The future starts today

Introducing Solar Impulse 2

SOLVAY
asking more from chemistry®


Si2
SOLARIMPULSE
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Solvay technical developments **on Solar Impulse 2**

1 Energy capture **Halar® ECTFE**

The photovoltaic (PV) cells are protected from harsh conditions during the flight by a transparent surface treated film, based on **Halar® ECTFE**. The film's thickness was reduced to 17-20 microns, or less than 0.02 millimetres, from 26 microns of a competing film, saving about 35% in weight while electrical performance remained the same. Experience with Solar Impulse 1 (Si1) showed that the PV cells with only a glass-epoxy layer at the bottom were vulnerable to moisture exposure. Using **Halar® ECTFE** film on both sides of the PV-modules solved this and turned Solar Impulse 2 (Si2) into a waterproof electric plane. **Halar® ECTFE** now entirely encapsulates all 17,248 photovoltaic cells – 300 sqm - placed on top of the wings, on the rear stabiliser and on the fuselage. This film was produced by Ajedium in the USA.

2 Energy capture **Solstick**

The challenge to efficiently capture the sun's energy required the most minute and careful planning and designing of details that are part of the plane's structure. Among those details were the narrow gaps between the solar panels on the wings. The air flowing through these gaps could slow the aerodynamics and lead to a loss of energy. These gaps had to be covered with a film able to withstand the stresses of low and high temperature cycles without delaminating. This film would also need to have sufficient elasticity to support the flexing of the wings during flight and be transparent for all solar cells to capture the sun's energy. Moreover, this film had to be light to avoid any extra weight. As such, Solvay Specialty Polymers developed and supplied **Solstick** tape based on its **Solef® PVDF** polymer.

3 Energy storage **Solef® PVDF**

The energy harvested from the sun and turned into electricity by the solar cells is stored in the 633 kg of lithium batteries. Energy storage is a bottleneck in the energy chain, which meant that the energy density (ED in Wh/Kg) of these batteries had to be optimized. The initial energy density of 180 Wh/Kg was increased to 240 Wh/Kg for Si1. For Si2, Solvay developed a new grade of **Solef® PVDF**, which is used as binder for both electrodes offering optimal adhesion to the electrodes and which also helps to reduce the weight of the batteries. In addition, the electrochemical stability of cells is improved, allowing for a repeated and more frequent cycle of charging and discharging and improving battery performance up to 260 Wh/Kg.

4 Energy storage **F1EC**

The monofluoro-ethylene carbonate solvent called **F1EC** or FIC can represent up to 20 percent of the electrolyte blend in rechargeable Li-Ion batteries. As this improves the ion flow, it allows the batteries to carry more current, at equal weight. These components, used on the batteries of Si2, bring their electricity density of the batteries to a new peak performance of 260 Wh/Kg.

5 Structure

Torlon® PAI

6

VTM®264 prepregs VTA®260 structural adhesive

The 70 metre wing spar is made of a sandwich structure entrapping a "honeycomb" between two carbon fibre foils.

The honeycomb is made of paper impregnated with the **Torlon® PAI** polymer. This refined composite structure, assembled by gluing, combines excellent mechanical properties (strength, torsion, flexion, vibration) with an incredibly light weight. The wing spar supports the 144 ribs that profile the curved shape of the wing with the encapsulated solar panels on top.

VTM® 264 prepregs and **VTA® 260 structural adhesive** were used in the manufacture of the large wing spar honeycomb sandwich structure and other composite parts. The use of low weight unidirectional and fabric composites allowed the flexibility to design and manufacture very light weight components which is a key benefit to the Solar Impulse project.

7 Structure

Solkane® 365 mfc

The 3.8 m^3 cockpit of Si2 had to be light weight, but also stable and providing optimal insulation against the freezing outside temperatures of -50°C high up in the air. Those challenges were met with polyurethane foams, which are produced from two monomers, a polyol and an isocyanate, as well as a foam expansion or blowing (BA) agent. Solvay's blowing agent **Solkane® 365 mfc** offers the best-in-class thermal conductivity. The excellent polyurethane foams combine a unique set of characteristics: insulation properties, dimensional stability, compressive strength as well as moisture resistance. This product was jointly developed with Bayer Material Science and Puren in Germany. Solvay on its own developed a solution for the cockpit's fairing, producing big blocks of foam which in turn are machined or carved into parts.

8

TegraCore™ PPSI based on Radel® PPSU

TegraCore™ PPSI is a cellular material mostly used with rigid skins ("sandwich"), based on highly successful **Radel® PPSU** polymer. **TegraCore™ PPSI** sandwiches exhibits oustanding resistance and tolerance to damage and exhibits structural and insulating performance.
TegraCore™ PPSI is a material that reduces waste and speeds up the production, refurbishment and maintenance of aircraft at a lower cost.
It is used for the floor of Si2 cockpit.

Light weight/metal replacement

9 KetaSpire® PEEK PrimoSpire® SRP

In both Si1 and Si2, screw fasteners attach various components within the wings. The very strong but light weight pieces made of **KetaSpire® PEEK** and **PrimoSpire® SRP** that form those components have drastically improved on Si2 compared to those used on Si1.

Instead of making the components in a two-step process by machining, components on Si2 are directly injection moulded, which significantly reduces the risk of cracks or brittle breaking.

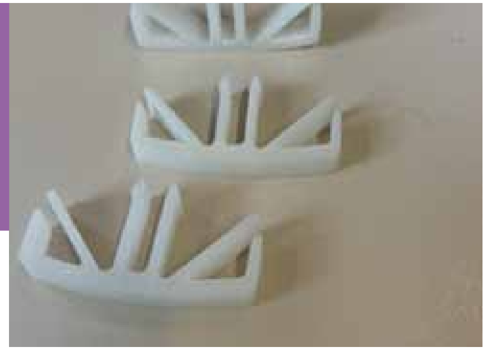
Light weight/metal replacement

10 Ixef® PARA

Pneumatic cylinders raise and lower the protective doors of the landing gear. They use pressure to change the position of a piston within the cylinder. In Si1 these pneumatic cylinders were made from metal, making them extremely heavy. For Si2 Solvay assembled a pneumatic cylinder made almost entirely from polymer **Ixef® PARA** – a robust, yet light weight material. Moreover, surface finish was one important element. The very smooth and glossy surface ensures that the piston remains airtight and allows it to run smoothly and efficiently. This is the first time ever that a pneumatic cylinder or actuator, was made entirely of plastics. All in all, this has saved 20 percent of the cylinder's original weight.

Light weight/metal replacement

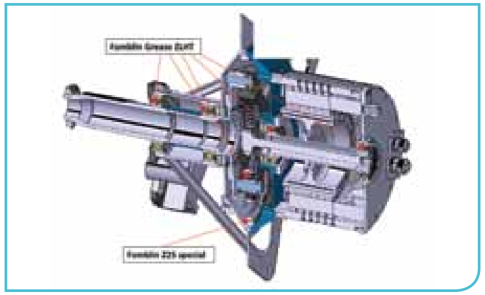
11 Sinterline® Polyamide 6



Selective Lase Sintering (SLS) is an industrial 3D printing technology that can rapidly create complex parts with a high degree of design flexibility. With **Sinterline® Polyamide 6** powders, Solvay produced two devices for Si2: inside the cockpit the Air Data Computer Housing (ADC) flight instrument and outside, the lighting clips that support the lights at the front of the wings. Thanks to this technology, 78 percent of weight was saved compared to aluminium.

Lubrication

12 Fomblin® PFPE



The positive results from using the **Fomblin® PFPE**-based grease in the propeller bearings on Si1, was extended to the use of **Fomblin® PFPE** liquid lubricants with special proprietary additives in the planetary gears. These additives enhance the anti-wear and anti-rust properties of the lubricant and increase its life span, thereby reducing maintenance.

13 Numerical simulations
Non-linear numerical modeling

Solvay's unique expertise in **non-linear numerical modelling** has been used for both Si1 and Si2.

For Si1 these simulations were performed in two keys areas: in the behavior of materials (solar cells encapsulation, epoxy bonding) and in the definition of the plane structure (solar panels, wing ribs, wing leading edges).

Solar Impulse 2 HB-SIB - ever lighter

All the simulated options selected for Si1 were confirmed by the aircraft's performance during the cumulative 500 hours of its flight missions through Europe, Morocco and the United States, sometimes in maximum permitted wind conditions. Therefore, the same options were selected for Si2. For the more powerful aircraft with 18,000 solar cells and a larger wingspan of 72 m, the engineers battled to reduce the weight of each single component. Again Solvay provided its expertise in assessing and testing the mechanical properties of materials.

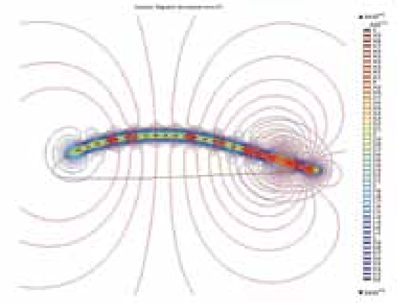
Traction project on solar cells

The solar cells on Si2 were shrunk to below 120 microns from 150 microns on Si1, without changing the yield per cell surface. Reducing the thickness of the cells could have made the new solar cells more fragile. Solvay designed a special tool to test the tensile strength of these two solar cell types on both planes, near the connectors. The outcome of the test showed that the new cells were just as strong as their thicker predecessors.

Bonding simulation project

To identify a robust structure that would be as light as possible Solvay, with its expertise in non-linear simulation, modelled the mechanical behavior of two types of adhesives. Various bonding specimens were tested at temperatures of -40°, 50° and 70° C, so Solar Impulse could select the best adhesives taking into account mechanical fatigue cycles at these different temperatures.

Where to place the compass?



For navigation and transmitting purposes Si2 needs a highly accurate compass on board. The challenge was to ensure that the electrical currents on the wings would not interfere with the functioning of the compass that uses the earth's magnetic fields. The perturbations of the magnetic field surrounding the plane were calculated by numerical simulation, which enabled finding the best place for the compass system.

14 Beyond the airplane
Emana® based on Polyamide 6.6

Solvay developed **Emana®**, a "smart fiber" based on **Polyamide 6.6**. **Emana®** contains a specific mineral filler, which absorbs the body's infrared radiation and re-emits it as a far infrared wave which interacts with the body. So clothing from **Emana®** yarns has specific properties. Worn on the skin it stimulates micro-circulation of the blood and enhances muscle performance. Both pilots tested with positive results **Emana®** as underwear during 72-hour flight simulations in February 2012 and in December 2013.

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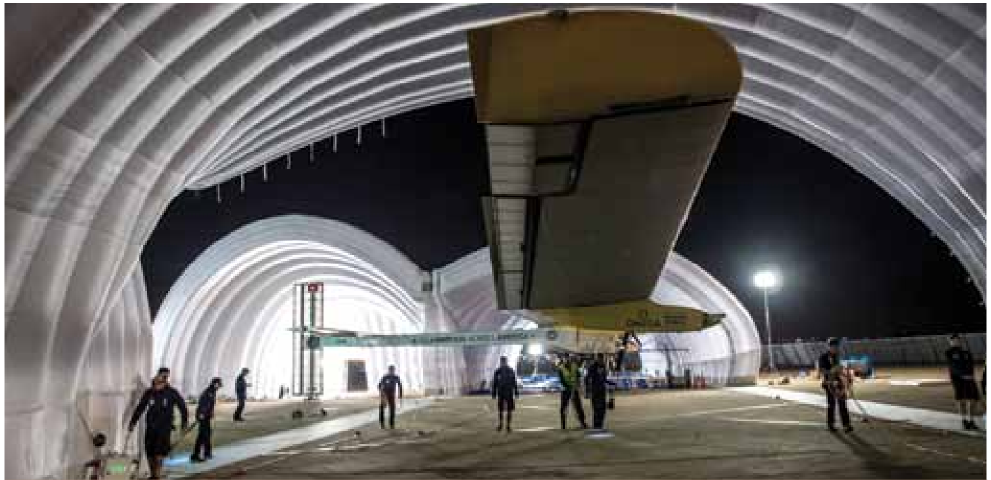
Beyond the airplane

Inflatable mobile hangar

The concept of this revolutionary structure, designed and built by Solar Impulse for its trip around the world in 2015, found its origins at Solvay as early as 2007. Largely made of PET film coated with polyurethane, this double-layer, inflatable arch structure is upheld without any metal parts. The parts touching the ground and many technical parts are made of PET coated with emulsion PVC. During its "Across America" flight in 2013, Solar Impulse once had to use its own inflatable mobile hangar to park and shelter the aircraft. Severe storm had damaged to the official hangar that was reserved in Saint Louis, United States. So on June 4th 2013, this hangar was put to use during "true" circumstances.



Inflatable hangar fact sheet

- Total length: 88 m (289 ft)
- Total weight: 3,500 kg (2 kg per m^2 ground surface) / 7716 lb (.05 lb per sq. ft. Ground surface)
- Number of modules composing the structure: 12
- Height of structure covering the wing: 8.5 m (28 ft)
- Height of structure covering the tail: 11 m (36 ft)
- Maximum width: 32 m (105 ft)
- Crew needed to deploy: 12 people
- Time needed to deploy: 6 hours
- Designed to resist winds of: 100 km/h (60 miles/h)

Solvay technical developments **on Solar Impulse 2**

Products on board

From Specialty Polymers GBU
Halar® ECTFE
Solstick tape based Solef® PVDF
Solef ® PVDF
Torlon®PAI
TegraCore™ based on Radel® PPSU
KetaSpire® PEEK
PrimoSpire® SRP
Ixef® PARA
Fomblin® PFPE grease
Fomblin® PFPE liquid lubricant

From Special Chem GBU
F1EC
Solkane® 365 mfc

From Composite Materials GBU
VTM® 264 prepregs
VTM® 260 structural adhesive

From Performance Polyamides GBU
Sinterline® Polyamide 6

From Fibras GBU
Emana® Polyamide 6.6

From Research & Innovation
Non-linear numerical modeling

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additional questions?
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