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Advances in Coated Airbag Fabrics: Materials, Processing, and Performance

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Abstract

Coated airbag fabrics are critical passive safety components in modern automotive restraint systems. This paper provides a comprehensive review of material innovations, coating chemistries, weaving architectures, and process engineering advances that have shaped airbag textile technology over the past two decades. We examine the transition from heavy neoprene and chloroprene formulations to lightweight silicone and polyurethane coatings, with emphasis on the thermomechanical requirements imposed by high-speed deployment (30–300 ms). One-piece woven (OPW) technology is discussed in the context of seam-eliminating design strategies and its implications for module miniaturization. Analytical results from tensile testing, burst pressure measurement, heat aging, and folding-fatigue protocols are presented for representative commercial substrates. The paper further addresses sustainability drivers, including bio-based nylon precursors, solvent-free coating processes, and end-of-life recyclability frameworks. Finally, emerging directions including smart sensor-integrated fabrics, nano-composite coatings, and AI-assisted quality inspection are identified as vectors for future research and commercialization.

Keywords: airbag fabrics; silicone coating; polyurethane coating; one-piece woven; OPW; automotive safety; passive restraint; textile engineering; nano-composites; sustainable textiles

1. Introduction

The use of technical textiles in the automotive field is one of the most challenging. According to data collected by the National Highway Traffic Safety Administration (NHTSA), airbags have been estimated to have saved about 29% of lives in frontal crashes and up to 37% in side crashes, since they became commonplace in the 1990s. The airbag cushion (the textile itself) should be able to resist the peak pressure of 30–80 kPa during deployment and also should be able to control the amount of gas retained, heat dissipation, and forces acting on the occupants.

The first airbag cushions were made using nylon 6,6 woven fabric coated in chloroprene or neoprene, which was sufficient for the gas tightness requirements, but was very heavy (200–350 g/m²) and did not allow for a good fold-pack efficiency. In the late 1990's, silicone coatings were introduced, and with the development of high tenacity low denier nylon yarns, a generational improvement in specific performance occurred. Highly engineered airbag fabrics today can be as light as 20–35 g/m2 with addition-cure silicone systems, enabling airbag modules to become lighter, and folding smaller, in instrument panels, door pillars and steering wheels, to fit more and more (Ali et al., 2021).

The review is organized to follow the entire development process of coated airbag fabrics from base fibre and yarn selection (Section 2) to the airbag fabric architecture and weaving (Section 3), coating chemistries (Section 4), processing and quality control (Section 5), performance testing and standards (Section 6), sustainability (Section 7), and future research directions (Section 8). When possible, quantitative references from published literature, standardized testing data and proprietary disclosures are quoted to provide a foundation for the discussion in engineering reality.

2. Fiber and Yarn Technology

2.1 Nylon 6,6 Dominance and Its Basis

The most widely used fiber in airbags worldwide is Polyamide 6,6 (PA 6,6), also known as Nylon, which is manufactured by DuPont (Smithers Apex, 2024). Its use is due to an exceptional combination of high tensile strength (700-950 MPa for industrial grades), excellent energy absorption and tolerance of the short duration thermal excursions associated with hot-gas inflation. The melting point of PA 6,6 at 264 °C establishes a relevant thermal margin over the gas temperature of 150–200 °C that is produced by the normal azide-free inflator chemistry.

2.2 Polyester and Specialty Fibers

The airbag material polyethylene terephthalate (PET) has been considered as a substitute for nylon, especially for cost-sensitive applications and markets where nylon prices fluctuate. Compared to nylon, which has a moisture absorption of 4-8%, PET absorbs less moisture (0.4%) and can be beneficial in humid climates where nylon fabrics may experience measurable strength loss after extended moisture exposure. However, due to its lower elongation at break and lower impact energy absorption per area, PET use has been limited in primary front cushion applications (Automotive Airbags Market, 2025).

3. Weaving Architecture

3.1 Plain Woven Fabrics

As the mechanical framework of airbag fabrics, plain (tabby) weave continues to be used because of its uniform performance in both directions in and across its plane, and its suitability for high-speed rapier and air-jet looms. The commercial airbag fabrics are woven by about 46–60 ends per 10 cm and consequently have a highly interlaced structure that is naturally resistant to yarn slippage under biaxial tensile loading. The crimp alternation of the warp and weft yarns provides nonlinear loading-extension characteristics which are especially useful during the initial rapid rate of deployment (El Messiry et al., 2024).

3.2 One-Piece Woven Technology

Developed in the late 1990s and mass produced on Jacquard looms with electronic shed control, is the one-piece woven (OPW) airbag technology that enables the entire three-dimensional airbag cushion to be woven in a single continuous process. The inflation chamber is created by locally unweaving the warp-beam layers, so that hollow volumes are formed, and the adjoining layers are re-weaved so that seam-like boundaries are formed without any stitching.

The OPW technology removes one of the most telling sources of gas leakage, and it is the most common failure point of sewn and coated cushions—seam-sewing. The seam-free construction features fewer post-weave manufacturing steps, allows more uniformity and can be achieved in complex 3-D shapes that would be impractical to weave from flat fabric panels, such as tubular side curtain airbags with internal baffles that adjust the roll-stability response (Fabric , 2026).

The challenge for coating OPW fabrics is that after weaving, the surfaces of the inside of the chamber are inaccessible. This means that gas tightness has to be provided entirely by the coating applied to the outer fabric surfaces, and must penetrate enough into the weave to seal the interstices of the yarns while still allowing the cushion to flex and keeping the inlet for the inflation gas unblocked. Based on SEM cross section analysis, 40–60% of the fabric thickness is the optimum coating depth to achieve gas tightness without stiffness (Kang et al., 2017).

3.3 Fabric Structural Parameters

The cover factor, fabric areal density and weave angle are important structural parameters that affect the performance of the airbag fabrics. In the construction of airbags, the covered area of yarn is usually between 0.85 and 0.96 of the total fabric area, that is, cover factor. The higher the cover factor, the lower the air permeability of the base fabric and the more difficult and dangerous the weaving will be if there is a risk of reed damage. The progressive drop in areal density (fabric weight before coating, g/m²) from 210–250 g/m² during the historical period to current premium grades 155–185 g/m² is due to the improvement in high tenacity fine denier yarns.

Table 1: Comparative mechanical and physical properties of airbag substrate fabrics

Property	Nylon 6,6 (OPW)	Nylon 6,6 (Woven)	Polyester (PET)	High-Tenacity PA
Tensile Strength (kN/m)	35–45	40–55	30–42	50–65
Elongation at Break (%)	25–40	20–35	15–28	18–30
Weight (g/m²)	155–200	170–230	160–210	180–240
Air Permeability (mm/s)	<5 (coated)	<3 (coated)	<4 (coated)	<2 (coated)
Seam Strength Retention (%)	85–95	80–92	78–90	88–96

4. Coating Chemistries

4.1 Silicone Coatings

Since around 2005, silicone rubbers, crosslinked using addition-cure (hydrosilylation) chemistry, have been the most prevalent airbag coating system. The qualities that make them the leaders at the forefront are: high heat stability (continuous service temperature up to 230°C, short term up to >350°C), flexibility at low temperatures (-60°C), low surface energy for clean folding and deployment and halogen-free chemistry to meet European Union environmental requirements such as REACH and ELV.

Airbag-grade silicone compounds are 2-component (2K) formulations which include a silicone base polymer, a crosslinker package and a platinum-based catalyst. The range of coat weights for silicone systems to be applied to airbag fabrics are from 20 g/m2 for side curtain systems that must be as flexible and compact as possible in packing, to 60–80 g/m2 for frontal cushions when a higher gas holding capacity at high pressure is desired (Market Intelo, 2025).

4.2 Polyurethane and Chloroprene Coatings

Polyurethane (PU) coatings are still important in cost-sensitive airbag applications and where the thermal demands are not as severe, e.g. knee airbags and rear seat systems. Because of VOC emission regulations, most formulations of PUs are now migrating toward waterborne dispersions, but waterborne systems have become more difficult to dry and surface defects have become an issue when fast moisture removal occurs. The PU coatings are very abrasion resistant and can be produced to achieve a higher elongation at break than silicone coatings, which is advantageous when the fabric is stretched in plane more than the membrane is stretched (Pongmuksuwan & Harnnarongchai, 2022).

4.3 Hybrid and Nano Composite Coatings

Hybrid coating systems consisting of silicone matrices and domains of polyurethane have been of great research interest because they have the potential to combine the thermal stability of the silicone with the abrasion resistant and adhesiveness to the fabric substrate of the polyurethane. In laboratory tests, interpenetrating polymer network (IPN) architectures (silicone and PU phases both crosslinked together to prevent macrophase separation) have been shown to exhibit peel strength improvement from 3.2 N/cm (standard silicone) to 6.8 N/cm (IPN hybrid) with no degradation of gas tightness or thermal performance (vorster, 2025).

Table 2: Performance comparison of primary airbag coating material families

Coating Material	Heat Resistance	Gas Tightness	Flexibility	Typical Application
Silicone	Excellent (>300°C)	High	Excellent	Driver/Passenger
Neoprene	Good (~200°C)	Moderate–High	Good	Side-curtain
Polyurethane	Moderate (~160°C)	Moderate	Very Good	Knee airbags
Chloroprene Blends	Good (~220°C)	High	Good	Multi-stage systems
Hybrid (Si + PU)	Very Good (~260°C)	High	Very Good	Advanced SRS modules

5. Coating Processing and Quality Control

5.1 Industrial Coating Processes

Coating the fabrics of an airbag is done on a continuous fabric coating line with 10–30 m/min coating speed. The application method of the coating has a big impact on the uniformity, depth of coating and surface topography of the coated layer. Knife-over-roll and knife-over-air methods are the most commonly used in primary airbag coating, providing good control of coat weight at production speeds and a lower sensitivity to variations in fabric tension (airbag, 2025).

Table 3: Comparison of industrial coating processes for airbag fabrics

Process	Coat Weight (g/m²)	Uniformity	Throughput	Preferred Coating
Knife-over-Roll	30–80	High	Medium	Silicone, Neoprene
Transfer Coating	20–60	Very High	Low–Med	Polyurethane
Spray Coating	15–40	Moderate	High	Silicone (low-add)
Calendering	40–100	High	High	Chloroprene
Dip Coating	50–120	Moderate	High	Multi-polymer blends

5.2 Curing and Post-Processing

After coating application, the fabric passes through a multi-zone convection oven where the temperature zones are set to obtain full crosslink density of silicone (usually > 95% as determined by the amount of extractable silicone according to the ASTM D5593 protocol) without causing any shrinkage or appearance defects. Typical residence times for production silicone systems are 90-150 seconds in the oven at 150-180°C set point temperature. Then the fabric is scanned immediately after leaving the oven using non-contact infrared thermography as they pass through it, so that any deviations in the uniformity of the coating can be determined before they become a major issue for the rest of the production lot (Ali et al., 2021).

5.3 Inline Quality Control

The airbag coating lines of today are equipped with different inline measuring devices for quality control at any time. Laser profilometry is used for measuring surface roughness with accuracy of ±1.5 g/m2 at 30 m/min. Air permeability testers attached to the fabric path give the permeability information in real time to feed back into the coating parameters in closed loop control. Surface defects, such as pinholes, edge wrinkles and coating streaks, are detected with false negative rates under 0.3% at line speed with the help of machine vision system, which more and more uses the convolutional neural network (CNN) algorithms (Automotive Airbag, 2020).

6. Use of performance testing and standards.

6.1 Mechanical Performance Characterization

A series of standard and proprietary tests are used to evaluate coated airbag fabrics. The grab test (ASTM D5034) also can be used to test tensile strength and elongation, and the standard frontal cushion fabrics are required to have a tensile strength of 1200–1600 N. The propagation resistance of the tear due to tears is tested by two methods: the tongue tear test (ASTM D2261) and trapezoidal tear test. The tear property of coated fabrics is very different from that of the uncoated bases and may be either beneficial (higher initial tear resistance) or detrimental (higher tear propagation rate when a tear has been initiated) depending on how soft or stiff the film is. It highlights the need for optimization of the fabric-coating system, instead of material selection (Automotive Airbags Market, 2025).

6.2 Environmental Durability

The airbag fabrics should be tested for 10-20 years of long-term use and for storage temperatures ranging from −40°C to +105°C. The tests are performed to simulate long-term degradation and the 80% tensile strength retention is the industry standard minimum requirements for retention. Humidity aging at 70°C / 95%RH for 500 hours tests hydrolytic stability, especially relevant for those fabrics where the coating is polyurethane and hydrolysis of the ester-linkages is a concern.

6.3 Regulatory Standards

There are several regional differences in the regulatory requirements for good airbag system performance, such as the FMVSS 208 in the U.S. and ECE Regulation 94 and 95 in Europe, as well as a number of regional standards in China (GB 11551), Japan (TRIAS) and South Korea (KMVSS). These standards do not refer directly to the properties of the fabrics involved, but they do set a performance envelope that the performance of any fabric should lie within. Fabric level specifications consist of industry material standards such as SAE J2404 Airbag Assembly and ISO 5628 Burst Pressure (El Messiry et al., 2024).

Table 4: Key standards and regulations governing airbag fabric and system performance

Standard	Issuing Body	Scope	Key Parameters
FMVSS 208	NHTSA (USA)	Occupant crash protection	Deployment force, timing
ECE R94 / R95	UNECE (Europe)	Frontal & lateral impact	Barrier speeds, dummies
ISO 5628	ISO TC 38	Airbag fabric burst strength	Pressure at burst
ASTM D5034	ASTM Intl.	Fabric grab tensile strength	Peak load, elongation
SAE J2404	SAE International	Airbag module assembly	Deployment validation
GB 11551	SAC (China)	Frontal collision protection	Test procedures (CN)

7. Sustainability in Airbag Fabric Production

7.1 Environmental Regulatory Context

There are several ways that the industry of fabric for airbags is facing increasingly tough regulations. The European Union End-of-Life Vehicle (ELV) Directive (2000/53/EC) sets a requirement to recover 85% of the vehicle's weight and recyclable by mass 80%: this has led to a reduction in the percentage of halogenated coatings in restraint systems. Some plasticizers and stabilizers have been restricted from being used in coating formulations due to REACH restrictions on substances of very high concern (SVHCs). In the U.S. the Corporate Average Fuel Economy (CAFE) regulations provide indirect incentive to reduce the weight of every vehicle component such as airbag modules (ET Auto, 2022).

7.2 Solvent-Free Coating Processes
One of the best environmental advances in airbag fabric production in the last decade has been the replacement of solvent-based with solvent-free coating systems. Historically, 30-50% of the volume of silicone formulations was made up of toluene or xylene, which were used as viscosity control agents, but today most silicone formulations are 100%-solids, applied at elevated temperature (60-80°C) without the addition of organic solvent. This change has resulted in the estimated elimination of 85-92% of VOC emissions from the coating process throughout the industry, while also eliminating the need for explosion risk and handling requirements and recovery energy costs (Fabric , 2026).

7.3 Bio-Based and Recycled Fiber Inputs
Some nylon manufacturers have produced PA 6,6 grades which contain a portion of renewable glucose-fermented adipic acid. Today, commercial nylon with 30-60% content of polymer carbon can be achieved, and continued development and improvement of the process is aimed at obtaining 100% carbon content derived from biomass. Initial fabric characterization data indicate that bio-based PA 6,6 airbag fabrics have similar mechanical performance characteristics to petroleum-based grades, but further data are being gathered over the complete automotive qualification temperature range (Huang et al., 2022).

8. Management of the Creative Process

8.1 Fabrics with smart and sensor technologies.
A new and emerging research avenue is the use of sensing materials directly in the fabric of airbag substrates. Capacitive or resistive sensing of cushion pressure and deployment completeness and contact force distribution can be achieved by weaving conductive yarn elements, such as silver coated nylon yarns and/or carbon nanotube impregnated fibers, into the airbag cushion structure. These capabilities would lead to the development of adaptive deployment algorithms that would be able to reduce the inflator power output based on real-time information about the cushion state that would permit the substantial reduction in deployment-induced-injuries to out-of-position occupants.

8.2 Nano-Composite Coating Advances
In addition to the nano-filler systems described in Section 4.3, structured nano-coatings that are deposited by atomic layer deposition (ALD) or initiated chemical vapor deposition (iCVD) have been shown to be a very thin layer for gas barrier applications at the laboratory scale on substrates for airbag applications. The ALD alumina (Al_2O_3) layers, which were deposited onto woven nylon fabric, achieved an air permeability reduction of 94%, adding 2-4 g/m² to the fabric, whereas conventional silicone systems added 30-80 g/m² per fabric, still allowing the fabric to breathe. Unresolved barriers include scalability in production widths and rates, and deployment thermal and mechanical transients (Kang et al., 2017).

8.3 Artificial Intelligence in Manufacturing
On production coating lines, machine learning techniques, especially deep convolutional neural networks, trained on hyperspectral imaging data, are being used to replace or supplement the human visual inspection. Defect classification models based on a library of over 50,000 labeled defect images have been used to achieve an F1 score greater than 0.96 in all major defect classes (pinholes, coating voids, surface contamination, and edge irregularity). Results of early trials of reinforcement learning algorithms for adaptive control of the coating knife gap and line speed in response to a real-time coat weight measurement signal are used to show that the standard deviation of coat weight can be reduced by 28–35% over that obtained from PID-controlled systems.

8.4 Additive Manufacturing and Novel Geometries
Three-dimensional printing of prototype TPU-based flexible airbag cushion has been used as a rapid tooling method for geometry validation before programming the OPW. Using digitalised tools to design textiles (CAD/CAM) combined with Jacquard systems, structural airbag cushion design takes a mere 2-4 weeks for complex 3D cushion geometry as opposed to 8-12 weeks for direct production by additive manufacturing. The pressure on the development lead-time has allowed for a wider design-of-experiments exploration in airbag cushion development programs (Market Intelo, 2025).

9. Conclusions

The present review has covered airbag fabrics from their early days in heavy neoprene-coated nylon constructions to the lightweight high-performance silicone-coated OPW systems which are the state of the art today and outline several general conclusions:

Today, silicone coating chemistry and high-tenacity PA6,6 substrates, ranging in areal density from 155–185 g/m², set the standard for performance and weight in the competition for alternative material systems. One-piece woven technology has overcome the seam failure problem inherent in sewn-and-coated airbag cushion technology, and allows for three-dimensional airbag shapes which meet the requirements for side curtain and multi-lobed restraint concepts.

Nano-composite coatings and hybrid silicone-polyurethane IPN systems provide superior performance in certain properties, but there is a need to ensure manufacturing scalability and establish durability before they can be commercialized.

The material selection across the value chain is changing due to sustainability requirements and the use of solvent-free coating technologies and bio-based fiber inputs are transitioning from research to production qualification.

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