A STUDY OF THE PLASTICS COATINGS USED ON PLAIN SLIDEWAYS OF MACHINE TOOLS

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Abstract. *In this paper, several types of plastics for facing machine tool slideways are described. They are the ones based on PTFE, epoxi and acetal resins. Tribological, mechanical and chemical properties of these coatings as well as their methods of application on plain slideways are described. The stick-slip motion which may occur on plain slideways is discussed. This article also presents an application of PTFE-Zerodur slideway for nanometric positioning system.*
Keywords: *plain slideway, plastics, machine tool, coating, polymers.*

1. INTRODUCTION

Guideways are machine component used to guide slides (saddle, table, etc) and to bear the loads applied on them. They are devised to constrain five degrees of freedom of the slide and allowing only the linear motion along the machine axis. To design these guideways for modern machine tools, a set of requirements should be met as follows: high positioning accuracy, high load capacity and stiffness, minimum friction and wear, motion without stick-slip, high damping of vibrations, long service life and low power-consuming. The types of guideways most used on machine tools are the following: *plain*, *rolling*, *hydrostatic*, *aerostatic* and *combined guideways* (one type in combination with another). The *magnetic guideways* are still little used on machine tools in comparison with the other types mentioned above.

The production cost of the plastics-coated slideways is the least expensive. The main feature of these plastics-coated slideways is its good damping capacity, specially in applications involving severe vibrations and high cutting power (> 40 Horsepower). Bates [1] mentions that both Giddings & Lewis and Mighty USA Inc. use these slideways to damp out tool-induced vibrations and, thus, increase the life of carbide and ceramic tools.

Applications of the plastics-coated slideways in precision instrumentation and precision machine tool working in the nanometer region have been developed recently. These slideways are constructed with thin-film PTFE (Polytetrafluorethylene) bearings pads sliding against optically polished glass prismatic bedways [2,3]. It has been found that these plain slideways are suitable for application in the area of precision engineering since some operating conditions and design requirements are encountered.

The materials used for the construction of plain slideways should have the following properties:

a) A low coefficient of friction, preferably even under dry friction conditions;

b) A coefficient of friction that does not decrease with increasing velocity and that does not vary markedly with lubrication conditions;

c) A low rate of wear and a high resistance to abrasion;

d) Good dimensional stability and damping behaviour with adequate stiffness;

e) Reasonable cost, simplicity of application and good machining properties;

f) Good chemical stability and good compatibility with lubricating oils and cutting fluids.

This article presents a study of the plastics used for coating plain slideways. The plastics studied are the ones based on PTFE, epoxi and acetal resins. Some of the tribological, mechanical, physical and chemical properties of these coatings are described. Also, their methods of application on the slideways are presented. The stick-slip phenomenon that may occur on machine tool axes is also considered regarding the use of these coatings on the plain slideways. This study also shows an application of PTFE pads sliding against a Zerodur (ultralow-expansion glass ceramic) counterface on a nanometric positioning system [4].

2. PLASTICS-COATED SLIDEWAYS

The types of plastics most widely used for facing slideways are given below:

a) PTFE-based plastics with fillers such as, bronze, glass, graphite, molybdenum disulphide (MoS_2), ceramic or a mixture of them;

b) Epoxi resin containing fillers;

c) Acetal resin with fillers such as MoS_2, ceramic or PTFE;

The properties of these plastics are primarily determined by the molecular structure of the resin, the processing conditions and types of fillers (or additives). These latter materials are utilized to improve properties such as mechanical, tribological, physical, etc. In contrast, chemical, electrical and thermal properties of the plastics are mainly determined by their resins [5]. However, these latter properties can be also modified with additives.

The tribological and mechanical characteristics are the most important regarding the application of these plastics on machine tool slideways. The properties of the polymers depend markedly on the working conditions under which they are tested. The main factors that have a influence on their tribological performance are the following:

i) Test method (reciprocating test rig, rotating-disc test rig, thrust washer, etc);

ii) Contact pressure at the mating surfaces;

iii) Relative velocity of the sliding surfaces;

iv) Operating temperature;

v) Nature of the motion (continuous, intermittent, reciprocating);

vi) Material, roughness and hardness of the counter-surface;

vii) Lubrication (continuous, intermittent, dry-running);

viii) Environment (temperature, moisture, wet, dry, vacuum, steam, etc.)

Nevertheless, it is very difficult to reproduce on any rig, the actual operating conditions found on machine tool slideways. Therefore, with the aim of ensuring the suitability of a polymer on a given machine tool slideway, prototype testing is absolutely necessary in the stage of application development.

The problems associated with the low contact stiffness of the plastics layer are not relevant due to its thinness [6]. In other words, the total deformation in a sliding joint is predominantly determined by the body deformation of the adjacent structures of the joint. The contribution of the contact deformation in the mating surfaces is small.

The roughness and hardness of the counter-surface affects the wear and friction of the plastics. For a metal as a counter-surface, the following general rules can be stated: a) the harder the metal surface, the better the wear and friction behaviour of the system; b) the rougher the metal counter-surface, the higher the wear on the plastics.

As far as the coefficient of friction is concerned, there exists an optimum surface finish: in the case of a metal surface that is too smooth, the coefficient of friction can increase due to adhesion between metal and polymer; a surface that is too rough leads to a ploughing of the plastics coatings by the metal surface, resulting in a higher coefficient of friction.

Figure 1 shows a typical curve of the coefficient of friction as a function of the velocity for a plastics coating sliding against steel counterface. As can be seen from Figure 1, this curve has a positive slope which is typical of many types of plastics used for facing. This behaviour prevents the stick-slip motion. This phenomenon causes fluctuations of the slide velocity as well as instability of positioning of the slide on CNC (computer numerically controlled) machine tools. Stick-slip is also a serious problem for contouring operations like, for instance, in circular interpolation of the machine tables. Moreover, the stick-slip degrades the machining precision and surface finish of the workpieces manufactured on the machine.

A positive "f x v" curve also raises the damping capacity of the slideways in the direction of motion which improves the dynamic rigidity of the machine. The types of plastics most used for avoiding stick-slip are the following: PTFE-based plastics, epoxi resin with anti-stick-slip fillers, acetal resin with MoS_2 or PTFE.

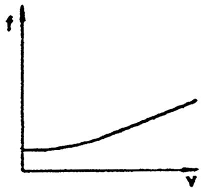

Figure 1. Friction x velocity curve for plastics sliding on steel.

In the following, several characteristics of the plastics mentioned in this text will be described as well as their method of application on the slideways.

2.1 PTFE-Based Plastics

The coefficient of friction of PTFE-based plastics increases from 0.075 (static) to around 0.15 (v = 25 mm/s) sliding against steel with a contact pressure of 0.4 MPa under dry conditions [7]. In general, the coefficient of friction of these polymers rises significantly with decreasing contact pressure. For continuous dry-running, the nominal pressure on slideways faced with PTFE-based material should be kept below 0.35 MPa. However, when loads and/or movements are intermittent, pressures of up to 1 MPa may be acceptable, with transient peaks to 2 MPa [6].

The PTFE has very poor wear resistance and load-carrying ability in its pure state. With the aim of upgrading these properties, a range of filler materials are commonly added as already mentioned in section 2. There is evidence that PTFE composites, when subjected to intermittent lubrication, deteriorates in both wear resistance and friction characteristics when compared to non-lubricated conditions. However, when ample lubrication is present this does not occur [6]. The PTFE-based materials have a high resistance to three-body abrasive wear. These materials have a soft PTFE matrix capable of embedding abrasives particles and thus reducing their effect [8].

The PTFE composites can resist continuous temperature of up to 260°C [9] and for short duration of 330°C [5]. Moreover, they absorb very little water (< 0.01%) and have very good chemical and corrosion resistance [9, 10]. They do not normally present any machining problems [6].

PTFE-based plastics exhibit creep (cold flow) of about 0.5% a year under a contact pressure of 2 MPa. Hence, a 2.5 mm thick strip can be expected to change by about 12.5 μm per year under a peak load not uncommon on machine tool slideways. For this reason, these materials should be used with thickness as thin as possible [6]. The PTFE composites are bonded to the steel (or cast iron) substrate using epoxi-based adhesive.

The tradenames of the reinforced proprietary PTFE composites most widely used on machine tool slideways are the following: *Turcite B*, *Rulon LR* (formerly *Rulon LD*) and *Rulon 142*. Turcite B is manufactured by Busak & Shamban Company. It is a bronze-filled PTFE (PTFE + 50% bronze). Rulon LR and Rulon 142 are trademarks belonging to Saint-Gobain Performance Plastics Corporation. These proprietary products are ceramic-filled PTFE.

2.1.1 PTFE-Glass Slideways on Nanometric Applications

Figure 2a shows a ultraprecision slideway used on nanometric positioning systems. The carriage has bearing pads of sintered PTFE-bronze-lead that are spherically radiused and carry a very thin film of PTFE on their surface. The carriage slides on a prismatic bedway made from Zerodur (ultralow-expansion glass ceramic). The main drawback of this type of slideway for nanometric applications is the *sliding hysteresis* (typically 100 nm). This hysteresis is a result of the stresses and strains present at the contact points between the moving carriage pads and the flat counterface [4]. The advantages of reducing the amount of hysteresis in the sliding system are the following: a) use of open loop control systems (lower complexity and cost); b) in the case in which feedback is a system requirement, a smaller amount of hysteresis can make the control system much more reliable and easier to design, providing better nanometric positioning accuracy.

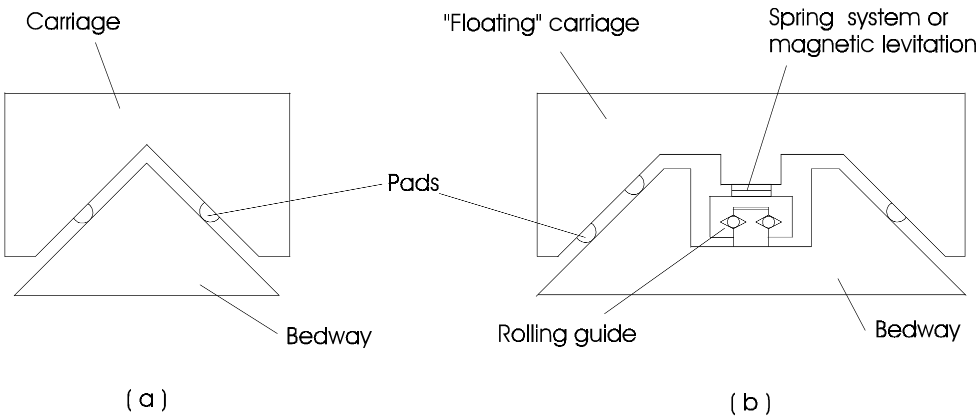

Figure 2. Ultraprecision slideways: a) basic model; b) plain slideway combined with rolling guide.

The hysteresis H of the sliding system of Figure 2a is given by [4]

$$H = \frac{0.22(2-\nu)E_{ef}^{\ 1/3} f_s P^{2/3}}{R^{1/3} G} \tag{1}$$

where,

ν : Poisson 's ratio ($\cong$ 0.33 for most materials);
E_{ef} : effective Young 's modulus of the sliding materials pair;
f_s : static coefficient of friction;
P : normal load on the slide bearings;
R : radius of contact of the pads;
G : shear modulus of the interface material.

On the basis of Eq. (1), for minimizing hysteresis on ultraprecision slideways similar to that of Figure 2a, the following design recommendations can be draw: i) Maximize the radius of contact of the pads; ii) Use material with low Young 's modulus; iii) Minimize the coefficient of friction and normal load; iv) Choose a shear modulus of the interface as high as possible. As some of these requirements are contradictory, a engineering compromise has to be achieved. For example, a higher shear modulus at the interface may increase the coefficient of friction and also may cause stick-slip motion. Figure 2b shows a schematic drawing of a positioning system for reducing the normal load on the slide pads. The load applied on the carriage is simultaneously carried by the bearing pads and a lower-precision rolling guide. The load sharing between these two guideways is done by either a set of adjustable springs or by the use of magnetic levitation. The system stiffness can be adjusted so that most of the load is carried by the rolling guide, thereby reducing the sliding hysteresis [4].

2.2 Epoxi Resin-Based Plastics

The castable polymer method is based on the technique of injecting or moulding an epoxi-based plastics into the gap between the two members of the sliding pair. These members are fixed rigidly and very accurately in the required alignment. After curing, a polymer layer of about 1.5 mm thick is adhered on the rubbing surface of the slide [11]. Cast polymers reduce significantly the production cost of slideways as well as the cost for repairing machine tools [12]. After this operation the sliding surfaces have good contact fitting without the need for subsequent machining [11]. The epoxi resin contains fillers to improve the wear and friction characteristics as well as dimensional stability.

Two manufacturers of epoxi resins for facing machine tool slideways are the following: a) ITW Philadephia Resins (USA); b) Gleitbelag-Technik GmbH (Germany). The latter company commercializes *SKC-3*, a two-pack polymer containing filled epoxi resin and hardener.

The method of application of the SKC-3 is by means of a spatula. The steps for moulding a slideway through this method is given briefly below [11]:

a) The sliding surface to be coated should be machined in the rough way and then thoroughly cleaned;

b) A release agent is applied to the bedway (counter-surface). This is done for preventing the polymer to adhere on the counter-surface;

c) The shapes of the oil grooves are sprayed with adhesive and then affixed on the rubbing surfaces of the slide. The release agent is then spread on these shapes. Another way to make oil grooves is to machine the polymer layer at the end of the moulding process.

d) The slide to be coated is positioned in relation to the counterface by setting screw, stops, etc, so that a gap between the opposing sliding surfaces results. The alignment should be within specified limits.

e) The slide is removed from the set-up in order to apply the SKC-3;

f) The epoxi resin and hardener are mixed and then applied to the rubbing surfaces of the slide by means of a spatula. Next, the slide is mounted again on the original set-up and the excess resin is squeezed out.

g) After curing, a polymer layer of about 1.5 mm thick is formed on the ways of the slide.

It is important to emphasise that the surface finish of the polymer layer is similar to that of the counterface. Therefore, it is recommended that the surface finish of the bedway (non-faced member) not exceed $R_a = 2.5$ µm [11].

Gleitbelag company has also a product called SKC-60 that is used on slideways of light machine tools. In this case, the castable polymer is applied by injection through a piston pump.

2.3 Acetal Resin-Based Plastics

The main features of the acetal resins are the following: good stiffness, fatigue endurance and resistance to creep; good wear and abrasion resistance; low coefficient of friction and water absorption; good dimensional stability. Acetal resins are degraded by ultraviolet light which causes surface chalking and reduces the molecular weight, leading to gradual embrittlement. To prevent this, a filler called carbon black is added to the acetals. Fillers such as, PTFE (20-25%), MoS_2, graphite, proprietary additives and ceramic are used to reduce the coefficient of friction and to increase wear resistance [13, 14]. For applications on sliding system, acetal resin against steel provides lower coefficient of friction and wear than sliding with other metals [13].

There are two types of acetal resins, acetal homopolymer and copolymer. The former has slightly better mechanical properties than the latter [13]. The acetals have excellent resistance to most organic solvents. They are unaffected by vegetable and mineral oils [15]. They are not resistant to strong acids and oxidising agents [13]. However, the copolymer exhibits excellent resistance to strong alkalis whilst the homopolymer is attacked [15]. Recommended maximum continuous use temperature in air are as follows: homopolymer (82°C); copolymer (104°C) [13].

The acetal resin most used on slideways is *Delrin AF* which is marketed by Du Pont de Nemours

& Company. It is a homopolymer which has a uniform filler with 20% PTFE fibres.

3. CONCLUSIONS

a) The types of plastics most widely used on machine tool slideways are as follows: PTFE-based plastics, epoxi resin with fillers to reduce wear and friction, acetal resin with MoS_2 or PTFE;

b) The plastics mentioned in item "a" are capable of working under non-lubricated conditions. However, they function better when an adequate lubricating system and lubricant are used. Therefore, they offer a very valuable backup feature in case of lubricant failure;

c) The tribological properties of the plastics are very important for applications on machine tool slideways. These properties are affected by many factors such as, contact pressure, sliding speed, counterface material, surface finish and hardness, service temperature and lubrication;

d) The plastics mentioned in item "a" have a positive "friction x velocity" curve. This friction characteristics not only prevents the stick-slip motion but also contributes to increase the damping capacity of the slideways in the direction of motion;

e) The main problem on application of the PTFE-glass slideways in nanometric positioning systems is the sliding hysteresis. It can be minimized by reducing the normal load on the slide pads;

f) Epoxi and PTFE-based plastics have high resistance to three-body abrasive wear. They are capable of embedding abrasives particles and thus reducing their effect.

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