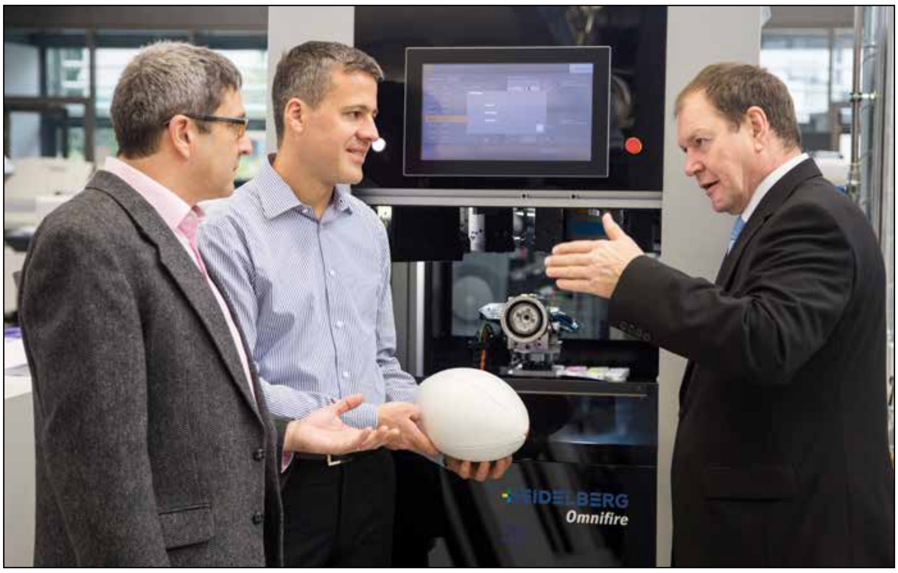
Plasma for reliable adhesion of UV inkjet digital printing on round surfaces

Mass-production, individually designed

It has only recently become possible to personalize round products such as balls or freeform objects using UV digital printing technology. In a world first, print machine manufacturer Heidelberg relies on a surface pretreatment with plasma to ensure optimum adhesion of uncoated printing inks.



Plasma expert Peter Langhof (right) explains to Heidelberg print specialists Ivar Emde (middle) and Ingo Ringle (left) how the rotary plasma beam works on round surfaces. The open Omnifire 250 can be seen in the background. (Photo: Heidelberger Druckmaschinen AG)

For some 3000 years, anyone wanting to kick a ball around made do with a pig's bladder wrapped in leather, but that all changed in the late 1960s: The outer casing of the football was replaced with plastics, while latex and butyl rubber were used for the air-filled inner. Once the first fully synthetic football had received official recognition at its 1986 World Cup premiere in Mexico, there was nothing to stand in the way of mass-produced plastic balls.

The use of elastomers made from soft polyvinyl chloride (PVC) and polyurethane (PUR) not only made the ball more robust, water-repellent, airtight and fast; the new material was also suitable for printing on an industrial scale. Pure white and multi-colored balls printed with images in all shapes and colors began to appear for the first time. The football was transformed into a product that was mass-produced and yet at the same time eye-catching; over 40 million of which are now produced each year in Asia for the global market.

The ball casing is the most mechanically stressed component of the ball and the imprints on it should be durable. The casing of modern footballs comprises several layers or shells; for example a plastic laminate composed of a segmented outer shell of pentagons or hexagons, followed by layers of foam rubber, latex and textile. These layers are bonded or pressed together and then applied to the rubber bladder. Before the punched segments of the outer shell are stitched together, the flat plastic is printed with the manufacturer's graphic elements (usually screen-printed) or decorated with laminated foils. Generally, a clear protective plastic film is then sprayed on forming the outermost coat, thus ensuring the adhesion of the imprint and preventing the ink from rubbing off.

Inspired by a football, in autumn 2013 digital printing experts at Heidelberg came up with a new business idea which was to prove sensational. The use of personalized printing to transform round and free-form mass-produced products into individual objects of desire. In other words, using state-of-the-art inkjet technology, they wanted to develop a printing system which made it possible for the first time to use UV inkjet digital printing techniques on round and 3D free-form objects as well, and so customize them with unique imprints in a matter of minutes.

At the time, UV digital printers were already available for printing flat or cylindrical objects such as bottles and cans, but completely round objects could only be printed using round screen or pad printing techniques or laminated with films. These tried and tested methods are standard practice for high volumes, but unsuitable for rapid printing of small volumes and individual items. Setup times are too high, production and drying times too long, handling and logistics uneconomical and the production of films, templates and printing plates too expensive. Furthermore, they are seldom environmentally friendly because the item to be printed requires pretreating – usually with solvent-based primers.

Unlike the Omnifire 250, the printer which embodies Heidelberg's vision. The new printing process – dubbed "4D" by the manufacturer – enables individual three-dimensional objects up to 300mm in diameter to be custom-printed at the press of a button. A laser ultrasonic sensor measures the object held by a suction cup and transmits the data to a 4-axis robotic controller. This controls the object's position to ensure that surface pretreatment, followed by drop-on-demand inkjet application, pinning (intermediate curing of individual colors) and final UV curing, are carried out at precisely defined points. The entire process is fully automated.

Demanding requirements for pretreatment

The most likely cause for the inability of plastics to be printed, bonded or coated effectively, or indeed at all, despite having clean surfaces, is that their surface energy is too low. Surface energy is the most important measure for determining probable wettability. Homogenous wetting, an ensuing consistent color gradient and good adhesion are conditional on the material surface being ultraclean and the surface energy of the solid material being higher than the surface tension (mN/m) of the liquid coating, be it ink, adhesive or paint.

Unlike water-based and solvent-based inks, which require time-consuming air drying to evaporate the liquid, with acrylic-based UV-curing ink, cross-linkage and ensuing polymerization occur immediately after application and radiation with ultraviolet light. Since the ink cures in a matter of seconds to form a solid layer, products can be used or reprocessed immediately. But the question is, how long will the printed image remain intact on the specific substrate? Footballs in particular require a robust, stress-resistant printed image and it was clear that the PU outer layer would have to be pretreated to ensure stable adhesion of the UV inks, since no further protective film – such as a coat of clear varnish – would be applied to the UV print. But by what means? Which technology could most easily be integrated into the compact Omnifire? What method offered optimum process reliability, reproducibility and effectiveness, whilst also taking sustainability into account?

A corona pretreatment is not suitable for all substrates and was developed mainly for 2D applications, so this method was ruled out right from the start. Although the integrated use of a nano flame was a possibility, it would require far more onerous safety precautions (e.g. explosion protection). Pretreatment with low-pressure plasma was not considered a viable option either, since it would not have been possible to fit a system of this kind into the machine. Never mind the fact that the vacuum would have reduced the external pressure, causing the air inside the ball – and thus the ball itself – to expand. And what about primers? Although there were no technical reasons to prevent the integration of a wet-chemical process into the print system, this should be regarded as an additional procedure reserved for such cases where other pretreatment methods would fail to achieve sufficient adhesion of the printing inks.

"Time and again", said Ivar Emde, 4D printing product manager at Heidelberg, „the spotlight fell on another pretreatment process – the use of atmospheric pressure plasma." Plasmatreat's Openair-Plasma technology, to be precise. The machine manufacturer already knew this technology was reliable, having acquired a laboratory unit ten years previously which was still running.

Dual effects

The atmospheric plasma jet process developed in 1995 by the Westphalian systems engineer and now used in virtually every branch of industry around the world is a dry process which combines the dual effects of microfine cleaning and simultaneous activation. The plasma is generated inside the nozzle by a high-voltage discharge and transported to the surface of the part being treated in a flow of air. The surface is activated through the chemical and physical interaction of the plasma with the substrate. When the 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, making the substrate polar. Energy-rich radicals, ions, atoms and molecular fragments present in the plasma release their energy at the surface of the material that is being treated and thus initiate chemical reactions which bring about this effect. Some of the functional hydroxyl, carbonyl and carboxyl groups that arise (as well as the oxygen compounds of nitrogen) form very strong chemical bonds with the coatings and so help to significantly enhance adhesion.

Openair-Plasma rotary nozzles work at speeds of 2700rpm. The plasma emitted at the side of the violet arc of light (not visible) strongly activates the surface of the ball, resulting in homogenous wettability. (Photo: Heidelberger Druckmaschinen AG)

During treatment, plastic surfaces are typically heated to below 30° Celsius. The plasma effect leads to homogenous surface wettability – an important consideration for ink jet printing, where the end result is largely determined by the way in which ink droplets strike the substrate and spread. Atmospheric pressure plasma is environmentally friendly; since it needs nothing other than compressed air and electrical energy, emissions of VOCs (volatile organic compounds) during production are avoided from the outset.

Rotating plasma

If you want to print a banner onto the equator line of a ball, the ball must turn on its own axis throughout the entire pretreatment process. Despite all the advantages offered by the plasma process which the Heidelberg developers had singled out, the all-important question remained: How could they ensure that the plasma beam impinging on the plastic surface from above would activate the flat area and the downward-sloping peripheral areas with the same degree of intensity?

"It's a good question", said Plasmatreat market manager Peter Langhof, "because stationary individual nozzles, which have only a relatively small outlet angle, would not achieve the uniform, large-area activation required." Rotary nozzles patented by Plasmatreat, on the other hand, achieve treatment widths of 50 mm and work at speeds of 2700 rpm. "With this rotary action", the plasma expert went on to explain, ,'plasma activation is slightly more intense at the edge of the treatment field (rounding of the ball) than in the middle because, although the nozzle is further from the edge, the rotation tracks overlap in this area. Conversely, in the middle, plasma input from the nozzle is slightly weaker even though the nozzle is closer to the surface. Ultimately, the plasma effect balances itself out, ensuring uniform activation intensity across the entire surface.

During a three-month test phase, Heidelberg used a Plasmatreat rental unit to test the effectiveness of plasma pretreatment on different materials. The results were unequivocal. "Not only was there a significant increase in adhesive strength compared with untreated substrates" Emde confirmed, "the quality was altogether higher – the sharpness and color brilliance of the printed image itself improved." Moreover, this plasma process was associated with a very high degree of process reliability, which was of the utmost importance to Heidelberg. So now there was no reason not to equip the Omnifire systems with Openair-Plasma technology.

Adhesion test under real conditions

BVD Druck+Verlag AG, a Lichtenstein-based specialist in offset and digital printing and advertising technology, was the first company to discover the 4D printing process for their own purposes. The company initially used a black printer, but since January 2016 it has also been using a four-color Omnifire 250.

The footballs printed in this system are almost exclusively branded ones, such as those supplied by Jako AG from Baden-Württemberg. They are supplied with a screen-printed imprint which the ball manufacturer

Personalized in two and half minutes, ready for shipment. The Balleristo product range has recently expanded from plasma-treated footballs, golf balls and volleyballs to include virtually all types of sports ball. (Photo: Balleristo.eu)

applies to the top PUR material and then protects with a clear PUR film. This final layer then has to be printed with UV-curing inks which must adhere securely of their own accord after curing because they themselves will not be protected by a film. „Laboratory tests are indispensable. But only the pitch will reveal whether the printed imagery on footballs can withstand the rigors of the game or whether it flakes off", chuckles Reto Knecht, Balleristo project manager at BVD and himself a keen football player. Knecht tests 'his' footballs under real conditions. The various PUR and PVC footballs initially each received three plasma treatments of varying length while they were being continuously rotated. After printing came the first field test: two two-hour football training sessions, including penalty shootouts. Only balls which survived the test with their print in better or at least as good condition as the manufacturer's screen-printed imagery were selected for the three-month pitch test. Then back to the laboratory for a visual inspection, and the results were clear: Thanks to the intensive plasma treatment, the UV printed image satisfied the specified requirements for adhesion.

In the Omnifire 250, the entire print process from ball insertion to removal lasts just two-and-a-half minutes, then the product is ready for shipment. The Balleristo 4D product range has recently expanded from plasma-treated footballs, golf balls and volleyballs to include virtually all types of sports ball. BVD also uses plasma technology with UV digital printing to personalize drinks bottles, shin pads and other free-form objects.

Plasma also suitable for large areas

What the 250 model can do in miniature, the Omnifire 1000 unveiled by Heidelberg in autumn 2016 can match on a large scale. With a six-axis robot, it is capable of printing any shape of free-form object up to 1.4 meters in length made from a range of different materials. For example, it is equally suitable for use with personalized motorbike helmets, composite ice hockey sticks and polycarbonate suitcases, or industrial production processes, for instance parts for automotive interior trims or overhead lockers in aircraft. Both series-production parts and after-sales parts can be enhanced with individual, colored motifs. Here too, surfaces are cleaned and activated with Openair-Plasma prior to UV printing. The plasma rotary nozzle can be operated trackwise to pretreat large areas.

Summary

The decision to opt for atmospheric pressure plasma has been worth it for Heidelberg. "The Plasmatreat rotary plasma is a key element of our production process which allows us to obtain good ink adhesion and wettability quickly and efficiently on a very wide variety of different materials", concludes Emde. The dry process is reliable and reproducible, the technology is low-maintenance and the pretreatment process environmentally friendly. Devotees of the 'Customize Your Life' megatrend can rejoice: Thousands of balls are now personalized in Lichtenstein for sports fans all over Europe and the Omnifire has become established in the USA and Asia to satisfy consumer demand for personalized goods.

Inès A. Melamies