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Surface Coatings for Energy Savings in Modern Engineering Industries

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ABSTRACT: With its surface engineering solutions, customers can save energy and resources, which increases the competitiveness of their products and processes. Modern coatings make it possible to significantly increase energy efficiency and to make sustainable use of renewable energy. The present paper gives an overview of the surface coatings for modern engineering industries that will contribute to reduce friction, use of renewable energy and energy and resource savings.

KEYWORDS: Coatings, energy, wear, friction.

I. INTRODUCTION

Serviceable engineering components not only rely on their bulk material properties but also on the design and characteristics of their surface. This is especially true in wear resistant components, as their surface must perform many engineering functions in a variety of complex environments. The behaviour of a material is therefore dependent on the surface of a material, surface contact area and the environment under which the material must operate. The surface of a metallic material is made up of a matrix of individual grains, which vary in size and bond strength depending on the means by which the material was manufactured and on the elements used to form those grains.

The surface characteristics of engineering materials have a significant effect on the serviceability and life of a component thus cannot be ignored in design. As described by Halling (1985), "Surface engineering can be defined as the branch of science that deals with methods for achieving the desired surface requirements and their behaviour in service for engineering components". The surface of any component may be selected on the basis of texture and colour, but engineering components generally demand a lot more than this. Engineering components must perform certain functions completely and effectively, under various conditions in aggressive environments. Engineering environments are normally complex, combining loading with chemical and physical degradation to the surface of the component. Surface wear damage is a phenomenon which effects how a component will last in service. Lubrication in tribological applications reduces friction and wear, however conventional liquid lubricants fail under extreme conditions, namely low pressure, oxidative or corrosive environments, high speeds and high loads. Surface engineered coatings can help deal with these circumstances.

II. RELATED WORK

K. Bewilogua described the important aspects of surface technologies in automotive industries. Tribological coatings like Diamond like carbon are of great interest for various automotive drive components and high performance injection nozzles[1]. The variety of plasma assisted surface treatments applied in the automotive industry will increase in the upcoming years due to higher loads in the engine, injection systems and the power train[2]. Renevier evaluated the performance of low friction Molybdenum disulphide / titanium composite coating used in forming operations. MoS₂ based coatings have been developed, combining very low friction with high hardness, very high wear resistance, high bearing capacity[3]. Podgornik and Hogmark carried out tribological evaluation of plasma nitride, Diamond like Carbon (DLC) coated and polished cold work tool steel in a load scanning test rig using austenitic stainless steel as the

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counter material. It was observed that Carbon based low friction coating of DLC type give a certain tolerance to surface roughness and can maintain low friction and high galling resistance at high loads in dry sliding. Fine polishing appears to be more competitive alternative to DLC Coating⁴. Plasma nitriding, a commonly used surface treatment to improve wear resistance and durability of forming tools, can give up to 40 % improvement in galling resistance, but only if the surface is polished after the treatment[4].

III. SURFACE COATINGS FOR ENGINE COMPONENTS

Efforts to make the optimum use of fuel in stationary gas turbines and aircraft engines basically concentrate on further increasing the gas temperatures and the pressure differences between the stages of the turbine. A very effective measure that is also cost-effective is the use of thermally sprayed abrasion-resistant coatings as a sealing system between the rotating and stationary components of individual turbine first stage. Savings in operating costs of USD 1 million per year have been achieved for a modern gas turbine through the reduction of the sealing gap by 1 mm in stages 1 and 2, whereby the hotter first stage provides two-thirds of the total savings. Along with energy use, greenhouse gas emissions are also minimized [5].

A major contribution was the development of the material Durabrade™ 2192, which is suitable for use as a turbine sealant up to temperatures of 1200 °C. Surface Coatings made from this material exhibit good abrasion-resistant behaviour combined with excellent thermal-shock resistance, which is twice that of yttrium-stabilized zirconium oxide coatings with comparable porosity. Further development programs are currently running to meet the requirements of the turbine manufacturers for additional increases in temperature and energy efficiency.

Coatings that improve the tribological properties of components in the vehicle drive trains can also lead to a remarkable increase in energy efficiency. For example, diamond-like carbon (DLC) coatings can significantly improve the friction and wear characteristics of bucket tappets. The smooth surface and the low frictional properties are retained while exhibiting high wear resistance and very good oil wetting, even while running. The finishing of the bucket tappets with DLC coatings can reduce the torque by up to 33%, depending on engine temperature and speed, without having to carry out any design or production engineering changes to the engine. This improvement translates into a fuel consumption reduction in the low percentage range. Furthermore, it produces a CO₂ emissions reduction of around 3 grams per kilometre—a decisive amount for compliance with increasingly stringent requirements, such as and Euro 6. It seems that there is still a great deal of potential in the reduction of friction losses in the near future.

IV. SURFACE COATINGS FOR FUEL CELLS

Solid oxide fuel cells (SOFC) have a great potential to make an important contribution to energy savings. The highest efficiency for the production of electrical energy is achievable with an SOFC having a power range between few and several hundred megawatts. Like that of gas turbines, the success of SOFCs with regard to performance and service life largely depends on surface coatings, some of which can be very efficiently produced by thermal spraying. Currently, several hundred thousand SOFC interconnectors are coated annually with a layer of lanthanum strontium manganate (LSM) to prevent chromium evaporation from the metal interconnectors.

The plasma spray thin film process (PS-TF) provides another coating solution for SOFC components. This technology has a chamber pressure of about 1 mbar (the ambient pressure for plasma flame and component) and creates a very long, wide plasma jet, through which the coating material is evenly distributed over a comparably large area (diameter of approximately 200 mm).

V. SURFACE COATINGS FOR POLYMER INDUSTRIES

Surface coatings has gained acceptance as a way to improve tools in the production of polymers. Depending on the application, different thin-film technologies are used for wear and corrosion protection and for the reduction of friction. The Beverage Companies produces all its caps with tools that have been coated by thin film technology. Surface

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coatings not only fulfil the high requirements of the food industry, they are also used in the demanding production of medical engineering products.. The surfaces of plastic moulds are subject to many different stresses in the production process. The major wear mechanisms in the production of plastics are corrosion, in the form of surface and pitting corrosion, fouling by the smallest particles or coatings on the tools, abrasive wear as a result of particles embedded in the plastic and cavitations (tool-damaging bubbles in the plastic material) through local vapor pressure differences in the flowing medium[6]

Additives enhance the wear mechanisms. The additives that are important for plastics can be dyes, plasticizers, or other fillings, such as glass fibers or chalk. They are used to influence component properties such as strength, elasticity, and hardness. At the same time, however, these modified plastics place more load on the tools during the production process and increase wear. A coating of the tools can reduce the abovementioned wear, which extend their service life and reduces the maintenance outlay. At the same time, a modified tool surface can considerably reduce energy costs by reducing punch force.

The thin-film technology offers individual solutions for many different requirements. These include plasma heat treatments and coatings as well as a combination of the two. The selection of the appropriate surface treatment depends on the polymer to be processed and the parameters of the production processes. Resistance to wear and friction and sliding properties can be improved with the plasma heat treatment, which can also be used for high-alloy steels, super alloys, and light metals such as titanium and titanium alloys. Cost savings are possible in these procedures, above all, through the replacement of expensive materials. For example, tempered steels, which are considerably cheaper, can be used in place of stainless steels. In coating processes, a distinction is made between physical vapour deposition (PVD) and chemical vapor deposition (CVD). Coatings with thicknesses in the micrometer range are applied in both procedures.

The following PVD hard coatings have proved effective in the area of the polymer processing industry. Titanium nitride (TiN), Aluminum titanium nitride (AlTiN), Chrome nitride (CrN), Multilayer chrome nitride and Modified chrome nitride layer CrNmod). PVD coatings contribute significantly to increasing performance and productivity: In the case of coil distributors coated with CrNmod for the production of films from polyvinylchloride (PVC) or polypropylene (PP), customers have reported increases in service life of a factor of 10. The sliding properties of wide-slit nozzles coated in this way were also improved by 30%.

Diamond-like carbon (DLC) coatings can be applied using the PVD process or the PACVD (plasma-assisted chemical vapour deposition) process. The PACVD process is a plasma-assisted variant of the CVD process, in which temperatures are considerably lower and do not exceed 200 °C. DLC coatings of the type a-C:H (hydrogen-bearing amorphous carbon coatings) are used above all in the polymer industry. The particularly smooth, amorphous a-C:H coatings are utilized for optically high-quality surfaces, for example, in CD and DVD production. DLC coatings are also used with great success on tools in the cosmetics industry, as well as for ejector pins, cores, and sliders in injection moulding. The benefits are reduction of scale formation, excellent wear and corrosion protection, even at the standard film thickness of 4 microns, prevention of slip-stick effects (these arise from a reduced difference between sliding and adhesion friction) elimination of burner streaking, improvement of the flow behaviour of the polymer melt and, thereby, an increase in the transport capacity

VI. SURFACE COATINGS FOR OTHER INDUSTRIES

Customer examples show how effective the coating of tools can be: cores for the manufacture of disposable syringes have to be cleaned every three to four hours if uncoated. After a DLC coating, no cleaning was necessary, even after one and a half years. Corrosion problems were also eliminated. Similar benefits were also seen in textured blow moulds coated with DLC: instead of regular reworking in a two-week cycle, production without rework could be continued, even after eight weeks.

The Psolid diffusion layer represents one of the most innovative approaches to tool surfaces in plastic injection Vacuum pump moulding and extrusion moulding. Using this method, a scratch-free passive layer that has a high corrosion resistance is formed on the surface of the moulds. The use of a PSolid coating on corrosion resistant steels or cold-working steels with high chromium content provides hardening without any loss in corrosion protection. In the coating of hot- and cold-working steels, the diffusion layer creates tool surfaces with values up to 1600 HV. With a diffusion depth of 10–50 µm, coated components remain constant in size and shape.

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Due to the large outlay in time and the enormous cost factors when machining high-gloss or polished mold surfaces, savings are urgently sought in the polymer processing industry. A time saving for converting a polished surface to a high-gloss surface is possible with the help of Psolid. The wear-resistant coating protects against adhesion, considerably reduces deposits, and facilitates mould cleaning. Users in the polymer-processing industry, polishing companies, and tool manufacturers profit from the considerable advantages of a Psolid coating. The time savings reduce production and repair costs dramatically, while simultaneously providing a considerable improvement in the uptime of the tools.

The combination of plasma nitration with subsequent coating using PVD or PACVD combines the advantages of both types of surface treatment. Steels that contain proportions of special alloying elements (chrome, aluminium, vanadium, molybdenum) can achieve high surface hardness and represent an excellent basis for the subsequent coating. The mechanical properties of the material core, such as toughness and crack resistance, remain unchanged. With the combined treatment, the load bearing capacity of the surface is decisively improved, so that the infamous “eggshell effect” does not occur. In the processing of glass-fiber-reinforced polymer materials, these kinds of hardened tool surfaces prevent the added hard additives from being pressed into the tool surface at high process pressures. In plastics processing, the tools have to be cleaned at the latest during a production change. Polymer residues are thereby usually removed using scrapers and spatulas made from steel, which can easily lead to damage to the surface.

Steel manufacturing processes dispose large volumes of gases. These gases are used for heat and power generation but are highly erosive and cause damage in the compressors. Damage to turbo machines can be classified in two categories namely predictable wear and unpredictable wear. Predictable wear is caused by the attack of the machine parts by chemical, thermal, or mechanical influences. This kind of damage can be characterized by its slow and degradation of the base materials. Predictable degradation can be taken into account by periodic inspections and planned production stops for maintenance, thus preventing further damage. Unpredictable wear is most feared—as it can emerge at any time and disturb critical processes, causing emergency shutdowns. Unpredictable wear can be characterized by its unsuspected and sometimes rapid progress, and, in some cases, catastrophic failure of the part. The root cause of unpredictable wear can be found in operational conditions not taken into account at the initial design stage of the part or the part being operated outside its original design parameters. With an extensive knowledge of process conditions and the use of better-performing materials, it is possible to slow down the predictable wear process and to avoid unpredictable damage.

Surface engineering companies carried out a lifetime increase of a single-stage, integral compressor rotor that was badly eroded and not meeting its expected performance. The rotor was used for compressing large amounts of converter gas. This gas is a by-product of the steel manufacturing process and is highly erosive due to its high solid-particle content. The damage to the rotor impeller was progressing rapidly because the additional turbulence created by the initial damage was increasing the rate of erosion. This factor combined with the high solids content in the gas flow and remains of the old epoxy coating were causing unbalance and vibrations. The customer had previously tried to protect the impeller by applying different wear protection coatings such as epoxy coatings and thermally sprayed hard facing on the most damaged areas of the impeller: Cladding of the impeller blades on the intake and pressure sides and of the shroud ring with Stellite using a suitable welding and manufacturing process is recommended to slow the wear on the impeller vanes[7].

To keep the Stellite layer within controlled parameters (thickness and location), Surface engineering company decided to apply the layer by laser cladding on the individual vanes before they were assembled and final welding was performed. Tests were performed to assess quality and continuity of the welding layer. After several test welds on a base material comparable to that of the impeller vane, samples were made to determine the achievable weld quality. Based on the best results, the welding procedure parameters for the laser cladding of the vanes were selected. The rotor model was analysed by means of a finite element model simulation to assess whether the additional centrifugal forces generated by the added weight of the cladded Stellite layer would result in unacceptable stress levels or in deformation of the impeller material.

This approach made it possible to measure and correct any deviations from the desired geometry after laser cladding and heat treatment. To generate the model for the 5-axis machining, the blade geometry was extracted from the available 3D model of the rotor/impeller and positioned it in the most convenient setup for machining and laser cladding. During production, during laser cladding, and after final machining, the correct geometry of all blades was

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confirmed by 3D measuring the blade curve and comparing the found coordinates with the nominal model. After the final inspection in the Stellite cladding process was passed, the blades were cut free by means of 3D laser cutting and were ready to be welded onto the pre machined rotor body.

To confirm that there were no material defects as result of the heat treatment, the rotor was given a complete non destructive inspection. Once it had successfully passed the non-destructive inspection, the rotor was machined to its final dimensions. After inspecting for defects and geometry, spin testing at 115% was performed and the rotor was balanced. When it was returned to the machine shop, the rotor was given a final inspection to ensure that there were no deformations. After it passed final inspection, the rotor was cleaned, conserved, and prepared for shipping to the customer, where it was installed the following week during a planned maintenance stop. The rotor has been running with satisfactory performance, and it is expected to have a significantly longer life time than the original configuration.

VII. CONCLUSION

In summary, it can be concluded that surface engineered coatings are already making a great contribution to energy transition today, with renewable energies and energy-saving measures that improve energy efficiency. In both cases, specially developed, tailor-made, functional coatings and surfaces are used.

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