Plasma Makes Skis Fly

New Impregnation Process for Race Skis

Using an atmospheric plasma technology a team of Italian researchers has succeeded to bring about a sixfold increase in the amount of adsorbable wax on the running surface of racing skis. Thereby a new impregnation process could be filed for patent.

By using the Openair-Plasma and the Plasma-Plus atmospheric pressure plasma technologies the UHMWPE bases of racing skis can be modified to make an up to sixfold increase in wax adsorption possible (figure: Environment Park)

Every thousandth of a second counts. Extreme skiers such as Italian Simone Origone hurl down the slope without any protective car bodywork or sophisticated braking systems and safety engineering. When the world champion of speed skier clocked up 252.454 km/h in Vars in the French Alps on 31 March 2014, he relied on nothing other than himself and his prepared skis (**Fig. 1**). And it's no different for his fellows of Olympic downhill ski. Although they reach top speeds of 'only' 130 km/h to 160 km/h, the courses are three or four times longer and present no less of a challenge to ski base impregnation.

An Innovative Idea

Modern racing skis are high-tech products. The multi-layered sandwich construction comprises a combination of materials which varies depending on the manufacturer and remains a closely guarded secret. Be it fiberglass or synthetic laminates, rubber, metal inserts or an high-class wooden core – each layer of material is responsible for a specific performance characteristic.

In 2013 Dino Palmi (**Fig. 2**), president of the Italian Association of ski service companies (Skiman), contacted Plasma Nano-Tech, the in-house research department of Turin-based science and technology center Environment Park S.p.A. He asked plasma researchers Dr. Domenico D'Angelo (**Fig. 3**) and Elisa Aimo Boot whether plasma might be able to modify the characteristics of ski bases to boost wax adsorption. Palmi is regarded as an expert in his field. He has extensive experience not just in ski preparation but also in the manufacturing process that lies behind the sintered ultra-high-molecular-weight polyethylene (UHMWPE) running surfaces of racing skis. He was convinced that plastic residues in the molecular base structure generated during the sintering process have a negative impact on wax adsorption. Palmi hoped that this contamination could be removed by fine cleaning with atmospheric pressure plasma.

Plasma – the 4th State of Matter

In 1995 Plasmatreat GmbH from Steinhagen in Germany developed a technology called Openair-Plasma, which is now used throughout the world. Before then, the so-called fourth state of matter could be used only under vacuum, but with the invention of plasma nozzles, it was now possible to use it inline under normal atmospheric conditions for material surfaces to undergo microfine cleaning and »

Fig. 1. Speed skiers like Simone Origone have to rely on their perfectly prepared ski bases (figure: TamTam-Photo.com)

activation in industrial scale production processes. The method is environmentally friendly, needing only compressed air and electricity to produce the plasma beam. The dry, contactless plasma treatment enables materials to undergo further processing immediately.

In recent years Plasmatreat, working in partnership with the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) in Bremen, Germany, has developed a further process based on this technology known as PlasmaPlus. This was the first time that a plasma coating process was implemented under an atmospheric pressure in industrial production. Concealed inside the plasma nozzles is an ingenious coating system which enables locally selective layer deposition to modify the functional characteristics of surfaces in a targeted manner. A precursor is added to the plasma to produce a coating. High-energy excitation within the plasma fragments this chemical compound and deposits it on the surface in the form of an ultra-thin vitreous coating. What is essential to a user is the fact that he can vary both precursor and plasma performance himself to define layer functionality. The layer chemistry can be controlled selectively by adjusting the plasma parameters and nozzle geometry.

How Can Wax Adsorption Be Enhanced?

In 2012, one year before Palmi's visit, Giovanni Zambon, director of Plasmatreat-Italy in Venice, had presented the two plasma processes to Environment Park and the Italian scientists decided now that the research project 'PlasmaSki' should be based on this technology. The aim was to maximize the amount of adsorbable wax and to strengthen the physical structure of the polyethylene ski base by applying a nanocoating in such a way that it would delay friction and heat-induced breakdown of the base structure arising from extreme stresses.

Ski expert Palmi explained the team that the wax needed to achieve high speeds rubbed off very quickly and the ski base was often worn right down to the substrate. This would cause the ski base microstructure to break down (**Fig. 4**). When this occurred, the ski could no longer be waxed. The surface of the base would then have to be machine-ground to the point where the pores in the plastic reopened and were able to take up a fresh application of wax. However, the structure of the UHMWPE surface could adsorb wax only up to a certain point. This would be due partly to the produc-

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Fig. 2. Environment Park press conference in June 2014. From left: Simone Origone, Dr. Domenico D'Angelo (Plasma Nano-Tech), Dino Palmi (president Skiman), Fabio Massimo Grimaldi (CEO Environment Park), Mauro Chianale (president Environment Park) (figure: Environment Park)

tion process, and partly the preparation process.

Racing skis are prepared using different layers of wax. Usually a hydrocarbon wax is applied first using a thermal process to create a base layer which penetrates deep into the surface cavities. This is then followed by a second fluorocarbon wax designed to increase speed. During a race, the outer layer of wax wears off after 200 to 300 m, depending on the frictional characteristics of the piste. As soon as this happens, the base layer of wax kicks in to maintain performance for as long as possible and delay the collapse of micro-cavities in the three-dimensional honeycomb structure of the UHMWPE. This layer of wax eventually wears down too in the end.

The question the experts had to cope with was how to increase wax absorption and delay collapse of the base microstructure without changing the established hot-waxing process itself?

Fig. 3. Project manager Dr. Domenico D'Angelo inspects the ski's polyethylene running surface (figure: Environment Park)

Inside the Running Surface

The gliding properties, behavior in snow and thus the speed of a ski are determined by its running surface or base. Nowadays the base of high-performance skis is made from sintered UHMWPE. This plastic combines strong wear resistance with water repellence. The non-polar, hydrophobic material, characterized by high molecular density, is combined with special additives such as black graphite. Graphite is a good electrical conductor which prevents the base from becoming electrically charged and attracting particles of dirt.

In the sintering process the UHMWPE powder and the additives are combined, heat-fused in a cylindrical mold and then compressed under high pressure. Once cool, a slice is cut from the UHMWPE cylinder and molded to the final shape of the running surface using a 'stripper'.

Microscopic analysis of a UHMWPE ski base shows a three-dimensional honeycomb structure which is created by the formation of micro alveoli. This configuration makes the base surface fundamentally receptive to wax. However, the walls of the individual cells have an irregular geometry, culminating in a pointed tip that twists back towards the center of the structure. This significantly impedes wax adsorption. Due to their sensitivity to heat, these tips tend to block the micro-cavities during the hot-waxing process. What limits wax adsorption by the cavities even more is the amount of polymer dust left in the cavities during the sintering process, which is enough to partly obstruct them (**Fig. 5**). So the aim was to remove these blockages and residues – a task for which atmospheric pressure plasma, which can perform dry, deep-pore microfine cleaning on plastic surfaces in a matter of seconds, was ideally suited.

Two-Stage Test Phase

Once project manager D'Angelo had described in detail the complex chemical/physical interactions of the structural characteristics to those involved, the test series got underway in September 2013. Not only system parameters such as nozzle type, and the plasma jet's spacing, speed and motion sequence had to be configured, the right combination of gases, the configuration of the plasma energy and contact time had to be found as well. Furthermore, functional and operational details had to be tested and established.

The first stage of research focused purely on cleaning. The success was evident: Light microscopy analysis revealed that after plasma cleaning, the cavities in the honeycomb structure of the UHMWPE were not only clean, they had also expanded; in other words their overall volume had increased (**Fig. 6**). But this outcome was just one of the effects of plasma treatment. Another effect was that the plasma had activated the previously non-polar plastic, thereby polarizing its surface. Normally this creates the perfect conditions for bonding or coating with polar substances – but not in the case of wax, which is non-polar. In order for the non-polar wax to adhere to a substrate, the mutual electrostatic interaction forces have to be similar, and that only happens if it encounters 'its own kind', i.e., another substance with non-polar molecules.

The department Plasma Nano-Tech therefore had to generate a new substrate, a layer whose chemical characteristics and surface energy values were again similar to those of the previously non-polar polyethylene. Palmi suggested that at the same time this layer could be functionalized in such a way that it reinforced the three-dimensional honeycomb structure and reduced the friction coefficient. PlasmaPlus technology provided all the criteria to implement these three requirements. The aim of the second stage of the test phase was to identify the exact chemical and physical mix for the coating. The right precursor had to be found and the plasma parameters for the layer deposition process had to be redetermined. In particular, the layer thickness had to be defined such that it neither blocked the 3-D structure nor adversely affected the electrostatic interactions between wax and base.

Patent Application

The final result which the researchers D'Angelo and Aimo Boot (**Fig. 7**) had achieved emerged after just nine »

Fig. 4. Micro-cavities in the three-dimensional honeycomb structure of UHMWPE have collapsed: At this stage it is no longer possible to apply wax (figure: Environment Park)

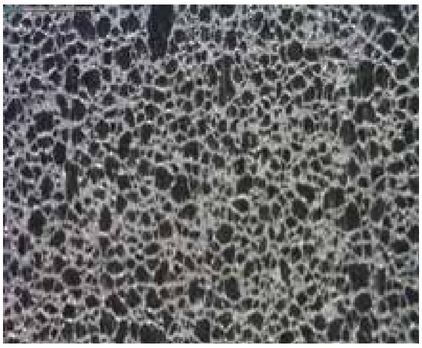

Fig. 5. The sintered UHMWPE structure of the ski base before treatment. Blockages and dust have accumulated in the micro-cavities (figure: Environment Park)

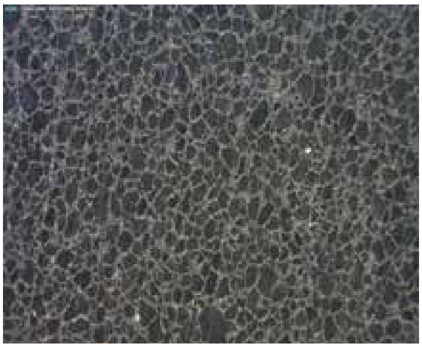

Fig. 6. Base structure after plasma treatment: The micro-cavities are clean and have expanded (figure: Environment Park)

Fig. 7. Dr. Domenico D'Angelo and Elisa Aimo Boot have turned the PlasmaSki project into a patentable process after just nine months of research (figure: Environment Park)

months and 40 laboratory tests and a patent application for the PlasmaSki process was filed. "Thanks to microfine plasma cleaning and the plasma coating which we developed specifically for our needs and applied with the aid of Plasmatreat technology, we were able to achieve a sixfold increase in wax adsorption compared with the conventional, but otherwise identical wax impregnation method", D'Angelo declared at a press conference in June 2014. The glide test showed that after waxing, not only were the gliding properties greatly enhanced; frictional resistance and adhesion endurance of the wax to the surface of the ski base also improved substantially. ■

