Heading to the Sun with Plasma

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To speed up the bonding process, optimize adhesion and save several kilos in weight, a team of students from KU Leuven University in Belgium pretreated the CFRP components of their solar racing car with atmospheric pressure plasma prior to bonding.

Für einen schnelleren Klebprozess, eine optimierte Haftung und zur Einsparung mehrerer Kilogramm Gewicht hat ein Studententeam der Universität Leuven (BE) die CFK-Bauteile seines neuen Solar-Rennwagens vor der Verklebung mit Atmosphärendruckplasma vorbehandelt.

Une équipe d'étudiants de l'Université de Louvain (Belgique) a prétraité les composants en PRC de sa nouvelle voiture de course solaire avant le collage à pression atmosphérique, afin d'accélérer le processus de collage, d'optimiser l'adhérence et d'économiser plusieurs kilos.

Production manager Dokus Soetemans and his fifteen Belgian colleagues who make up the 'Punch Powertrain Solar Team' are budding electronic and mechatronic engineers with an average age of 21 years. For over ten years Leuven University has worked closely with industry partners to offer its masters students a special postgraduate course: Those taking part in the biennial Solar Car Project have to build a single-seater racing car powered entirely by the sun and enter it in contests for the world's most efficient electric cars. The first aim is to compete successfully in the longest and toughest solar car rally in the world: The World Solar Challenge in Australia (Fig.1).

The young team – who were entirely responsible for every detail of this one and a half million euro project – had just 15 months to make it a reality. In June 2015 the car was unveiled to the public for the first time, by the end of August all home road tests had been completed and in September the team and its aerodynamic masterpiece «Punch One» headed off down under. However, before all this could take place, the solar car had to be designed and built from scratch.

Fig. 1: Powered only by the sun: The energy-efficient «Punch One» solar car at the World Solar Challenge rally in Australia. The plasma bonding process reduced the weight of the CFRP body by several kilos. (Photo: Punch Powertrain Solar Team)

Every gram counts

Less mass means less energy consumption and with a maximum overall weight of 165 kg, «Punch One» should be 10 kg lighter than its predecessor and a good 25 kg lighter than most of its rivals. Six square meters of the vehicle's surface are covered with 391 ultra-thin silicon solar cells. Yet despite their light weight, they still amount to a total weight of 8 kg. The heaviest part of the car is the solar battery with a specified maximum weight of 21 kg. Here, nothing could be shaved off. So to achieve the desired weight reduction the first job was to replace the two previous motors with a single 5 kW electric motor. The suspension and steering system were also replaced; they are now made mainly from carbon. But the car was still too heavy and the only area left to save weight was the vehicle body itself.

The self-supporting body made by the students is a 1.72 m wide and 4.50 m long monocoque construction comprising a top and a bottom shell made from carbon-fiber-reinforced plastic (CFRP). Using a labor-intensive laminating process (vacuum infusion), the students manufactured the shells from different prepregs; a 0.0 8mm strong Textreme, a UD (unidirectional) fabric and a 0.23mm twill. The core material is Rohacell, A PU rigid foam with high compressive strength. Once cured and demolded, plastic shells of this size are strong as far as the material is concerned,

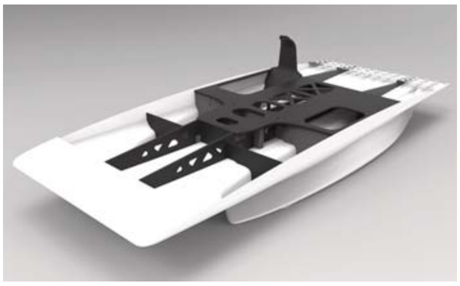

Fig. 2: Plasma-treated monocoque bottom shell, ribs and torsion box. (Photo: Punch Powertrain Solar Team)

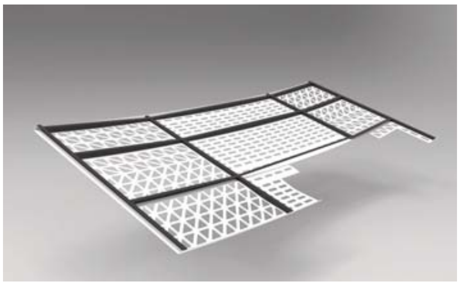

Fig. 3: Structure of the stiffening ribs in the top shell (Photo: Punch Powertrain Solar Team)

Fig. 4: Assembly of the different car body layers (Photo: Punch Powertrain Solar Team)

but still very unstable due to their light weight, curved shape and large surface area. Therefore the top and the bottom shell needed a framework of stiffening ribs with an extra stiffening construction (Fig. 2 and 3), the torsion box, for the bottom shell, to prevent bending and twisting of the substructure. After assembly the two shells will give the solar car its final aerodynamic shape (Fig. 4 and 5).

Bonding instead of lamination

The joining force between the different rigid foam ribs encased in Textreme and the bodywork must be strong enough to produce a back pull and counteract any tensile or compressive stresses in the shells in any direction. In view of the challenges the car body would have to face during races, previous student teams had always chosen to laminate these static elements. Multiple layers and lengths of prepreg strips were applied at each attachment point of the ribs to ensure that the ribs were firmly bonded to the shell surface after lamination. But this joining method was not only extremely labor-intensive and time-consuming; all the extra prepreg strips also increased the weight. So the question was whether it would be possible after all to achieve a high-strength bond using adhesives instead of a lamination process.

Various adhesives manufactured by Henkel were tested to find an alternative. Due to the car's strong vibrations, an adhesive was required which had both high elasticity and a short open time for fast bonding operations. «Loctite EA 466» was ultimately chosen, a fast curing, 2-component epoxy resin adhesive. However, in the first tensile-shear-force tests failure occurred as a result of an adhesive fracture instead of the expected cohesive fracture (Fig. 6). At the fracture point there was no adhesive on the CFRP surface that was to be bonded, despite the fact that this had been pretreated with a special cleaner. "We were told", says Soetemans, "that the problem lay not with the adhesive, but with the material. It was thought that the poor adhesion was due to the surface energy, which was apparently too low. Henkel advised us to treat the plastic surfaces of the ribs with atmospheric pressure plasma (AP plasma)." The team took this advice and immediately got in touch with the Belgian representative of the German plasma company Plasmatreat.

Cleaning and activation with AP plasma

Openair-Plasma jet technology developed by Plasmatreat twenty years ago is employed today in almost all fields of industrial production. The process uses virtually potential-free plasma for surface treatment. Produced inside plasma nozzles by an intensive, pulsed arc discharge, the plasma is conditioned at the nozzle outlet. A targeted flow of air along the dis-

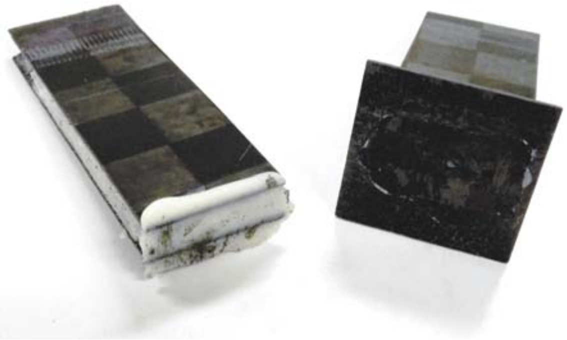

Fig. 6: Adhesive failure before plasma treatment (Photo Punch Powertrain Solar Team)

Fig. 5: The finished solar car «Punch One» (Photo: Rob Stevens, KU Leuven)

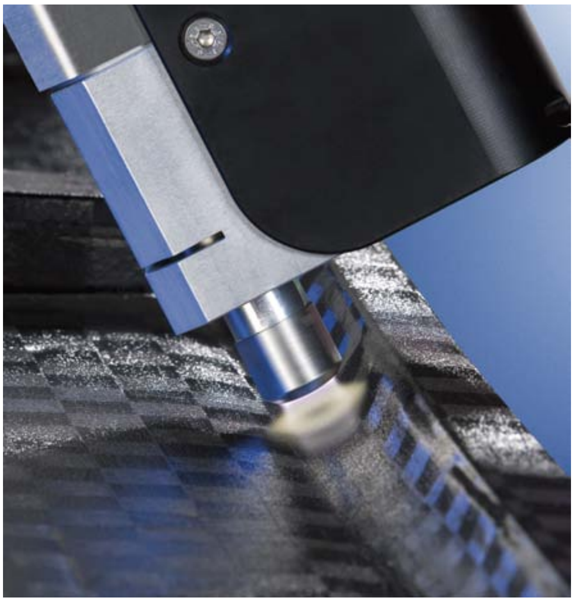

Fig. 7: Pretreating the CFRP surface with an «Openair» plasma rotary nozzle brings about simultaneous microfine cleaning, electrostatic discharge and strong activation of the plastic significantly enhancing its wettability and adhesive properties. (Photo: Plasmatreat)

charge path separates parts of the plasma and transports them via the nozzle head to the surface of the material being treated, whilst retaining the voltage-carrying parts of the plasma flow inside the nozzle head. The nozzle head also determines the geometry of the plasma beam being emitted.

The process performs three operations in a single step lasting only a matter of seconds: It simultaneously brings about the microfine cleaning, electrostatic discharging and activation of the plastic surface (Fig. 7). This triple action far outweighs the effectiveness of conventional pretreatment systems. The result is homogeneous wettability of the material surface and long-time stable adhesion of the adhesive bond or coating even under challenging load conditions.

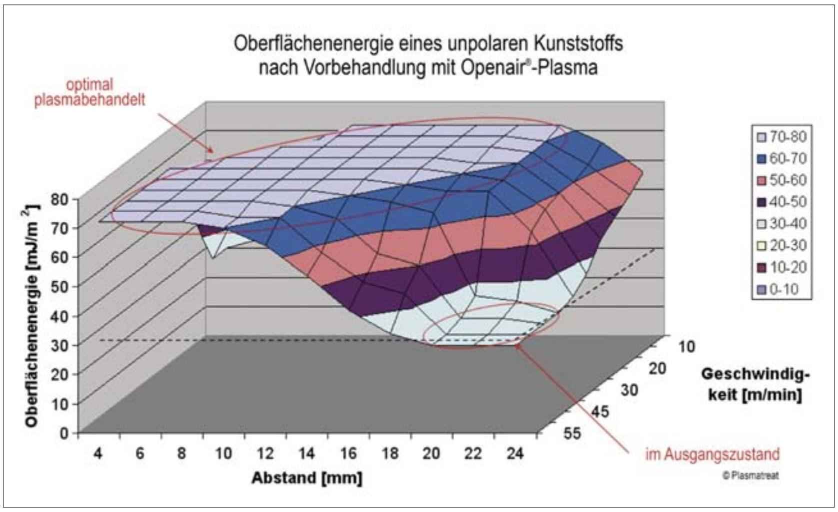

Fig. 8: The diagram shows a non-polar plastic surface which was pretreated with atmospheric pressure plasma as a function of distance and speed. Rendered polar by the treatment, the surface energy rises to >72mJ/m² (>72 dyne). (Diagram: Plasmatreat)

The surface is activated through the chemical and physical interaction of the plasma with the substrate. When the AP plasma hits a plastic surface, groups containing oxygen and nitrogen are incorporated into the mainly non-polar polymer matrix. Plasma activation brings about an increase in surface energy, rendering the substrate polar (Fig. 8).

Convincing test results

Never before had the students experienced a material pretreatment with plasma and they were keen to see the process. Two different tests had to be performed to verify the effect, one before and one after the bonding process.

The aim of the first test was to determine the surface energy of the CFRP before and after plasma treatment. Plasmatreat measured the contact angles using a Mobile Surface Analyzer (MSA) from Krüss. The portable instrument automatically applies two parallel drops from two liquids, then measures the contact angle and calculates the free surface energy in a process which lasts no more than a second. The results provide valuable information about the wettability of the surface by aqueous or organic liquids. The findings: The smooth side of the CFRP sample which was to be bonded had a surface energy of only 24mJ/m² (24 dyne) before treatment, but after plasma treatment this figure rose to 74mJ/m² (74 dyne) – ideal conditions for the subsequent adhesive process.

Again the epoxy resin adhesive was applied to pieces of the test ribs and bonded to the Textreme surface. A repeat of the tensile-shear-strength test provided the proof: The fracture behavior had changed. Instead of the earlier adhesive fracture, this time the desired cohesive fracture was obtained (Fig. 9). Construction of the «Punch One» bodywork could continue.

Lighter and faster

Under the direction and supervision of their production manager, three members of the team carried out the plasma treatment and bonded all the stiffening ribs to the two body shells. To make the job easier, Plasmatreat provided a hand-held rotary nozzle jet normally used for laboratory work or small-scale applications which weighed only 2.5 kilograms. The process proved to be very straightforward: Whilst one person guided the plasma nozzle across the surfaces

Fig. 9: Cohesive fracture in the adhesive after plasma treatment (Photo Punch Powertrain Solar Team)

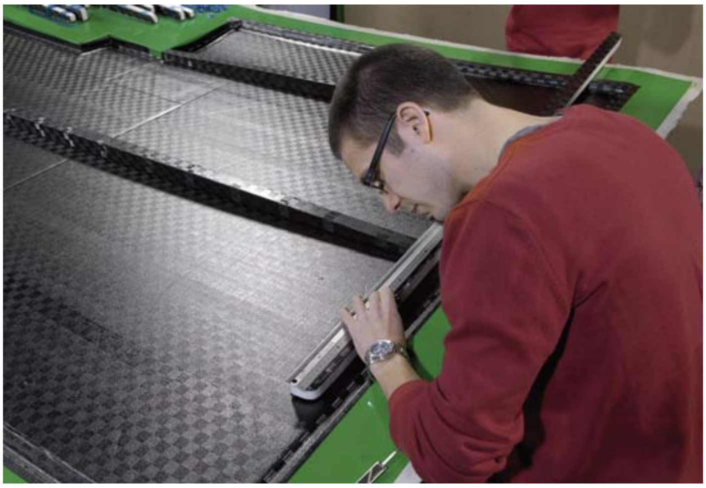

Fig. 10: Production manager Dokus Soetemans measures and marks the adhesive surface with millimeter precision. (Photo: Plasmatreat)

Fig. 11: Plasma treatment of the rigid foam rib using a hand-held rotary nozzle. (Photo: Plasmatreat)

to be treated, the next person followed on behind applying the adhesive (Fig. 10 – 13). Some pressure was applied to the bonded ribs and off the shell went into the oven for one hour at 90 °C to cure the adhesive.

While previously it had taken far longer than a week to laminate the stiffening ribs, now with the aid of plasma the job was completed in three days. But even more importantly: The new plasma bonding process had reduced the weight of the solar car body by almost three kilograms and the targeted 165 kilogram overall weight had now been achieved.

Prospects

After 3000 kilometers through the Australian outback at temperatures of well over 40 °C a proud and happy solar team finished fifth out of thirty international student race teams in Adelaide on October 25, 2015. The flat tire and a one hour penalty right at the start of the race, which unfortunately allowed a number of competitors to pass them, were soon forgotten. Now this year's Sasol Solar Challenge in South Africa is waiting. And the solar car «Punch One» might be heading to the sun again. ■

Fig. 12: Immediately after plasma treatment, the rib is bonded with a 2-component epoxy adhesive. (Photo: Plasmatreat)

Fig. 13: The monocoque outer shell receives its final stiffening rib. (Photo: Plasmatreat)