Additive manufacturing

Additive manufacturing technologies at Sulzer

Hybrid manufacturing for closed impellers

High-integrity rapid repair of pump parts

How termites 3D print their homes
About Sulzer
Sulzer’s core strengths are flow control and applicators. We specialize in pumping solutions and services for rotating equipment, as well as separation, mixing, and application technology. Our customers benefit from a network of over 180 production and service sites around the world. Sulzer has been headquartered in Winterthur, Switzerland, since 1834. In 2017, we achieved sales of roughly CHF 3.0 billion with around 14’700 employees. Our shares are traded on the SIX Swiss Exchange (SIX: SUN).

Pumps Equipment
The Pumps Equipment division specializes in pumping solutions. Intensive research and development in fluid dynamics, process-oriented products, and special materials as well as reliable service solutions help the company maintain its leading position in its focus market segments.

Rotating Equipment Services
The Rotating Equipment Services division provides cutting-edge maintenance and service solutions for rotating equipment dedicated to improving customers’ processes and business performance. When pumps, turbines, compressors, generators, and motors are essential to operations, Sulzer offers technically advanced and innovative solutions.

Chemtech
The Chemtech division is represented in all important industrial countries and sets standards in the field of mass transfer and static mixing with its innovative solutions. The product offering ranges from process components to complete separation process plants. The customer support covers engineering services for separation and reaction technology and tower field services to perform tray and packing installation, tower maintenance, welding, and plant turnaround projects.

Applicator Systems
Customers of the Applicator Systems division benefit from advanced solutions in the field of precise applications as well as two-component mixing and dispensing systems for adhesives, dental, healthcare, and beauty applications. A global network ensures that local knowledge and competence help Sulzer to keep its leading position in its market segments.

Additive manufacturing

“This edition highlights some projects that Sulzer is working on in the field of additive manufacturing (AM). We are now using AM widely in our businesses: for products, product development, and tooling. The Sulzer offerings apply AM technology for repairs, upgrades, rapid prototyping, as well as new parts. We already use a broad spectrum of materials for AM: metal alloys, plastics, and even ceramics. To guarantee the reliable functionality of parts produced with AM, we are building the material specifications and conducting endurance tests across the Sulzer businesses and with our external partners. The main benefit of AM is that we can produce parts and repairs faster and be more flexible to customer wishes and market demands.

Charles Soothill, Head of Technology RES, Member of the Additive Manufacturing Council, Winterthur, Switzerland
Additive manufacturing technologies and 3D scanning will massively change our future. As a technology pioneer, Sulzer evaluates additive processes and materials newly available on the market. Suitable processes are optimized by technical specialists, material experts, and process engineers, and tested in close cooperation with customers and partners.

In the early 1980s, the American inventor Charles Hull developed the first additive manufacturing process, which he called stereolithography. He applied for a patent for the principle in 1986. This invention paved the way for additive manufacturing (AM), also known colloquially as 3D printing. Sulzer started its development of the laser metal deposition process in the 1980s as an industrial process, obtaining patents during the 1990s. Today, lasers are established as the energy source during the process of AM for metals.

3D printing processes and technologies in the industrial sector
The various additive manufacturing processes are developed for specific materials (plastic, metal alloys, ceramics, sand, and wax). The method of consolidation (polymerizing, laser melting or sintering, fusing, UV curing, etc.) is specific along with the form of the material (liquid, powder, wire, etc.). As the technical maturity of the additive manufacturing processes grows, their use in industrial environments is becoming state of the art. Each technique is aligned to the place where it brings most customer value. One day we may see spare parts produced “just-in-time” on customer sites.
Typical areas of application at Sulzer

Sulzer uses a variety of additive manufacturing processes in all divisions and for a wide variety of applications. “With additive manufacturing, small quantities or customized products can be produced quickly and cost-effectively,” says José Ettlin, development engineer in the strategic innovation department.

Sulzer uses 3D printing processes primarily for the production of prototypes or functional samples. Ettlin explains: “Product optimization with 3D printed prototypes greatly improves the functionality of our applicator solutions. At the same time, we can significantly reduce the time required for product development.” Sulzer Applicator Systems does not only use additive manufacturing technologies. We also supply packaging solutions for additive processes where two-component material is employed for accelerated processes.”

Printing laboratory in Haag, Switzerland

“Our goal is that our development engineers can acquire solid detailed knowledge in the field of additive manufacturing. That is why we have installed our own 3D printers in our printing laboratory. And our process specialists love tinkering with it, even after work for their own projects,” Ettlin adds. The 3D printed components were usually still too expensive for series production in the past. The potential of AM for individual, faster, and resource-efficient production drive the development of new materials, machines, processes, and IT solutions rapidly. More and more serial components can be produced directly with AM technologies in a cost-efficient way.
Most of the commercially sold 3D printers employ the Fused Deposition Molding (FDM) process. During this process, a wire-shaped plastic material is melted and then extruded. The FDM unit in Haag allows processing two different materials at the same time, which can have different material properties.

The two 3D printers, which operate according to the stereolithography process (SLA), are permanently in use. Short plastic chains are polymerized into long plastic chains by UV light and thus solidified. After hardening, the building platform is lowered. One squeegee distributes the polymer liquid evenly and the next polymer layer is formed with the help of the laser. After finishing the job and removal of the support structures, the finished components are cured under UV light.

Sulzer as early adopter

For geometrically complex components, additive processes are ideal. The Chemtech division started to produce static mixers from metal powder more than ten years ago, using the Selective Laser Melting (SLM) process. The components are solidified from metal powder in a bed layer by layer using a laser beam. Support structures are also used, which not only provide stability but are also used to transfer heat away. This prevents thermal stress in the workpiece.

“Sulzer Chemtech led the way in process development for the industrial production of high-performance polylactic acid (PLA). This bio-based and biodegradable polymer is used in numerous FDM printers (Fig. 3) for home use,” explains Emmanuel Rapendy, Head of Polymers and Crystallization. “It is a safe polymer – historically used in biomedical applications – requiring no particular safety precautions unlike other polymers when heated.”

3D printed parts for model pumps

“Additive manufacturing processes provide a fast and economical approach to assess the merits of different hydraulic design variants during model pump performance testing. The test results of the best hydraulic variant is reviewed against proprietary design rules and computational fluid dynamics (CFD) calculations. AM is currently employed in model pumps on stationary hydraulic components such as guide vanes and adaptation pieces, but also in some cases for rotating hydraulic components,” explains Arnaldo Rodrigues, Head of Hydraulic Development in Winterthur.
Hybrid manufacturing for pumps

In hybrid production, a combination of additive build-up, using Laser Metal Disposition (Fig. 5), and a subtractive process, 5-axis milling, is used to rapidly make impellers with the new material properties and also achieve the required hydraulic surface quality. For closed impellers, the hybrid process is ideal.

Regular knowledge exchange

Sulzer has established an Additive Manufacturing (AM) Council to enable engineers from various Sulzer divisions to share their knowledge. Charles Soothill, Head of RES Technology and member of the AM Council, explains: “This exchange allows us to participate in the knowledge of other engineers. We also learn together across Sulzer about new finishing methods or new materials. What experience do engineers from other divisions have with 3D printing and hybrid processes?”

Soothill adds: “In addition to the optimization of our 3D designs, we can optimize materials and reduce costs. We are also looking to the future. What inspection procedures, test methods, and machine process monitoring are required to ensure the quality of the 3D printed parts? How can material defects be avoided? What features can be optimized when building up the structure of components? How can Sulzer use bionics and adopt examples from nature for lightweight design?”

Visions for the future

Pharic Smith, Head of Engineering in the Rotating Equipment Services division, explains: “Sulzer already uses additive processes for the rapid repair of complex damaged parts in the turbo industry. In future we see additive manufacturing also being applied to the rapid repair of pump parts to restore to as-new condition in short lead times. Functional and endurance tests are in progress for the creation of complete parts with additive processes to ensure high quality and repeatability. Once this is assured, we see enormous potential in these processes to offer our customers faster solutions.”

What are the advantages of printing spare parts on-site? Quick repairs without long downtimes. No storage, shipping, or customs complications. Sulzer is thinking intensively about new business models to make this vision come true and to offer our customers these advantages in the near future.
One part. One machine. Two manufacturing processes combined. Sulzer is developing a hybrid manufacturing process for closed impellers in which subtractive milling and additive material buildup are combined. Sulzer has applied for patents for the process. Extremely reduced lead times and innovative part geometries are the main advantages.

To date, the best way to produce closed pump impellers has been to use casting technologies because of their unique geometry. Features such as a high wrapping angle and twist of the blades lead to high performance when pumping common fluids like water or oil. This optimized geometry does not allow the internals of an impeller to be machined from a forged material. The restricted accessibility for the tools prevents to use of classical, subtractive manufacturing technologies like milling or electric discharge machining (EDM) without compromising the original impeller geometry. Casting was – up to now – the traditional way to manufacture closed impellers.

Limitations in casting production

Even with state-of-the-art casting technologies, there are risks of defects on the surface and inside the metal, a fair but sub-optimal surface quality and geometry. These issues affect the overall performance of the part and determine the extent of post-casting manufacturing costs – such as surface treatment and balancing. The average lead time for casting is about 35 days.

Laser metal deposition is a process where the laser generates a weld pool on the component surface. A nozzle then automatically adds metal powder. This creates beads that are welded to each other, and can form structures on existing bodies. For LMD, a wide variety of materials in powder form is available. In general, all materials that are weldable with conventional welding methods can be used. The LMD method has been in use at Sulzer already since its early years, mainly for repair welding of used components.
With so-called rapid casting technologies, the lead time to produce a finished part is still quite long, taking about 25 days. Optimizing the time to market is important for Sulzer and its customers and it has become the driving reason to seek a new, time-saving manufacturing method.

**Parameter setting for LMD**

For the LMD process, many production aspects are important: the material specification, production settings, quality control, and performance tests. The settings include metal powder feed, process speed, laser power setting, focal position, material deposition height, and much more. The optimization of these parameters is very important and constantly monitored by sensors on the LMD machine to guarantee material buildup without imperfections. Only constant quality control of the process and the initial performance tests allow Sulzer to guarantee the high quality of the parts, which have to withstand high loads over their lifetime in the pump.

**Sulzer as a pioneer for hybrid manufacturing**

The solution to much faster and better impeller production is a combination of two production technologies. Sulzer uses the LMD method for material buildup, which is followed by 5-axis milling to achieve high-quality surfaces and accuracy. As a pioneer in innovative manufacturing methods, Sulzer already operates such a hybrid manufacturing process.

**Laser metal deposition plus 5-axis milling**

The potential for hybrid manufacturing processes is significant. Since its first introduction, major 5-axis machine tool manufacturers are developing hybrid machines. With a hybrid process, the amount of additive buildup can be limited. This helps to keep costs of the process reasonable. Additive buildups quite often need support structures – but with hybrid manufacturing, these structures are often not necessary due to the variable build direction. Thanks to the final

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**Working steps of hybrid manufacturing**

For hybrid manufacturing, additive and subtractive methods are combined in one machine. The patent-pending hybrid production process for a closed impeller starts with a small wrought billet (Step 1), which is machined to its final geometry with 5-axis milling operations (Step 2). This milling step is only possible because the radial dimension of this core part is smaller than the size of the final impeller. Thus, all channels are accessible with milling tools. When the impeller core is finished, the remaining geometry for the final impeller is radially built up via laser metal deposition (LMD). The added material is later milled to the final geometry and surface quality. Depending on tool accessibility, this additive step with subsequent final machining can be repeated several times in order to grow the impeller radially to its final diameter (Step 3).

**Fig. 2** The main manufacturing steps of a closed impeller with hybrid manufacturing.
5-axis milling, the material surface quality complies with the accepted industry standards. Because of the high geometrical precision, these hybrid-manufactured parts require less post-processing efforts.

The hybrid manufacturing method allows Sulzer to speed up product development cycles. The engineering teams can produce prototypes much faster and get customer feedback quickly from field tests. The subsequent product optimization increases the quality of the Sulzer products. For computer-aided manufacturing (CAM), Sulzer uses adapted software tools to

Fig. 3  Working steps during hybrid manufacturing.
improve hybrid manufacturing processes. Applying the material in layers requires a definition of the layer buildup. In other words, after designing a part the program has to cut the part geometry into multiple slices, which, depending on the part geometry, can have three-dimensional shapes. The buildup is done layer by layer in defined regions and creates the part.

**Closed pump impellers produced in 48 hours**

To optimize the parameters and to automate the toolpath programming, Sulzer joined forces with a company producing very similar closed impellers for turbo compressors. The two companies are working cooperatively in Zurich, Switzerland, on preliminary studies and proofs of concept. Together, they have already produced the first impellers with the new method.

With the dedication and experience of both companies, Sulzer is convinced that it will be able to achieve the ambitious goal of producing high-quality stainless steel closed impellers within 48 hours in the future. This is a radical drop from the current standard of 25–35 days using traditional casting methods.

![Fig. 4  Comparison of production lead times for closed impellers with different manufacturing processes.](image)

Of course, hybrid manufacturing is neither limited to impellers alone nor to single materials. Therefore, future developments aim to use hybrid manufacturing for other pump components or to use different materials within one part.

One example of the use of different materials is the application of a wear-resistant coating via LMD during the manufacturing process. For example, this coating can be applied in the respective impeller area to replace an impeller wear ring. The hybrid manufacturing method has a big potential for cost-effective manufacturing in our industry and will find its way into all fabrication halls of Sulzer.
High-integrity rapid repair of pump parts

When the repair of damaged high-value castings and forgings is not possible using conventional methods, additive manufacturing offers solutions and shorter lead times.

Shafts and impellers are the most important parts with respect to pump integrity and operational reliability. Because of the high load during their operation, they have to be manufactured with high quality and fine tolerances.

Conventional repair methods are often insufficient
Current industry repair methods such as conventional welding or coatings will often result in unacceptable changes to material properties and design intent. For most of the cases, it is necessary to replace the whole component. Both forgings and cast parts can have lead times of more than six weeks. In the case of obsolete or third-party components, there is additional time needed for reverse engineering.

Additive manufacturing plus precise control
Conventional welding is not always a feasible solution. Welding has an impact on material properties, which require a post-weld heat treatment in some cases. Furthermore, the surface quality is not easy to control with welding.
In these cases, laser metal deposition (LMD) offers a viable repair solution. LMD combines the established additive technique of material buildup with the delicate control of laser power and the accuracy of CNC robotic control. In contrast to electric arc welding, LMD has low heat input to the base material as well as a comparatively small size and controllability of the weld pool.

LMD manufacturing repair offers several advantages, including:
- significantly reduced heat-affected zone (HAZ), which, for most common stainless steels used in pumps, can be considered insignificant due to low heat input
- precise control over weld deposition
- ability to create small, complex deposits
- equal or superior material properties to base material

LMD uses a laser (typically 2–10 kW) to generate a weld pool on a metallic component surface. Either powder or wire filler material is automatically added and simultaneously melted to form a deposit. The powder is inserted with an inert gas. Thus, the part is built up layer by layer on the substrate. Both the laser and nozzle from which the powder is delivered are manipulated using a robotic arm and CNC control.

Manufacturing settings for repairs
For this impeller repair using (Fig. 2) the LMD process, the material was deposited in layers 2–3 mm wide and approximately 1 mm high. The layer height and the surface structures are directly influenced by the particle size of the powder. A high-quality surface finish of LMD manufactured parts is necessary in many cases and can be done on conventional milling machines.

The first impeller repaired with this method took three working days. Tests have shown that the deposited material can achieve all required metallurgical properties, including hardness, strength, toughness, and interfacing with the base material. These properties are mainly influenced by the metal powder in use and by the LMD machine settings.
In the trial impeller shown in Figs. 2 and 3, a segment of the shroud was intentionally removed to permit the trial repair. Only the outer periphery of the repair deposit was dressed to show the quality of the weld material. The rest was left to make the weld layers visible for illustration purposes (Fig. 3, Zone 2). After final machining, there was almost no evidence of the repair (Fig. 3, Zone 3).

**High-integrity repair within days**
Sulzer is currently working on a number of projects to qualify LMD processes for the repair of high-integrity duplex shafts as well as high-energy impellers. In the near future, Sulzer customers can benefit from high-integrity repairs in a matter of days.

For the future, Sulzer is working towards an integrated reverse engineering process through 3D scanning combined with CAD-CAM hybrid manufacturing for fast repairs.
Although additive manufacturing is currently being hailed as a ground-breaking innovation, termites have been using this method to build their enormous mounds for millions of years.

Termites use sand, clay, and soil to construct their three-dimensional nests in layers. They then harden these structures with their saliva. Though a computer program must be used to control laser-hardening for technical 3D printing, termites are genetically predisposed to working with the necessary construction data.

There are well over 2,000 species of termites. And they build a wide range of nests – from ones the size of a soccer ball nestled beneath the Earth’s surface to gigantic, cathedral-like structures reinforced by a myriad of small towers. For example, African Giant termites build residential complexes that measure up to seven meters in height with walls that are between 30 and 60 cm thick and as hard as cement. Each of these complexes is home to around two million termites. Because termites are just a few millimeters in size, they are dwarfed by their homes. The equivalent for humans would be a structure the size of the Matterhorn, with enough space inside to house two million people.

Refined architecture

Termite mounds are built on top of large “cellar” vaults that extend meters below the ground. Columns extend upwards from the cellar floor; with the help of intermediate floors, they support the nest above. Meanwhile, the “attic” opens up onto another large, hollow space. There is a rock-hard chamber at the heart of the termite mound that looks like a giant potato with a few
small holes bored into it. This is where the blue bloods live in captivity for their entire lives: A king just a few centimeters in size rests beside his queen, whose abdomen is swollen like a sausage. The queen (Fig. 1) acts as a breeding machine, laying an egg every one to two seconds. Over the course of twenty years, she gives birth to several hundred million descendants.

To meet their nutritional needs, the workers gather wood and plant material from their surroundings. Once they have digested their food, they layer their dung along the interior of the mound, creating compost heaps. Mushrooms grow on top of the compost. These secrete enzymes that break down cellulose. This, in turn, creates fortified food that is rich in vitamins and an excellent source of protein. The workers continuously gather small white mushroom heads from the mushroom crops on the compost heaps and use these to feed their young. The queen and king are fed a pulp made from the fortified compost, as are their coterie of soldiers, who can not chew due to their massive jaws.

Regulatory air-conditioning technology
Making mammoth termite mounds livable requires sophisticated building techniques. After all, thousands of liters of fresh air need to be fed into the mound each day, and the carbon dioxide produced by the termites and the mushrooms needs to be discharged. To meet both of these needs, the outer wall of the termite mound is built with a rib-like structure. A large number of air ducts are constructed just below the surface of the ribs, running from the mound’s attic to the cellar. The warm air that rises at the center of the mound flows laterally out into the ribs at the attic and slowly sinks down through the ducts. During the process, oxygen gets in from outside the mound, and carbon dioxide produced inside the mound is discharged into the surroundings. The regenerated air then collects in the cellar for its next trip through the nest. So that the air inside the mound remains at a comfortable 30 °C (86 °F) day and night despite significant vacillations in exterior temperatures, worker termites ceaselessly close or open parts of the air ducts with the standard building material.

Clever geographical optimization
The compass termites of Northern Australia demonstrate how efficiently these animals can adjust their air-conditioning technology to respective geographic conditions. This species needs to be prepared for temperatures that sink as low as 5 °C (41 °F) at night and reach tropical heights of 33 °C (91 °F) during the day. To cover both ends of the spectrum, compass termites construct a particularly striking type of nest. Its base contains a structure that looks like a slit eye, the longitudinal axis of which is precisely oriented along the local north/south meridian (Fig. 2). The mound tapers towards the top, forming a narrow ridge at the peak. All in all, the mound looks like the upward-facing blade of an ax that is lying on the ground. When the sun rises each morning, the entire broadside of the mound is exposed to its rays, giving the termites inside the warmth they need. At the sweltering midday, though, the sun is positioned above the narrow edge of the mound, which protects the nest from overheating.
Key pumps for Aksay concentrated solar power plant

Sulzer has been contracted to supply 18 pumps for both solar and power islands of the Aksay 50 MW CSP plant in China. Aksay is a molten-salt parabolic trough plant with a 15-hour molten-salt heat storage system.

To promote renewable energy, the Chinese government has launched its first batch of 20 concentrated solar power (CSP) pilot projects using various technologies: central tower, parabolic trough, and linear Fresnel collector. Most projects will be equipped with a molten-salt heat storage system to last 6–15 hours. The Aksay plant is one of these 20 pilot projects.

A dedicated Sulzer team including engineers from China, Belgium, Spain, Switzerland, and USA worked closely together to develop the optimal comprehensive pump package for this project. The package includes boiler feed pumps, condensate extraction pumps, molten salt pumps, and attemperation pumps. The pumps will be manufactured in Sulzer’s factories in China and Belgium.

The Sulzer Suzhou factory in China is one of the main production units for the power market with its state-of-the-art order-related engineering, packaging, and testing facilities. It focuses on domestic and export markets.

Guijun Zhu, Beijing, China
Large pumps orders from GE Power India Limited

Sulzer India has been contracted to supply 21 barrel-type boiler feed pump sets for GE Power India Limited.

The pumps are destined for the three new thermal power plants, i.e. 3x 660 MW Ghatampur, 2x 660 MW Obra “C” UPRVUL, and 2x 660 MW Jawaharpur JVUNL. Those plants are being built in Uttar Pradesh, India, and owned by Neyveli Uttar Pradesh Power Limited, Uttar Pradesh Rajya Vidyut Utpadan Nigam Limited, and Jawaharpur Vidyut Utpadan Nigam Limited, respectively. The delivery is scheduled from mid-2018 to mid-2019.

Included in the orders are 21 barrel-type boiler feed pumps (20 MW drive) and 21 booster pumps. The pumps are specifically designed for use in arduous industrial applications and are optimized for high-efficiency operations. The scope of supply also includes 12 condensate extraction pumps and 14 heater drain pumps. All pump sets will be engineered, assembled, and packaged in India.

Sulzer is a key player in the supercritical power segment, and is investing in employees and sites in India, setting up a new 8 MW test bed in Mumbai. After a detailed evaluation, the customer has chosen Sulzer as its partner in this important project thanks to its technology and well-recognized global experience.

Claudia Pröger,
Winterthur, Switzerland
Sulzer at ACHEMA 2018

Sulzer will be delivering service and product excellence through innovation at ACHEMA 2018, which will be held in Frankfurt from June 11–15, 2018. The exhibition will bring together experts from across the world, and Sulzer is taking the opportunity to demonstrate its expertise in separation technology for chemical manufacturers, pump design, and rotating equipment services at two booths.

Sulzer’s experts in separation technology will be on hand in Hall 4.0, at Booth D48, to discuss the latest developments in tray technology, structured and random packing applications, feed inlet devices, separators, static mixers, coalescers, crystallizers, and the use of carbon products in column internals. Sulzer offers skid-mounted solutions that minimize costs and disruption on-site.

In Hall 8.0, at Booth A71, Sulzer offers insights into the latest pump designs as well as developments in asset management and pump optimization software. Visitors will also be able to see and discuss the company’s comprehensive offering for the maintenance of turbines, compressors, pumps, generators, and large motors.

Upcoming events in 2018

Around the globe, Sulzer takes part in numerous events, exhibitions, and conferences. Please check our event calendar to stay informed. Have you already used our calendar export function? You can easily add interesting events into your personal calendar. For more details please visit www.sulzer.com/events.
And the winner is …

Manuel Montero, Reliability Engineer at Chevron in Bakersfield, California, United States, is the lucky winner of our contest. The Apple Watch Nike+ will be in his hands soon.

Chevron is one of the world’s leading integrated energy companies. They explore for, produce and transport crude oil and natural gas; refine, market, and distribute transportation fuels and lubricants; manufacture and sell petrochemicals and additives. Their net oil-equivalent daily production was around 2.7 million barrels in 2017.

Contest for new subscribers

If you sign up by June 15, 2018, you will automatically be entered in our drawing to win an Apple Watch (Series 3, GPS). The winner will be randomly selected and informed by e-mail on June 19, 2018.

Sign up under www.sulzer.com/str-newsletter.

Terms and conditions

The prize is an Apple Watch (Series 3, GPS). The winner will be chosen randomly from all participants who subscribe to the STR newsletter between April 24, 2017, and June 15, 2018. The winner agrees to have his/her name published in the next Sulzer Technical Review. There is no written information concerning the contest. Limited to one entry per person. Sulzer employees and their family members are excluded and cannot participate in the contest. Exclusive place of jurisdiction is Winterthur, Switzerland.

News ticker

+++ The first Sulzer Bluebox™ installation was delivered to Phillips 66 to gather pipeline data. +++ Geka presents the new collection “urbanHeat” for glittering eyes and fresh skin. +++