A new cladding increases the wear protection of screws, particularly for use with reinforced plastics (figures: Engel)

Wear Protection. Modern injection molders add increasing amounts of mineral additives and glass fibers to their plastics molding compounds to modify the material properties. These mixtures make severe demands on the wear resistance of the plastifying components. A new screw system significantly improves the wear protection.

Resistant Screws

GOTTFRIED PÖCKL
ERICH HOCHREITER
GEORG STEINBICHLER

Standard plastics are generally processed using plastication components with surfaces hardened chiefly by nitriding or boriding. When the demands are increased by higher filler contents, higher alloy tool steels are used, which are given long lifetimes by vacuum hardening. In this context, Engel Austria GmbH presented the "Marathon" screw system in 2000, which offers outstanding hard-metal wear protection, though it is more sensitive to mechanical influences.

After a two-year development project and extensive tests at selected injection molders, the Materials Center of the Austrian injection molding machine manufacturer now offers a hard-metal cladding under the trade name "Engel Onyx," for which a patent application has been filed (Fig. 1). The new system offers the desired improvements in cladding toughness and adhesion strength. These characteristics could be improved by up to 300 %. At the same time, the abrasion resistance in technical tests could be improved from the already very high level of powder-metallurgical steel solutions. The Onyx screws have been available in the diameter range from 25 to 70 mm since April 2009.

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Latent Tendency to Crack

For processing high-performance plastics with a high filler content, economical lifetimes can only be achieved with hard-metal-clad plastication screws (Fig. 2). The hard-metal cladding provides the necessary abrasion resistance; the steel below it supports the mechanical loads and, thanks to its high toughness, provides high resistance to impact loads.

What appears clear and simple in theory proves technically difficult to realize in practice because the steel core and hard metal cladding have different material characteristics. Unlike steel, hard metals only have low toughness and cannot fully comply with the elastic deformation of the steel. They therefore tend to crack. Another specific property of hard metal is its low tendency to bond to the steel component. This runs the risk of the cladding detaching. This is initiated by a crack caused either by local straining or by mechanical damage. The aim of a development project at Engel material technology was to improve the mechanical properties of the hard metal/steel bond to exploit the high wear-protection potential of hard metals in practical applications.

The hard metal achieves the best abrasion properties when the hardness and composition of the matrix are matched to the content and type of the carbides so as to produce a low-defect cladding with the greatest possible hardness and carbide content (Fig. 3). Defects in claddings such as pores, cracks and non-metal inclusions, e.g. oxides or slags, are the preferred attack points for wear. The wear mechanisms start at just such defects. The demand for a long lifetime therefore requires a manufacturing process that at least minimizes, and preferably com-

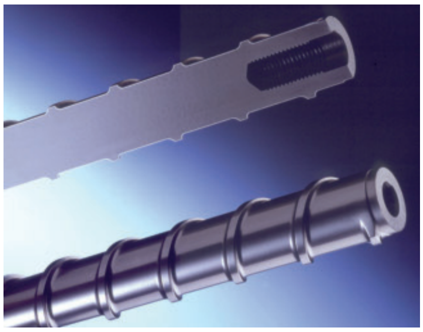

Fig. 1. A characteristic feature of the highly wear-resistant Onyx screw system is the uniformly applied hard-metal cladding over the entire screw contour, with high adhesion strength

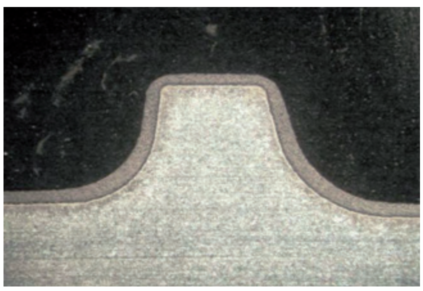

Fig. 2. With the new screw, unlike familiar flight hard-facing, the entire conveying channel, including the flight, is protected by a hard-metal cladding that is several tenths of a millimeter thick

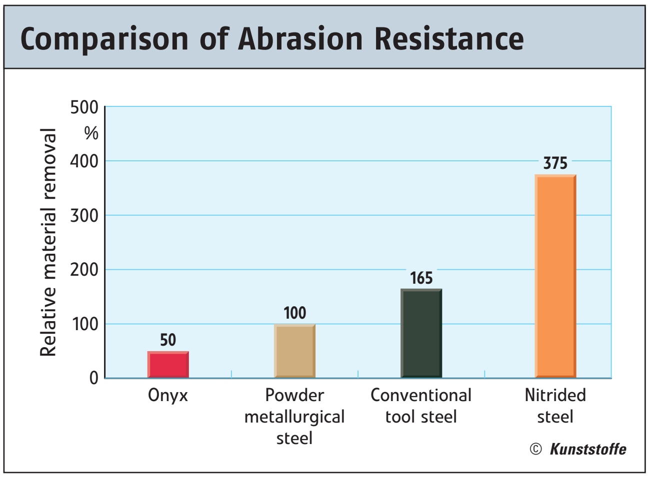

Fig. 3. The abrasion resistance of the Onyx system can be at least doubled compared to alternative materials, such as powder-metallurgical steels

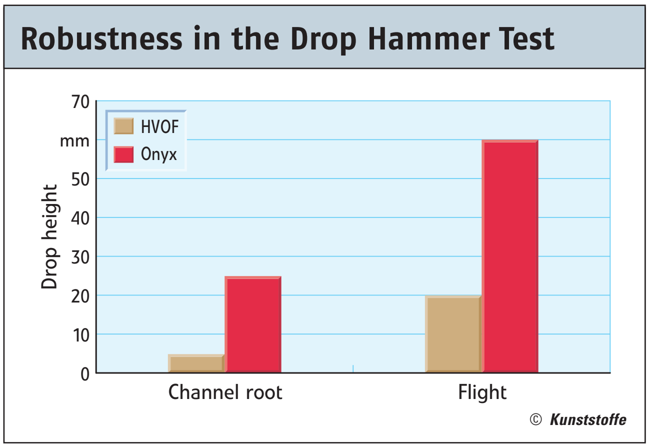

Fig. 4. The drop height (drop energy) until appearance of the first surface cracks is several times higher for the Onyx cladding than for HVOF-coated screws

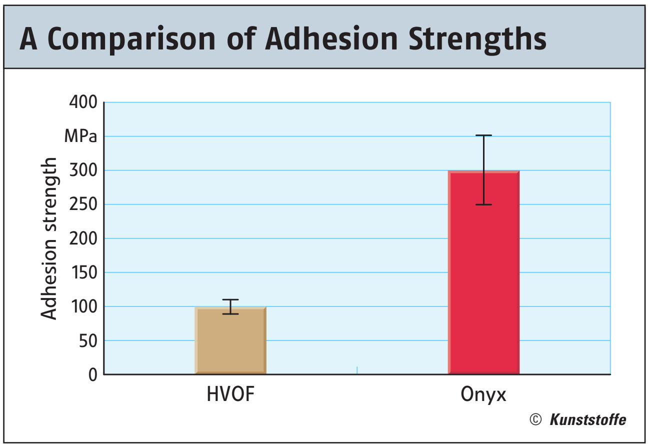

Fig. 5. The adhesion strength of the new cladding is about 300 % higher than for standard HVOF coatings

pletely avoids, these flaws. This is achieved with the development of the new wear-protection system for plastication screws.

Hot Particle Beam Generates Homogeneous Layers

Only straight and stress-free rod material is used for screw production. The rod is given the rough screw contour by milling or whirling. However, removal of a large proportion of the volume means that internal stresses are exposed. A stress-free, almost entirely straight screw blank can only be manufactured by repeated annealing and straightening.

The screw blank is tensioned in the coater and the burner is ignited. To remove any residual moisture, the burner is guided several times along the longitudinal axis over the surface of the blank without powder feed. Only then is the powder feed activated. In the burner, the hard-metal powder is heated to about 1,200 °C and accelerated to sonic or supersonic velocity (300 to 2,000 m/s). The partly fluidized particles strike the surface at this high velocity and key into the roughened surface. The hot powder jet is difficult to focus – the diameter of the impact surface is about 10 to 20 mm. Since screw blanks have a complex three-dimensional geometry and coating is most effective at an incident angle of 90°, it is necessary to angle the burner.

With an adequate particle velocity, it is ensured that a low-pore coating is applied even if the incident angle at the edge of the beam is not quite 90°. The incident red-hot powder particles are rapidly quenched from 1,200 to about 150 °C. The resulting decrease in volume causes tensile stresses in the cladding. This is countered by the high kinetic energy of the subsequent particles, which cause plastic deformation of the cladding on impact and build-up compressive stresses. In 30 to 60 strokes, a highly homogeneous cladding is applied over the entire screw contour – the flight land, flight flank, radius at the transition from the flight to the root, and the screw root diameter.

The cladding is applied in an oven under inert gas or vacuum. To prevent warpage or rotation, the screws are loaded in a hanging position. The entire coated screw blank is heated slowly and uniformly; the resulting small temperature interval minimizes thermal stresses. The heating transforms the cubic body-centered ferrite into cubic face-centered austenite – the cladding remains unchanged. During the residence time, there is a diffusion equalization of the alloy elements of the cladding layer, which is in extreme thermodynamic disequilibrium.

The boundary layer to the base material also changes, increasing the adhesion strength. After the holding time, the steel cools in multiple stages. The cooling rate greatly influences the structural transformation and the properties of the screw base material. If the cooling is too slow, the ferritic structure is very soft. The mechanical properties are then no longer adequate to withstand the injection pressures and torques occurring in the injection molding machine during plastication of the polymer. Rapid cooling causes length changes in the base material and strong thermal stresses between the base material and cladding. This results in cracking of the cladding, and warpage of the screws.

i Manufacturer

Engel Austria GmbH
Ludwig-Engel-Strasse 1
A-4311 Schwertberg
Austria
Tel. +43 50 620-0
Fax +43 50 620-3009
www.engelglobal.com

Setting the Desired Steel Properties

A staged cooling process that varies the cooling rate appropriately avoids these sources of error, optimizes the properties of the cladding and base material, and allows screws to be manufactured with virtually no cracks or warpage. Thanks to the controlled cooling, the screws only have to be straightened to a very low extent, since the required straightness is retained for the most part. The subsequent single or repeated heat treatment and annealing at 400 to 650 °C (depending on the base material used) sets the required steel properties. Then the screws are machined to give them the surface roughness required for plastication – circular grinding of the outer diameter, contour grinding of the flight geometry and shaping and polishing of the flight feed and outlet.

The cladding system is principally characterized by improved robustness. This is impressively confirmed by the results of the so-called "drop-hammer impact test," which simulates mechanical influences during manipulation in the workshop or during transportation as a spare part. Compared to other cladding systems, the maximum drop energy until appearance of the first cracks increases by up to 300 % (Fig. 4).

Additionally, the adhesion strength could be significantly increased by the heat treatment. While HVOF (high-velocity oxygen fuel) standard claddings have adhesion strengths between 90 and 110 MPa, the Onyx cladding system achieves values of 250 to 350 MPa (Fig. 5). The practical benefit of these improved measurement values lies in the fact that the risk of cracking and detachment of the cladding is greatly reduced.

Stable Process Window over a Long Time

This material combination of a tough base material and highly abrasion-resistant cladding is economically interesting because of the locally tailored properties and the long lifetimes that can be obtained as a result. The new anti-wear system for plastication screws, thanks to the extremely uniform screw channel geometry, ensures a stable process window over a long period, even for processing highly filled polymers. ■

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The Ultratemp 6000 temperature measuring device determines the homogeneity of the melt and detects material scorching (photo: Sikora)

THE AUTHORS

DI DR. GOTTFRIED PÖCKL, born in 1967, is head of material development at Engel Austria GmbH, Schwertberg, Austria; gottfried.poeckl@engel.at

DIPL.-ING. ERICH HOCHREITER, born in 1969, is head of technology development of plastication systems at Engel; erich.hochreiter@engel.at

DI DR. GEORG STEINBICHLER, born in 1955, is head of R&D at Engel; georg.steinbichler@engel.at