Flock Association of Europe

# 28th INT. FLOCK SYMPOSIUM

11.-12.06.2026, Prague

WE LIKE TO FLOCK IT

2026




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Sustainability and Environmental protection

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Closed-loop Flocks: Collect & recycle

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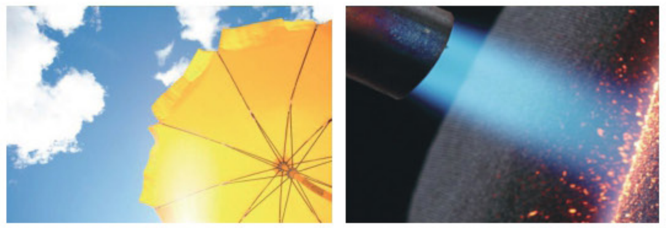

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# Preamble


**Dear Participant,**

the board of the Flock Association and I would like to welcome you to our 28th international Flock Symposium, this time in Prague in Czech Republic.

Our association's symposia are among our most important events. They have been taking place since the 1970s. Every two years, experts from the flock industry meet in person to exchange ideas and learn about new developments in our specialist presentations.

Together with you, we will take the opportunity to take a look into the future of our industry, network, experience new things and learn – because "Flock creates connections".

Our speakers this year are looking forward to informing you about innovations that affect our industry. We have once again deliberately sought out contributions from different areas of the industry in order to present you with a varied and interesting programme.

We are delighted that you are attending our event. Take advantage of the opportunity for personal dialogue and to make new contacts.

Please do not hesitate to contact me if you have any questions about our Flock Symposium or our Flock Association. On behalf of all Flock Association board members, I wish you a successful, enjoyable Symposium 2026 and networking!

Yours Stephanie Wegner

Stephanie Wegner
Flock Association of Europe

# The Association

## ACHIEVING GOALS TOGETHER

The Flock Association of Europe was founded in 1981 in Büdingen (Germany) and sees itself as the central representing of the interests of all companies involved in flock-technology. The elements of the organisation are the members-assembly and the board. Our members and interested parties are supported in questions related to all aspects of flock, its application and use.

## JOIN US...

... to establish FLOCK as a high tech solution in functionality and comfort.
... to establish FLOCK as a premium solution for application.
... to get inspiration from international events.

## MEMBERSHIP

We welcome all who are interested in flock, its uses and applications. More information about flock, and our association, along with a membership form, can be found online at www.faoe.eu.

GET IN TOUCH!



# 1. Controlled Humidity: Enhancing process reliability with state-of-the-art humidification technologies

**Klaus Achenbach**
CONDAIR GMBH

**Lars Knacke**
CONDAIR GMBH

Klaus Achenbach has been with Condair since 2007. He currently serves as Managing Director of Condair Austria and holds the position of President of Condair Poland HVAC. Since 2013, he has been responsible for market development in HVAC across Central Europe. Mr. Achenbach holds a degree (Dipl.-Ing.) in Building Technology from the University of Applied Sciences Trier and completed an MBA in General Management at the International University Erfurt.

Lars Knacke holds a degree in Business Administration and has been the Business Development Manager at Condair since 2000. His responsibilities include export sales and global KAM, focusing in particular on the DRS (direct-room humidification systems) segment. In this area, Mr. Knacke works on developing solutions tailored to the needs of international clients and navigating the specific requirements of the humidification market.

*Precisely regulated humidity is a crucial factor for process reliability and product quality in flock technology. The use of advanced humidification methods enables companies to meet requirements for electrical conductivity and adhesive properties with confidence, while also improving the overall production environment.*

In electrostatic flocking, controlling the ambient air can be just as decisive for the optimised result as the choice of fibre, the applied voltage level or the adhesive system. Flock fibres must be charged, accelerated and deposited into a still-open adhesive film in a precisely upright orientation. This interaction can only be controlled reliably under stable climatic conditions.

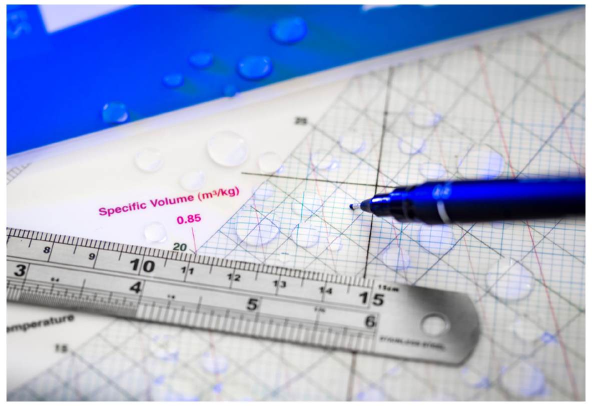


Figure 1
With technical humidification precisely tailored to individual conditions, flocking processes can be reliably standardised.

If humidity is too low, electrostatic overcharging, uncontrolled fibre movement and increased airborne dust are promoted. Fibres repel each other more strongly, distribute less evenly and can lead to visible surface defects. At the same time, air that is too dry accelerates the drying of many adhesives- especially water-based systems - which can impair bonding. If humidity is too high, the electric field becomes less stable, charges dissipate too quickly and the fibres reach the substrate with significantly reduced momentum; the risk of fibre agglomeration also increases. In industrial practice, a range of around 50–60% relative humidity (RH) has proven particularly stable. This range supports reliable electrostatic behaviour, a clean fibre trajectory and reproducible adhesive performance.

## MATERIALS, PROCESSES AND PEOPLE

Controlled humidity not only affects electrostatic properties, but also the behaviour of many materials used in production. Hygroscopic substrates such as textile webs, foams or fibre composites respond immediately to changes in moisture. Without climatic stabilisation, they can change dimensions or mechanical properties. This may cause tension, warping or insufficient flatness, further complicating the flocking process. Dust levels in production areas also drop significantly once humidity is maintained within an optimal range. Fine fibres and particles adhere more readily to one another, remain airborne for a shorter time and settle faster. The production environment stays cleaner, system components are exposed to less contamination, and sensitive surfaces are better protected.

In addition, controlled humidity improves thermal comfort and supports employees' health and performance. Continuous humidity control can increase workplace satisfaction and may help reduce respiratory irritation, the spread of virus-laden aerosols, and adverse effects on eyes, skin and voice. Maintaining a minimum of 40% relative humidity (RH) therefore supports preventive health protection and employee comfort.

For industrial applications, two basic humidification approaches are commonly used: direct room humidification (typically high-pressure nozzle systems, adiabatic) and indirect humidification in the air-handling unit (AHU) / HVAC ductwork (adiabatic or isothermal). Both approaches achieve the same objective, but differ in operating principle, effect, installation requirements and controllability.

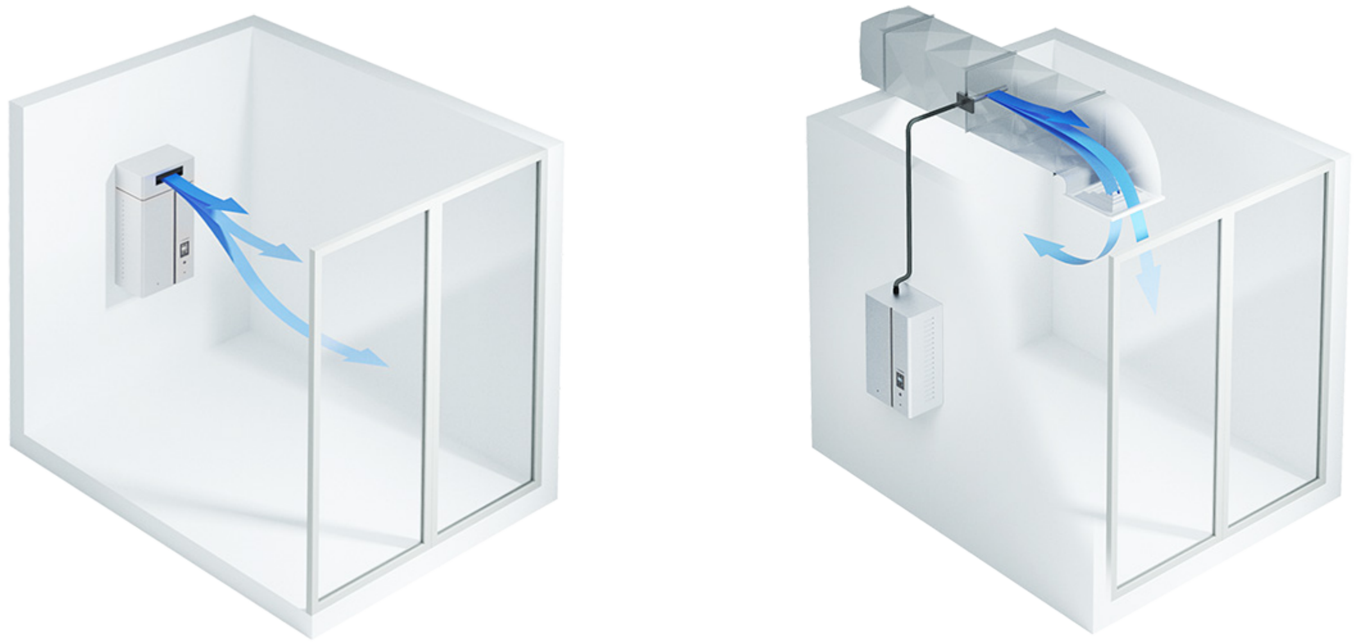


Figure 2
The two basic principles of air humidification: direct humidification in the room (left) and indirect humidification via the ventilation ducts of the air handling unit (AHU).



## DIRECT IN-ROOM HUMIDIFICATION

In many industrial applications, adiabatic in-room humidification is used. With this method, purified, demineralised water is pressurised by high-pressure pumps to up to 70 bar and atomised through precision nozzles into a micro-fine fog. The droplets are so small that they evaporate immediately and are absorbed by the room air. In addition evaporation removes heat from the air and provides a noticeable cooling effect, which is particularly beneficial in production areas with waste heat and high machine density - without requiring additional cooling energy.

A key advantage of this process is its proximity to the process zone. Entire halls, sub-areas or individual production rooms with high electrostatic sensitivity can be conditioned in a targeted manner; different areas within a line can also be operated with individual humidity setpoints. An integrated multi-stage water treatment provides hygienically safe pure water. Because the systems operate decentrally and require only low electrical power, retrofitting in existing production buildings is comparatively straightforward. Where sufficiently sized HVAC ducts are not available, in-room humidification is often a technically and economically practical solution. Control is via sensor-based measurement points that continuously monitor humidity and activate the system only when humidity fall below the defined setpoint.

Figure 3
Example of a in-room humidifier with high-pressure nozzles. The water is atomised into a micro-fine fog at up to 70 bar and is immediately absorbed by the ambient air.

## INDIRECT HUMIDIFICATION IN THE HVAC DUCT

In addition to in-room humidification, many plants use indirect humidification via ventilation and air-conditioning systems (AHUs). With adiabatic humidification in the HVAC duct, water is, for example, atomised through low-pressure nozzles and captured on air-permeable contact media, where it continues to evaporate into the air stream. Because adiabatic humidification also cools the air, the supply air is typically preheated using a heating coil. Energy demand is low; however, sufficient duct length (evaporation distance) is required to ensure complete evaporation and prevent droplet carryover.

Isothermal steam humidification, by contrast, uses heated water (via electricity or gas) to generate steam, which is introduced into the air stream as clean vapour. The air temperature remains almost constant, which is why the process is referred to as isothermal. It is regarded as particularly hygienic and enables precise humidity control. This method is primarily used where high cleanliness requirements apply or where processes depend strongly on a constant temperature.

Figure 4
Example of steam humidification in an AHU. Steam is discharged from steam lances at only a slight overpressure into the air stream to be humidified.

## HUMIDIFICATION FOR FLOCKING

Direct and indirect humidification systems serve different purposes. While humidity generated centrally in the HVAC system typically provides basic conditioning for a whole building, in-room humidification offers targeted, fast-responding control at the process. In production areas or zones with sensitive substrates, immediate humidity control is crucial for consistent quality. The adiabatic operating principle of high-pressure systems also helps compensate for unwanted heat loads (for example, waste heat from machinery). In buildings or production halls with homogeneous use, humidification via the HVAC duct can be advantageous - especially if isothermal steam is preferred for hygienic reasons.

The best solution therefore depends strongly on structural conditions, the energy framework and the sensitivity of the respective production process. In many cases, a combination is beneficial: the AHU provides a stable base humidity, while in-room humidification systems control humidity in critical zones. This enables the overall production environment to be managed reliably and cost-effectively.

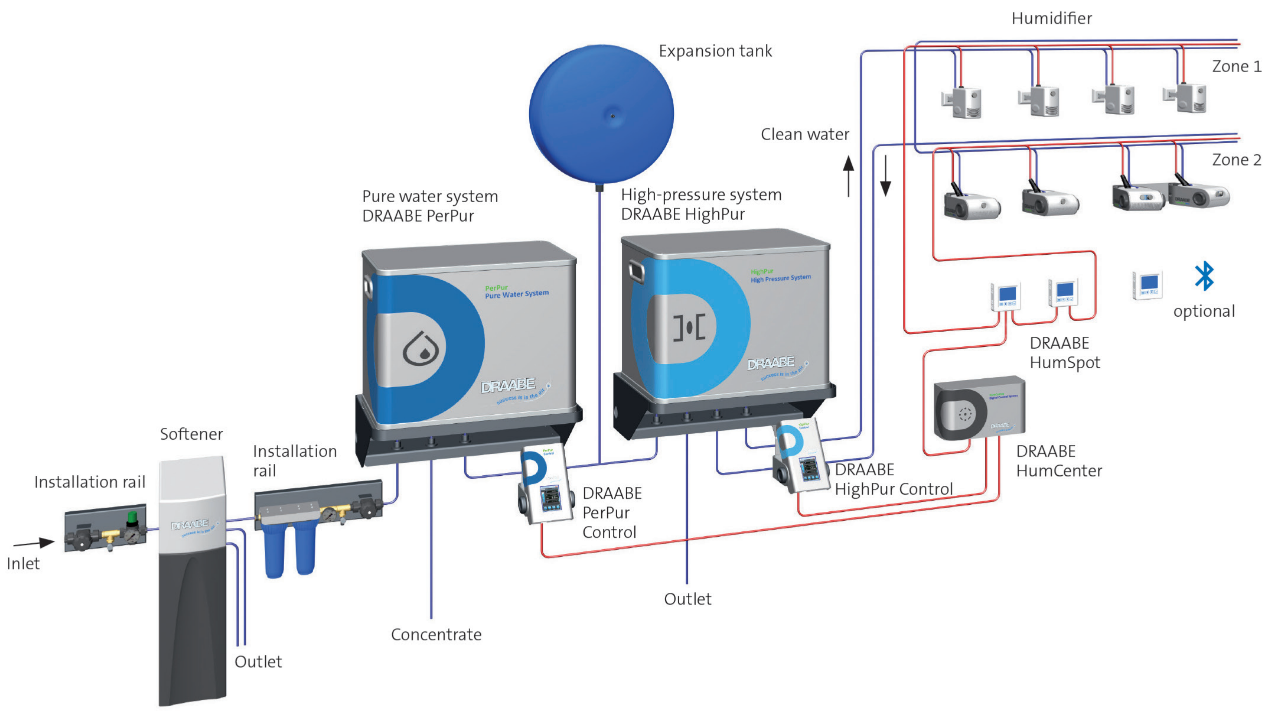



Figure 5
Schematic diagram of a direct in-room humidification system with multi-stage water treatment and individual control of humidification zones.

## DEHUMIDIFICATION SYSTEMS IN THE FLOCKING PROCESS

Just as excessively low humidity can negatively affect the flocking process, excessively high humidity can also have adverse effects. This can be counteracted by using appropriate dehumidification systems. To protect against high humidity levels, various dehumidification systems are available; typically, condensation dehumidifiers based on refrigeration cycles or desiccant (adsorption) dryers are used. The selection of a suitable system depends on the environmental conditions as well as the specific requirements of the process.

In particular, dehumidification systems contribute to uniform fiber distribution and provide a stable environment for the adhesive process. They are therefore an important element in ensuring consistent product quality.



## HUMIDITY CONTROL AS PART OF PROCESS RELIABILITY

The benefits of controlled humidity in flock technology clearly show that humidity is a key factor in quality assurance. Regulated humidity influences the stability of the electrostatic field, the physical integrity of materials and the reproducibility of adhesive bonding. At the same time, it affects dust generation in the production environment as well as employee comfort and health protection.

A professionally designed humidity control system - whether implemented directly in the room, within the HVAC system, or as a combination of both - is therefore an essential component of optimised flocking processes. It contributes to standardisation, higher process reliability and long-term cost-effectiveness, creating the conditions for consistently high product quality.

# NOTES

# 2. Sharing Perspectives for a More Sustainable and Competitive Flock Industry

**Anna María González Salgado**
VELUTEX FLOCK S.A.

Anna María González Salgado is an Industrial Engineer with a specialization in Textile Chemistry and over 20 years of experience in the textile and materials sector.

She currently works as Technical Business Manager at Velutex Flock S.A., where she leads the technical-commercial strategies, drives innovation in sustainable textile solutions, and collaborates with cross-functional teams to deliver client-focused products and services.

Previously, Anna held the position of Product Health & Safety Manager within the Sustainability Department at Oysho (Inditex Group). In this role, she was responsible for ensuring product compliance with international safety and chemical regulations, managing risk assessment processes, and contributing to the development of safer and more sustainable textile products across the supply chain.

Her career has been marked by a strong commitment to sustainability, innovation, and technical excellence in textile applications.

## Abstract

This lecture explores key aspects that can help make the flocking industry more sustainable and competitive in a rapidly evolving textile framework.

The presentation will share practical examples of sustainable developments.

In parallel, the impact of emerging legislations on the flocking industry will be discussed, with a focus on material choices, testing approaches, and regulatory compliance.

Finally, the lecture will examine how sustainability can be effectively measured and communicated within the flock industry.

During the FaOE Symposium held in Barcelona in year 2022, we have already explained the evolution and history of the European Flock Business since 1940's when the first flock patents and the flocking market started to emerge.

This year we would like to focus in the present and possible future of the FLOCKING business seen from the point of view of an European flock supplier. Possible other interpretations or points of view, are also totally valid.

The first thing we would like to share in this symposium is a short SWOT analysis of the flocking market in Europe, considering key applications such as automotive interiors, textiles, packaging, and industrial coatings among others.



### QUICK SWOT ANALYSIS FOR THE EUROPEAN FLOCKING BUSINESS IN YEAR 2026

### Strengths & Opportunities

| | |
|---|---|
| **High value-added manufacturing**<br><br>European producers typically focus on high-performance flock fibers (precision length, color consistency, specialty fibers), giving them an advantage in premium applications such as automotive interiors, luxury textiles, and electronics. | **Advanced textile and material Ecosystem**<br><br>We can still find in Europe the best expertise in technical fibers, adhesives, flocking capabilities and flock developments, with a flexible and fast reaction to the new trends in the market and, enabling innovation in flocking technologies and high-quality flock fibers. |
| **Stable industry demand**<br><br>There is a large automotive manufacturing base, where flock fibers are widely used for different reasons (improve haptics, acoustic and weather insulation, antivibration, etc).<br><br>OEM's emphasize the need for noise reduction and premium interior finishes, increasing demand for flocked surfaces and acoustic materials. Other industrial sectors as packaging, cleaning, cosmetics and medical are also stable demand drivers. | **Strong R&D, Sustainability and Circular Economy Initiatives**<br><br>European regulations and market preferences are pushing the adoption of recycled & biodegradable flocks, materials and challenged applications as low-VOC flocks & adhesives, FR materials, Water repellent flocks among others, driving innovation & eco-friendly flock products as a must.<br><br>Reduction of $CO_2$ footprint, new materials research and Regional Km0 intersectoral initiatives are reenforced leading to emerging Industrial and Technical Applications such as:<br>• filtration materials<br>• electronics insulation<br>• aerospace and defense components |

Some of these high-value technical markets can offer higher margins and differentiation to the European flocking companies related with these new developments.

## QUICK SWOT ANALYSIS FOR THE EUROPEAN FLOCKING BUSINESS IN YEAR 2026

### Weaknesses & Threats

| | |
|---|---|
| **Variable cost exposure**<br><br>In our current worldwide uncertain scenario, European flocking manufacturers face higher labor, energy, and regulatory costs, making production more challenging compared with other regions. It is important the investment in efficient processes and technology to compensate this effect and increase competitiveness. | **Dependency on raw materials and supply chain**<br><br>Few worldwide fiber manufacturers can produce tow monofilament to be used for flocking. Some of these companies in Europe have closed their business since Covid-19 leading to a lack of supply in Europe of some specialty fibers. Raw material price volatility and transport transits can significantly affect production costs and flexibility. There is a risk of supply chain disruptions and raw material shortages for some specialties. |
| **Mature market in traditional segments**<br><br>Some segments as textiles or packaging are mature with limited growth in Europe due to the fact that new designers and decision makers in those sectors either, do not know flocking as technology or they prefer other surface solutions considered easier to apply.<br><br>Many professionals are still unfamiliar with flock, but more importantly, many brands or end consumers, perceive it negatively due to past experiences. Flocking does not enjoy the same level of social perception as other finishing products, laminates, coatings and paintings despite facing similar challenges in terms of cleanliness and application technologies. As we all know, there are different ways to flock, ranging from the simplest manual methods to highly sophisticated production lines that can even be used in cleanroom environments. The key issue lies in selecting the right flocking system or the appropriate applicator based on the specific requirements of each project.<br><br>As a sector, leaded by the European Association of Europe, we should work together to change this perception and increase the awareness of our materials and technologies. | **Stringent European regulations and contracts**<br><br>There are many flocking applications that require for European manufacturers the strictest quality and Product Health & Safety standards, manufacturing high standard regulations as well as suffer long-term supply contracts with low flexibility for price adjustments or new product validation flexibility. |



## QUICK SWOT ANALYSIS FOR THE EUROPEAN FLOCKING BUSINESS IN YEAR 2026

### Weaknesses & Threats

| |
|---|
| **Competition**<br><br>Competition is relatively intense because the flock market is fragmented with specialized flocking manufacturers in different areas and niche applications.<br><br>At the moment, occidental premium suppliers and low-cost Asian producers show an strong competition for leading automotive, textiles and technical applications such as electronics, and cosmetic & medical applications.<br><br>Currently, the highest technical Know-How and expertise to do a premium flocked product remains in Europe although the insistence by the Asian government to priorize local materials in Asia gives an unfair competition to export European flocked products in that region.<br><br>The European flocked market have a capacity for quick adaption to produce new flocked materials with new flocks, adhesives and new implementations with highly knowledgeable professionals in this field.<br><br>As an example, the main Flock producers in Europe have a knowledge of more than 75 years producing flocks with an strong R&D team, their knowledge about materials, finishing, dyeing, adapted formulations is very high compared with other regions which cannot adapt or adjust production or formula to special requirements in such efficient manner. |

## SOME EUROPEAN SUSTAINABILITY POLICIES AFFECTING THE FLOCKING BUSINESS

In recent years, the European Union has been actively developing a range of sustainability policies and regulations that are expected to have a direct impact on the flocking industry in our region. Rather than attempting to cover all of these measures in detail, this presentation aims to provide a general overview of the current landscape and highlight the key points that companies and partners in this market should consider when making future decisions.

At the same time, the broader political and social context is evolving rapidly. Ongoing conflicts, such as the war in Ukraine and tensions in regions including Palestine, Lebanon, and Iran, are significantly affecting global trade, logistics, energy supply, and raw material costs. These dynamics are changing quickly and add a layer of uncertainty to the market.

In addition, policy directions in regions such as the Americas and Asia may not always align with European approaches, potentially influencing future developments and shaping the conclusions drawn in this report. With this in mind, our objective is to provide a snapshot of the European situation as it stands at the beginning of year 2026.

## THE EUROPEAN GREEN DEAL

It is a strategy launched by the European Commission in 2019 to transform the European Union into a climate-neutral economy by 2050. It aims to reduce greenhouse gas emissions, protect the environment and promote sustainable economic growth.

### Key actions include:

- Reducing emissions by at least 55% by 2030 compared to 1990 levels.
- Expanding renewable energy and improving energy efficiency.
- Promoting sustainable transport and cleaner industry.
- Supporting a circular economy that reduces waste and reuses resources.
- Protecting biodiversity, forests and ecosystems.
- Ensuring a just transition, helping regions and workers adapt to the green economy.

The main goal is to fight fast climate change while creating new jobs, innovation and sustainable development in Europe.

**The Circular Economy Action Plan** is a key initiative of the European Green Deal, adopted by the European Commission in 2020 to make the economy of the European Union more sustainable and resource-efficient. It aims to reduce waste and keep products, materials, and resources in use for as long as possible.

### The main objectives are:

- Design products to last longer, making them easier to repair, reuse and recycle.
- Reduce waste generation and improve recycling systems.
- Promote sustainable consumption so consumers can make greener choices.
- Focus on sectors that use many resources, such as electronics, batteries, packaging, plastics, textiles and construction.
- Support innovation and new business models based on reuse, repair, and recycling.

Overall, the plan seeks to move from a linear economy (produce–use–discard) to a circular economy where resources are reused and waste is minimized.

## HOW THE FLOCKING INDUSTRY IS ADAPTING TO THESE CHALLENGES?

Most factories related with the flocking business are already working on reducing emissions by using Green-Energy (installing solar panels, renewal sourced electricity, optimize consumption of gas, etc). External verification of our $CO_2$ footprint and a comprehensive LCA assessment, ideally Cradle to Cradle and encompassing our full supply chain (logistics, fibers, chemicals, etc.), are now increasingly demanded for our existing product ranges, especially when working for Automotive and Textile sectors.

In year 2024, some LCA comparative studies done by an external technological center in Barcelona (Leitat) by request of Velutex Flock showed that polyamide flocks made of European materials have a 35% lower environmental impact than same materials coming from other regions in Asia.

Furthermore, numerous projects and initiatives have been launched by flockers to improve the recyclability of flocking waste generated at flocking facilities, in close cooperation with flock suppliers. According to the same study, to promote reusable flocks can help to reduce up to a 80% the $CO_2$ equiv x kg flock footprint.



In parallel, several efforts are underway to promote the circular economy by developing recycled flocks made from polyester or polyamide fibers from post-consumer and post-industrial waste among others. Flocks made of cellulosic materials both, recycled and biodegradable, are also a key target for different sectors such as packaging and textiles.

In next chart we share a simple comparison of some EU Sustainable policies for plastics, textiles, packaging and automotive, which is useful for introducing the European circular economy policies, and its possible approach to the flocking market.

| Sector | Main EU Sustainable Policy | Main Objectives | Key Measures | Possible impact for Flocking Applications |
|---|---|---|---|---|
| **Textiles** | EU Strategy for Sustainable and Circular Textiles | Make clothing more durable, reusable and recyclable | Separate textile waste collection by 2025, promote recycled fibers, introduce producer responsibility | Strong push toward recycled fibers in flock production; need for traceability and circular design; opportunities for sustainable flock products |
| **Plastics** | European Strategy for Plastics in a Circular Economy and Regulation (EU) 2023/2055 | Reduce plastic pollution and increase recycling | Recyclable plastic packaging by 2030, restrictions on microplastics, reduction of single-use plastics | Potential restrictions on synthetic polymer flocks; need to develop biodegradable or recyclable alternatives; increased compliance and reporting requirements |
| **Packaging** | Packaging and Packaging Waste Directive and Packaging and Packaging Waste Regulation | Reduce packaging waste and increase recycling | Recycling targets (70% by 2030), recyclable packaging design, reuse and refill systems | Pressure to use flocks compatible with recyclable packaging; limitations on multi-material coatings; need for easy separation and recycling |
| **Automotive** | End-of-Life Vehicles Directive | Reduce environmental impact of vehicles and improve recyclability | Minimum 85% reuse/recycling and 95% recovery targets, restrictions on hazardous substances, design for dismantling and recycling | Requirement for flocks compatible with dismantling and recycling processes; preference for mono-material or easily separable systems; restrictions on certain additives and polymers |

## TEXTILE SECTOR PERSPECTIVE

The EU Strategy for Sustainable and Circular Textiles (2022) is part of the Circular Economy Action Plan and the European Green Deal.

### Main objectives:

By 2030, textiles sold in the EU should be durable, repairable, recyclable
- increasingly made from recycled fibers.
- Reduce fast fashion and textile waste.

The EU is also promoting the Extended Producer Responsibility (EPR) systems for the textile sector, where
- clothing producers and brands must take responsibility for the end-of-life management of their products.
- They may have to finance the collection, sorting, and recycling of textile waste.
- The policy encourages companies to design clothes that are easier to recycle.

Most Textile relevant retailers, apart from country legislation, have an specific path with their own sustainability targets for 2030's. For example:
- Inditex (Spain): focuses strongly on material transformation and circular fibers, with a major target of 100% lower-impact fibers by 2030.
- H&M Group (Sweden): one of the most ambitious in circular materials, targeting 50% recycled materials by 2030 and full sustainable sourcing.
- Gap Inc (USA).: emphasizes renewable energy and long-term climate neutrality, with material targets focused mainly on cotton and recycled inputs.

### And the Flocking industry?

As explained during the Symposium of Barcelona in 2022, most of the start of the flocking business in 1940's in Europe was with the aim of giving a second life to waste of wool, cotton short fibers to be used for several applications as wallpapers.

The evolution of the different applications for flock in different fields is well known for the sector, where, by the end of last century most of the flocks used were for technical applications in automotive, industry, textiles and also packaging applications which used mostly virgin fibers to give the most luxury and beneficial technical properties to the flock.

Trend started changing just before 2020's where recycled materials started being seen as a solution and a target in the sales and strategy for big retailers and not like a low-grade material.

The European textile industry has recently recognized that **flocks made from short fibers** can offer a viable solution for the large volumes of post-consumer textile waste that cannot be reused in knitting or nonwoven applications due to their short length. This represents a significant field of opportunity if the European flocking companies are able to promote and validate this type of **recycled flocks for different type of innovative applications**.

A significant portion of global textile waste consists of short fibers generated during mechanical recycling or from end-of-life garments. These fibers are often too short to be reused in spinning, knitting, or conventional nonwoven processes, which severely limits their revalorization pathways. Since flocks are intentionally produced from cut short fibers, the flocking industry is uniquely positioned to integrate recycled fiber fractions that would otherwise be downcycled or disposed of.

This approach not only reduces waste streams but also contributes to measurable $CO_2$ reduction, lower raw material dependency, and improved circularity indicators. Furthermore, it enables OEMs and brand owners to incorporate higher recycled content into their products without compromising technical performance, aesthetics or durability.



### Typical Fiber Composition of European Textile Waste (Estimate %)

| Fiber type | Approximate percentage |
|---|---:|
| Cotton | 50–52% |
| Polyester (PET) | 25–28% |
| Cotton–polyester blends (polycotton) | 10–15% |
| Viscose / regenerated cellulosic fibers | 5–8% |
| Polyamide / nylon | 2–4% |
| Wool | 1–3% |
| Acrylic and other fibers | ~1–3% |

In Catalonia, each person generates approximately 19.8 kg of textile waste per year. Of this amount, only 2.7 kg per person per year (13.6%) is collected separately and can be used for other applications. With comparable data across Europe and a population of about 750 million people, this would translate into more than 2 million tons of material.

In general terms, it is possible to produce recycled flocks with technical properties comparable to those of virgin materials for textiles and other uses. However, certain limitations remain, particularly regarding luster, color brightness, and the available range of thickness and fiber lengths.

Nevertheless, processing recycled materials is more complex than working with virgin fibers. It may require multiple dyeing stages, along with more demanding selection, cutting and sieving processes. As a result, the overall cost of using recycled materials is still not economically beneficial when compared to virgin alternatives, although the environmental benefit is huge.

We have been working with different Technological Centers in Spain (AITEX & Technical Advice) to find possible solutions for these challenges where some interesting products and optimized processes associated to the use of recycled materials have been found. More collaborative research involving end users, applicators, and adhesive manufacturers will be essential to deliver competitive solutions to the market.

In this context, flocking can evolve from being a niche finishing technology to becoming a strategic enabler of circular textile systems. The alignment between recycled short-fiber availability and flock production requirements creates a strong foundation for sustainable growth and innovation.

## PACKAGING SECTOR PERSPECTIVE

This sector is one of the most advanced in terms of recyclability and sustainability initiatives, as it was among the first to implement regulations aimed at eliminating single-use packaging, promoting reuse, encouraging the use of recyclable materials, and prioritizing compostability and biodegradability. This made a big change on the perception of the flocked materials for this sector tending to recyclable mono-product packaging (Example. recycled polyester flock boxes (PET), full cellulosic flocked cardboard etc.) and the use of recycled fibers to many type of applications.

The Packaging and Packaging Waste Directive establishes the main legal framework for packaging management in the EU. Specific actions have been already put in place by most of the countries.

### Key points:

- It sets targets for recycling and recovery of packaging waste.
- By 2030, at least 70% of all packaging waste must be recycled.
- Specific recycling targets exist for different materials such as plastic, paper, glass, aluminum, steel, and wood.
- It aims to reduce the environmental impact of packaging and packaging waste.

Within this field, there are several specific flock applications in packaging for Cosmetics, Medical and other technical devices. which have requirements for this type of materials which are very specific for each sector. For example, in case of cosmetics, apart from complying the Cosmetics Regulation (1223/2009) (Safety and labeling of cosmetic containers) they have to follow the Packaging Waste Directive and the Packaging and Packaging Waste Regulation, which have some goals affecting cosmetic packaging:

- All packaging must be recyclable by 2030.
- Reduce unnecessary packaging and empty space.
- Increase the use of recycled materials, especially in plastics.
- Promote reuse and refill systems, which are particularly relevant for cosmetics.

Apart from those EU Regulations and Directives, normally the cosmetic brands are distributing worldwide and must fulfill the packaging requirements for different countries, for that reason they issue an strict technical requirement cahier that must be compliant for all materials, including is some cases Food Contact Material requirements, Medical Requirements and others. For these sectors, specific flocks, adhesives and processes need to be studied and validated at the beginning of each project and exact reproducibility and quality must be supplied afterwards. In this case the introduction of recycled post-consumer flocks, which cannot warranty 100% the exact reproducibility, makes this sector difficult for a sustainable change on a recycled packaging range. This is why they are currently focusing on post-industrial recycled materials and also work in mono-product and alternative fiber materials.

## PLASTIC PERSPECTIVE AND APPROACH TO MICROPLASTICS REGULATION

In general, packaging & automotive are sectors highly affected by the European Strategy for Plastics:

Its main objectives are:
- All plastic packaging in the EU should be recyclable or reusable by 2030.
- Reduce single-use plastics and restrict the most harmful plastic products.
- Increase plastic recycling rates and improve waste management.
- Encourage innovation in sustainable materials and recycling technologies.
- Reduce microplastics and prevent plastic waste from entering the environment, especially oceans.

Overall, the strategy seeks to move from a linear "use and throw away" plastic model to a circular economy where plastics are reused, recycled, and kept in the economy for as long as possible. Plastic suppliers are already working very intensively to find solutions for Mechanical recycling with a high percentage of recyclability, which is leading to acceptable qualities for most applications but still not obtaining the high-premium performance for critical parts in automotive. The quantities and qualities obtained are not in high scale to achieve the values and percentages targeted by EU in near future.

The sector is working hard to obtain:
- Higher percentage of recyclability with a competitive price (ABS, PP, etc)
- Possibility to recycle plastics with a % of other products in order to achieve bigger quantities without need of a previous separation.

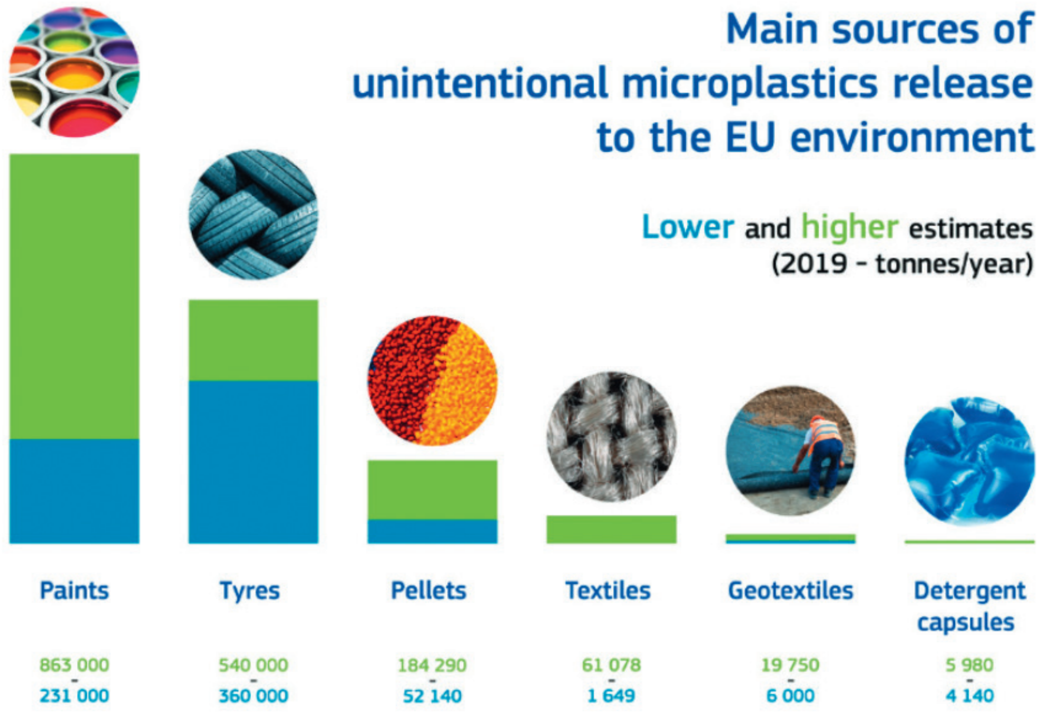
In this field, plastic suppliers are already working on sandwiches of different materials which treatment can be easily separated. They have been found ways to recycle mixed materials (ex. Polypropilen, ABS) with a high percentage of the final plastic with a final product with good performance for automotive. A similar approach could be considered for flocked plastic materials.



### A microplastic regulation approach

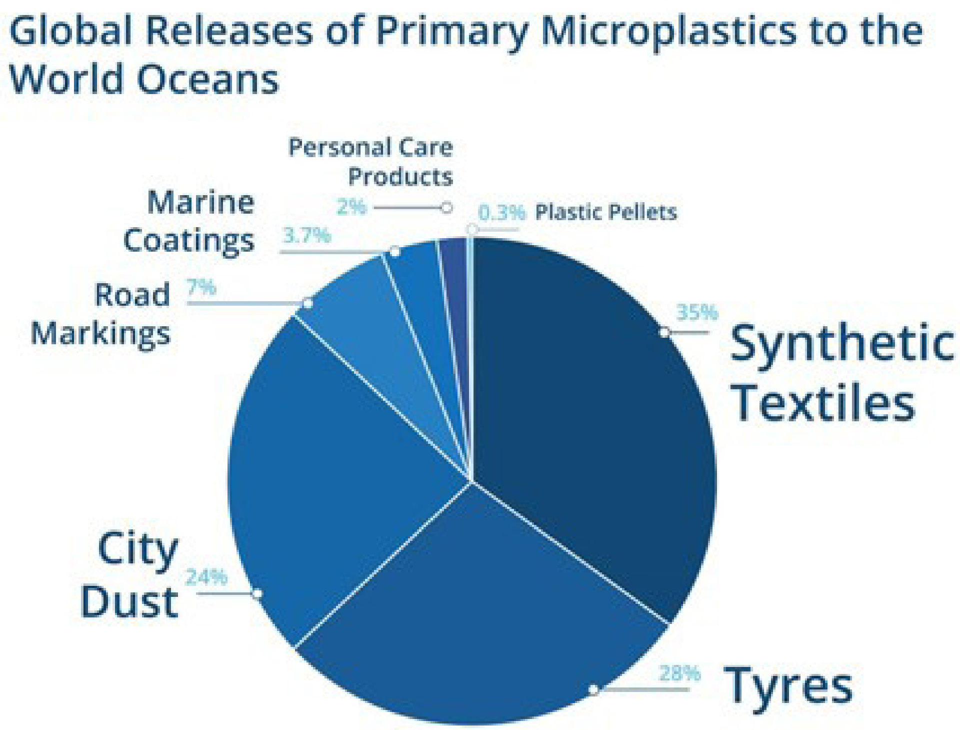
There are several concerns about microplastics persistence in the environment, as they accumulate in water, soil, air and food chains.

In year 2017, the European Commission requested the European Chemicals Agency (ECHA) to carry out a scientific assessment of the impact of unintentionally and intentionally added microplastics. Several publications were done defining the most important sources for the release of microplastics in the environment.




European Commission: Directorate-General for Environment, EU action against microplastics, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2779/917472

At that time, another study determined that two-thirds (63.1%) of microplastics released into the oceans were due to the laundering of synthetic textiles (34.8%) and the erosion of the tyres while driving (28.3%).




Source: Boucher, J. and Friot D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources, IUCN- https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

Compared to the total volume of microplastics, the contribution from flock fibers and flocking materials is so low that it cannot be reliably quantified and can be considered negligible, but it is our obligation as members of the Flock Association of Europe to take this matter very seriously and do our best to reduce the impact of our operations and materials the best we can.

Following with the evolution of the subject, in 2018, the European Parliament called on the European Commission to introduce a ban on intentionally added microplastics in cosmetics, personal care products, detergents, and cleaning products formulas by 2020.

In 2019, the Agency published its dossier concluding that the intentional use of synthetic polymer microparticles, which results in releases to the environment, poses a risk that is not adequately controlled and should be addressed at the EU level.

For that reason, the Commission Regulation (EU) 2023/2055 of 25 September 2023 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) as regards synthetic polymer microparticles which is aligned with key European Union strategies:

- The European Green Deal
- The European Strategy for Plastics in a Circular Economy
- The Circular Economy Action Plan
- The Zero Pollution Action Plan, which includes a target to reduce the amount of microplastics released into the environment by 30% by 2030

The purpose of the Regulation (EU) 2023/2055 is to restrict intentionally added synthetic microplastics in products or mixtures that may release microplastics into the environment during their use.
The regulation focuses on synthetic polymer microparticles (SPM) that are organic, insoluble, and resistant to degradation.

It also includes transitional periods and specific exemptions for certain applications, with a phased approach depending on the type of product or use.

This Regulation (EU) 2023/2055 defines microplastics as synthetic polymer microparticles (SPM).
These include solid particles that are insoluble in water and resistant to degradation.
Dimensional criteria (spherical, irregular, and fibrous): Particles with a size ≤ 5 mm.
Fibres are included when: Length ≤ 15 mm, and Length-to-diameter ratio > 3.
Materials: synthetic polymers such as: Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyester (PET), Polyamide (PA), etc

**Main Exclusions:**

- Natural polymers that have not been chemically modified
- Water-soluble polymers
- Substances that rapidly degrade in the environment
- Plastics that are part of solid articles with no intentional release of particles

Based on the criteria outlined above, flock fibers made of synthetic polymers and measuring less than 15 mm in length fall within the scope of this regulation **only** when they are supplied in a loose form for specific small-scale applications where intentional release to the environment may occur. In contrast, all the other 99% of flock applications in which the flock is incorporated into a solid article, are not considered within the scope of this regulation.

Nevertheless, from 17 October 2025, suppliers & distributors of synthetic flock in Europe shall provide to the industrial and professional users with instructions on the proper use and disposal of synthetic flock fibers, including guidance on how to prevent the release of synthetic polymer microparticles into the environment. The Flock Association of Europe has fully supported companies on this topic by publishing, on its website, the agreed guidelines for the use and disposal of flock fibres during production:
flock.de/this-is-flock/faq/flock/reachxvii-78#c535



## Instructions for use and disposal

**Product: Flock fibres (synthetic polymer fibres)**

In accordance with the requirements of Annex XVII, entry 78.7 a), the following measures shall be observed in the use and disposal of flock fibres by industrial users in order to prevent the release of synthetic polymer microparticles into the environment:

1. Use

- Design production processes in such a way that dust and fiber flight are minimized (closed systems, extractors, filter units).
- Cleaning machines and work surfaces preferably dry (vacuuming with HEPA filter); Wet wipe only if collection and filtration systems are in place.
- Wastewater from processes with flock fibres must be routed through suitable filtration systems (e.g. micro- or ultrafiltration) before it enters the sewer system.
- Separately collect workwear contaminated with flock fibres and clean it in industrial washing processes with wastewater filtration.

2. Disposal

- Keep production waste (offcuts, excess fibres, dust) collected and dispose of as special waste or within the framework of approved disposal channels; Do not put it in the household waste or sewer system.
- Liquid residues containing flock fibres must not be released directly into the environment; these are to be collected in sealed containers and treated by specialised waste disposal companies.
- Dispose of packaging materials contaminated with flock fibres separately, preferably by thermal recycling.

3. Documentation and disclosure

- These instructions must be documented as part of the company's environmental management.
- Downstream users are obliged to pass on the information to their own customers in the supply chain.

Continuing with the discussion about microfibers, Regulation (EU) 2023/2055 covers intentionally added microplastics but it does NOT directly regulate microfiber shedding (unintentional release).

EU technologists continue working on this field, targeting to reduce the impact of unintentional microplastic releases which could have an affectation on unintentional flock release, for example during laundering of garments

Fibers released > wastewater > rivers/oceans
Treatment plants capture most but not all

At the moment there is no specific EU regulation yet targeting microfiber release from textiles but there are under discussion to include different Eco-design requirements for textiles to improve durability and have low fiber release during laundering.

New wastewater regulations are also expected, aimed at improving laundering processes and industrial filtration systems to prevent microplastic releases into the environment. However, there does not yet appear to be a confirmed timeline for the publication or implementation of these regulations.

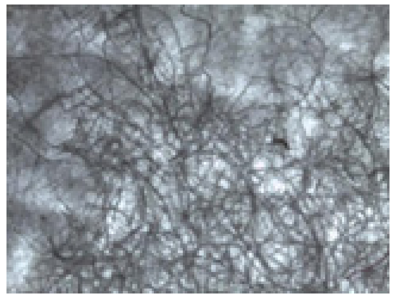
To understand the impact of microfiber shedding of flocked materials during laundering, Velutex Flock technical team has requested an independent laboratory to do a comparative study to evaluate the microfiber shedding from various flocked textile samples.

The main goal was to establish a clear, technical relationship between fabric construction, and flocking treatment, and measure the release of microfibers during washing conditions to assess the impact of flock on the overall results.

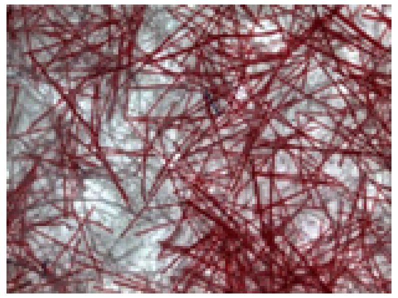
The tests were done based on ISO23231:2021 "Textiles-Determination of Microfiber Release During Domestic and Commercial Washing of Synthetic Fabrics". The procedure was designed to simulate realistic small-scale washing conditions and measure the amount of microfibers released from different unflocked and flocked fabrics.

The samples were subjected to washing in the Gyrowash machine. This device emulates the movement and mechanical action of a conventional washing machines, applying controlled agitation cycles and temperature in the presence of water. The samples were placed in sealed containers with the washing medium and 50 stainless steel balls; once the cycle is complete, the wash liquid is filtered through a 1,6 um filter to collect the released microfibers.

Microfiber release is quantified as grams of microfiber per gram of fabric (g MF / g fabric). An illustrative example of fibrils obtained after the testing from the base fabric and from the flocked material is presented below, along with their corresponding quantitative values and microscopic characterization:



6,71x10-3 g MF / g main fabric

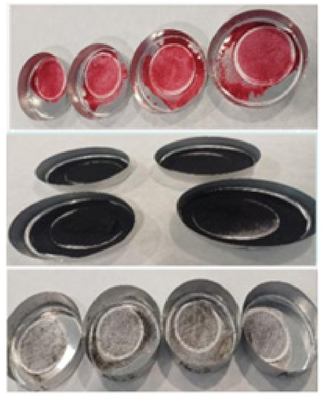


5,47x10-3 g MF / g flocked fabric

The study drew several interesting conclusions:

- The levels of fiber releases obtained with flocked fabrics are equivalent to values obtained from previous studies with standard fabrics of similar characteristics of yarn types and fabric construction, but not flocked.
- Fundamental fabric properties-including structure, yarn parameters, spinning method, and fiber type-are decisive in determining shedding behavior. Part of the shedding obtained is due to the base fabric.
- Flock can even reduce microfiber shedding when applied to unstable, high-shedding base fabrics, such as knitted loose textiles..
- In some cases, flock may significantly increase shedding if flock adhesion and compatibility with the base fabric are not optimized.

  Pictures on the right show photographs from results obtained for different type of flocked fibers which reached between 2 g shedding upto 47 g per each Kg of flocked material. In this case, all 3 fabrics used a similar roll-to-roll flocking process. Part of this shedding is due to the base fabric



Overall, the report shows that both the fabric construction and the specific treatments applied play a key role in microfiber release during washing. Textile flocking does not necessarily worsen the results. Nevertheless, careful selection of base materials and flocking processes is essential to minimize the fiber release.



## AUTOMOTIVE PERSPECTIVE

As an example, to support the Circular Economy Action Plan and the European Green Deal, the EU wants to promote the resource efficiency and material recovery in the automotive sector, for that reason they have stablished the End-of-Life Vehicles Directive (ELV Directive) aims to reduce waste from vehicles and ensure that cars are reused, recycled, or recovered when they reach the end of their life.

### Key objectives:

- Prevent waste from vehicles and reduce their environmental impact.
- Promote reuse, recycling, and recovery of vehicle materials.
- Ensure vehicles are treated in environmentally safe facilities.

### Main requirements:

- Car manufacturers must design vehicles that are easier to dismantle, reuse, and recycle.
- Certain hazardous substances are restricted, including lead, mercury, cadmium, and hexavalent chromium.
- Vehicles must be delivered to authorized treatment facilities (ATFs) when scrapped.
- EU countries must reach recovery and recycling targets.

By 2036, Europe will increase the recycled plastic content targets to

- 25% recycled plastics content in new vehicles
- 5% closed-loop recycled plastics content in new vehicles
- 30% of plastics to be recycled from ELVs in the future

This evolving landscape is creating new opportunities for the flocking industry, as automotive OEMs will need to adopt broader sustainable strategies to meet EU targets. Compliance will not only depend on vehicle manufacturing itself, but also on end-of-life management and the development of local repair and recycling ecosystems.

**Delocalization** is becoming a key priority. There is increasing pressure to source local materials in order to reduce $CO_2$ footprints and integrate a higher share of "Km 0" content into vehicles. De-globalization and regional supply chains are now central strategic themes.

**Asian-European joint ventures** are also gaining momentum. European governments are supporting partnerships that allow Asian brands to enter the market while maintaining European production and employment. The emerging trend is clear: vehicles sold in Europe should be at least partially produced in Europe, creating new opportunities for local suppliers.

The upcoming **European ELV (End-of-Life Vehicles) Regulation** will further accelerate circularity requirements. This will directly impact R&D, sourcing strategies, and supply chain organization, which will increasingly need to be managed close to both production sites and consumers. European flocking companies are well positioned to respond to this shift.

The next 5 years are expected to be dynamic and uncertain, with OEMs adopting different pathways to meet sustainability targets. The future of the flocking business in this sector will depend on how effectively we position and promote flocking within this changing framework.

### Key strategic directions can include:

- Expanding the use of recycled materials across a broader range of vehicle components and integrating them into supplier portfolios.
- Promoting easy-to-recycle plastics and monocomponent solutions to enhance end-of-life treatment efficiency.
- Improving the recyclability of flocked products by optimizing flock-adhesive systems and ensuring compatibility with recycling streams.
- Strengthening collaboration between adhesive manufacturers, flock applicators, and flock suppliers to drive eco-design innovation.
- Providing transparent data to justify the recyclability of flocked components, beyond adhesive content, to support communication with OEMs and end-consumers.
- Developing a next generation of flocked materials that are biodegradable or easily recyclable at end of life.

### In conclusion

We hope this lecture has provided useful insights and practical guidelines to support a more sustainable and competitive development of the flocking industry within the current evolving landscape.

## NOTES



# 3. Flock Coating: Diverse Applications in Advanced Materials and its Potential for Thermal Comfort in Cold-Weather Clothing

**MAHMUT OĞUZ KESIMCI**
Textile Engineer

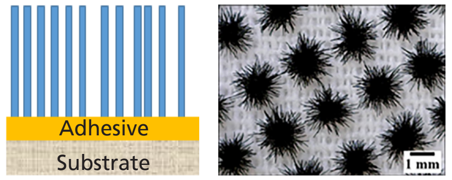
Mahmut Oğuz Kesimci began his work on flock coating in 2014 at Bursa Uludağ University, investigating diverse applications of flock coating in the literature – including composite materials, impact energy absorption, liquid wicking, thermal conduction, and biomaterials – which led to developing a Ph.D. research proposal focused on textile comfort.

From 2016 to 2022, he carried out both experimental and theoretical research on the thermophysiological comfort properties of flock-coated fabrics, resulting in a peer-reviewed publication in the Journal of The Textile Institute.

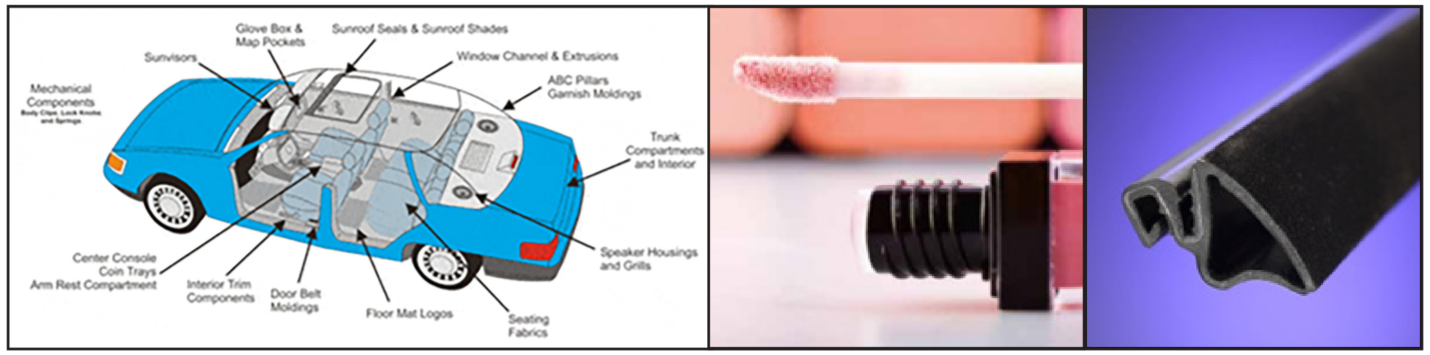
His expertise includes electrostatic flock coating processes, textile comfort properties, and surface phenomena. He currently works as a textile consultant.

### FLOCK COATING TODAY AND SHORT HISTORY

Flock coating is the application of natural or synthetic fibers, called flock fibers, to adhesive-applied surfaces. Flock coating consists of the following basic steps: flock fiber, adhesive and substract




**Today:** Flocking spans textiles, packaging, automotive, consumer goods, and medical devices; modern fibers include nylon, polyester, and rayon with advanced adhesives and transfer processes (American Flock Association).



## FLOCK COATING TODAY AND SHORT HISTORY

- B.C. 1000–700 (Ancient China): Earliest known flocking: resin glues brushed on textiles, then dusted with natural fibers for ornament and texture. (Flock Association of Europe).
- 12th century (Medieval Europe, esp. Nuremberg, Germany): Documented use of fiber "dust" pressed into adhesive on walls and cloth as decoration. (flockit.com)
- Late 17th–18th centuries (England > Europe & America): "Flock wallpaper" Invented to imitate costly cut velvet; made by shaking powdered wool (a textile waste) onto adhesive designs. Britain became a major exporter; by 1748 flock wallpaper was fashionable in Paris. (Victoria and Albert Museum, https://www.vam.ac.uk/articles/flock-wallpaper)
- 19th century (industrialization & wallpaper revival): Flocking resurges with mechanized wallpaper production; industrial flock wallpaper widely cited as starting c. 1870. (flockit.com)
- Early 20th century (USA, pre-electrostatic): First sustained industrial use of textile flocking reported in the U.S. around 1910, using mechanical methods. (AIGLE Macchine Srl)
- 1930s (United States) 1940s (Germany): Electrostatic era begins: Electrostatics introduced to orient fibers and improve quality; 1930s U.S. patents describe electrostatic flocking machines/processes. Technique spreads to Europe after WWII. (AIGLE Macchine Srl)
- 1940s–1950s (process maturation): More dedicated flocking apparatus and process patents appear (e.g., 1947–55 filings), reflecting scaling beyond paper/wallcoverings into textiles, rubber goods, and molded parts. (Google Patents)
- 1960s–1970s (consumer products & automotive): Widespread adoption in automotive interiors (glove boxes, bins, guides) for anti-rattle, noise dampening, and premium tactility—now considered standard practice in interior engineering. (flocking.biz)
- 2000s–2010s (biomedical): Nylon flocked swabs (COPAN) apply electrostatic flocking to diagnostic sampling—patents from 2003–2005 onward and global adoption during the 2010s. (Google Patents)

## FABRIC FLOCK COATING PROCESS

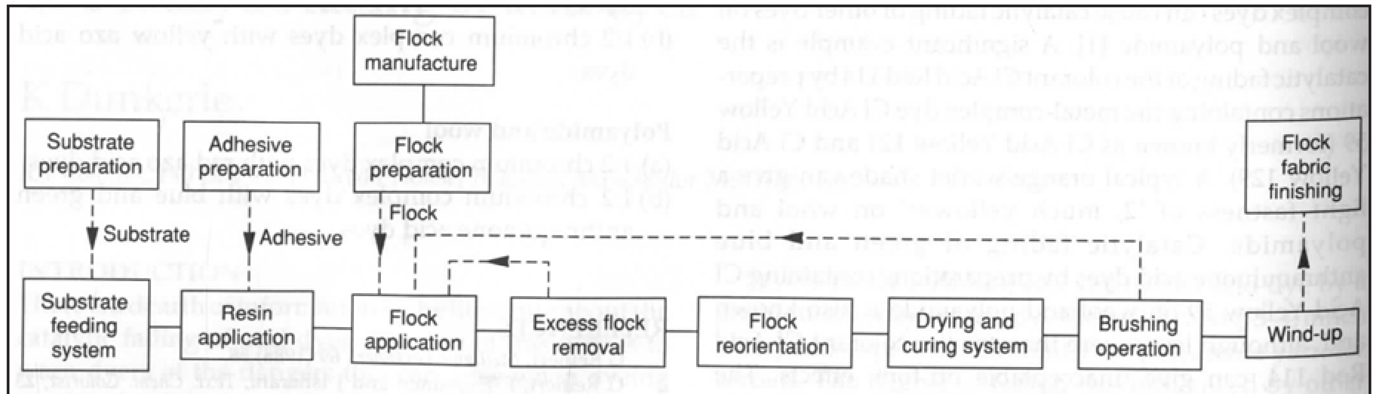



**Figure 1** Sequence in the manufacture of flock fabrics

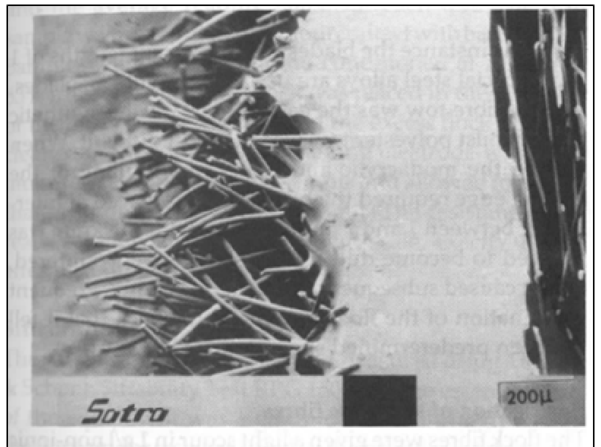


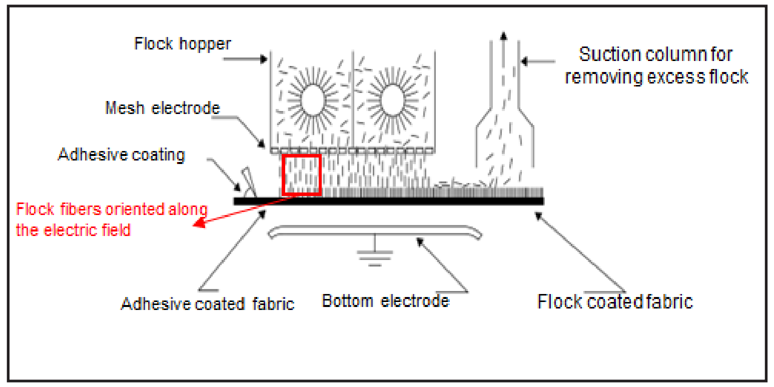

**Figure 3** Flock fibres embedded end-on into adhesive

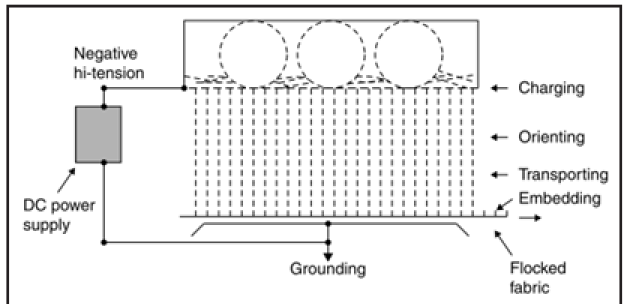
Ingamells W and Ramadan N. Influence of finishing agents on the performance of fibres during electrostatic flocking.
J Soc Dyers Colour 1992; 108(5/6): 270–278.



## ELECTRO STATIC FLOCK COATING

The electrostatic flock coating method was first included in a patent describing the production of fabric with a pile structure in 1939. (Meston and Wintermute, 1939)[1]. This patent shows that flock fibers can be oriented in the direction of the electric field formed between parallel metal plates with alternating or direct current and can be coated on the adhesive applied to the fabric.




12.3 A DC flocking process. The dosing unit has three feeding rotating stiff-bristle brushes, which push the flock fibers through the charging stainless steel screen.

## FLOCK COATING USAGE AREAS IN LITERATURE

We have classified the studies on the flock coating materials in five subheadings depending on the usage areas of the developed materials.

Materials procudec by flock coating:
1. Composite Materials
2. Impact Energy Absorbing Materials
3. Liquid Wicking-Transportating Materials
4. High Thermal Conduction Materials
5. Flock Coated Biomaterials

## 1. COMPOSITE MATERIALS[2]

| | Flock Type | Flock Fineness (denier) | Flock Diameter (μm) | Flock Length (mm) | |
|---|---|---|---|---|---|
| Mironov ve Park 2000 | Karbon | - | 7, 6.4 | 2, 2-5 | • Carbon fiber- reinforced hybrid laminated plastics are produced.<br>• Z-direction placement of fibers, impact and interlaminar shear strength, Fcritic<br>• Flock fibers improve the delamination fracture toughness up to 7 times.<br>• Laminar composite z-directional microfiber reinforcement (by a flocking process) in improving fracture toughness was compared with that of a 3-D braided 8-layer glass fiber preform/epoxy composite plate. |
| Rice et al. 2007 | Nylon, Polyester | 3 | - | - | |
| Liang et al. 2011 | Nylon<br>Polyester | 3<br>3 | -<br>- | 1.172<br>0.657 – 1.177 | |
| Jia Ren et al. 2011 | Nylon | 3 ve 20 | - | 2 | |
| Kim et al. 2017 | Nylon<br>Polyester | 3<br>3 | -<br>- | 2<br>0.6 - 1.2 | |
| Chen et al. 2017 | Carbon nanofiber | - | 20 - 40 (nm) | 5 - 15 (μm) | |

[1] Meston, A. F., Wintermute, H. A. Production of Piled Surfaces in Pattern Form. No. Patent No: US 2152077, Behr-Manning Corporation, (Massachusetts, US), 1939.

### Z-axis flock fibre interlaminar reinforcement methodology

*Wet flocking*

In the original variation of the process, flock fibres were applied to an uncured, liquid resin impregnated fabric ply-layer surface

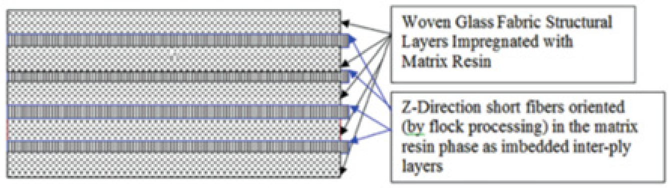



Fig. 1: Schematic diagram of glass fabric/Z-oriented short fibre Z-axis interlayer OPLC

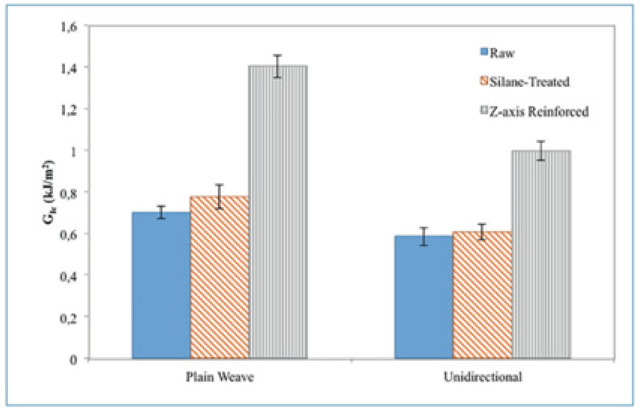



Fig. 3: Comparison of initiation DCB toughness values for various 16-layer jute fabric/epoxy laminar composites – Effect of jute fabric surface treatment

## 2. IMPACT ENERGY ABSORBING MATERIALS[4]

| | Flock Type | Flock Fineness (denier) | Flock Diameter (µm) |
|---|---|---|---|
| Lewis et al. 2018 | Nylon | 20 | 2 |
| Fodor et al. 2019 | Nylon | 20, 60, 100 | 2, 3 |
| Correia et al. 2020 | Nylon | 6, 20, 45, 60 | 1, 2, 3 |
| Kim et al. 2021 | Nylon | 20 | 2 |

Corsair Innovations' Revolutionary FEAM Material is a special Flock construction that helps absorb, dissipate and transfer momentum to lessen the impact of head injuries.

The NFL, Under Armour, GE and the National Institute of Standards & Technology team up to support companies developing technology to reduce the impact of head injuries (https://www.flocking.org/afa-blog/head-health-challenge-grant-awarded-to-corsair-innovations).

American Flock Association Design With Flock In Mind

[2] Mironov, V. ., Park, M. 2000. Electroflocking technique in the fabrication and performance enhancement of fiber-reinforced polymer composites. Composites Science and Technology, 60(6):, 927–933. https://doi.org/10.1016/S0266-3538(99)00142-6
Rice, J. M., Kim, Y. K., Lewis, A. F., Lee, J. S. 2007. Fracture Toughness of Through-Thickness Reinforced Composites. National Textile Center Annual Report, Project Number F04-MD12, November 2007, 1-10.
Liang, F., Mayur, K., Kim, Y. K., Rice, J. M. 2011. Fracture Behavior of Flock Fiber Reinforced Laminar Composite. Journal of Materials Science and Engineering B 1, 1:, 1–13.
Jia Ren, Kim, Y. K., Rice, J. 2011. Comparing the fracture toughness of 3-D braided preform composites with z-fiber-reinforced laminar composites. Textile Research Journal, 81(4):, 335–343. https://doi.org/10.1177/0040517510385172
Kim, Y. K., Rice, J. M., Chalivendra, V., Lewis, A. F. 2017. Flock fibre-reinforced laminar composites for improved Mode I fracture toughness. JEC Composites Magazine, 110:, 4–9.
Chen, C., Li, Y., Gu, Y., Li, M., Zhang, Z. 2017. Effect of MWCNTs added by electrostatic flocking method on adhesion of carbon fiber prepreg/Nomex honeycomb sandwich composites. Materials & Design, 127(37):, 15–21. https://doi.org/10.1016/j.matdes.2017.04.025

[3] Kim, Y. K., Rice, J. M., Chalivendra, V., Lewis, A. F. 2017. Flock fibre-reinforced laminar composites for improved Mode I fracture toughness. JEC Composites Magazine, 110:, 4–9

[4] Lewis, A. F., Matos, H., Rice, J. M., Kim, Y. K. 2018. Impact force loss behavior of flocked surfaces. Textile Research Journal, 88(4):, 392–412. https://doi.org/10.1177/0040517516679149
Fodor, K. F., Chalivendra, V., Kim, Y. K., Lewis, A. F. 2019. Dynamic mechanical behavior of flocked layer composite materials. Composite Structures, 207(4):, 677–683. https://doi.org/10.1016/j.compstruct.2018.09.083 Correia, J., Chalivendra, V., Kim, Y. 2020. Parametric study of a fibrous energy absorbing material under impact shear loading. Composite Structures, 232(October 2019):, 111583. https://doi.org/10.1016/j.compstruct.2019.111583
Kim, Y. K., Chalivendra, V. B., Lewis, A. F., Fasel, B. 2021. Designing flocked energy-absorbing material layers into sport and military helmet pads. Textile Research Journal, 004051752110106. https://doi.org/10.1177/00405175211010689



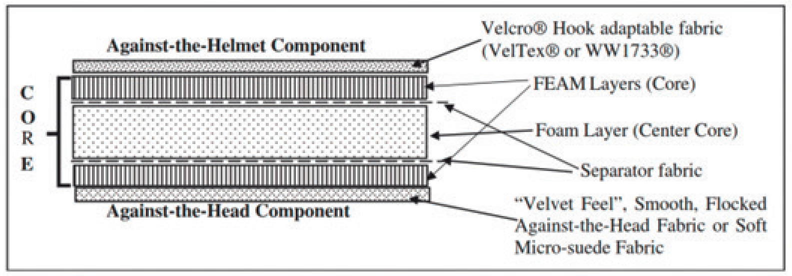



Figure 5. Sketch of a generic three-component FEAM/foam IFA helmet pad structure.

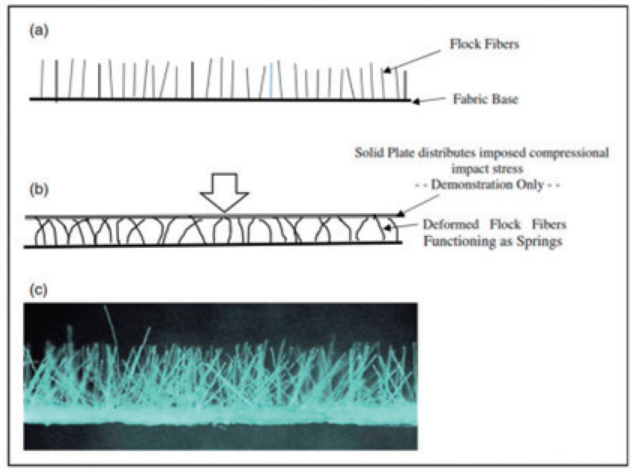



Figure 1. Sketch and photograph of typical flocked surface element used to construct FEAM IFA pads.

## 3. LIQUID WICKING-TRANSPORTATING MATERIALS[6]

| | Flock Type | Flock Fineness (denier) | Flock Diameter (µm) |
|---|---|---|---|
| Coskuntuna et al. 2007 | Nylon | 3, 20 | 2 |
| Hitzbleck et al. 2013 | Nylon | 20, 60, 100 | 2, 3 |

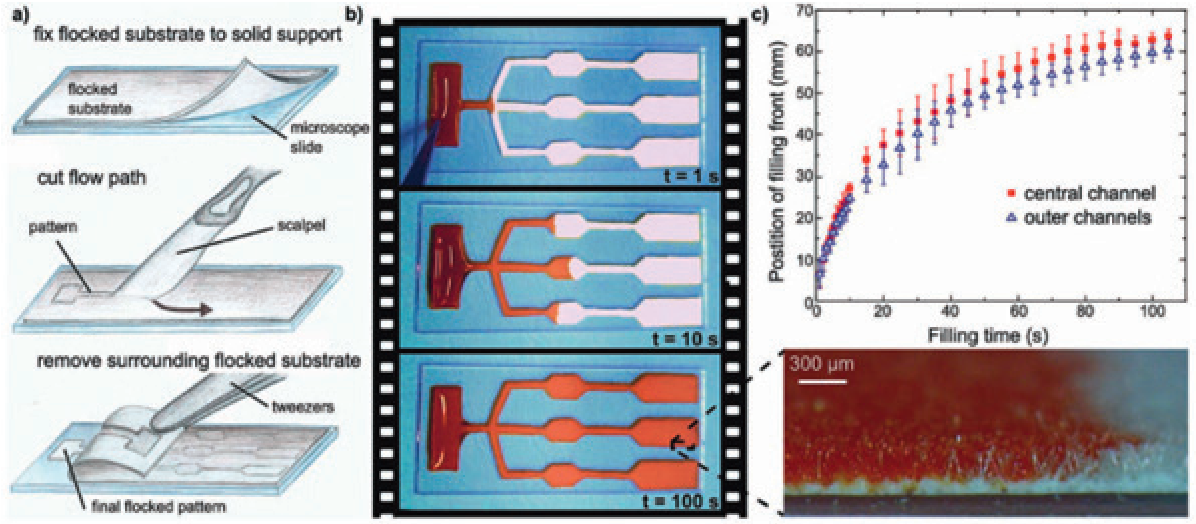



Figure 2. Patterning of a flocked substrate and characterization of its wicking properties. (a) A microfluidic network can be directly defined by cutting the desired pattern from a flocked substrate, which was placed on a glass slide, and removing the surrounding substrate. (b) Example of a network having a common loading pad and three parallel flow paths, which are being filled with colored water, and (c) corresponding advancement of the filling front in the flow paths.

Hitzbleck et al.'s 2013 study investigated the conduction of liquids parallel to the surface in flocked areas. The flocking process produced surfaces that provided controlled liquid conduction by using hydrophilic and hydrophobic fibers. It was demonstrated that **flocked liquid conduction and storage structures** could be created by using an additional masking electrode in the flock coating process.

[5] Kim, Y. K., Chalivendra, V. B., Lewis, A. F., Fasel, B. 2021. Designing flocked energy-absorbing material layers into sport and military helmet pads. Textile Research Journal, 004051752110106. https://doi.org/10.1177/00405175211010689
[6] Coskuntuna, E., Fowler, A. J., Warner, S. B. 2007. Fibrous Structures with Designed Wicking Properties. Textile Research Journal, 77(4):, 256–264. https://doi.org/10.1177/0040517507080250
Hitzbleck, M., Lovchik, R. D., Delamarche, E. 2013. Flock-Based Microfluidics. Advanced Materials, 25(19):, 2672–2676. https://doi.org/10.1002/adma.201204854

## 4. HIGH THERMAL CONDUCTION (ELASTOMERIC) MATERIALS[7]

| | Flock Type | Flock Fineness (denier) | Flock Diameter (µm) |
|---|---|---|---|
| Knowles 1996 | Carbon | 7 | 1 -3 |
| Seaman et al. 1999 | Carbon | 7 | 2 |
| Uetani et al. 2014 | Carbon | 10 | 1 |
| Ji et al. 2018 | Carbon | | |
| Sun et al. 2018 | Carbon, Graphite grain, Vapor deposit Carbon | | |
| Yu et al. 2019 | PAN based, pitch based Carbon | | |

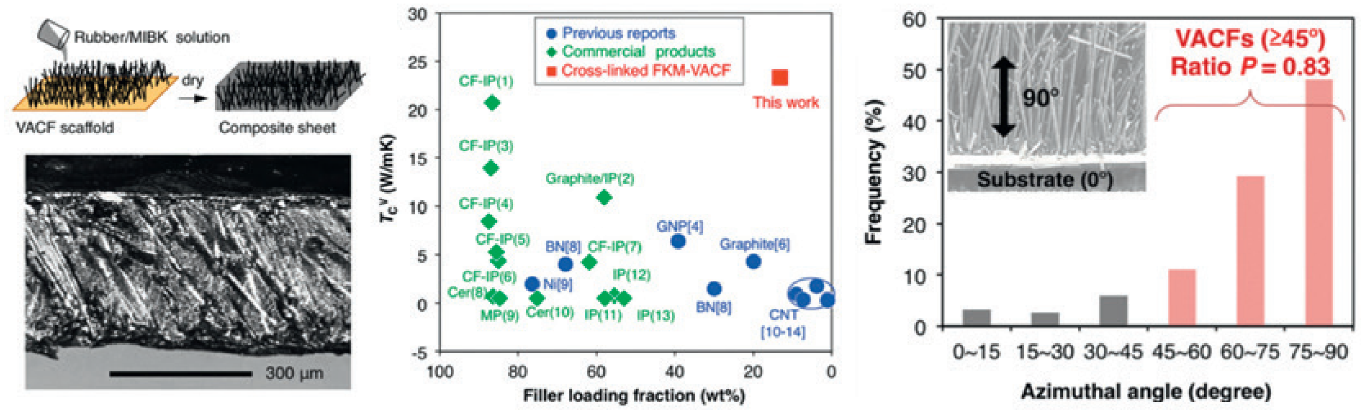



**Figure 2.** VACF-impregnated rubber composites. (a) Schematic illustration of the production of FKM–VACF composite sheets. (b) DFOM image of the cross-section of the FKM–VACF composite. (c) $T_C^V$ as a function of filler fraction for reported materials (blue) and commercial TIM products (green). The filler types for the reported materials are indicated together with the citations in square brackets. The abbreviations of fillers are defined as follows; boron nitride (BN), graphite nanoplatelet (GNP), inorganic particles (IP), nickel (Ni), metal particles (MP), and ceramics (Cer). The commercial products (1) "WW-LTR-201C", (2) "WW-90VG" and (11) "WW-GAP-S10" were purchased from Wide Work Co. (Japan), (8) "TMS-22", (9) "AT-10", and (10) "TMS-14" were purchased from Takeuchi industry Co., Ltd. (Japan). The other commercial TIMs, (3) "Manion50α", (4) "Manion35(E20)", (5) "PT-V", (6) "PT-VS", and (7) "PT-UT", were kindly supplied by Polymatech Japan Co., Ltd. The commercial materials (1) to (7) consisted of the multifillers as designated in the figure.

[7] Knowles, T. R. 1996. PCM Composite Cold Plate. Air Force Contract Number F29601-95-C-0098, Report #PL-TR-96-1104, April 1996, 1-40.
Seaman, C. L., Ellman, B. M., Knowles, T. R. 1999. Enhanced thermal conductance of ORU radiant fin thermal interface using carbon brush materials. AIP Conference Proceedings : AIP Conference Proceedings (Vol. 458), AIP: , 565–574. https://doi.org/10.1063/1.57622
Uetani, K., Ata, S., Tomonoh, S., Yamada, T., Yumura, M., Hata, K. 2014. Elastomeric Thermal Interface Materials with High Through-Plane Thermal Conductivity from Carbon Fiber Fillers Vertically Aligned by Electrostatic Flocking. Advanced Materials, 26(33):, 5857–5862. https://doi.org/10.1002/adma.201401736
Ji, T., Feng, Y., Qin, M., Li, S., Zhang, F., Lv, F., Feng, W. 2018. Thermal conductive and flexible silastic composite based on a hierarchical framework of aligned carbon fibers-carbon nanotubes. Carbon, 131:, 149–159. https://doi.org/10.1016/j.carbon.2018.02.002
Sun, Y., Wang, S., Li, M., Gu, Y., Zhang, Z. 2018. Improvement of out-of-plane thermal conductivity of composite laminate by electrostatic flocking. Materials & Design, 144:, 263–270. https://doi.org/10.1016/j.matdes.2018.02.031
Yu, Z., Wei, S., Guo, J. 2019. Fabrication of aligned carbon-fiber/polymer TIMs using electrostatic flocking method. Journal of Materials Science: Materials in Electronics, 30(11):, 10233–10243. https://doi.org/10.1007/s10854-019-01360-7
Uetani, K., Ata, S., Tomonoh, S., Yamada, T., Yumura, M., Hata, K. 2014. Elastomeric Thermal Interface Materials with High Through-Plane Thermal Conductivity from Carbon Fiber Fillers Vertically Aligned by Electrostatic Flocking. Advanced Materials, 26(33):, 5857–5862. https://doi.org/10.1002/adma.201401736



## 5. FLOCK COATED BIOMATERIALS[8]

| | Flock Type | Flock Fineness (denier) | Flock Diameter (µm) |
|---|---|---|---|
| Sherepo 1997 | Teflon | | |
| Walther et al. 2007 | Nylon | 30 | 1 |
| Steck et al. 2010 | Nylon | | 1 - 3 |
| Walther et al. 2012 | Nylon | | 1 - 3 |
| Balasubramanian and Boccaccini 2015 | | | |
| Gossla et al. 2016 | | | |
| Tonndorf et al. 2018 | | | |
| McCarthy et al. 2021 | | | |
| McCarthy ve Avegnon and et al. 2021 | | | |

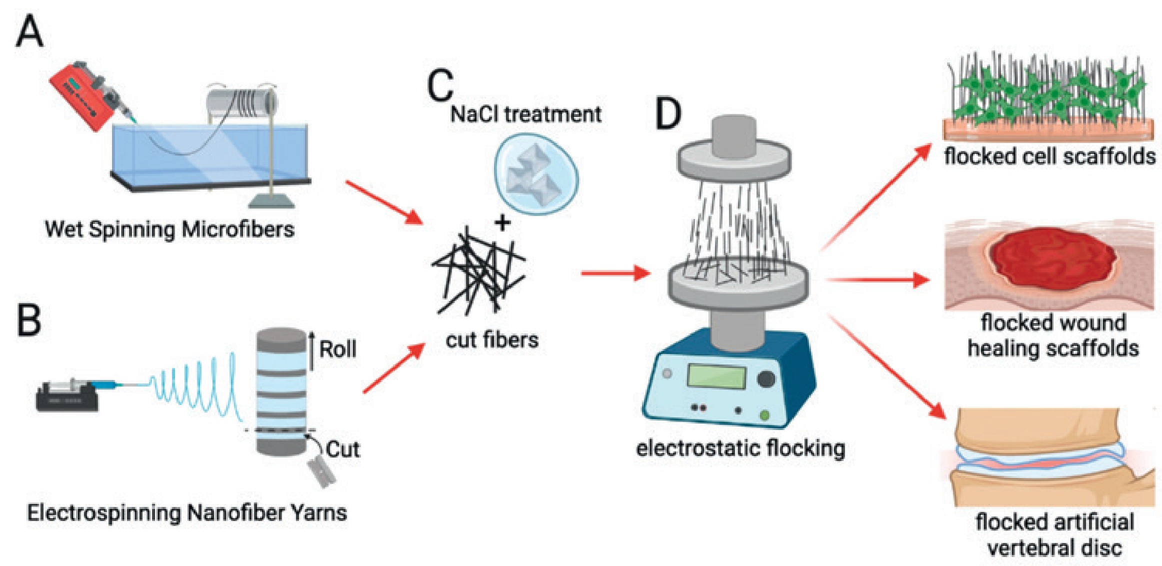



**Fig. 1.** Schematic illustrating the fabrication of scaffolds by electrostatic flocking for potential biomedical applications. (A) Microfibers fabricated by wet spinning. (B) Electrospun nanofiber yarns fabricated by cutting and rolling. (C) NaCl treatment. (D) Electrostatic flocking and obtained scaffolds for cell growth, wound healing, and artificial vertebral disc replacement.

[8] Sherepo, K., 1997. A Flocking Thigh Joint Implant. Biomedical Engineering, 31(4):, 216–222.
Walther, A., et al. 2007. Development of Novel Scaffolds for Tissue Engineering by Flock Technology. Textile Research Journal, 77(11):, 892–899.
Steck, E., et al. 2010. Enhanced Biochemical and Biomechanical Properties of Scaffolds Generated by Flock Technology for Cartilage Tissue Engineering. Tissue Engineering Part A, 16(12):, 3697–3707.
Walther, A., et al. 2012. Novel Textile Scaffolds Generated by Flock Technology for Tissue Engineering of Bone and Cartilage. Materials, 5(12):, 540–557.
Balasubramanian, P., Boccaccini, A. R. 2015. Bilayered bioactive glass scaffolds incorporating fibrous morphology by flock technology. Materials Letters, 158:, 313–316.
Gossla, E., et al. 2016. Electrostatic flocking of chitosan fibres leads to highly porous, elastic and fully biodegradable anisotropic scaffolds. Acta Biomaterialia, 44:, 267–276.
Tonndorf, R., et al. 2018. Factors affecting the mechanical and geometrical properties of electrostatically flocked pure chitosan fiber scaffolds. Textile Research Journal, 88(17):, 1965–1978.
McCarthy, A., et al. 2021. Electrostatic Flocking of Insulative and Biodegradable Polymer Microfibers for Biomedical Applications. Advanced Healthcare Materials, 10(19):, 2100766.
McCarthy, A., Avegnon, K. L. M., et al. 2021. Electrostatic flocking of salt-treated microfibers and nanofiber yarns for regenerative engineering. Materials Today Bio, 12(October):, 100166.

## Experimental Study and Theoretical Model: Influence of flock coating on the thermophysiological comfort properties of woven cotton fabric[9]

**Comfort and Clothing Comfort**
The broadest definition of the word comfort is the state of being in harmony and enjoying the individual's environment in physiological, psychological, neurophysiological and physical aspects (Roy Choudhury et al. 2011).

Clothing comfort can be defined as the ability of a person to achieve and maintain the state of harmony and enjoyment mentioned within the definition of comfort against the weather conditions of the environment such as temperature, humidity and wind, thanks to the features provided by her clothing.

**Clothing Comfort**
- Thermophysiological clothing comfort: Maintaining body temperature balance during different body activities
- Sensory wearing comfort: The feeling of softness and flexibility during contact between the garment and the body outweighs the sensory sensations such as irritation and stinging.

**Body temperature balance is determined by: 36,5 °C - 37,5 °C**
- Metabolism: It is the conversion and use of the energy from food necessary for life. We can only convert 20% of the energy in food into usable energy, while 80% emerges as heat. The heat energy produced by the body per unit of time is called the Metabolic Rate. On average, 58.2 W/m^2 × (1.7 m^2) = 100 Watts. (1.7 m^2 is the average human body surface area),
- Function of the Heart, Veins and Skin Organs and Sweating,
- Clothing properties

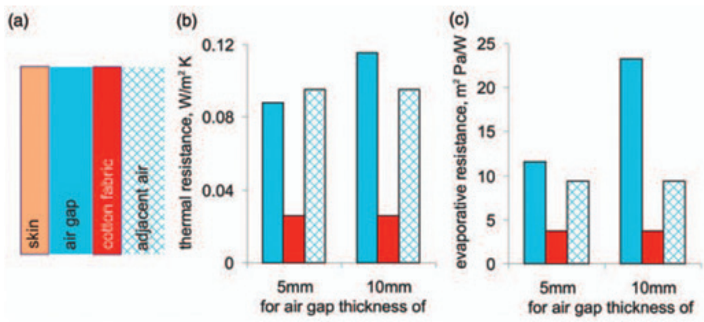
## Body – Microclimate – Clothing – Climate

**Clothing properties**
Metabolic rate allows a person to live comfortably in a temperature range of 26°C to 30°C (A. Das and Alagirusamy 2010). Whether in higher or lower temperatures, clothing with specific features is necessary to maintain body temperature balance.

**Thermal Properties**
- Thermal conductivity (λ, W/mK)
- Thermal resistance (R, m2K/W)
- Thermal absorptivity
  (b, λ, a function of density and specific heat)

**Water Vapor Permeability**
- Water vapor resistance ($R_{et}$, m2Pa/W)
- Relative water vapor permeability ($P_{wv}$, %)

**Air Permeability (mm/s)**




**Effect of Microclimate and Microclimate Thickness**
Clothing creates an air gap between the body's skin and the environment. The temperature and humidity in the air gap differ from those of the surrounding environment and depend on the clothing's comfort characteristics (thermal resistance and water vapor permeability), and the surrounding environment. The air gap is called a microclimate and helps maintain a constant body temperature by reducing heat loss (A. Das and Alagirusamy 2010).

[9] Roy Choudhury, A. K., Majumdar, P. K., Datta, C. 2011. Factors affecting comfort: human physiology and the role of clothing. Improving Comfort in Clothing : Improving Comfort in Clothing, Ed.: G. Song (Ed.), Elsevier: , 3–60. https://doi.org/10.1533/9780857090645.1.3
Saville, B. P. 1999. Comfort. Physical Testing of Textiles : Physical Testing of Textiles, Ed.: B. P. B. T.-P. T. of T. Saville (Ed.), Elsevier: , 209–243. https://doi.org/10.1533/9781845690151.209
Das, A., Alagirusamy, R. 2010. Thermal transmission. Science in Clothing Comfort : Science in Clothing Comfort, Ed.: A. Das, R. B. T.-S. in C. C. Alagirusamy (Eds.) (Vol. 31), Elsevier: , 79–105. https://doi.org/10.1533/9780857092830.79
Psikuta, A., Frackiewicz-Kaczmarek, J., Frydrych, I., Rossi, R. 2012. Quantitative evaluation of air gap thickness and contact area between body and garment. Textile Research Journal, 82(14):, 1405–1413. https://doi.org/10.1177/0040517512436823



**Thermal Properties[10]**
- Thermal conductivity (λ, W/mK)
- Thermal resistance (R, m2K/W)
- Thermal absorptivity (b, λ, a function of density and specific heat)

Thermal resistance (R, m^2K/W) is directly proportional to the fabric's dispersion and inversely proportional to thermal conductivity. Fabrics with high thermal resistance have lower water vapor permeability due to their thickness, preventing sweat from evaporating from the body.

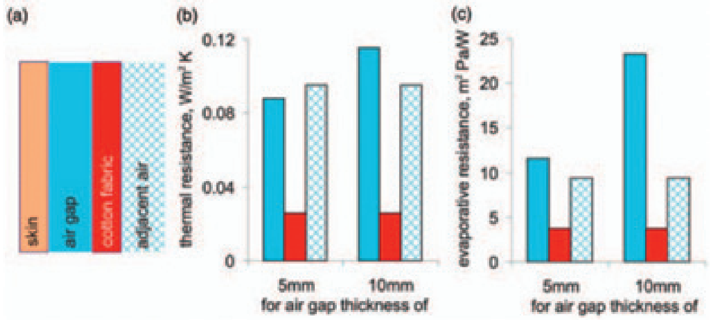
| | Thermal conductivity (mW/(mK)) |
|---|---|
| Cellulose acetate | 230 |
| Nylon | 250 |
| Polyester (PET) | 140 |
| Polyethylene | 340 |
| Polypropylene | 120 |
| Polyvinyl chloride (PVC) | 160 |
| Still air layer | 25 |

Gibson 1993 points out that the water vapor permeability of fabrics is very important both to cool the body by evaporation of sweat in hot climates and to prevent sweat accumulation in the fabric in cold environments.

**Water Vapor Permeability**
- Fabric water vapor permeability depends on the fiber material and the number and size of fabric pores (A. Das and Alagirusamy 2010).
- Water vapor permeability has been found to depend on fabric porosity, regardless of the type of fiber used in the inner and outer layers of the fabric (Long, 1999).
- Significant correlations have been noted between thermal resistance and fabric thickness, water vapor permeability and fabric weight, and air permeability and the permeability index (Stoffberg et al. 2015).

**Microclimate Thickness**
- Roh et al. 2014 reported that thermal resistance in raised fabrics depends on the length and quantity of pile fibers rather than the fabric thickness.
- Microclimate thickness varies depending on fabric moisture content in different body areas (Frackiewicz-Kaczmarek et al. 2015a, Frackiewicz-Kaczmarek et al. 2015b).
- Hes and de Araujo 2010 measured the water vapor permeability of fabrics with different moisture contents by creating 2 mm and 4 mm air gaps between the measuring head of the Permetest device and the fabric sample.

[10] Morton, W. E., Hearle, J. W. S. 2008. Thermal properties. Physical Properties of Textile Fibres : Physical Properties of Textile Fibres, Ed.: W. E. Morton, J. W. S. B. T.-P. P. of T. F. (Fourth E. Hearle (Eds.), Elsevier: , 168–177. https://doi.org/10.1533/9781845694425.168
Gibson, P. W. 1993. Factors Influencing Steady-State Heat and Water Vapor Transfer Measurements for Clothing Materials. Textile Research Journal, 63(12):, 749–764. https://doi.org/10.1177/004051759306301208
Das, A., Alagirusamy, R. 2010. Thermal transmission. Science in Clothing Comfort : Science in Clothing Comfort, Ed.: A. Das, R. B. T.-S. in C. C. Alagirusamy (Eds.) (Vol. 31), Elsevier: , 79–105. https://doi.org/10.1533/9780857092830.79
Long, H. Long, H. 1999. Water transfer properties of two-layer weft knitted fabric. International Journal of Clothing Science and Technology, 11(4):, 198–205. https://doi.org/10.1108/09556229910281948
Stoffberg, M. E., Hunter, L., Botha, A. 2015. The Effect of Fabric Structural Parameters and Fiber Type on the Comfort-Related Properties of Commercial Apparel Fabrics. Journal of Natural Fibers, 12(6):, 505–517.

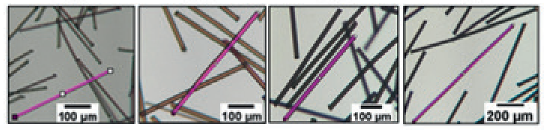



- In their 2007 study, Min et al. investigated the mathematical model of heat loss and moisture transfer through fabric structures in terms of microclimate and fabric thickness. They found that increasing microclimate thickness from 1 mm to 5 mm would reduce both microclimate humidity and total heat loss from the skin. Conversely, they concluded that the same increase in fabric thickness would result in a smaller reduction in total heat loss and could increase microclimate humidity, creating an undesirable feeling of cold.

## Experimental Study: Influence of flock coating on the thermophysiological comfort properties of woven cotton fabric

### Materials and Methods

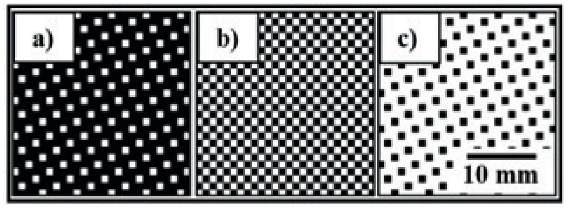
| Flock type | A | B | C | D |
|---|---|---|---|---|
| Fineness (dtex) | 0.9 | 1.7 | 3.3 | 3.3 |
| Length (mm) | 0.4 | 0.5 | 0.5 | 1.0 |

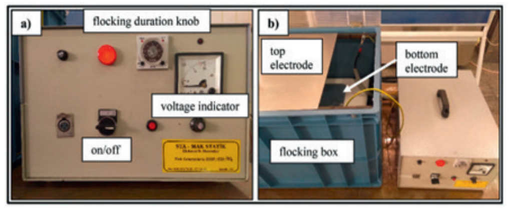
Image



Coated base fabric: Plain woven cotton fabric with a thickness of 0.29 mm, a weight of 104 g/m^2, a warp density of 33 warp/cm and a weft density of 21 picks/cm.

Adhesive: Water-based acrylic copolymer (Eracryl EMK 320) was used as flock coating adhesive.

### Partial Adhesive Application and Flock Coating




a) Low (L), b) Medium (M) and c) High (H) coating ratio (CR) adhesive application templates.

Electrostatic flock coating device, production in 2 different flocking times, 2 and 12 seconds at 70 kV voltage.

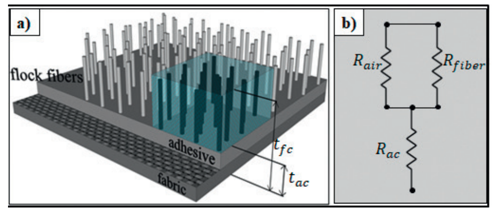
**Tests:**

Thermal properties and thickness, Alambeta
Water vapor permeability, Permetest
Water vapor permeability index ($i_m$), $i_m$=60.06×(R/$R_{et}$)
$i_m$: It is a measure of the fabric's breathability based on its thermal insulation. It is a value between 0 and 1.
Thermal resistance (R, m2K/W) - Su buharı direnci ($R_{et}$, m²Pa/W)
Air permeability, SDL Atlas M021A, 38 cm2, 100 Pa
Weight, ISO 3801:1977

Roh, E. K., Oh, K. W., Kim, S. H. 2014. Effect of raising cycles on mechanical, comfort, and hand properties of artificial suede. Textile Research Journal, 84(18):, 1995–2005. https://doi.org/10.1177/0040517514528561
Frackiewicz-Kaczmarek, J., Psikuta, A., Bueno, M.-A., Rossi, R. M. 2015a. Air gap thickness and contact area in undershirts with various moisture contents: influence of garment fit, fabric structure and fiber composition. Textile Research Journal, 85(20):, 2196–2207. https://doi.org/10.1177/0040517514551458
Frackiewicz-Kaczmarek, J., Psikuta, A., Bueno, M.-A., Rossi, R. M. 2015b. Effect of garment properties on air gap thickness and the contact area distribution. Textile Research Journal, 85(18):, 1907–1918. https://doi.org/10.1177/0040517514559582
Hes, L., de Araujo, M. 2010. Simulation of the Effect of Air Gaps between the Skin and a Wet Fabric on Resulting Cooling Flow. Textile Research Journal, 80(14):, 1488–1497. https://doi.org/10.1177/0040517510361797
Min, K., Son, Y., Kim, C., Lee, Y., Hong, K. 2007. Heat and moisture transfer from skin to environment through fabrics: A mathematical model. International Journal of Heat and Mass Transfer, 50(25–26):, 5292–5304. https://doi.org/10.1016/j.ijheatmasstransfer.2007.06.016



## Theoretical Model: Influence of flock coating on the thermophysiological comfort properties of woven cotton fabric




Measured thermal resistance of flock coated fabrics ($R_{fc}$, m²K/W), thermal resistance of adhesive coated fabric ($R_{ac}$, m²K/W), flock fiber ($R_{fiber}$, m²K/W) and still air ($R_{air}$, m²K/W) thermal resistances.

Predicted (theoretical) thermal resistance ($R_p$, "m²K/W)"

$$\boxed{R_p = R_{ac} + 1/\left({(1-\varepsilon_r)}/{R_{fiber}} + {\varepsilon_r}/{R_{air}}\right)}$$

$\varepsilon_r$ : It is the ratio of the air volume to the fiber volume in a volume shown in color in the figure. This value, defined as the air-fiber ratio, gives the volume ratio occupied by the air and (1- $\varepsilon_r$) is the volume ratio occupied by the flock fibers.

$$n, (flok/mm^2) = \frac{(M_{fc} - M_{ac})}{D \times l \times 10^{-1}}$$

- $M_{ac}$, (g/m²) ve $M_{fc}$, (g/m²) The values are the weight of adhesive coated and flock coated fabric respectively,
- D, (dtex) linear fiber density,
- l (mm) flock length.

$$\varepsilon_r = \left(1 - \frac{M_{fc} - M_{ac}}{(t_{fc} - t_{ac}) \times \rho_{flock} \times 10^3}\right)$$

($\lambda_{fiber}$) The value was taken as 0.25 W/mK (Morton ve Hearle 2008, s. 173).

$P_{flock}$, (g/cm³) is the flock fiber density. The density of nylon flock fiber is taken as 1.14 g/cm³. (Morton ve Hearle 2008, s. 165).

$$R_{fiber} = \frac{(t_{fc} - t_{ac}) \times 10^{-3}}{\lambda_{fiber}}$$

relative error in the prediction (ΔR)

$R_{air}$, m²K/W, (M Matusiak 2006) and (ISO 6946:2017) obtained by linear interpolation as described in references.

$$\Delta R = \frac{R_{fc} - R_p}{R_p}$$

## Experimental Results: Control Group (Only Adhesive Coated Samples)

### Thermal Properties

| Sample | CR | Thickness ($t$, mm) | Mass per unit area ($M$, g/m²) | Thermal conductivity ($\lambda$, $10^{-3}$ W/mK) | Thermal resistance ($R$, $10^{-3}$ m²K/W) | Thermal absorptivity (b, $Ws^{1/2}/Km^2$) |
|---|---|---|---|---|---|---|
| Ham | | $0.29^1 \pm 0.007$ | $104^1 \pm 0.42$ | $39.09^1 \pm 0.93$ | $7.37^{1,2} \pm 0.12$ | $183.44^1 \pm 3.13$ |
| Adhesive-coated | (L) | $0.29^1 \pm 0.012$ | $112^2 \pm 0.90$ | $39.34^1 \pm 1.31$ | $7.41^2 \pm 0.09$ | $187.44^1 \pm 3.78$ |
| | (M) | $0.29^1 \pm 0.012$ | $120^3 \pm 1.82$ | $39.93^1 \pm 1.10$ | $7.34^{1,2} \pm 0.09$ | $197.11^2 \pm 3.41$ |
| | (H) | $0.31^2 \pm 0.006$ | $148^4 \pm 1.97$ | $42.61^2 \pm 1.06$ | $7.23^1 \pm 0.15$ | $228.67^3 \pm 5.74$ |

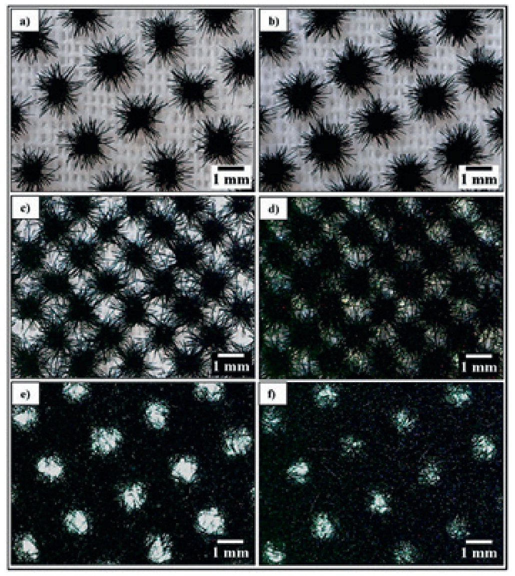
Superscripts indicate the homogeneous subsets of the mean values at the 0.05 significance level.

### Air and Water Vapor Permeability, permeability index

| Sample | CR | Air permeability (mm/s) | Water vapor resistance ($R_{et}$, m²Pa/W) | Relative water vapor permeability ($P_{wv}$, %) | Permeability index ($i_m$) |
|---|---|---|---|---|---|
| Ham | | $656^4 \pm 11.15$ | $2.06^1 \pm 0.36$ | $75.74^3 \pm 2.24$ | $0.22^2 \pm 0.041$ |
| Adhesive-coated | (L) | $563^3 \pm 10.10$ | $1.92^1 \pm 0.28$ | $74.84^3 \pm 0.81$ | $0.24^2 \pm 0.033$ |
| | (M) | $380^2 \pm 10.74$ | $2.46^1 \pm 0.44$ | $69.10^2 \pm 1.56$ | $0.19^2 \pm 0.033$ |
| | (H) | $118^1 \pm 1.870$ | $7.82^2 \pm 0.84$ | $40.82^1 \pm 2.46$ | $0.06^1 \pm 0.006$ |

Superscripts indicate the homogeneous subsets of the mean values at the 0.05 significance level.

## Experimental Results: Flock Coated Sampled (Structural and Thermal Properties)

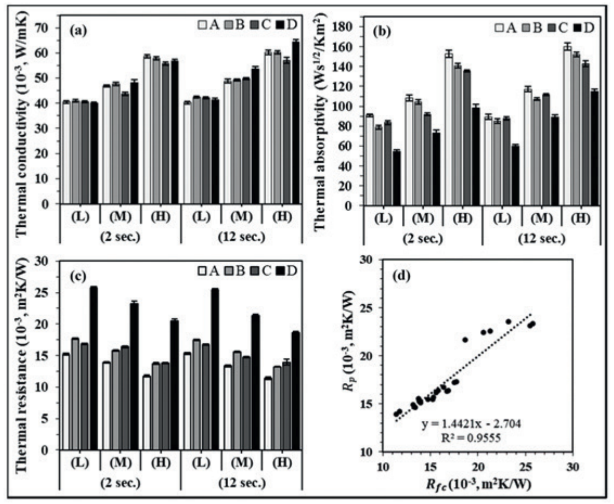



| Sample code (FT-FD-CR) | Thickness ($t_{fc}$, mm) | Mass per unit area ($M_{fc}$, g/m²) | Flock per unit area (n, flock/mm²) | Air-to-fiber ratio ($\varepsilon_r \times 10^2$) |
|---|---|---|---|---|
| A-2-L | 0.62 ± 0.009 | 119.3 ± 0.5 | 202 ± 13 | 98.03 ± 0.13 |
| A-2-M | 0.65 ± 0.006 | 135.6 ± 3.1 | 427 ± 85 | 96.24 ± 0.75 |
| A-2-H | 0.69 ± 0.005 | 187.7 ± 0.8 | 1114 ± 21 | 90.77 ± 0.17 |
| A-12-L | 0.62 ± 0.003 | 118.4 ± 0.5 | 179 ± 14 | 98.27 ± 0.13 |
| A-12-M | 0.65 ± 0.008 | 144.6 ± 1.9 | 679 ± 51 | 94.03 ± 0.45 |
| A-12-H | 0.69 ± 0.009 | 191.7 ± 0.7 | 1225 ± 19 | 89.73 ± 0.16 |
| B-2-L | 0.73 ± 0.013 | 123.6 ± 0.7 | 136 ± 8 | 97.66 ± 0.13 |
| B-2-M | 0.75 ± 0.005 | 148.8 ± 2.2 | 336 ± 26 | 94.56 ± 0.42 |
| B-2-H | 0.80 ± 0.011 | 202.9 ± 1.9 | 651 ± 22 | 90.04 ± 0.33 |
| B-12-L | 0.74 ± 0.009 | 128.3 ± 1.2 | 192 ± 14 | 96.82 ± 0.23 |
| B-12-M | 0.77 ± 0.007 | 156.1 ± 1.5 | 422 ± 18 | 93.34 ± 0.28 |
| B-12-H | 0.80 ± 0.010 | 217.6 ± 2.2 | 824 ± 26 | 87.44 ± 0.39 |
| C-2-L | 0.68 ± 0.007 | 124.0 ± 0.6 | 73 ± 3 | 97.31 ± 0.12 |
| C-2-M | 0.71 ± 0.005 | 135.2 ± 0.5 | 91 ± 3 | 96.88 ± 0.11 |
| C-2-H | 0.77 ± 0.006 | 198.6 ± 2.7 | 309 ± 16 | 90.27 ± 0.51 |
| C-12-L | 0.71 ± 0.005 | 129.6 ± 0.0 | 107 ± 0 | 96.28 ± 0.00 |
| C-12-M | 0.73 ± 0.007 | 157.3 ± 2.2 | 225 ± 13 | 92.63 ± 0.44 |
| C-12-H | 0.80 ± 0.015 | 212.6 ± 1.7 | 394 ± 10 | 88.30 ± 0.30 |
| D-2-L | 1.03 ± 0.003 | 124.5 ± 1.0 | 38 ± 3 | 98.52 ± 0.11 |
| D-2-M | 1.12 ± 0.003 | 151.8 ± 4.9 | 96 ± 15 | 96.65 ± 0.52 |
| D-2-H | 1.17 ± 0.003 | 212.2 ± 4.7 | 196 ± 14 | 93.41 ± 0.48 |
| D-12-L | 1.05 ± 0.010 | 131.7 ± 1.3 | 60 ± 4 | 97.73 ± 0.15 |
| D-12-M | 1.15 ± 0.005 | 176.1 ± 4.1 | 169 ± 12 | 94.26 ± 0.42 |
| D-12-H | 1.20 ± 0.007 | 240.1 ± 1.9 | 280 ± 6 | 90.92 ± 0.18 |

Top view of samples coated with Type D flock fiber (black color). a, b: Low, c, d: Medium, e, f: High coating rate. Flocking time for a, c, e is 2 seconds, for b, d, f is 12 seconds.

The results show that thickness, weight, and flock fiber content per unit area increase with the coating rate and flocking time, while the air-to-fiber ratio decreases.

The only exceptions to this were Type A flock-coated samples at low coating rates. The effect of flocking time on the structural properties of samples A-2-L and A-12-L was statistically insignificant.




a) Thermal conductivity -λ,
b) Thermal absorptivity-b,
c) Thermal resistance ($R_{fc}$),
d) Plot of predicted ($R_p$) vs. measured ($R_{fc}$) thermal resistance.

Thermal conductivity is inversely proportional to the air-to-fiber ratio, with a high and negative Pearson correlation coefficient of -0.92.

Flock coating reduces the thermal absorbency of the raw fabric, providing a "warm" feel. This result is consistent with the decreased thermal absorbency in raised fabrics (Gunesoglu et al. 2005).

Compared to the raw fabric thermal resistance, A flock type and D flock type coating provided on average 82% and 204% higher thermal resistance values, respectively.

With D fiber, thermal resistance increased by 249% with a maximum fabric mass increase of 20% compared to the base fabric.

While the thickness increases by 14% with the coating ratio, the thermal conductivity increases by 49%. Thus, the Pearson correlation coefficient was found to be 0.76 although the correlation of thermal resistance with thickness is expected to be high.



## Theoretical Model: Flock Coated Sampled (Thermal Properties)

| Sample code (FT-FD-CR) | $R_{ac}$ (10⁻³, m²K/W) | $\left(\frac{1-\varepsilon_r}{R_{fiber}}\right)$ | $\left(\frac{\varepsilon_r}{R_{air}}\right)$ | $R_p$ (10⁻³, m²K/W) | $R_{fc}$ (10⁻³, m²K/W) | $\Delta R \left(\frac{R_{fc}-R_p}{R_p}\right)$ |
|---|---|---|---|---|---|---|
| A-2-L | 7.33 | 15.61 | 107.03 | 15.484 | 15.211 | -0.018 |
| A-2-M | 7.33 | 26.80 | 97.79 | 15.356 | 13.889 | -0.096 |
| A-2-H | 7.33 | 59.18 | 85.73 | 14.231 | 11.756 | -0.174* |
| A-12-L | 7.33 | 13.54 | 106.56 | 15.657 | 15.333 | -0.021 |
| A-12-M | 7.33 | 42.35 | 95.34 | 14.593 | 13.356 | -0.085 |
| A-12-H | 7.33 | 66.61 | 85.43 | 13.907 | 11.411 | -0.179* |
| B-2-L | 7.33 | 13.75 | 86.65 | 17.290 | 17.722 | 0.025 |
| B-2-M | 7.33 | 30.02 | 80.11 | 16.411 | 15.822 | -0.036 |
| B-2-H | 7.33 | 50.13 | 71.26 | 15.568 | 13.744 | -0.117* |
| B-12-L | 7.33 | 17.90 | 83.38 | 17.203 | 17.511 | 0.018 |
| B-12-M | 7.33 | 35.75 | 77.54 | 16.157 | 15.578 | -0.036 |
| B-12-H | 7.33 | 63.09 | 69.08 | 14.896 | 13.211 | -0.113* |
| C-2-L | 7.33 | 17.49 | 92.84 | 16.393 | 16.856 | 0.028 |
| C-2-M | 7.33 | 18.83 | 87.61 | 16.724 | 16.389 | -0.020 |
| C-2-H | 7.33 | 51.87 | 74.59 | 15.238 | 13.822 | -0.093 |
| C-12-L | 7.33 | 22.89 | 88.26 | 16.327 | 16.733 | 0.025 |
| C-12-M | 7.33 | 42.38 | 80.96 | 15.437 | 14.733 | -0.046 |
| C-12-H | 7.33 | 58.88 | 69.88 | 15.096 | 13.967 | -0.075 |
| D-2-L | 7.33 | 5.06 | 57.49 | 23.318 | 25.789 | 0.106* |
| D-2-M | 7.33 | 10.24 | 51.35 | 23.569 | 23.222 | -0.015 |
| D-2-H | 7.33 | 18.95 | 47.22 | 22.442 | 20.556 | -0.084 |
| D-12-L | 7.33 | 7.54 | 55.71 | 23.140 | 25.467 | 0.101* |
| D-12-M | 7.33 | 16.95 | 48.70 | 22.563 | 21.300 | -0.056 |
| D-12-H | 7.33 | 25.16 | 44.52 | 21.681 | 18.667 | -0.139* |

*: where the absolute prediction error is more than 10%.

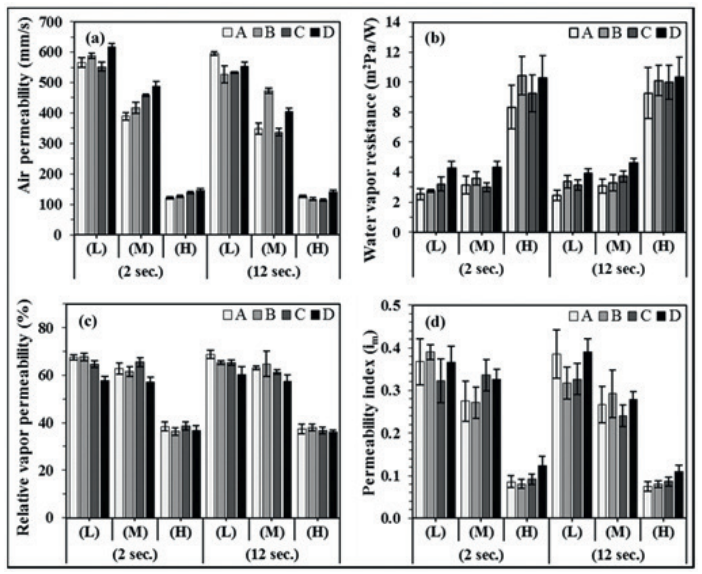
Measured thermal resistance values ($R_{fc}$), predicted thermal resistance ($R_p$) and its components and prediction error (ΔR).

For all fiber types, prediction errors reach their highest absolute negative value at high coverage ratios.

A negative prediction error indicates that the measured thermal resistance is lower than predicted.

It is plausible that some degree of air convection occurs because of the three-dimensional, rather than two-dimensional, structure of the flocked surface. Work on electrostatically producing flocked fin thermal interface materials confirms this idea (Seaman et al. 1999).

## Experimental Results: Flock Coated Sampled (Air, Water Vapor Permeability and Permeability Index)…




a) Air permeabilitiy –(mm/s), b) Water vapor resistance (m² Pa/W),
c) Relative water vapor permeabilitiy (%) , d) Permeability index ($i_m$)

Seaman, C. L., Ellman, B. M., & Knowles, T. R. (1999). Enhanced thermal conductance of ORU radiant fin thermal interface using carbon brush materials. AIP Conference Proceedings, 458, 565–571. https://doi.org/10.1063/1.57622
Stoffberg, M. E., Hunter, L., & Botha, A. (2015). The effect of fabric structural parameters and fiber type on the comfort-related properties of commercial apparel fabrics. Journal of Natural Fibers, 12(6), 505–517. https://doi.org/10.1080/15440478.2014.967370

The coating ratio is the most important parameter on air and water vapor permeability properties. It is observed that the average water vapor permeability values are lower than those of adhesive coated samples at the same coating rate. Longer flock (D) coating provided lower relative water vapor permeability and higher water vapor resistance.

At high coverage rates, the effect of fiber type disappears. This result is due to the fabrics becoming impermeable and water vapor diffusion being suppressed at high coverage rates.
It was confirmed that the effect of fiber type was not statistically significant on the relative water vapor permeability and water vapor resistance of highly coated samples with p values of 0.196 and 0.108, respectively.

The permeability index appears to decrease with increasing coating ratio, as thermal resistance (R) decreases and water vapor resistance (Ret) increases.

$$\mathbf{i_m = 60.06\times(R/R_{et})}$$

The high correlation coefficient of 0.99 between air permeability and permeability index is consistent with the literature (Stoffberg et al. 2015).

Unlike water vapor resistance and relative water vapor permeability, fiber length is observed to be important for the permeability index at high coverage rates. Type D flock-coated samples provide at least 27% higher permeability index at high coverage rates.

## Summary

- The results show that the amount of fiber per unit area and fabric thickness increase with the coating rate and flocking time, but the air-fiber ratio decreases.
- Thermal conductivity and thermal absorptivity were found to be inversely proportional to the air-to-fiber ratio, with correlation coefficients of -0.92 and -0.91, respectively. Flock-coated fabrics were found to provide lower thermal absorptivity and a "warmer" feel.
- Thermal resistance is directly proportional to thickness, with a correlation coefficient of 0.76. The relatively lower correlation was found to be due to an increase in thickness with a decrease in the air-fiber ratio.
- Short and long flock fibers provided 82% and 204% higher thermal resistance, respectively.
- The thermal resistance mathematical model results were found to be in good agreement with the actual values with a correlation coefficient of 0.95.
- It was found that for long flock fibers, the mathematical model could be improved by including heat loss by convection.
- The most significant finding is that thermal resistance increases from higher to lower flock coatings. This may be beneficial in the production of light-weight cold-weather garments.
- A maximum thermal resistance increase of 106% was achieved with type A flock fiber and a maximum relative water vapor permeability of 67%. A maximum thermal resistance increase of 248% was achieved with type D flock fiber and a maximum relative water vapor permeability of 57%.
- While the fiber type is unimportant at low and medium coverage rates according to permeability index values, it is observed that long flock fiber is advantageous at high coverage rates.
- As a result of the findings, it is thought that partial flock coating is applicable to sportswear and cold weather clothing.
- It should also be noted that the application of flock coating with modified adhesives (Shaid et al. 2016) can improve protective clothing performance (Y. Kim et al. 2002) (Song 2007).

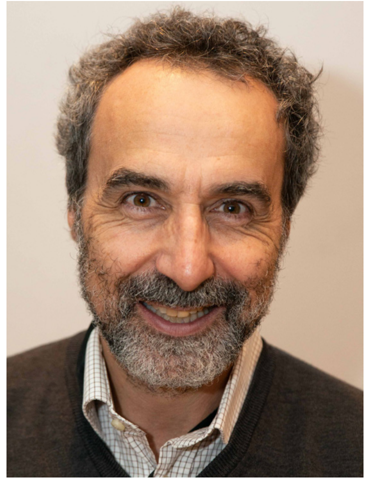
Shaid, A., Wang, L., Padhye, R. 2016. The thermal protection and comfort properties of aerogel and PCM-coated fabric for firefighter garment. Journal of Industrial Textiles, 45(4):, 611–625.
Kim, Y., Lee, C., Li, P., Corner, B. D., Paquette, S. 2002. Investigation of air gaps entrapped in protective clothing systems. Fire and Materials, 26(3):, 121–126.
Song, G. 2007. Clothing Air Gap Layers and Thermal Protective Performance in Single Layer Garment. Journal of Industrial Textiles, 36(3):, 193–205.



# NOTES

Flock Association
of Europe

# 4. Beyond Flocking: From What Exists to What's Possible: From Sensory Finish to Measurable Material System



**Alberto Sadun**
AIGLE MACCHINE SRL

Alberto Sadun was born on 1966. He studied economics at the University of Florence and worked for a while in England. Since 1995 he works for AIGLE SRL and is shareholder and managing director of the company. His main tasks are sales & marketing and developing innovative products.

Aigle is one of the leading companies in manufacturing flocking and coating plants. Flocking has been part of Aigle's culture for the last 65 years.

In the last years Aigle has developed new technical solutions for flocking automotive profiles, 3D objects and roll to roll.

## Abstract

Flocking has been widely used as a surface finishing technology for decades across multiple industrial sectors. Despite its diffusion and functional relevance, its adoption in engineering-driven applications could be expanded. One reason for some engineering driven miss -application could the lack of clearly defined and standardized performance parameters.

This lecture explores whether the creation of standard and recognized values of key technical characteristics – such as abrasion resistance, light resistance, lifetime, fibre loss, and operational temperature range – expressed through measurable and comparable ranges, could significantly expand the range of applications of flocking technology.

By analyzing current industrial practices, particularly within the automotive sector, and reviewing existing scientific standards, the study proposes a structured classification system – referred to as Flocking Performance Classes – aimed at transforming flocking from a finishing process into a defined engineering material system.



## 1. INTRODUCTION

Flocking is traditionally appreciated for its tactile, aesthetic, and functional qualities. The perception of softness, surface uniformity, and visual refinement has historically guided its adoption in applications ranging from fashion to automotive interiors.

In addition, its functional properties have enabled its use in technical sectors such as noise reduction, medical applications, and specialized coatings.

Despite these advantages, flocking is rarely treated as a fully defined engineering material. Its selection is often based on qualitative perception rather than quantifiable performance criteria. This might represent a limitation for its broader industrial adoption.

## 2. INDUSTRIAL CONTEXT AND CHALLENGES

### 2.1 Industrial Decline and Market Pressure

In Europe, parts of the flocking industry – particularly in the textile and fashion sectors – have experienced a gradual decline in industrial relevance.

This trend is driven by:
- increasing production costs
- regulatory constraints
- reduced margins
- progressive loss of specialized expertise

As a consequence, flocking is often perceived as a secondary or niche process rather than a strategic manufacturing technology.

### 2.2 Competition from Alternative Materials

At the same time, alternative materials – such as advanced polyester microfibres widely introduced into textile market – have reached high levels of performance in terms of:
- tactile quality
- visual consistency
- durability
- cost efficiency

These materials can replicate several characteristics traditionally associated with flocked surfaces, especially when performance parameters are clearly defined.

### 2.3 Innovation Gap

Despite its potential, flocking has shown limited structured innovation in recent years, both in:
- fashion applications
- technical developments

This contributes to reduced industrial attractiveness and limited technological evolution.

## 3. TECHNICAL LIMITATIONS

Several technical challenges continue to affect flocked surfaces, especially for the extra-European productions:
- fibre loss over time
- surface defects (e.g. craters, uneven distribution)
- edge effects and process variability

These factors can impact repeatability and performance consistency, particularly in demanding applications.

## 4. AUTOMOTIVE INDUSTRY PERSPECTIVE

The automotive sector provides a relevant framework to understand how flocking is currently evaluated.
Different OEMs adopt different approaches:
- Stellantis: flocking is evaluated at component level and not defined as a standalone material
- Volkswagen Group: partial integration within structured coating systems
- Tesla: extensive functional use (e.g. noise reduction), but without formal standardization
- Chinese OEMs: rapid industrial application driven by efficiency rather than formal frameworks

Despite these differences, a consistent observation emerges: Flocking is not defined as a standalone engineering material in any major automotive specification system.

## 5. EXISTING SCIENTIFIC STANDARDS

All relevant performance parameters of flocked materials are already measurable using established scientific standards related to automotive sector.
These include:
- Abrasion resistance (SAE J1530, ISO 12947)
- Fibre loss (SAE J1530)
- Adhesion strength (ASTM D903)
- Light resistance (SAE J1885, Xenon Arc)
- Thermal resistance (OEM climatic cycling tests)
- Flammability (ISO 3795)
- Emissions (VOC, ISO 12219)

These methods are reproducible, quantifiable, and widely accepted in engineering practice.

## 6. THE MISSING ELEMENT

We wonder if the creation of common standard of technical performance parameters could help flock industry to find more possibilities uses. Technical decision makers in front of clear and achievable standards that the flock technology should reach could be more confident to use flock. This principle could be extended in the wide range of sectors in which flock technology could be used.

The absence of flocking standardization does not originate from a lack of measurement capability.
Rather, it derives from the absence of:
- a unified framework,
- a structured classification system
- a shared technical language

Currently, parameters are applied individually, with lack of integration into a coherent system.



## 7. PROPOSED FRAMEWORK: FLOCKING PERFORMANCE CLASSES

To address the identified gap, this work proposes the introduction of a structured classification framework based on existing, widely accepted test methods. The proposed system – referred to as Flocking Performance Classes (FPC) – is built on a set of key measurable parameters:
- F-A: Abrasion resistance
- F-FL: Fibre loss over time
- F-AD: Adhesion strength
- F-L: Light resistance
- F-T: Thermal resistance

Each parameter is classified into performance levels (for example, from Class 1 to Class 4), defined through measurable and reproducible ranges derived from existing standards. The objective of this framework is not to introduce new testing methodologies, but to structure and integrate existing measurements into a coherent and usable system.

## 8. FROM QUALITATIVE PERCEPTION TO ENGINEERING SPECIFICATION

The adoption of Flocking Performance Classes would enable a clear transition from subjective description to technical specification. Currently, flocked surfaces are often defined using qualitative terms such as:
- soft
- durable
- uniform

Within the proposed framework, these descriptions can be replaced by structured coding, for example:
F-A3 / F-FL2 / F-AD3 / F-L3 / F-T2

This approach allows:
- objective comparison between materials
- integration into engineering specifications
- improved communication between suppliers and OEMs
- higher reproducibility across different production environments

## 9. INDUSTRIAL AND ENGINEERING IMPLICATIONS

The introduction of a standardized classification system for flocking could have several direct industrial impacts:

**Design integration**
Flocking becomes a selectable and specifiable element within engineering design processes.

**Risk reduction**
Defined performance ranges reduce uncertainty and variability.

**Industrial consistency**
Standardized parameters improve repeatability across suppliers and production sites.

**Application expansion**
New technical applications become accessible once performance is clearly defined and comparable.

In this perspective, flocking shifts from being a finishing process to becoming a defined and engineerable material system.

## 10. CONCLUSION AND PROPOSAL

Flocking is a mature and versatile technology, already capable of delivering both functional and aesthetic performance across a wide range of industrial applications.

All relevant performance characteristics are measurable using existing and well-established scientific standards.

However, its industrial potential remains partially unexpressed due to the absence of a structured and shared engineering framework.

This work proposes the introduction of Flocking Performance Classes as a practical and immediately applicable solution. This proposal does not require the development of new technologies or new testing methods. Instead, it requires:
- the formalization of measurable parameters
- the integration of existing standards
- the adoption of a common technical language

Such a framework could enable:
- comparability across suppliers
- integration into OEM specifications
- increased confidence among technical decision makers
- expansion into new industrial applications

In this context, the future development of flocking may not depend on technological disruption, but rather on its redefinition as an engineering material.

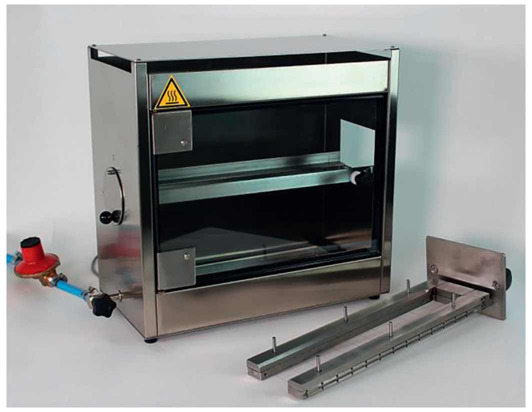
Once performance parameters are structured, classified, and communicated in a consistent way, flocking can move beyond perception-driven evaluation and fully enter the domain of engineering design.

Abrasion Tester

Fluorescent UV Lamp Weathering Test Chamber

Temperature Cycle Testing Chamber


Textil Fabric Martindale Abrasion Tester



Horizontal Flammability Tester for Automotive Interior



# 5. Flocking is always a good idea...

**DIPL. ING. (FH) ULRICH BÜTTEL**
BUE-ENGINEERING

Ulrich Büttel studied mechanical engineering at Reutlingen University. After working as a freelance design engineer for several years, he and a partner founded an engineering company, Büttel und Marx GmbH, which specializes in the development and manufacture of automated special machines.

At the end of 1998, Mr. Büttel took over shares in Maag Flockmaschinen GmbH, which he managed as managing director from 2000 to 2020. Since the end of 2020, Mr. Büttel has been working as a freelance engineering service provider and consultant for the flocking technology, machine safety and explosion protection.

Mr. Büttel is an active member of the German Committee DKE K 239 for the standardization of electrostatic spraying equipment.

## FOREWORD

Flocking involves applying fibers to a surface coated with adhesive. This is done mechanically by sprinkling, blowing, shaking, or, if maximum density or vertical alignment of the fibers is required, with the aid of an electric field. Once the adhesive has dried, the flocked surface is ready for use.

The origins of 'flocking' date back to the Middle Ages. At that time, paper was coated with resin and sprinkled with fibers to be used as wallpaper. The first electrostatic 'flocking' was used in the 1930s to manufacture sandpaper. The hard material particles are aligned by high voltage and shot into the adhesive.

Detail of a flocked doormat

Flock fibers can be made from a variety of materials. Depending on the material, this can produce very different mechanical or physical effects in addition to an attractive look and feel.

The possible applications for flocked surfaces are diverse and always exciting. Over the past few decades, a wide variety of product ideas have been developed using flock and put into practice. Many flock applications in the textile and automotive sectors have become an integral part of everyday life. But not every idea has been a success.

Flocking has evolved from the visual enhancement of surfaces, which was common in the past, to many technical applications. The presentation will provide an overview of the properties and possible uses of flocking - from established applications to exotic and other flashes of inspiration.

# 1. How does Flock work?

Flocking can generally be applied to all surfaces and materials on which adhesive can adhere sufficiently.

To do this, these surfaces must be stable, clean and free of grease and release agents. This is achieved through suitable pre-treatment, such as mechanical roughening, application of primer, flaming, corona treatment, plasma treatment, or fluorination. Flocking follows the shape of the surface coated with adhesive and can be applied over the entire surface or only in certain areas.

Flocking can be carried out either electrostatically or electrostatically-pneumatically, depending on the geometry of the workpiece to be flocked.

Picture of section cleaning pad and cosmetic tip

### 1.1 Electrostatic flocking

The simplest solution is to dispense the flock into a high-voltage field using a hand-held device and an applicator. The fibers are accelerated by the electrostatic field forces and shot into the adhesive layer in an aligned manner.

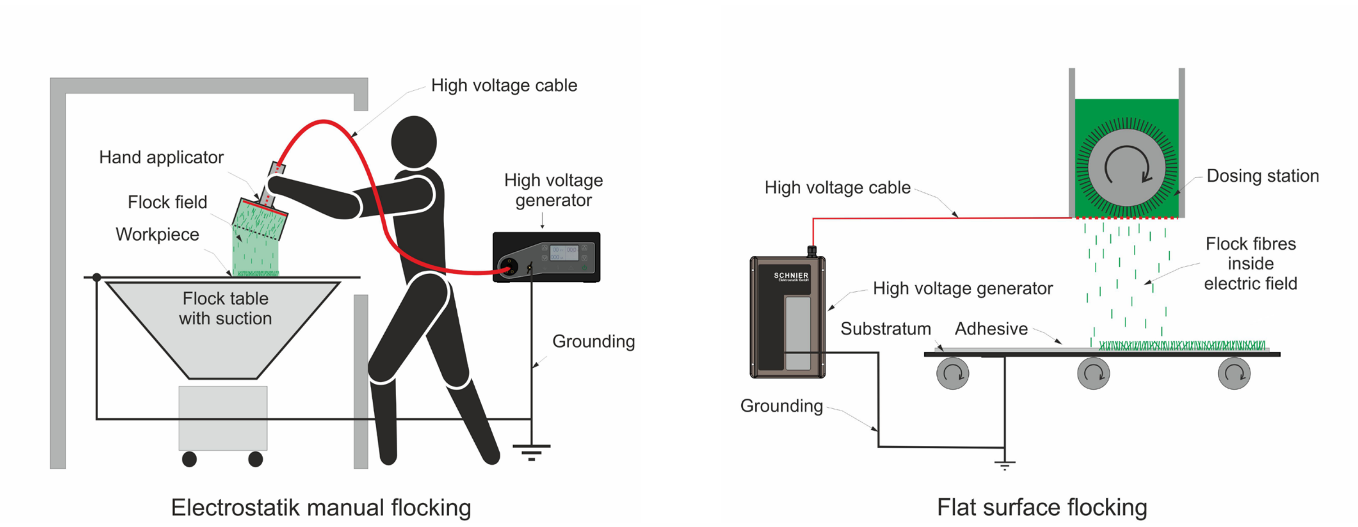



Illustration of Manual and automatic electrostatic flocking

For larger production volumes, an automated process such as a continuous flow system is recommended. Important process parameters such as dosing rate and field strength are stored in a reproducible manner.



### 1.2. Elektrostatic-Pneumatic flocking

As soon as recesses or undercuts are to be flocked, the flock must be applied electrostatically-pneumatically. This can also be done with a hand-held device or by means of a continuous system.

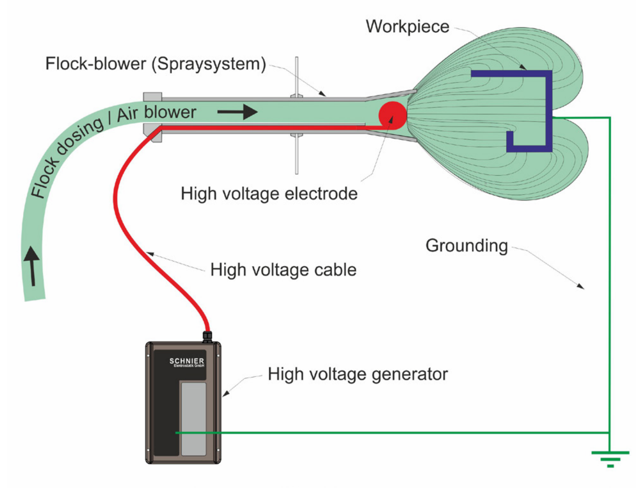



Illustration of electrostatic-pneumatic flocking

With the support of directed air flow, the fibers are also moved into the depth of the component and align themselves there.

### 1.3 The vacuum flocker – unfortunately a flop

The idea seemed promising: Vacuum flocking eliminates air resistance, allowing the lightweight flock fibers to move faster and penetrate deeper into the adhesive.

A prototype flocking machine based on this principle was built and failed during the very first test. The reason was that the dielectric strength of air decreases significantly in a vacuum, causing the high voltage at the flock dosing unit to collapse immediately. However, without high voltage, no advantage can be achieved for flocking. It remained at this one prototype...

# 2. Materials required

The substrate, adhesive, and flock must be adjusted as a system in order to achieve the optimum utility value of the flocked surface.

### 2.1 Adhesive

The adhesive is the link between the substrate and the flock coating. It not only holds the fibers in place but must also be tailored to the subsequent use.

The adhesive should be applied in as even a layer as possible. A guideline is a layer thickness of the dried adhesive of 10% of the flock fiber length. This ensures that the fibers are optimally and resiliently anchored in the adhesive. The adhesive can be applied either over the entire surface or partially, by hand or automatically. Common methods of applying adhesive are brush application, spraying, rolling, squeegeeing, or dipping.

Common types of adhesives are water-based dispersions or solvent systems. Plastisols, light-curing adhesives, or ceramic binders are also used for special applications.

### 2.2 Flock

Flock is available as cut flock or ground flock in different materials, fiber strengths, cut lengths, and finishes. Common flock materials are:

- Synthetic fibers made of polyamide, polyester (for automotive parts and profiles)
- Organic fibers made of rayon, cotton (for textile applications and household use)

Common cut lengths for flock fibers range from 0.3 to 4 mm, depending on the titer, which is usually between 0.9 and 22 dtex.

However, flock can also be made from other materials:

- Fibers made from Kevlar, aramid (for higher temperatures and abrasion resistance)
- Fibers made from carbon (for conductivity and higher temperatures)
- Fibers with a silver-plated surface (antibacterial and high conductivity)
- Fibers with a bioactive surface (for better cell growth on flocked surgical implants)
- Leather grinding dust to create a suede-like surface
- Or graphite flakes for coating bitumen sheets as fire protection

But not everything makes sense:

- For example, stainless steel flock to produce insulation sheet metal panels. The aim here was to achieve the lowest possible weight and good thermal insulation using a composite of two layers of thin stainless-steel sheet with a web connection made of stainless-steel flock. The result was of little technical benefit, but it was priceless. In addition, risks for operators during processing were identified. The flock fibers had sharp cutting edges that could penetrate the skin.
- In contrast, the uniform coating of potato chips with spice mixtures in a flocking system was almost a serious application.

## 3. Fields of application

Flocking has developed from the previously widespread practice of visually enhancing surfaces to many technical applications. But not every idea has been a success.

### 3.1 Appearance - because it simply looks better

The classic - Flocking makes surfaces appear more valuable. Flocking can be applied to the entire surface or partially, in one color or multiple colors. Further finishing touches are possible, such as laser marking or foil embossing.

Examples include:

- Fabrics, clothing, furniture upholstery, curtains, wallpaper, floor coverings
- Interior parts in vehicles, trim parts, wall panels
- Graphic printing, postcards, calendars, packaging
- Ceramics, glasses, stainless steel drinking vessels, tableware
- Exhibition aids, busts, heads, mannequins, model making
- Decorative materials, flocked Christmas trees, brushwood, plants
- Artificial beards and hair growth for make-up artists
- Flocked fingernails as eye-catchers and 3D fashion effects
- Decoy ducks, pigeons, and geese are flocked to make them appear more lifelike and thus improve their decoy effect

Pictures of flocked PVC shoe and jewelry box



### 3.2 Haptics - because it simply feels more pleasant

The vertical orientation of the fibers results in a velvety surface. Depending on the type of flock used, the surface can be adjusted from soft to hard and bristly. Short fibers tend to feel harder than long fibers.

Examples include:

- Packaging for high-quality or sensitive products
- Cell phone cases, small appliances, toys
- Helmet shells for skiing, riding, and motorcycle helmets
- Orthoses, surfaces that come into contact with the body
- PVC shoes, rubber gloves, shoe insoles
- Costume jewelry, rings, imitation suede, imitation fur

**Curious fact:** Flocked fishing lures are said to be better suited for catching squid due to their slimy surface. The side effect was that scents and attractants remained on the lure longer.

### 3.3 Avoiding noise

The flocking acts as a cushioning layer. Moving parts do not rattle or run more smoothly. At the same time, the flocking protects parts from scratching.

Examples include:

- Glove compartments, storage compartments, belt sliders, and adjustment elements
- Flexible shafts, torsion bars, compression and tension springs
- Guide profiles and tubes for cables
- Furniture or dish inserts, packaging boxes
- Guide rails and profiles in furniture construction, moving elements

Picture of flocked eyeglass compartment

**Curious fact:** During most series production runs of new car models, ‘rattling points’ subsequently arise, which can usually be eliminated with a piece of flocked adhesive tape.

### 3.4 Light and sound refraction

Light and sound waves are refracted multiple times by the flocking, thereby minimizing their intensity. At the same time, a flocked surface calms the contact surface when gas or liquid flows around it and prevents noise.

Examples include:

- Noise-absorbing interior coating of fan housings or engine cover parts
- Sound-absorbing acoustic elements in interiors or office spaces
- Microphone protection to prevent wind noise
- Flocked player numbers on sportswear to prevent reflections during filming
- Prevention of stray light through internally flocked housings of high-quality film cameras

**Unusual:** Attempt to flock the outside of boat hulls to reduce ‘friction losses’ to the water and thus lower fuel consumption.

Pictures of flocked engine cover and sportswear

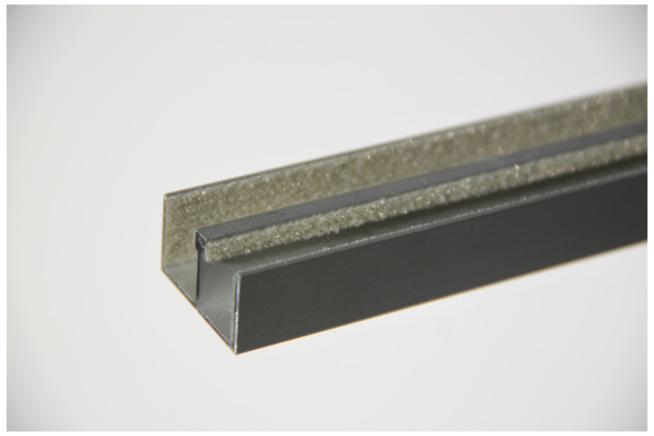
### 3.5 Sliding effect or damping

Flocking can be used to influence the sliding behavior of two surfaces in relation to each other. The surfaces only touch each other via the tips of the fibers. This reduces friction. However, if both surfaces are flocked, it is no longer possible to move them.

Examples include:

- Rubber profiles in vehicles prevent windows from freezing in winter
- Aluminum profiles in furniture construction enable smooth, gentle movement
- Gentle, smooth movement of the jigsaw foot on workpiece surfaces
- Quick and non-slip installation of flocked floor panels at trade fairs

**Somewhat exotic:** Overload protection or torque limitation through flocked coupling elements. The break-away torque can be determined by selecting a suitable flock pairing.



Pictures of flocked rubber and aluminum profiles

### 3.6 Non-slip surface

Flocking with high-titer, short-cut flock types create a surface with excellent grip. Flocking allows a higher torque to be transferred from hand to tools, for example. A secure grip is guaranteed even with dirty or greasy hands.

Examples include:

- Better grip with flocked screwdriver handles
- Flocked vibration conveyors gently transport small parts
- Flocking touring skis with long fibers, high titer, and subsequent rolling in one direction enables uphill climbing without slipping back. Fur coatings were typically used for this purpose.



**Something a little bizarre:** Flocking the handles of military handguns to ensure a secure grip even with sweaty hands.

Pictures of flocked screwdriver handles

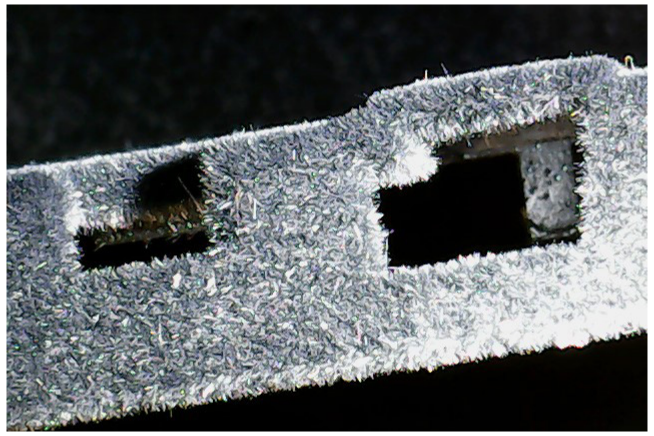
### 3.7 Compensation for tolerances

Flocking acts as the perfect gap filler. In addition to compensating for gaps, flocking prevents unnecessary rattling. Flocking can either be applied directly to the component or as tape that can be stuck to the required areas.

Examples include:

- Flocking ensures that interior parts in motor vehicles fit perfectly to the next contact surface
- Construction parts for blinds or shading elements in motor vehicles and building technology run more smoothly and without play thanks to the flocked contact surfaces
- Flocking of self-adhesive tape for sticking in areas where direct flocking for tolerance compensation is not possible

**Somewhat exotic:** Flocking of rotating shafts on control elements that are installed without bearings and are operated with only slight movement



Pictures of flocked  housing part and screws

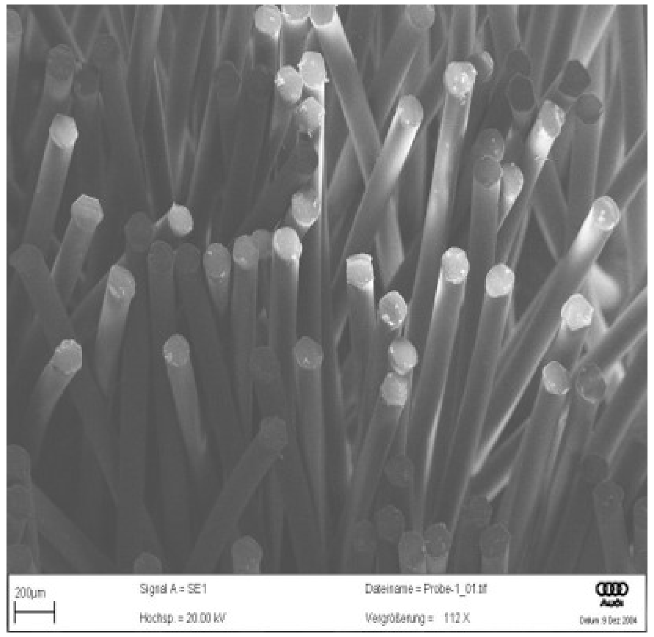
### 3.8 Insulationg surfaces

Flocking covers only approx. 10% of the flocked surface; the calm air between the fibers has an insulating effect. Flocking the opposite side of cold surfaces shifts the dew point and minimizes condensation. Flocking hot surfaces prevent burns on skin contact and frostbite on cold surfaces.

Examples include:

- Flocking the inside of boat hulls, caravan parts, snow groomer cabins, and construction machinery prevents condensation when outside temperatures are cold.
- Flocked cover parts on photocopiers and sauna heaters prevent burns on skin contact.
- Externally flocked microwave dishes prevent burns when touched
- Handles on pneumatic tools are flocked to insulate against the cold

**Somewhat exotic:** With appropriately equipped fibers, flocked surfaces can be created that slow down the spread of fire and protect underlying surfaces.




Pictures of flocked surface with approx. 10% flock coverage

**3.9 Functional surfaces**

Suitable flock fibers can be used to create highly effective cleaning systems. Typical applications include door-mats and carpets. Partially flocked cleaning cloths or sponges can remove even stubborn dirt.

**3.10 Absorption/release of moisture**

Depending on the flock material used, the flocked surface can absorb and store different amounts of liquid. Organic fibers are therefore often used to flock the inner surface of rubber gloves to minimize perspiration and thus increase wearing comfort. The same applies to the flocking of orthoses and medical aids.

**3.11 Depot function**

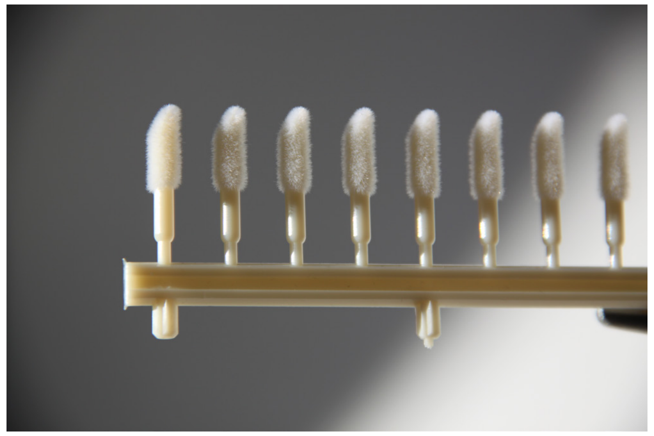
The free space of at least 90% between the flock fibers can be used as a reservoir for many substances. Flocked cannula ends for applying dental primer also serve as micro brushes.

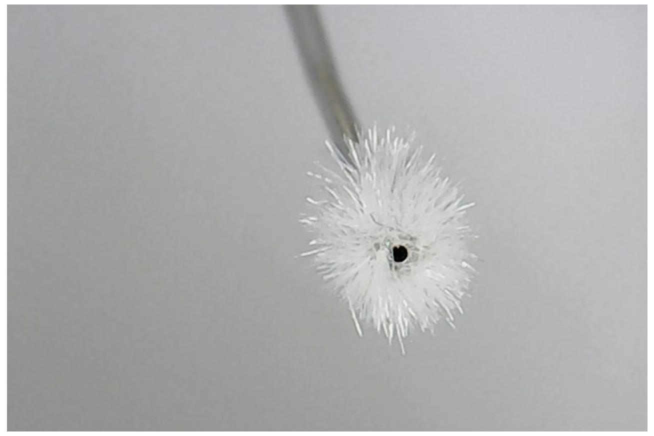
Examples include:

- Paint rollers, paint application systems, and foam pads hold more paint due to the flocking and distribute it better on the surface to be coated
- Even distribution of cosmetics thanks to flocked foam pads
- Depot effect on lubricated surfaces with grease
- Abrasive carriers and polishing discs hold the hard material emulsion or grinding paste thanks to the flocking



**Current news:** Flocked spatulas or sticks are also popular for taking saliva samples, known as corona swabs.





Pictures of flocked cosmetic swabs and cannula outlet

**3.12 But there's more**

There are no limits to the imagination...

Examples include:

- Flocked polystyrene parts in interior design combine with the stucco applied later to form a resilient surface
- Boat hulls and aquaculture nets are flocked to prevent the growth of algae, mussels and other organisms
- Flocking to increase the filter area for better microbiological growth or as an active ingredient depot
- Surface enlargement of active areas on catalysts by flocking with metallized flock
- The surface of drill pipes was experimentally flocked on the inside to extract drilling mud as sample material. The experiment remained just that.

## 4. Variants of flocking

It doesn't always have to be direct flocking.

**4.1 Transfer-flock**

Flocked transfer foils can be used for the subsequent decoration of flat or cylindrical workpieces. Pre-made transfers such as logos or numbers are ironed onto the textile or molded part. Transfers can be purchased externally from specialist companies. How does it work?

1. Flock transfers are manufactured by specialist companies according to customer requirements and can be purchased as rolls, sheets, or cut-to-size pieces.
2. For “flocking,” the transfer is placed with the hot melt side facing the product and ironed on with pressure and heat.
3. After the hot melt has cooled, the carrier foil with the dissolving adhesive is peeled off the transfer.
4. A clean, ready-to-use flock surface remains on the product. Suitable for single or multi-color subse-quent decoration of textiles, flat parts, or cylindrical bodies. Cost-effective process for customizing small series (e.g., team soccer jerseys with consecutive back numbers).

Pictures of removing the transfer foil from a mouse rug

### 4.2 In-Mould-Flocking

It couldn't be any faster...
Flocked films can be used for in-mold decoration. Pre-cut pieces of flocked film are placed in the injection mold and then back-injected with plastic. This is currently the only reliable method for producing multi-colored flocked plastic parts in a single step. How does it work?

1. In an upstream process, a carrier film is flocked with the desired design and flock and then punched. This is usually done by suppliers.
2. The blank is then placed in the open injection mold and back-injected with plastic.
3. After the plastic part is removed from the injection mold, the flocked surface is ready for use and free of residual flock.

The process is demanding and the prefabrication of the blanks is expensive. Therefore, this solution is usually only suitable for medium-sized parts – and for small series.

Picture of Interior part with in-mold decoration

## 5. Requirements and solutions

The requirements for flocked surfaces are diverse. An important property, abrasion resistance, is ensured by the fact that each fiber is deeply anchored in the adhesive. Depending on the application, other requirements include light and temperature resistance or chemical resistance.

But challenges can be overcome: Flocking functional ceramics such as cups, microwave dishes, or glasses? That's not possible, right? An idea for individual pieces turned into an entire product series (Kahla "Touch")! The flocking was certified by Rosenthal with 1,000 washing machine cycles without significant abrasion or color changes. It's worth trying out new product ideas with Flock!


Picture of flocked Kahla "Touch" mug



# IMPRINT

Flock Association of Europe

### 28TH INT. FLOCK SYMPOSIUM

**Organizer**
Flock Association of Europe (FAoE) e.V.
Ohmstr. 11
96175 Pettstadt, Germany
www.faoe.eu

**Event Chairwoman**
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### MANUAL OF LECTURES

**Publisher**
Flock Association of Europe (FAoE) e.V.
Ohmstr. 11
96175 Pettstadt, Germany
www.faoe.eu

**V.i.S.d.P. //**
**Responsible in the sense of the German ‚Pressegesetz'**
Stephanie Wegner, Office Manager FAoE

**Layout**
Markenwirt GmbH
Hauptwachstraße 5
96047 Bamberg, Germany

**Translation**
Speakers and FAoE

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ALL ABOUT FLOCK

THANKS FOR YOUR ATTENTION.