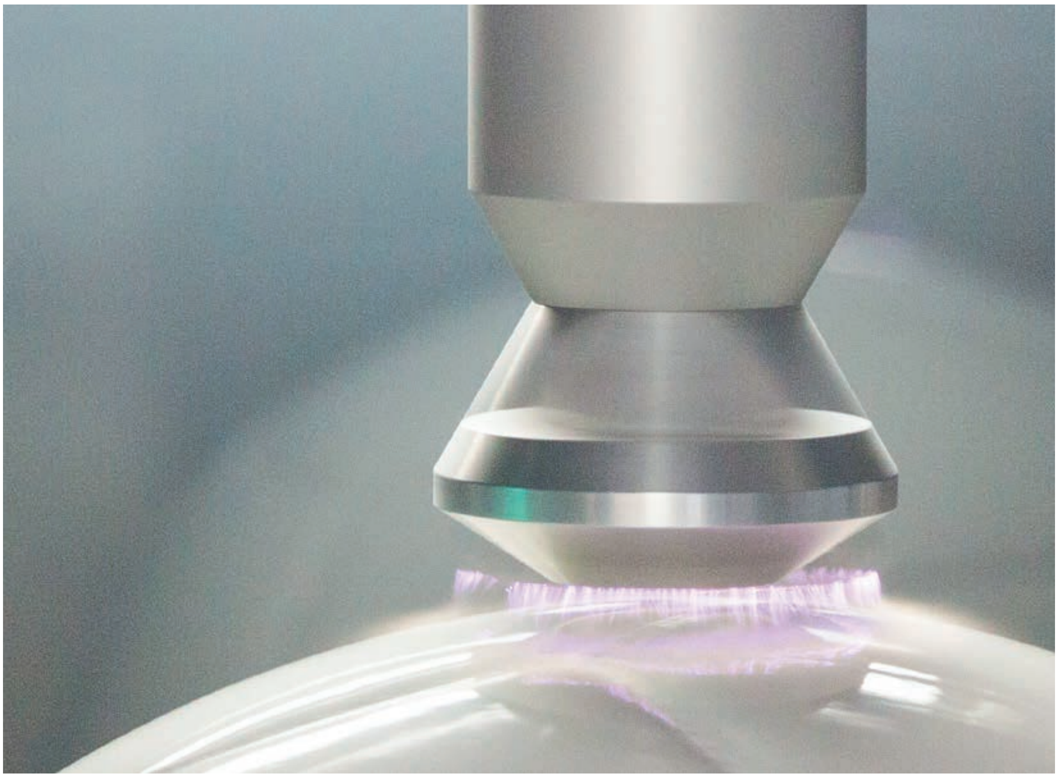
On the Ball

Rotary Plasma Ensures Adhesion of UV Digital Print to Free-Form Objects

A leading printer manufacturer benefited from using rotary plasma beams to develop a world first. The process involved pretreating three-dimensional objects with atmospheric pressure plasma in the printing unit before they were individually printed.



The yellow plasma (right and left of the violet arc) emerges from the high-speed rotary noozle. It cleans and activates the plastic on the equator line which is subsequently printed (© Heidelberger Druckmaschinen)

The casing is the most technically challenging 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 graphic elements (usually screen-printed) or decorated with laminated foils. In most cases a final coat of clear protective plastic is then sprayed on which ensures the adhesion of the imprint and prevents the ink from rubbing off.

Individually Designed Mass Product

In this digital age, the use of personalized printing now makes it possible to transform the hallowed ball, though mass-produced, to an individual object of desire. Printer manufacturer Heidelberger Druckmaschinen AG ("Heidelberg") came up with the idea of developing a print system based on UV inkjet digital printing technology which makes it possible for the first time to decorate round and free-form objects individually in minutes. Printers were already available for flat or cylindrical objects such as bottles and cans, but round objects could only be printed using round screen or pad printing techniques or laminated with films – tried and tested methods which are standard practice for high volumes, but unsuitable for small volumes and individual items: Setup times were too high, production and drying times too long, handling and logistics uneconomical and the production of films, templates and printing plates too expensive. In addition, solvent-based primers are often used to pretreat the objects to printed, which are not exactly environmentally friendly.

Fig. 1. 4D printing process: The Omnifire 250 UV digital printer with integrated plasma system decorates three-dimensional objects up to 300 mm in diameter at the press of a button (© Heidelberger Druckmaschinen)

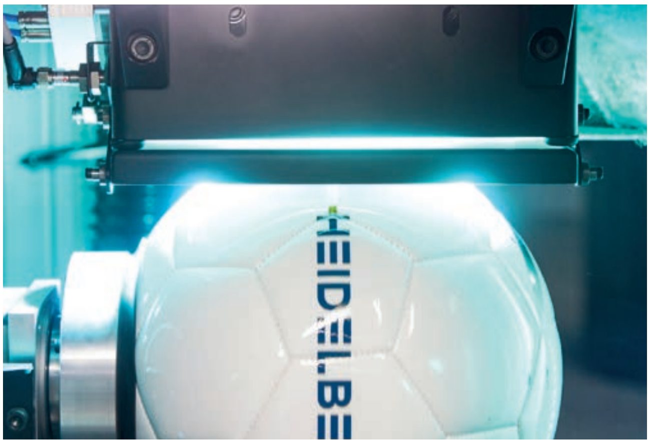


Fig. 2. Four-color UV inkjet digital printing: The energy-saving UV LED system ensures that inks in the Omnifire cure in a matter of seconds (© Heidelberger Druckmaschinen)

Heidelberg's 4D printing process (**Fig. 1**) relies on a laser ultrasonic sensor to measure the object, which is held in position by a suction cup. A four-axis robotic control system uses the data obtained to position the object such that surface pretreatment, followed by drop-on-demand inkjet application, pinning (intermediate curing of individual colors) and final UV curing can be carried out fully automatically at precisely defined points (**Fig. 2**).

It's all a Matter of 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. This is the most important measure for determining probable wettability. Homogenous wetting and an ensuing consistent color gradient as well as good adhesion are conditional on the material surface being ultraclean and the surface energy of the solid material being higher than the surface tension 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 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. Footballs in particular require a mechanically robust, stress-resistant printed image. The PU outer coating must therefore be pretreated to ensure stable adhesion of the UV inks, since no further protective film (such as a coat of clear varnish) is applied to the UV print.

A corona pretreatment is not suitable for use with all substrates and was developed mainly for 2D applications, so this method was ruled out. The integrated use of a nano burner would be possible, but it would greatly increase safety efforts (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 and the reduced external pressure would have expanded the ball. Although there were no technical reasons to prevent the integration of a wet-chemical process into the print system, this should be reserved for such cases where other pretreatment methods would fail to achieve sufficient adhesion.

The decision was finally made in favor of Plasmatreat's atmospheric pressure plasma technology, which the machine manufacturer already knew to be reliable, having acquired a laboratory unit ten years previously which was still running.

Rotating Plasma Nozzles

If a banner is to be printed on the equator line of the ball, the ball must turn on its own axis throughout the entire pretreatment process. To do this, it is essential that the plasma beam impinging on the plastic surface from above activates the flat areas and the downward-sloping »

Atmospheric Pressure Plasma

The Openair plasma process, which is now used in virtually every branch of industry around the world, is a dry process that combines the dual effects of microfine cleaning and simultaneous activation. The plasma is generated inside the nozzle by an atmospheric high-voltage discharge and transported to the surface of the part being treated in a flow of air. 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.

During treatment, plastic surfaces are typically heated to below 30 °C. The plasma effect leads to homogenous surface wettability – an important consideration for inkjet 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 volatile organic compounds (VOCs) are avoided from the outset.

Fig. 3. Personalized in two and a half minutes: The plasma-treated Balleristo range now includes virtually all types of sports ball as well as drinks bottles, shin pads and other non-round objects (© balleristo.eu)

peripheral areas with the same degree of intensity. Stationary individual nozzles, which only have a relatively small outlet angle, would not achieve the large-area activation required. However, patented rotary nozzles (**Title figure**) provide uniform activation intensity because the rotation paths on the edge of the treatment field overlap where the distance between the nozzle and the surface is slightly larger and the plasma input from a nozzle is therefore slightly weaker.

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, 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 utmost importance to Heidelberg.

Practical Test of Print Quality

BVD Druck+Verlag AG, a specialist in offset and digital printing and advertising technology, was the first company to discover the 4D printing process for their own purposes (**Fig. 3**). 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. They are supplied with a screen-printed imprint which the ball manufacturer applies to the top PU material and then protects with a clear PU film. This uppermost coating has now 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", chuckels Reto Knecht, Balleristo project

The Author

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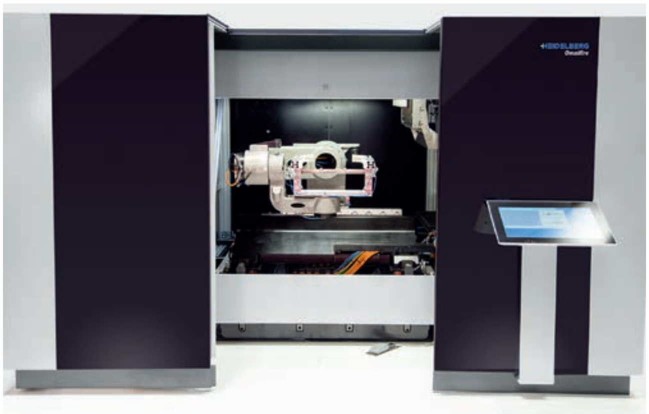

Fig. 4. Six-axis robotics: The Omnifire 1000 can print free-form objects of any shape up to 1.4 m long, from ice hockey sticks to suitcases (© Heidelberger Druckmaschinen)

Materials for Modern Footballs

For some 3000 years, anyone wanting a kick-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 the mass production of plastic balls.

The use of elastomers made from soft polyvinyl chloride (PVC) and polyurethane (PU) not only made the ball more robust, water-repellent, airtight and fast, the new materials were 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 distinctive and mass-produced at the same time, with over 40 million now produced each year in Asia for the global market.

Fig. 5. Personalized: A motorcycle helmet printed in the Omnifire 1000 (© Heidelberger Druckmaschinen)

manager at BVD and himself a keen football player. The PU and PVC footballs initially each received three plasma treatments of varying length while they were being continuously rotated. After printing, Knecht tested the balls under real conditions: two two-hour football training sessions, including penalty shootouts. Only balls which survived the test with their print in at least as good condition as the manufacturer's screen-printed imagery were selected for the three-month pitch test. The subsequent visual test in the laboratory showed that the quality of the UV print satisfied the specified requirements for adhesion.

Plasma also Suitable for Large Areas

What the 250 model can do in miniature, the Omnifire 1000 (**Fig. 4**) 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 m in length made from a range of different materials. For example, it can be used to personalize motorcycle helmets (**Fig. 5**), ice hockey sticks made from composite materials, or polycarbonate suitcases. And it is also suitable for industrial production processes, for instance parts for automotive interior trims or overhead lockers in aircraft. After surface cleaning and activation with Openair plasma, series-production parts as well as after-sales parts can be enhanced with individual, colored motifs. 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, concludes 4D printing product manager Ivar Emde. "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 materials." He goes on to say that the dry process was reliable and reproducible, the technology was low-maintenance and the pretreatment process environmentally friendly. ■