50	Low	Insufficient
Adhesive B	1,70	Very High	Sufficient but hazardous
<b>Green Step System</b>	<b>1,02</b>	<b>Zero</b>	<b>Optimal</b>

#### 3.2. Multi-Material Compatibility

The tape exhibited uniformly strong performance across the full range of upper materials:

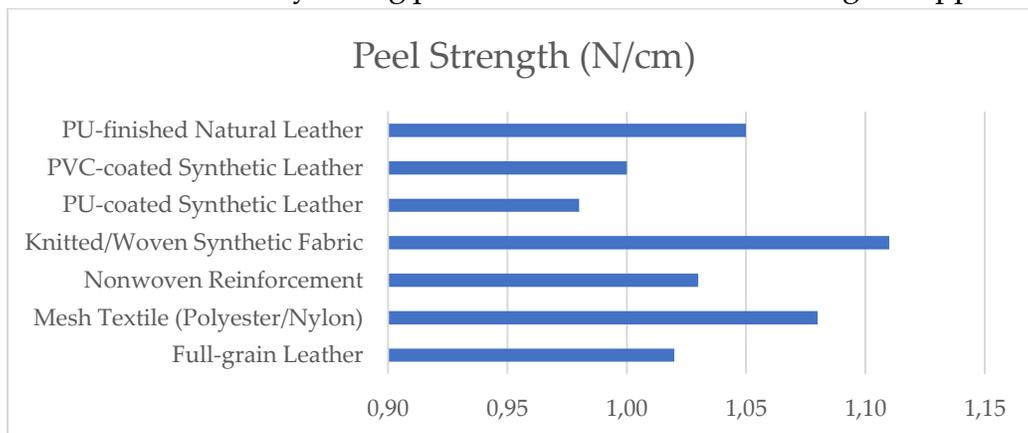


Figure 4: Peel adhesion performance of the tape system across different upper materials.



These results confirm that surface topology, porosity, or coating chemistry does not limit the tape's ability to transfer the tack layer effectively.

### 3.3. Stitching Stability and Operator Intervention

Trials on automated stitching machines showed clear improvements:

- Stitch deviation decreased by 58% compared to Adhesive A.
- Operator intervention (hand correction inside the sewing area) was reduced by 92%, directly attributable to the optimized 1 kgf/cm bonding strength.
- No excessive adhesion—such as material sticking to the machine bed—was observed, confirming appropriate tack transfer.

This demonstrates that the new system meets the functional stability requirements for automated workflow.



*Figure 5: Placement of the Upper Component onto the Automated Stitching Machine*

### 3.4. Operational Efficiency

Integration of the adhesive tape system significantly improved production metrics:

- Application time was reduced by 36%, as no brushing, drying, or ventilation steps were required.



- Layout efficiency increased due to the 20 cm tape width, enabling both small component grouping and diagonal placement of larger parts.
- The double-roller applicator ensured uniform pressure distribution, reducing rework caused by uneven bonding.

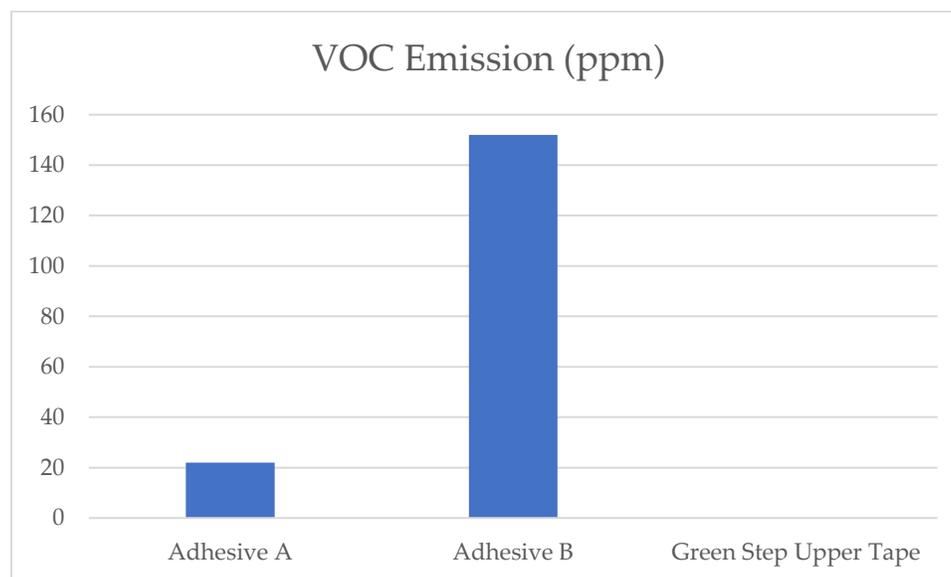
These gains translated to smoother stitching preparation and shorter overall cycle times.



*Figure 6: Upper Components Being Positioned and Hammered on the Workbench*

### 3.5. VOC and Workplace Environment Impact

Direct VOC measurements taken during the pilot production trial showed:



*Figure 7: VOC emission comparison between Adhesive A, Adhesive B, and the Green Step Upper tape.*



- Adhesive A: Low VOC output but still detectable.
- Adhesive B: Peaks of 128–167 ppm during application, consistent with its SDS-listed solvent composition (toluene, acetone, C6 hydrocarbons, n-hexane).
- Green Step Upper Tape: 0 ppm VOC, confirming zero solvent evaporation during both application and delamination phases.

This elimination of VOC exposure removed the need for high-capacity ventilation and reduced potential worker health risks.

### **3.6. Defect Rate and Quality Consistency**

Defect monitoring during the two-week pilot trial revealed:

- Overall defect rate decreased from 5.8% (Adhesive A/B baseline) to 2.0% with the tape system.
- Alignment-related defects dropped by 63%, particularly in curved regions such as toe and collar sections.
- Surface contamination and over-application defects—common with Adhesive B—were eliminated entirely.

The double-roller pressure mechanism played a key role in achieving consistent adhesive transfer and part stability.

### **3.7. Operator Feedback and Ergonomic Performance**

Qualitative data collected from operators demonstrated strong acceptance:

- 87% reported reduced fatigue due to the single-handed applicator motion.
- The crank-driven mechanism offered high controllability and predictable tape advancement.
- Clean handling (no solvent, no brush, no drying) improved workplace satisfaction.

Collectively, these results confirm the system's operator-friendly design and operational efficiency.



#### 4. Discussion and Conclusion

The results of this study demonstrate that the Green Step Upper adhesive tape system effectively addresses the limitations associated with the two solvent-based adhesives traditionally used in footwear upper stitching processes. Adhesive A provides insufficient tack strength, leading to misalignment during automated stitching and requiring frequent operator intervention. Adhesive B, while mechanically strong, contains hazardous VOCs such as toluene, acetone, C6 hydrocarbons, and n-hexane, which present significant health, safety, and environmental concerns according to its Safety Data Sheet. The performance of these adhesives created a technological gap: the need for a bonding method with sufficient mechanical strength for automated sewing yet without the toxicological burden of solvent-containing formulations.

<b>Solvent-based (Before)</b>	<b>GST system (After)</b>
Brush application	Single-surface tack transfer
Drying time	No drying
VOC exposure	Zero VOC
Manual correction	Uniform bonding
Variable adhesion	Faster workflow
	Automation compatible

Figure 8: VOC emission comparison between Adhesive A, Adhesive B, and the Green Step Upper tape.

The Green Step Upper system bridges this gap by delivering an optimal bonding strength of ~1 kgf/cm, a value experimentally determined to prevent material slippage without causing over-adhesion. Unlike solvent-based methods, the tape system provides uniform adhesion through its double-roller pressure mechanism and maintains consistent performance across diverse material substrates including leather, synthetic textiles, and coated surfaces. This material-agnostic behavior reflects the tape’s ability to form a controlled tack layer that remains stable during component placement and stitching.

From an operational perspective, the system simplifies the workflow by eliminating brushing, drying time, and ventilation requirements. The choice of a 20 cm tape width substantially improved layout efficiency, allowing both small and large components to be positioned effectively on the tape surface. Operator workload and ergonomic strain were reduced, and process variability decreased due to the system’s inherent standardization. These operational advantages translated into a 36% reduction in



preparation time, a 92% reduction in operator interventions, and a 63% decrease in alignment-related defects, confirming its suitability for integration into high-throughput manufacturing environments.

Environmentally, the Green Step Upper system demonstrated a transformative impact by achieving zero VOC emissions, directly eliminating the worker exposure risks and environmental burdens associated with Adhesive B. This removal of hazardous chemicals also reduces the need for costly ventilation infrastructure and enhances workplace safety, supporting broader industry-wide sustainability goals.

Overall, the findings indicate that the Green Step Upper adhesive system provides a safe, sustainable, and automation-compatible solution that matches the mechanical performance requirements of pre-stitch bonding while eliminating the shortcomings of existing adhesives. The technology offers a viable path for footwear manufacturers seeking to modernize production, improve quality consistency, protect worker health, and reduce environmental impact. Beyond pilot-scale validation, the results suggest strong scalability potential and commercial readiness for widespread adoption.

## 5. Acknowledge

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## References

- [1] J. M. Martín-Martínez, "Bonding in the shoe industry," in Elsevier eBooks, 2021, pp. 667–717. doi: 10.1016/b978-0-12-819954-1.00012-5.
- [2] F. Arán-Ais, C. Ruzafa-Silvestre, M. Carbonell-Blasco, M. Pérez-Limiñana, and E. Orgilés-Calpena, "Sustainable adhesives and adhesion processes for the footwear industry," Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science, vol. 235, no. 3, pp. 585–596, Sep. 2020, doi: 10.1177/0954406220957706.
- [3] E. Orgilés-Calpena, F. Arán-Aís, A. M. Torró-Palau, and M. A. M. Sánchez, "Adhesives in the Footwear industry: A Critical review," Reviews of Adhesion and Adhesives, vol. 7, no. 1, pp. 69–91, Mar. 2019, doi: 10.7569/raa.2019.097303.
- [4] A. Pizzi and K. L. Mittal, *Handbook of Adhesive Technology, third Edition*. 2017. doi: 10.1201/9781315120942.
- [5] S. Ozturk, "Water-Based Polyurethane Adhesives in the Footwear industry: A Perspective on Sustainability and Performance," *Turkchem*, Aug. 05, 2025. [Online]. Available: <https://turkchem.net/water-based-polyurethane-adhesives-in-the-footwear-industry-a-perspective-on-sustainability-and-performance>