SIX DOMAINS PROVIDING OPPORTUNITIES TO EXCEL

A wide-ranging survey of Belgian manufacturing industry, Original Equipment Manufacturers and Tier 1 and Tier 2 subcontractors have identified six domains providing opportunities to excel within precision manufacturing. The fourth domain goes into functionality as a result of surface engineering.

By making changes to the surface a component can be given new functionalities with a higher added value. Hydrophobicity is one such functionality. Research has shown that the addition of micro- or nanotextures to the surface of a component can provide with water repellent properties. The water no longer sticks to the surface, but forms droplets and rolls off.

Successfully competing in a global market requires a combination of having a range of unique advantages and ways of standing out from the crowd. Precision manufacturing offers this opportunity, but at the same time it poses challenges in terms of machinery, control and tooling. Six domains were identified in which a company can make the difference.
MARKET NEED

Surface functionality is an important feature of modern components and consumer products. It adds value, enhances their overall performance or even allows them to take on completely new applications. In general, surface functionalisation can be seen as a collection of potential novel functions that can be given to a surface.

One example of this is hydrophobicity. The increased contact angle with the water in the case in question will ensure that the water on a surface will not form a sticky film but instead droplets which will roll off the surface quite easily, meaning that they also carry dust particles away without much difficulty (self-cleaning), preventing the formation of layers of ice or biofilms (anti-fouling). In addition, controlling the contact angles for certain areas can allow designers to create preferable fluid pathways. As well as hydrophobicity, the aerodynamic behaviour of a part may be altered by introducing turbulent boundary layers (which take longer to release materials than laminar boundary layers) or create a golf-ball effect. Moreover, the friction coefficient can be reduced by introducing textures. Dimples can become local lubricant reservoirs which considerably reduce the wear of moving parts such as axles and gears. In addition, the surface functionalisation can play a role in altering the thermal behaviour, producing aesthetic effects and novel haptic behaviour such as soft touch. To be able to bring functionalised products to market, both texture design (to ensure functionality) and texture machining technology need to be developed, and their cost reduced to a competitive level.
POTENTIAL & OPPORTUNITY

Nature provides us with various prime examples of functionalised surfaces, which aid plants and animals in their survival, so for instance lotus leaves, rose petals and shark skins all exhibit highly hydrophobic (or superhydrophobic) behaviour.

This surface functionality is due to the texture, i.e. small pillars or grooves which increase the contact angle with water. This example can be used as a starting point to create novel functionalities for existing products, or even allow completely new products to be developed. Prime examples of articles that could benefit from this added surface functionality are food containers and packaging. Currently, LDPE and HDPE are often used as low-energy materials to ensure easy cleaning; however, the material properties of these polymers are not always optimally suitable. Thermal behaviour, an oxygen barrier function, strength and stiffness are very often part of the equation along with the contact angle with water. In addition, surface engineering can increase the contact angle (up to 160 degrees) far beyond what is possible with both coatings and low-energy materials, increasing the hydrophobicity and at the same time the self-cleaning properties. The functionality of these food containers and packaging has to be transferred from a metal mould during injection moulding, indicating that the machining technology developed should focus on this issue. In addition to transferring functionality, mould texturing can also enhance the injection-moulding process by increasing the flow length (by 5-7%) and lowering the ejection force (by up to 50%), allowing shorter total cycle time.
Alongside these potential applications, car parts such as bumpers, tailgates and rear mirror housings may also benefit from hydrophobicity, due to the self-cleaning properties and the ongoing ‘recently waxed’ surface appearance produced by this approach. Soft-touch surfaces allow users to interact more comfortably with switches and electronic devices. Biomedical applications such as syringes, instruments and even prostheses can avoid being subject to biofouling due to the hydrophobic behaviour added by these textures. In addition, hydrophobicity means that syringes can be emptied more easily, thereby ensuring more accurate control of the desired dosage. Surface texturing can make bicycle frames more aerodynamic and easier to clean. Therefore, it can be reasonably concluded that surface texturing will potentially have a major industrial impact, mainly based on its possible novel applications, and the advantages it brings with it with regard to alternative technologies such as coatings.

Based on surveys, it is estimated that as a result of successful implementation of surface texturing in for example the value chain of plastic parts, the total turnover arising from novel products will be increased by 5% while the cost per product will be reduced by 8%. OEMs can market novel products or products with increased functionality, while injection moulders can benefit greatly from the increased productivity. Novel machining methods and machining parameters will help mould makers to supply injection moulders and OEMs with the desired moulds.
RESEARCH RESULTS

Research has focused on achieving hydrophobic (water-repellent) surface behaviour. The effect is quantified by measuring the contact angle between a drop of water and the component surface. A small contact angle (< 90°) indicates that the drop of water will spread out over the surface, while a large contact angle (> 90°) suggests that the water drop will remain spherical and will roll off easily.

In general, hydrophobicity can be achieved in three ways: (1) using a low-surface-energy material which already has a tendency to repel water, (2) applying coatings or (3) engineering the surface topography. While low-surface-energy materials such as HDPE and LDPE are already widely used, they limit other component functions due to their inherent material specifications (E-modulus, strength, conductivity, etc.). Coatings on the other hand are very effective in increasing the hydrophobicity or tribological behaviour, but they wear off after time and need to be re-applied to retain their functionality. Therefore, current and future research needs to looks into modifying the surface topography (surface texture) and the most cost-effective machining technologies to apply the texture to a 3D free-form shape.

Surface texture and measurement of the contact angle, using micro-milling
Five-axis micro-milling offers all of the advantages that are needed: flexibility with regard to free-form shapes, small features and its reputation as a cost-effective process. Using an end mill with a diameter of 0.8 mm at an angle of 45°, the texture as shown in the figure below (left-hand side) is machined onto stainless steel 316L. This has a depth of 100 µm and a pitch distance of 125 µm.

The results indicate an increase in the contact angle from 75° (polished 316L) to 130° entails a clear shift from a hydrophilic surface to a hydrophobic surface (figure right-hand side). It can be seen from the graph above that changing the width or pitch distance between the peaks has a strong influence on the attainable contact angle, with lower widths resulting in a larger such angle. The reason for this is that the texture becomes sharper, allowing more air to be trapped beneath the droplet. This air has a contact angle of 180° and therefore increases the total contact angle between the steel and the water.
Double curved and complex shapes can also be textured using micro-milling. Using the five-axis capabilities of a high-precision milling centre (Fehlmann Versa 825), a double curved surface measuring 60 mm in diameter is machined. It is clear that even on a curved surface the texture can maintain its ability to increase the contact angle with water.

Future research will focus on ultrafast laser texturing. The literature has already shown that the feature detail level and size are important for the attainable level of functionality. Pico- and femtosecond lasers allow for very precise, fast and small-scale texturing. Due to the very high pulse speed of these lasers, heat does not dissipate into the bulk of the material. This inhibits the formation of cracks, subsurface damage and recast layers, resulting in a very clean texture with tailored properties. In addition, a variety of texture shapes and dimensions are possible, opening the way to hierarchically textured surfaces. These offer all kinds of functionalities, encompassing improved tribological behaviour, thermodynamic isolation and superhydrophobicity.

Results of milling experiments in terms of changing pitch distances between peaks

Droplet on double curved surface
INDUSTRIAL EXAMPLE

So that they can be used in actual products, functional surfaces should be created using low-cost technologies. There is a lot of potential to be tapped by transferring a given functionality from a mould to a plastic end product by means of injection moulding. However, it is one thing to machine a texture onto the mould surface, thus creating the desired functionality - copying it through injection moulding and realising a surface functionality on the plastic part is quite another matter.

So as to verify whether it is feasible to copy functionality from a mould to a part, feasibility studies were carried out:

• creating a 3D scan of a lotus flower surface, creating a copy through UV soft embossing, electroforming a mould insert and producing plastic parts by means of injection moulding;
• creating a 3D scan of a lotus flower surface, direct laser texturing of a mould insert and producing plastic parts by means of injection moulding.

The conclusion that can be drawn from all this is that a transfer of functionality by means of injection moulding is feasible. However, more research is needed to further optimise flow behaviour, mould design and filling and so on to achieve a perfect copy. Simulation models incorporating surface textures, giving an insight into the filling of the texture and the end surface of the plastic part, need to be developed further.
SEIZING THE OPPORTUNITY

Creating added value through surface functionality is clearly a way of setting your company apart from the competition. There are two challenges here. First, there is the need to outline a relationship between functionality and texture geometry, as certain patterns, shapes and pitch values strongly influence the texture functionality. Secondly, an appropriate machining method and machining parameters to create these patterns need to be developed. Alongside micro-milling, ECM, structured tools and etching, ultrafast laser texturing appears to be the technology that is most likely to achieve this.
EXPERTISE AND FACILITIES AT YOUR DISPOSAL

The Precision Machining Lab at Sirris:

• the Fehlmann Versa 825 five-axis high-precision milling centre;
• the high-precision Erowa clamping system;
• the Mitutoyo Apex-S 3D coordinate measuring machine;
• a laser texturing machine for surface functionalization
• an acclimatised chamber.

Various specifications:

• milling of precision components to an accuracy of 3 μm;
• machine travel range: X: 820 mm; Y: 700 mm; Z: 450 mm;
• spindle: 20,000 rpm, 24 kW and 120 Nm at 50-1,920 rpm;
• clamping with micrometric repeatability;
• CNC-controlled (scanning) measurements from CAD;
• measurement accuracy of 1.7 μm + 0.3 L/100 μm (L in mm).

The precision machining lab, its infrastructure and engineers, are at your service to:

• realise your prototype precision components for new applications;
• become conversant with precision machining before investing yourself;
• provide you with support with regard to the machinability and cost-effective manufacturing of precision components.
THE AUTHORS

Sirris is the collective centre for the Belgian technology industry. The Advanced Manufacturing Department boasts more than 60 years of experience in the field of machining technology. Sirris was the first organisation in Belgium to introduce NC programming, damped-boring bars, tool management, high-speed milling, five-axis simultaneous milling, hard turning and laser ablation. Over the last four years the focus has been on achieving micrometric precision levels on five-axis milling machines that, while high-end, is within the reach of SMEs. Working with industry, our applied research has led to game-changing results.

Peter ten Haaf
*Program Manager - Precision Manufacturing*
As responsible for the Precision Manufacturing department Peter defines the research strategy and supports industry in detecting their own opportunities.

Olivier Malek
*Expert Machining Advanced Materials and Surface Functionality*
Olivier is responsible for research and industrial projects on high precision machining. His interests lay in non-traditional machining technologies and advanced materials in particular.

Krist Mielnik
*Expert High-precision Milling*
Krist focuses on the finishing process optimisation of the gear prototype, realignment problems and precision finishing of additive manufactured parts and methods to evaluate and improve machine precision.

Tom Jacobs
*Expert Machining Advanced Materials and Monitoring Solutions*
As a senior engineer, Tom is helping companies with research on methods to control precision during production with the help of sensors and real-time data.
PARTNERS

The research described within this publication was a collaboration between

[sirris]

This publication has been made within the framework of “VIS” and supported by Agentschap voor Innovatie door Wetenschap en Technologie (IWT).