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Application of advanced surface treatment technologies in the modern plastics moulding industry

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Abstract

The advantages of surface treatment, which are very well known for cutting tools, are almost unexplored for plastics-moulding tools. Several factors contribute to this situation, including the use of relatively soft and/or low-tempered steels or soft aluminium and copper alloys as tool materials, the wide usage of spark-eroding technology, the high tolerances and the residual plastics material embedded in the tool surface. Nevertheless, advanced surface treatments like PVD coatings and ion implantation are slowly gaining ground in this uncommon and difficult market. In the following paper, the major problems connected with tooling in the plastics-moulding industry are described along with the appropriate surface treatments for solving or reducing these problems; examples from commercial surface treatment at the DTI Tribology Centre are given. © 1997 Elsevier Science S.A.

Keywords: Plastics moulding; Surface treatment; PVD; Ion implantation

1. Introduction

Heavy demands for increased productivity and product quality are forcing the application of new materials and surface treatments in more and more branches of modern industry. The plastics industry is one industry in rapid expansion due to the fact that plastics materials are increasingly replacing many other materials such as textiles, wood, paper, glass, metals or even stone-based materials. Improvement of production tools in the plastics industry is a growing need. Besides new tool materials, better design and modern technologies, surface treatment is one of the most important means to attain this goal.

2. Process temperature as a barrier to implementation

Industrial implementation of very-hard wear-resistant coatings started with CVD coatings [1]. The process temperature, however, which exceeds 1000 °C, limited the application to sintered carbide materials and steel materials for tools not requiring too-high tolerances due to the risk of dimensional changes during treatment. Later, the development of PVD processes producing Ti-based coatings at temperatures of about 450 °C made possible the coating of high-speed and hot-working steels without subsequent heat treatment. This development also started a very rapid implementation of protective coatings for cutting tools [2] and recently for standard punching tools. Not until recently did the development of low-temperature PVD techniques make it possible to coat other types of steel, including low-tempered steels.

As regards the surface re-alloying processes, the standard diffusion processes such as carburizing and nitriding also require high process temperatures. The laser re-alloying technique is very new and still needs to be developed for commercial use. Ion implantation which, as will be shown here, can be an efficient surface treatment in some applications, is increasingly applied in niche applications in some countries. However, its commercial significance is still relatively low compared to PVD in most parts of the world [3].

In practice, this means that surface treatment and improvement of plastics-moulding tools, the majority of which are made of cold-working steels was, until recently, limited to the so-called cold-electroplating processes [4].

3. Tribological problems in the production of plastics

Tribological problems in tools for moulding of plastics are mainly concentrated in the following areas:

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- adhesive wear and galling of tool-part surfaces which are in contact with each other and in relative reciprocating cycling movement, ranging from several hundred to several million cycles;
- abrasion from the flow of the molten plastics material in contact with the tool surfaces;
- corrosion of tool surfaces subjected to corrosive exhaust gases or decomposition products from the plastics;
- severe wear due to the use of rather soft tool materials;
- release problems on surfaces in contact with the plastics in which the product sticks to the mould or in which the plastics leave deposits on the surfaces of cavities and air outlets;
- filling problems in which appropriate filling of the mould cavities of plastics is troublesome.

Table 1 is an attempt to give a systematic presentation of these problems and the corresponding possibilities of solving them by advanced surface treatment.

4. Barriers to widespread implementation

Although the barrier of the process temperature has been removed through the development of low-temperature surface-treatment processes and through the progress in their commercialization, other difficulties still remain impeding a broader application of surface treatment of plastics tools.

Most of the tools received at the job-coater for surface treatment have been in contact with molten plastics material, mainly due to the necessary run-in procedures performed by the customer. Often, however, due to the fact that surface treatment is made a part of the refurbishing process, residual plastics material is frequently present on the tool surfaces. These deposits are difficult to remove even by very careful cleaning and will normally de-gas during heating in the vacuum chamber with, especially for PVD coating, a detrimental influence on the treatment process. The presence of the quenched defect zone, the so-called white layer on the surface of the spark-eroded parts, often requires special preparation. Complicated shapes, large numbers of cooling channels and large dimensions and loads frequently make PVD treatment in particular even more difficult. For ion implantation, which is not a coating technique, these matters are of less concern but should not be ignored. Nevertheless, treatment of a vast number of such critical parts has become a routine job treatment work at the DTI Tribology Centre. Many of these tools are precision tools tempered at low temperatures (often down to 180–200 °C). Due to the very low process temperature of ion implantation (typically below 100 °C) such tools are implanted without any problems due to process-induced heating. By utilizing the CemeCon PVD technique applied at the DTI Tribology Centre (the unbalanced magnetron sputtering PVD technique), low temperature PVD coating procedures (down to 180 °C) have been optimized in order to apply high quality coatings on low tempered precision tools.

The low temperature PVD coatings applied to forming tools have the same properties as PVD coatings made at higher temperatures and, together with ion implantation, PVD coating of plastics forming tools has, in recent years, attracted increasing commercial interest and now exhibits great possibilities, as will be shown in the following section.

5. Practical examples from job treatments

5.1. Routine coating of ejectors and cores against adhesive wear

Ejectors and cores are subjected to cyclic relative movement in metal-to-metal contact which results in seizing and adhesive wear. Coating of these parts has become a routine job treatment at the DTI Tribology Centre. The optimum coating is normally PVD TiAlN but recently, good results have also been obtained with PVD CrN. The coatings, which typically are 3 μm thick, isolate the metallic surfaces which reduces or virtually stops the wear. Additionally, these coatings reduce the coefficient of friction between the moving surfaces and make it possible to operate without lubrication, which is very important in some applications, e.g. for medical or food packaging purposes.

5.2. Routine implantation of air outlets against corrosion

Many plastics materials emit highly-corrosive gases when heated. This causes corrosion of all the parts which come into contact with these gases, particularly the air outlets. With Cr ion implantation it is possible to re-alloy the outermost surface to a concentration of more than 30 at.% Cr, making it highly corrosion resistant. The ion implanter at DTI Tribology Centre has a focussed ion beam with computer-controlled beam steering, allowing localized treatment of the problem areas only. This makes Cr ion implantation, which prolongs tool life by 3–10 times or more, a very attractive treatment economically, especially for tools with localized corrosion.

5.3. Routine coating of steering elements against adhesive wear

As in the case of ejectors and cores, steering elements in moulds are subjected to cyclic movement resulting in adhesive wear including seizing and tearing. A protective coating, preferably PVD TiCN, will reduce or eliminate the wear.

5.4. Routine coating of soft copper alloy cores against wear

Cores made of copper alloys are routinely coated with PVD CrN in order to reduce wear, both abrasive and adhesive, and often also corrosive. An illustration of the protective effect of CrN on this very soft material is provided by a core for injection moulding of buckets. Due to abrasive wear from the

Table 1
Tribological problems in plastics moulding tools

Type of problem	Appearance	Cause	Parts subjected	Possible solution by surface treatment
Adhesive wear	Galling, tearing and seizing, micro-welding, especially when lubrication is not used.	Relative movement of steel and/or metal surfaces in contact.	All parts in relative movement: cores, ejectors, die sets, steering elements.	Coating with PVD TiAlN or CrN coatings which results in rather low friction and very low adhesive wear especially when subjected to moderate or low contact pressures.
Abrasive wear	(a) Alteration of the finish of surfaces in direct contact to the plastic flow (roughening of very smooth surfaces and polishing of textured surface); (b) blunting of sharp edges; (c) in more severe cases changes of dimensions and shape.	Abrasive particles from fillers and dyes in the plastics.	All parts in direct contact with filled plastics, liquid or solid: screws, cavities, runners, gates, nozzles.	For mild and moderate abrasive wear: Nitrogen ion implantation. In more severe cases: PVD coating with hard wear resistant coating, e.g. 3 μm of the very hard TiAlN, or perhaps 5–10 μm of the medium hard but more ductile CrN.
Corrosive wear	(a) Pits at various sizes, changes of surface finish; (b) deposition of the corrosion products on the tool, often transferred to the products.	Corrosive gases or decomposition products from the plastics, hot corrosive exhaust products.	All parts in direct contact with the corrosive plastics or gases e.g. cavities, cores and especially the air outlets.	For air outlets, cavities and cores: re-alloying by chromium ion implantation for high corrosion resistance. For cavities and cores coating with protective PVD CrN.
Rather severe wear of soft tool surfaces	Mixture of abrasive and adhesive wear, often combined with corrosion (see above).	All above-mentioned causes, but wear is enhanced because of the softness of the tool material.	All parts made of soft tool materials, like Cu- and Al-alloys and non-hardened steel.	PVD coating with medium hard and ductile CrN protective layer.
Release problems	Finished products difficult or impossible to remove from the tool	(a) Inappropriate tool design etc.; (b) poor release properties of the tool material due to high affinity between the plastics and the tool material.	Parts in contact with the finished product: cores and cavities.	Changing surface affinity properties by nitrogen ion implantation, PVD coatings or by ion-implanting PVD coatings.
Accumulation problems	Build-up, accumulation and deposition of decomposition products from plastics on the tool	Affinity between decomposition products and the tool material. Can be enhanced by corrosion.	All parts on which the decomposition products can spread out.	As for release problems and corrosive wear.
Filling problems	The molten plastics does not fill the entire mould. The end products are defective.	(a) Inappropriate tool design etc.; (b) inappropriate process parameters; (c) high friction between plastics and tool surface.	Cores and cavities.	Coating with low-friction coating (type depending on plastics material).

white TiO_2 filler, repolishing of the core was necessary every week. Preliminary reports after CrN coating: no sign of wear after running for four months without re-polishing.

5.5. *Release properties*

Many cores and moulds for details in thermoplastic elastomers have been coated with PVD TiAlN. So far, this coating has been found to give the best release properties against this rubber-like plastics material and is on the way to becoming a standard treatment.

5.6. *Release properties*

A mould and a core for injection moulding of tubes in polypropylene and polyester were coated with PVD TiAlN. Before coating, the produced items were removed from the tool with great difficulty using both air blasting and ejection. After coating, blasting was enough to easily remove the items.

5.7. *Release properties*

Cores for moulding small details of polyethylene have been coated with PVD TiN and then implanted with N^+ ions. The treatment eliminated sticking problems; however, the cores failed due to the relatively low corrosion resistance of TiN. Coating the same parts with PVD CrN and subsequent implantation with N^+ ions eliminated sticking as well as corrosion problems.

5.8. *Abrasive wear*

Gates for injection moulding made in cold-working steel annealed at 250 °C to 58 HRC were subjected to mild abrasive wear. N^+ ion implantation reduced wear and enhanced tool life by 3.5 times.

5.9. *Abrasive wear*

A core for injection moulding of packing material made in cold-working steel annealed at 250 °C giving a moderate hardness of about 52 HRC was subjected to highly-abrasive wear. Abrasive filler particles eroded craters several millimeters deep in the core around the gate. The medium-hard but rather ductile PVD CrN coating was chosen for the relatively soft steel and practically eliminated the wear problems. According to preliminary results, tool life has been prolonged by a factor of eight, but the tool is still running with no sign of wear.

5.10. *Abrasive wear*

Nozzles and calibration gates for extrusion moulding of profiles made in corrosion resistant, 300 HB hard steel were subjected to abrasive wear. Large (up to 20 μm) abrasive filler particles eroded deep tracks along the flow. Repolishing was necessary for every 70 000–100 000 m of the product, and frequent polishing of the tool surfaces resulted in altered tool dimensions, limiting the total tool life due to unintended increase of the product dimensions. Coating the tool parts with rather thick PVD CrN (thickness about 8 μm) reduced the wear significantly. Preliminary results report no sign of wear for a period in which the tool would normally have been polished three times.

6. Summary

It has been shown that tribological problems in the plastics mouldings industry can often be solved by an appropriate surface treatment. The DTI Tribology Centre at the Danish Technological Institute frequently and successfully improves the performance of mould parts using mainly the low-temperature technologies like ion implantation and unbalanced magnetron sputtering PVD. It is, in many cases, considered rather difficult to apply an appropriate surface treatment on such tools. However, at the DTI Tribology Centre, surface treatment of parts for plastics moulding has become routine in many cases. The development performed at the Centre of surface treatments of plastics moulds is still progressing and new applications are on the way to becoming routine. In addition, the Centre disseminates information to more industries in order to enhance the use of modern surface treatment on plastics moulds in industry.

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