Unique silicone-organic synthetic leather first to combine genuine leather qualities with advanced sustainability

Designed for automotive interiors, applicable for furniture, fashion, many other markets

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Globally, and especially in China, the leather industry market is being rapidly reshaped by the demand for environmental protection and sustainability. Genuine leathers are traditional, luxurious and have excellent hand-feel, but they are increasingly rejected by customers demanding animal-free products. Synthetic leathers made from polyurethanes (PU) or polyvinylchlorides (PVC) have been available for decades but they remain inferior alternatives due to volatile organic compounds (VOC), odor issues, poor hand feel, cracking, brittleness, and cheap appearance. Synthetic leathers made from silicone (Si) have superior hand feel, durability, recyclability, ease of cleaning and inherent fire resistance, but have poor abrasion and scratch resistance due to the inherent properties of silicones. LuxSense™ is a first of its kind silicone-organic hybrid synthetic leather that combines the benefits of both to become the first synthetic leather that competes with authentic leather on performance and exceeds all leathers on sustainability.

LuxSense™ silicone synthetic leather can be used throughout the automotive interior, including seating, the most demanding performance application.

Unique chemistry and 4-layer structure design mechanisms

Traditional silicone leathers are comprised of only three layers. LuxSense™ adds a fourth layer that modifies the other three layers and the dynamic of how all the layers work in concert to meet the structure-property targets. An empirical solution was impractical due to the large number of variables involved. Thus, the team developed a fundamental understanding of the structure-property relationship between a material and its resistance to abrasion, using this model to guide the innovation process. The solution pointed to the need for a new chemistry that is hybrid at both the chemical and physical levels (Figure 2).

Figure 2: LuxSense™ silicone (Si) synthetic leather – a unique chemistry and structure design with four layers to produce high abrasion resistance as well as a better health profile and a high-level touch-feel experience.

Topcoat 1: The goal of the first topcoat is to deliver excellent hand feel, good stain resistance, abrasion resistance, and good adhesion to the next layer. In traditional silicone leathers, the topcoat is pure silicone, which has poor abrasion resistance. The abrasion model pointed to a highly crosslinked Liquid Silicone Rubber (LSR) top layer with embedded abrasion resistant microparticles. This LSR layer is co-worked with the microparticles, eco-solvent (which is later evaporated away in the assembly process), and adhesion promoters. This is unlike the solution for Topcoat 2, which changes the silicone backbone itself to a silicone-organic.
Topcoat 2: The LX-2120 Organic-PDMS (polydimethylsiloxane) hybrid layer is designed to combine the advantages of silicone and organic components at the molecular level. The organic segments are introduced into the polymeric network through the reaction between carbinol PDMS and the organic, which achieves outstanding abrasion resistance through a different mechanism than Topcoat 1. Topcoat 2 is made in two steps (as shown in Figure 3, below): (1) A pre-polymer is made in an eco-solvent (again, later evaporated off); (2) This pre-polymer is crosslinked and cured for the organic-PDMS hybrid layer. The keys to performance are the balance of organic to PDMS, as well as the chemical structure of the organic and how the organic is distributed in the polymer. The organic segments significantly improve the intermolecular interaction to deliver high mechanical strength and abrasion resistance. The silicone segments retain good hand-feel, UV/thermal resistance so the organic-silicone combination is the best of both worlds.

The two topcoats are then chemically bonded into an overall hybrid topcoat layer (as shown in Figure 4).

**Step 1:** Pre-polymer chemistry to integrate organic segments into the silicone.

\[
\text{Silicone segment (Si) + Organic segment (Org) \to \text{Pre-polymer}}
\]

**Step 2:** Crosslinking reaction to get the cured silicone-organic hybrid.

\[
\text{Pre-polymer + Crosslinkers \to \text{Crosslinked silicone-organic matrix}}
\]

**Figure 3:** Preparation of Topcoat 2 in two steps. LuxSense™ Si synthetic leather – silicone-organic reaction mechanism for excellent abrasion resistance and a new class of chemistry.

**Figure 4:** Topcoats 1 and 2 are chemically bonded for long-term durability. The figure shows the mechanism between Topcoat 2- LX-2120 hybrid layer and Silicone matrix (Topcoat 1-LX-2010 gravure coating layer or Skin layer-LX-2351 LSR).

**Skin layer (3):** The skin layer (LX-2351) is an intermediary layer that provides additional abrasion resistance and low viscosity for easy processing. Key requirements here include good adhesion to the new organic-PDMS hybrid topcoat and to the primary silicone layer without compromising other performance attributes. The skin layer is an LSR with > 65 Shore A hardness and adhesion promoters.

**Adhesive layer (4):** The primary layer (LX-2401) is a LSR layer with ~30 Shore A hardness for softness and a comfortable feeling. Adhesion promoters also ensure good fixation to the fabric support (typically polyester, PLA, or other).

Assembly of the four layers is also critical, both for final product performance and for ease of manufacturing. The thickness of each layer – together with the surface texture and carefully selected support fabrics – were optimized to provide the unique hand-feel of LuxSense™. The pot life and shelf life of the formulation were studied to ensure easy processing at the fabricator site. Synthetic leather fabricators can use their existing PVC or polyurethane leather production lines for high productivity manufacturing of LuxSense™ (as shown in Figure 5).

**Performance evaluation**

The materials properties were tested to confirm and refine the model predictions for structure-property relationships. The samples of LuxSense™ were then tested for sewability and finally in simulated applications of automotive interiors, especially car seating.

1. **Gakushin abrasion resistance**

Abrasion resistance is evaluated by the Gakushin abrasion test using test method JIS L0849, which is close to Ingress/Egress in many Asian automotive OEM seating tests.

**Figure 5:** LuxSense™ Si synthetic leather – 4-layer coating production process with high productivity that can be done on existing PVC/PU leather production lines. Topcoat 2-LX-2120 hybrid layer, skin layer-LX-2351 LSR, and adhesive layer-LX-2401 LSR can be completed in a continuous production line at one time before gravure coating of Topcoat 1-LX-2010 gravure coating layer.

**Figure 6:** Excellent Gakushin abrasion resistance of LuxSense™ against traditional Si leather.

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![Gakushin abrasion resistance](image)

**Figure 6:** Excellent Gakushin abrasion resistance of LuxSense™ against traditional Si leather.
Excellent abrasion resistance is achieved because the organic-PDMS has a higher mechanical energy density at break compared with traditional Si leather (pure silicone is only 5~10 MPa). Tests show the modulus is increased from 10 MPa to more than 100 MPa, while the elongation at break is increased from 40% to 300%. This is consistent with the abrasion equation:

\[ D = k_1 \frac{\mu P}{UB} \]

where \( D \) is the linear rate of abrasion loss, \( k_1 \) is the dimensionless constant, \( P \) is the normal load, \( \mu \) is the friction coefficient, and \( UB \) is the energy density at break.

2. Hand feel performance
Hand feel performance is one of the key requirements for OEM customers, especially for high end automobiles where luxury and sustainability are paramount.

3. Odor and VOC
The use of harmful solvents or additives is avoided and thus odor is inherently low. The eco-solvent also ensures negligible environmental impact throughout the entire product life cycle of design, production, packaging, transportation, application, and end-of-life (or recycling).

4. Soil resistance
For synthetic leathers, soil resistance performance is becoming more and more important, especially against ball point pen markings and coffee spills. Ball point pen resistance is considered a new potential "selling point", especially with the increasing popularity of lightly colored leathers. Ball point pen ink easily stains genuine and PU/PVC synthetic leathers and is very hard to remove as seen in Figure 8.

For decades, silicones have found widespread use in many soiling resistant, water repellent, low release force applications, and/or fluorocarbon-free applications due to the inherent low surface energy of silicones. Synthetic leathers are just the latest application to exploit this unique property. The unique chain structure of silicones (Figure 9) enables more free rotation of chemical bonds, and thus easier adjustment of polymer conformation to spontaneously form a \(-\text{CH}_3\) covered surface driven by the tendency to lower energy status. Figure 10 shows the exceptional stain resistance performance of LuxSense™.

5. Flame retardance
Flame retardance has always been important in automotive applications. It is increasingly critical now with the accelerated growth of electric vehicles stricter government regulations, especially regarding passenger evacuation time in case of fire. PVC and polyurethane synthetic leathers are both inherently flammable. Even with the addition of flame retardants, they can burn and emit hazardous materials. PVC emits dioxin and HCl, and PU emits hydrogen cyanide. Silicones and the silicone-organic hybrid structure of LuxSense™ are inherently flame retardant without additional additives. When exposed to fire, including those caused by car accidents, LuxSense™ is safer since the material is self-extinguishable and does not emit any associated off-gas emissions (Figure 11).
6. Seat Ingress/Egress robot abrasion resistance

The final step for synthetic leather qualification is assembly into a seat and robot testing of abrasion resistance (also known as Ingress/Egress robot abrasion testing) using test method GMW 14364. The specification is a minimum of 25,000 cycles (equivalent to approximately 10 years of life). Traditional silicone leather often fails at less than 4000 cycles, and LuxSense™ easily passes at more than 30,000 cycles shown in Table 1.

<table>
<thead>
<tr>
<th>Ingress/Egress test, Cycles</th>
<th>Traditional Si Leather</th>
<th>LuxSense™ Si Leather</th>
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<td>&lt; 4,000</td>
<td>30,000-50,000</td>
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Table 1: Ingress/Egress robot abrasion test of LuxSense™ against Traditional Si synthetic Leather

7. Sustainability

The initial motivation for LuxSense™ was a more sustainable alternative to authentic or synthetic leathers. Leather tanning is very traditional and often small scale, but animals are slaughtered. In addition, harsh agents (e.g., chromium, formaldehyde, arsenic) and high volumes of water are required. Corresponding waste is generated that is often disposed of near or within communities. In contrast, PU or PVC leathers are made in more controlled environments but require materials that are less sustainable and solvents that put workers at risk. DMF is used for PU leather and plasticizers are used for PVC leather.

LuxSense™ is made in a controlled environment without waste to the community and does not use harmful solvents, which protects workers and provides low VOC products. LuxSense™ has strong UV/Aging resistance, another inherent property of the high bond strength of the Si-O bond compared to the C-C bonds of PU and PVC leather (435 kJ/mol vs. 350 kJ/mol). Thus, products made with LuxSense™ are more durable and longer-lasting materials for an overall resource efficiency gain.

Overall comparison

The synergies between silicone and organic components introduced with LuxSense™ provide breakthrough performance, as summarized in Table 2.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>LuxSense™ Si Leather</th>
<th>Traditional Si Leather</th>
<th>Genuine Leather</th>
<th>Ordinary PVC</th>
<th>Ordinary PU</th>
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<tbody>
<tr>
<td>Abrasion resistance</td>
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<td>Easy to clean</td>
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<td>Stain resistance (carbon black+blue jeans)</td>
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<td>Achieve bright colors</td>
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<td>Low odor</td>
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<td>Low VOC</td>
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<td>Hand-feel (soft touch haptics)</td>
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<tr>
<td>Skin-friendly (non-irritant)</td>
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<tr>
<td>Avoids harmful solvents or chemicals</td>
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<td>Flame resistance/no emission of harmful gases</td>
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<tr>
<td>UV/Age resistance</td>
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Table 2: Overall performance of LuxSense™ Si synthetic leather for auto interiors vs. other leathers (genuine, traditional Si leather, ordinary PVC, and ordinary PU).

New applications

Although the motivation for LuxSense™ was automotive interiors, additional applications are envisioned beyond automotive, such as furniture, apparel, bags, luggage, etc. LuxSense™ also has the potential to open new uses for leather-like materials such as smart buttons or indicator illumination since it is fully pigmentable with more brightness than alternatives, as well as sharp light transmission.

Conclusions

LuxSense™ Silicone Leather is the first ever synthetic leather (PU, PVC, or silicone) that competes with authentic leather on performance and exceeds authentic leather on sustainability. Several long-standing technical issues were overcome by using fundamental science to understand the underlying mechanisms, to interrogate abrasion, and then to develop a complex, yet elegant solution via chemistry. A 4-layer structure was designed to meet and exceed design criteria and can be used on existing processing equipment. A new class of materials was created from silicone-organic hybrid materials that combine the advantages of silicones (aesthetics, flame resistance, durability, recyclability, UV stability) with those of organics (outstanding abrasion resistance) in a cost-effective, sustainable (low VOC) system. These principles and products offer a new platform for material science and applications.

As a result, LuxSense™ Si Leather has become the world’s first silicone luxury leather approved and commercialized in automotive interiors. It easily meets automotive interior specifications, including car seating applications. It also exhibits the unique features of 4S: sense of sight, sense of smell, sense of touch, and sense of sustainability.