

SELECTION OF SURFACE TREATMENTS AND COATINGS FOR COMBATING WEAR OF LOAD-BEARING SURFACES

1. INTRODUCTION

It is most unusual for an engineering material to combine, simultaneously, both optimum structural properties and optimum resistance to wear and corrosion. Consequently tribological surfaces must perform a variety of functions completely different from those required of the bulk material. The specification of these surfaces has, of course, always been of great importance since a large proportion of failures occur at or are initiated at the surface.

Many techniques are available for treating surfaces to improve their wear resistance. These treatments either modify the existing surface structure and/or composition or provide a surface coating. Traditionally only a few materials have been considered suitable for treatment and the degree of control over the surface properties has been limited. For example, surface hardening treatments, such as induction hardening and carburising, are only applied to a few ferrous materials and the attainable surface hardness is limited by the base chemistry of the material. Coatings produced by traditional processes, such as electroplating, can have poor adhesion or other defects and the structural properties of the bulk material can be degraded. Nevertheless, the utilisation of these surface treatments will continue to increase in response to demands for increased performance and longer component life and at the same time economic pressures to reduce costs and conserve materials.

In recent years a number of new techniques have been applied to both surface modification and to coating. The new treatments that are now available offer considerable flexibility and process economies combined with close control of surface properties, structure and composition. New coating processes, in particular, allow a wide range of soft and hard compounds as well as metals to be deposited onto metallic and non-metallic substrates. They can permit combinations of coatings, for example a well adhered soft overlay on a hard coat, in such a manner that no further finishing of the component is required.

Selection of a suitable surface treatment is aided by an appreciation of the possible mechanisms of wear as well as a consideration of the mechanical requirements of the contacting surfaces in practical tribological applications. Accordingly, Sections 2 and 3 of this Item provide background information on these two topics.

A procedure for selection is given in Section 4 which is supported by guidance notes and tabulated information on the properties of treated surfaces and on the principal treatment methods. Individual process specification sheets may be referred to for more general information.

2. WEAR MECHANISMS

The selection of appropriate materials for the type of wear being encountered is probably the most important step in effective wear control. This section discusses four separate mechanisms of wear (abrasive, adhesive, chemical and fatigue) and the surface factors affecting the wear rate for each mechanism. In many practical situations several of these mechanisms may occur simultaneously, an important example being fretting (see Section 3.3). Other forms of wear exist that are not dominated by any combination of mechanisms discussed in this Section, for example, percussive wear or hammering (see Section 3.4). Erosion of surfaces by high speed impingement of solid particles or by cavitation of a liquid is not considered. In all cases the practical aspects relating to the type of bearing surface, the type of motion and the operating conditions, discussed in Section 3, should be considered. Where a particular mechanism of wear or combination of mechanisms can be identified then Table 6.1 will serve as a guide in selecting an appropriate treatment or process.

2.1 Abrasive Wear

Abrasive wear is the most common type of wear and can involve the removal of surface material by the asperities of a harder mating surface or by hard particles within the system. Abrasive wear may, depending upon the particular situation, be reduced by

- (i) prevention of ingress of hard particles,
 - (ii) promotion of removal of hard wear debris,
 - (iii) improved finish on the harder surface,
- and (iv) increased hardness of the softer surface[†].

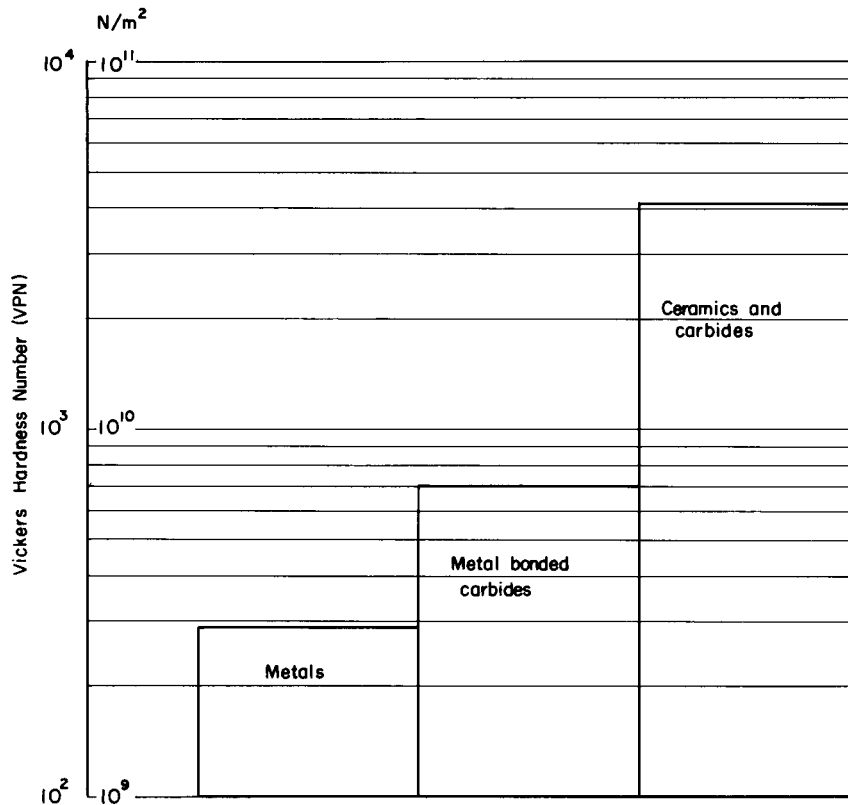
Hard abrasion resistant surfaces can be provided by the surface materials listed in Table 2.1.

TABLE 2.1 Surface materials for combating abrasive wear

Hardness ranking	Surface material	Comments
1	Ceramic	Greatest hardness potential of all surface materials. Usually provided by a coating process.
2	Ceramic in metal matrix	Can often provide unique properties. Usually provided by a coating process.
3	Hard metal	Can often be provided easily by a simple surface hardening heat treatment or coating process.

It should be noted that many materials, particularly metals, work-harden when subjected to abrasion. This work-hardening may or may not increase the resistance to abrasive wear. Where material removed from the softer material work-hardens to the extent that it acts as abrasive particles the wear rate will be accelerated. In other circumstances the rubbing surface may work-harden sufficiently to reduce the rate of wear. Attainable hardness values are compared in Sketch 2.1.

[†] A soft bearing material can protect the opposing surface from damage by embedding abrasives (see Section 3.1)



Sketch 2.1 Attainable hardness values

2.2 Adhesive Wear

Adhesive wear involves adhesion or welding of surface asperities and may be reduced by

- (i) increased surface hardness,
- and (ii) changing one or both of the surface materials to obtain a more “frictionally compatible” combination,
- or (iii) introducing a barrier film to separate “frictionally incompatible” materials.

2.2.1 Adhesive wear resistance

For a given combination of materials the adhesive wear rate is determined by the surface hardness.

Frictionally compatible material combinations exhibit low friction and low adhesive wear during sliding. The tendency for certain materials to adhere or weld is not fully understood but certainly with metals is indicated by high mutual solubility and high surface energies. A mild form of adhesive wear occurs in many moderately loaded sliding applications. Surface hardness is a principal factor indicating resistance to this form of wear but microstructural factors are also important. For example, steels with a discontinuous lamellar pearlitic structure usually have enhanced resistance.

A severe form of adhesive wear, with wear rates an order of magnitude greater than that in the mild form, may occur at higher speeds and/or loads. The transition from mild to severe adhesive wear is thought to be related to the disruption and formation of the oxide films that are usually present on metallic surfaces. High temperatures developed at the contacting surfaces is often an additional factor in, for example, scuffing (see Section 3.2). Retention of hardness at these high temperatures and the microstructure of the surface material can be important factors in providing wear resistance.

The severity of adhesive wear is very difficult to predict in practical situations and reliance should be placed on experience of particular material combinations (see Reference 1)[†] that have been used in similar contacts complemented wherever possible by test results.

2.2.2 Barrier films

Barrier films for reducing adhesive wear are usually relatively soft coatings often incorporating a soft metal or solid lubricant and may be provided by the coatings listed in Table 2.2 (see also Table 6.2). Barrier films may also be of use in reducing chemical wear (see Section 2.3).

TABLE 2.2 Barrier Films for Reducing Adhesive Wear

Barrier film or coating	Principal application/comments
Soft metal or solid lubricant	Used for vacuum operation and for high temperatures.
Crystalline inorganic conversion coating (<i>e.g.</i> phosphating)	Mainly used in presence of liquid lubricant to aid running-in and the establishment of hydrodynamic lubrication.
Soft metal or solid lubricant in metal or ceramic matrix	In operation the soft metal or solid lubricant is smeared over the surface of the matrix giving, in effect, a soft-on-hard layer.
Soft metal or solid lubricant in organic binder	For light loads and moderate conditions only (slow speed, modest temperature, non-vacuum).

With solid lubricant coatings, significant transfer of coating material between mating surfaces occurs during operation. This material transfer is sometimes relied upon to distribute the solid lubricant.

2.3 Chemical Wear

Chemical wear occurs most commonly as oxidation wear in which the products of chemical reaction with the environment are continuously rubbed away and further oxidation results in a progressive loss of material. This type of wear may also occur where highly reactive extreme pressure additives have been used in order to reduce adhesive wear. In general chemical wear is accelerated by high temperatures.

Chemical wear is a minimum for

- (i) materials that are chemically inert in the environment of operation,
- and (ii) materials that form stable, strongly adherent and protective reaction products.

[†] Reference 1 contains a list of the names and addresses of suppliers of materials and of coating/hardfacing contractors.

In general, metals (except the noble metals) are highly reactive and will only resist chemical wear by forming stable surface films. Some special alloys, such as triballoys, resist high temperature wear by developing tough glazed oxide coatings.

In some circumstances chemical wear may be reduced by a barrier film (see Section 2.2.2) provided of course, the material deposited to form the barrier film is chemically stable in the environment.

Where the environment is particularly chemically aggressive, ceramics or polymers may provide sufficient resistance to chemical wear.

2.4 Fatigue Wear

Fatigue wear occurs in several forms. In rolling contacts cracks initiated at micro-discontinuities due to repeated stress cycling result in pitting failures. During sliding sub-surface cracks can propagate to produce delamination of the surface layers. Fatigue can also occur microscopically to produce asperity fatigue failure which is usually the initiating mechanism in fretting (see Section 3.3).

Resistance to fatigue wear is difficult to predict but in general is improved by

- (i) more uniform surface structure,
- (ii) lower modulus,
- (iii) increased yield strength (increased hardness),
- (iv) smoother surfaces

and (v) residual surface compressive stresses.

In addition, the fatigue resistance can depend critically upon the surface treatment process applied to the component. For example, many of the surface hardening treatments such as flame hardening, induction hardening, carburising and nitriding are known to be beneficial because they induce residual surface compressive stresses. On the other hand, most electrochemical plating is detrimental because it leads to residual tensile stresses and a “micro-cracked” surface.

3. PRACTICAL CONSIDERATIONS IN CONTACTING SURFACES

The material requirements of the bearing surfaces will, in general, be entirely different from the bulk material requirements of the components. Traditionally this has often implied a degree of compromise or has required additional component parts to form the bearing surfaces, for example, cylinder liners and bearing bushes. Even so, certain treatments have become well established for directly providing bearing surfaces. Some of the less well established treatments have the potential for providing surface layers with unique properties not attainable by the more traditional methods. Surface treatments also find use for protecting bearing surfaces from damage, for example, during lengthy shut-down periods, while running-in, or when subjected to hostile environments or vibration.

This section discusses the properties required by surface layers or coatings employed in bearings. Bearing contacts are regarded as having conformal surfaces, in which the load is distributed over a large nominal area of contact, or counterformal surfaces, in which a concentrated contact occurs. Motion can be continuous, oscillatory or percussive.

3.1 Conformal Contacts

Highly conformal bearing surfaces are found in plain journal and thrust bearings, ball joints, threaded fasteners and screw jacks, piston/cylinders, many types of seals, machine slides and guides and certain types of shaft couplings.

In these bearing contacts the load is distributed over relatively large surface areas and localised high stresses are avoided during normal operation. Consequently relatively soft materials are able to support the bearing loads without extruding or yielding and the use of very thin hard coatings or layers on relatively soft substrates is entirely feasible.

Traditionally a hard on soft combination of materials is often used in journal bearings and thrust bearings particularly when hydrodynamically lubricated. This combination has several desirable properties one of which is the ability of the softer surface to embed dirt particles and thus prevent damage of the opposing surface[†]. With metallic surfaces, overlay plating[‡] of the softer surface is commonly used to enhance these properties.

Fatigue wear of conformal bearing surfaces is rare except with high dynamic loading. Usually the softer surface is the more prone to this type of wear especially when the bearing has overheated. Thin coatings of such materials, for example when overlay plated, usually exhibit greater resistance to fatigue than would be expected of the bulk material.

Material compatibility, or the ability to tolerate asperity contact without unacceptable adhesive wear (galling), is usually an important consideration. Lubricating films^{††} are, of course, often present to protect the surfaces and to control the friction characteristics but some degree of surface interaction is usually inevitable^{‡‡}, if only short periods. With hydrodynamic lubrication for example, asperity interaction can occur at start-up or during running-in. Conversion coatings applied to the harder metallic surface are particularly useful for protecting the surfaces during these periods. Where only very thin liquid lubricating films can be developed, for example with low viscosity fluids (see Reference 2), material compatibility can be critically important. In some applications where break down of the lubricating film can occur during normal operation, for example internal combustion engine piston rings/cylinders, porous surfaces able to retain the lubricant are often preferred. Where lubricating films are absent, metal on metal contacts may not be satisfactory and plastics, ceramics and composites find increased use (see References 3 and 4). In some apparently dry metal on metal contacts, such as threaded fasteners, a contaminating film is usually present to prevent metallic adhesion. In more demanding applications or where seizure must be positively prevented some form of barrier film incorporating a solid lubricant might be employed.

[†] With severe contamination, a hard on hard material combination is often used (see Reference 2). Also, the use of a soft material to embed dirt particles and protect the opposing surface from damage is probably only fully effective with liquid lubrication.

[‡] In overlay plating a soft bearing alloy (usually based on lead with tin, copper and/or indium) is applied over a somewhat harder interlayer to improve embeddability and conformability and, sometimes, to protect the interlayer from chemical attack.

^{††} A lubricating film is an essentially mobile fluid or solid layer between the component surfaces. Some lubricating films, in particular so called solid lubricant films, may be applied to one or both of the mating surfaces by certain coating processes (see Table 6.2).

^{‡‡} In some specialised hydrostatic bearings the surfaces are separated under all conditions of operation by the maintenance of a high pressure supply of fluid.

3.2 Concentrated Contacts

Concentrated or Hertzian contacts are found wherever the geometry of the mechanism or the type of motion precludes the use of a more conformal bearing in, for example, cam/follower systems, gears and wheel/track systems and in low friction devices such as rolling bearings, knife-edge supports and instrument pivots.

Concentrated contacts are characterised by relatively small contact areas and high contact pressures which can induce high and localised stresses in the surface layers of the components (so called Hertzian stresses). The development of these high stresses can, to some extent, be avoided by using low modulus materials, such as plastics, for one or both of the surfaces but allowable operating speeds and temperatures will be limited. Wherever appreciable loads or powers are to be transmitted harder materials are required to support the high stresses without yielding and hard metallic surfaces are often used. Ceramic materials, while providing extreme hardness, tend not to be successful when used for both surfaces due to their very high moduli and the development of excessive contact stresses.

Hertzian maximum shear stresses reach a maximum some distance below the surface (see Reference 5), the depth increasing with the load and the radii of the contacting surfaces. Coincidence of this maximum Hertzian stress and the surface layer/substrate interface should always be avoided otherwise adhesion of this layer will be at risk. Any treatment applied to the component must, therefore, be capable of providing surface layers of a greater thickness than this depth[†]. For many applications, such as power transmission gears, this requirement has traditionally ruled out all treatments except the thermal and thermochemical treatments. In rolling bearings, surface treatments have been used rarely to provide the required material hardness, except for very large sized bearings, in which case a thermo-chemical treatment would be used.

Fatigue failure (pitting or spalling) of surfaces subjected to high cyclic stresses may be particularly important and in some applications, such as rolling bearings, may be the life determining factor. The surface material, in addition to being hard, must be homogeneous and free from inclusions, porosity or defects, and treatments that provide surfaces with residual compressive stresses, such as the thermo-chemical treatments, will be preferred.

Concentrated contacts may be damaged by contaminating particles and wherever possible are protected from the ingress of such particles (see References 6 and 7). Where full protection cannot be applied fatigue may be accelerated but the hardness of the contacting surfaces, which is usually made relatively high for fatigue and stress resistance purposes, is often sufficient to provide adequate abrasion resistance. Usually the component experiencing the more severe duty, for example the smaller of two meshing gears, is made the harder.

Adhesive wear or scuffing (see Reference 8) involving welding of surface asperities is often the most important type of wear in concentrated contacts especially when appreciable sliding is involved. Even when adequately lubricated, penetration of the lubricant film by surface asperities (see Reference 9) may lead to scuffing and is particularly liable to occur during the running-in of components such as gears. Careful choice of surface material combination is usually essential and, in metallic contacts, different alloys with different hardnesses are usually required. Thermochemical treatments involving nitrogen, such as nitriding, are particularly effective in providing long-term resistance to scuffing. Chemical conversion treatments such as phosphating or low temperature thermochemical treatments involving sulphur are used to provide scuff resistance during the running-in process. Coatings of a soft metal such as silver or copper are also applied to facilitate running-in but care is required since some plating processes can adversely affect fatigue strength.

[†] In most applications a treatment depth (or coating thickness) not less than RH/E' will be required, where R is the effective radius of curvature, H is the current Vickers hardness in N/m^2 of the surface material and E' is the effective modulus. Surface layers an order of magnitude less than this depth are sometimes used but in that case a high strength "core" material would be employed to support the surface layer.

In pure rolling contacts significant adhesive wear is unlikely to occur under normal operating conditions especially when a liquid lubricant is present. However, in vacuum or at high temperatures where liquid lubrication is impracticable, surface damage due to adhesion may initiate fatigue and considerably shorten the life of the component. Usually for such applications one or both of the surfaces would be coated with a soft metal, such as lead, or a recognised solid lubricant, such as molybdenum disulphide[†]. The choice of coating process requires care since some processes can reduce fatigue resistance.

3.3 Contacts Undergoing Small Amplitude Oscillatory Sliding

Contacting surfaces that are nominally at rest may undergo minute oscillatory sliding as a result of vibration or cyclic loading. Such contacts can be found in stationary bearings subjected to vibration, in splined couplings, riveted or bolted joints and wherever components, such as rolling bearings, are interference-fitted into housings and on to shafts. These contacts may suffer from fretting wear which can, depending on the situation, cause surfaces to seize, destroy interference-fits or initiate complete fatigue failure of the components. Fretting is thought to be initiated by a combination of surface asperity adhesion and fatigue but may involve abrasion by oxidised wear debris. Oil or grease lubrication may be of benefit in preventing the access of oxygen and in removing debris but usually solid lubricant films and soft metals such as copper, silver, cadmium or aluminium are more effective in preventing fretting. Conversion coatings (phosphating or anodising) or low temperature thermo-chemical treatments involving sulphur may also prove effective.

3.4 Contacts Undergoing Impact Loading or Hammering

Surfaces in which a nominal clearance is repeatedly closed and re-opened under the influence of inertia loads or external vibration can be found on the abutment faces of turbine blade shrouds, on compressor and fan blade snubber faces, on valve seats, in percussion tools and in high-speed linkages. Where a liquid lubricant is present, impacts will be cushioned by squeeze-film effects but in dry applications very high loads can be transmitted to the surfaces producing hammer wear. In some applications simultaneous sliding may also occur. Surface layers to resist hammer wear must, in addition to having high hardness, have some impact strength and high adherence to the substrate. Soft substrates can be beneficial in absorbing impacts but the harder surface layer must then be thick enough to distribute any localised surface stresses without cracking. Metal or cermet surface materials provided by a thermal or thermo-chemical treatment or coating process such as thermal spraying usually combine the required properties.

[†] Transfer of solid lubricant from an impregnated cage is often relied upon in rolling bearings designed for dry operation.

4. SELECTION OF TREATMENTS AND COATING PROCESSES

There are many ways of treating surfaces to improve their wear resistance but they all involve either modifying the existing surface of the component or adding a layer of material to the surface. Modification treatments can usually only be applied to metallic substrates and may or may not alter the chemistry of the surface layers. Some coating processes, on the other hand, offer increased versatility and may be applied to both metallic and non-metallic substrates.

A categorisation of surface modification treatments is shown in Figure 1 and of coating processes in Figure 2. This division into either a modification treatment or a coating process is made for convenience only and very similar techniques can sometimes be employed for both purposes. For example, virtually identical equipment can be used for both surface alloying and surface welding as shown in Figure 2. Also a significant degree of surface modification can occur simultaneously with deposition in, for example, chemical vapour deposition where high temperatures are involved. Treatments from both categories are sometimes applied in combination. For example, electroplating may be followed by a diffusion treatment.

Surface treatments may also be categorised according to the mechanism of the process. For instance, coating processes, with the exception of painting or resin bonding, rely on one, or a combination, of the following mechanisms of deposition and bonding:

- (i) melting of coating material and/or substrate and subsequent fusion,
- (ii) high speed impingement or mechanical working of coating material onto substrate,
- (iii) chemical or electrochemical reactions at the substrate,
- (iv) condensation directly from vapour to solid state onto substrate.

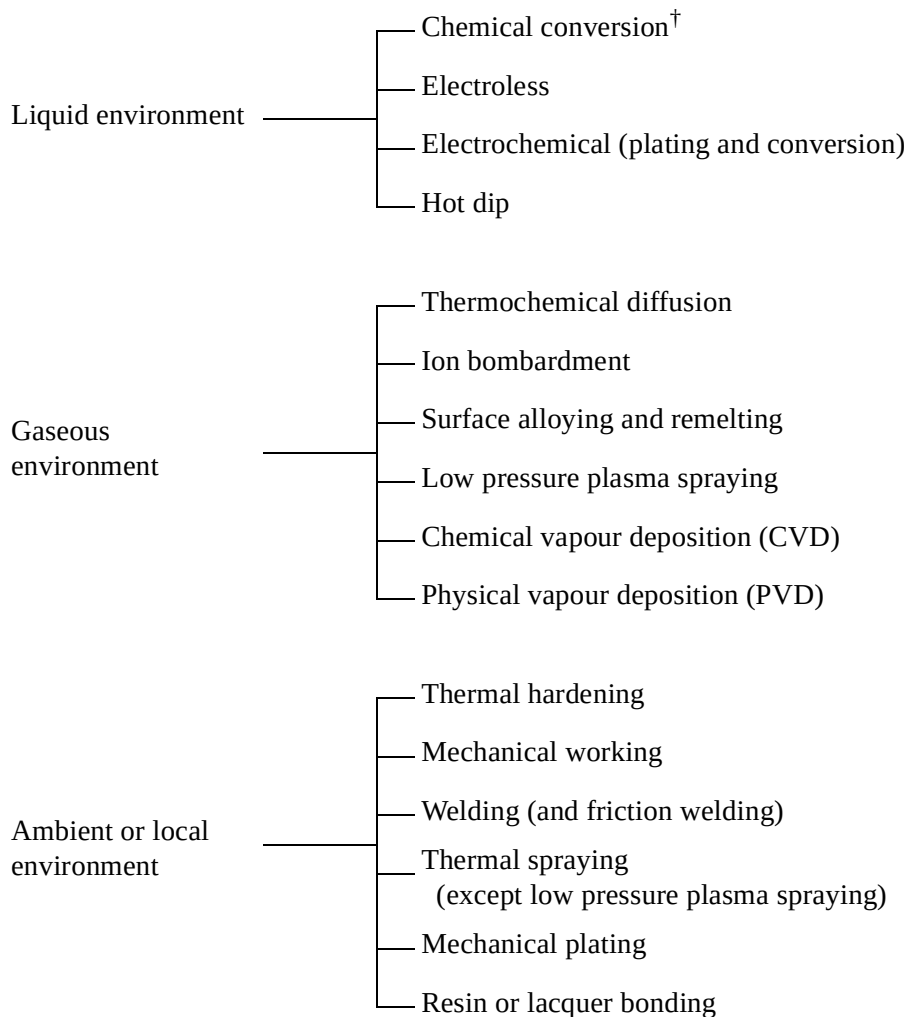
These basic mechanisms of deposition together with the corresponding mechanisms of surface modification are indicated on Figure 2.

Many treatments require that the component be placed in a special liquid or gaseous environment. Processes requiring a liquid environment involve immersing the component in a bath containing an aqueous solution, a molten salt, a molten metal or, occasionally, a specially formulated non-aqueous liquid. It is sometimes possible to apply the liquid locally by a spray or brush technique, two examples being chemical conversion by spray application and selective electroplating.

Processes requiring a gaseous environment involve placing the component in a chamber which may contain a vapour of the coating material, as in physical vapour deposition, or reactive gases, as in chemical vapour deposition. The chamber is sometimes maintained at very low pressure (the so called “vacuum coating” techniques) and some form of electrical assistance is often used (*e.g.* plasma assisted chemical vapour deposition and ion plating).

Some processes can be carried out in an ambient atmosphere or require only a localised special environment. Many of the welding processes fall into this category as do most spraying processes and offer the possibility of on-site repair or selective coating.

Sketch 4.1 indicates the most usual environment involved in each of the principal surface treatments. Alternative versions of some treatments are possible. For example, thermo-chemical treatments may be carried out in a liquid salt bath environment.



Sketch 4.1 Categorisation by environment

† Chemical conversion can be carried out by spraying and techniques exist for selectively electroplating.

4.1 Selection Procedure (Guidance notes to be used In conjunction with Figure 3)

A suggested surface treatments selection procedure is given in Figure 3 and this Section forms a set of guidance notes to aid the selection. This selection involves firstly determining the properties required of the surface layers of the component in order to meet the intended duty. At this stage a list of candidate treatments will have been suggested. Final selection involves considering the practicalities of applying the treatment to the component, the availability of the treatments and the economics.

4.1.1 Structural requirements

The “structural” requirements of the component will, in most applications, involve satisfying strength, rigidity and dimensional stability criteria imposed by the loads applied to the component and its intended purpose. Associated with this may be special requirements for such material properties as thermal and electrical conductivity and specific heat capacity. In all applications where it is intended to take full advantage of surface treatments, the bulk material specified will be of minimum cost and involve the minimum of manufacturing operations consistent with the structural requirements.

4.1.2 Mechanical requirements of the contact

The geometry of the contacting surfaces together with the loads applied will be fundamental in determining the stresses in the surface layers at the contact. In concentrated contacts where the apparent area of contact depends on the load applied, the surface stresses can be high. In all other contacts, where the surfaces are highly conformal, the apparent area of contact depends only on the dimensions of the components and surface stresses are in general much lower. The practical aspects of these two types of contact and some of the implications for the surface layers of the components are discussed in Section 3.

The relative motion of the contacts should be defined in order to be able to estimate, for example, the thickness of any liquid lubricating films present. In general, sliding, rolling or a combination of such motions may be involved. The motion may be continuous or oscillatory. It should be noted that the motion (and the loads) may differ from that intended when, for example, vibration is transmitted to the contact from elsewhere. This can be particularly important in giving rise to fretting or hammering wear (see Sections 3.3 and 3.4). Lengthy shut-down periods may also be important especially in high temperature or vacuum environments.

Other requirements of the contact, for example, impact absorption, might dictate resilient surfaces, whilst a requirement for extreme precision of motion might dictate very rigid surfaces. In addition there may be special thermal or electrical resistance requirements of the contact. Where liquid lubrication is intermittent or absent a coefficient of friction requirement will almost certainly be specified.

4.1.3 Conditions at the contact

It should be noted that the conditions at the contact can influence the mechanical requirements of the contact. For example, the squeeze film effect of liquid lubricants can reduce the intensity of impact loads transmitted at the contact.

4.1.4 Implications of mechanical requirements

Before considering the likely mechanisms of wear it is essential to ensure that the mechanical requirements of the contact have been satisfied. The stresses and subsurface stresses at the contact are particularly important in limiting the range of surface materials that will prove acceptable and in determining the required thickness of such layers. The implications of some of these mechanical requirements are discussed in Section 3 and should be included in the list of properties required of the surface layers of the component.

4.1.5 Likely mechanisms of wear

Consideration of the likely wear mechanisms will involve an assessment of the intimacy of contact between the two surfaces. In particular, where the surfaces are liquid lubricated, an estimate of the film thickness will be required that will then be compared with the surface roughness in order to assess the degree of surface asperity interaction. In all applications it must be borne in mind that all engineering surfaces are, to varying degrees, contaminated by a surface film of oxides or other compounds that can influence the type of wear and the wear rate. The ease with which these surface films are formed and destroyed will in turn be influenced by the chemical environment of the contact as well as the temperature and the ambient pressure. In vacuum operation, for example, these films may be slow to form or may be all but absent and adhesion between incompatible materials will be a likely wear mechanism.

Whenever contaminating particles are able to enter the contact, abrasive wear (three body wear) must be suspected. With liquid lubrication an estimate of the film thickness will again be required to compare with the size of the abrasive particles. Particles large enough and hard enough to give abrasive wear can of course be generated by an initiating adhesive wear mechanism in, for example, fretting. Direct abrasion of one

surface by the other can often be avoided by specifying a fine surface finish on the harder surface but deterioration of this fine surface should not be ruled out. Composite materials, for example, incorporating hard ceramic particles may suffer preferential wear of the matrix in some situations.

Contaminating particles in the contact may also initiate fatigue wear especially in concentrated contacts of, for example, rolling bearings. Again, the size of these particles in relation to any liquid lubricating films should be assessed (see Reference 6). Fatigue wear may also be initiated by chemical attack of the contacting surfaces.

In all applications the mechanical and environmental conditions at the contact should be closely examined. Once this has been done the likely wear mechanism or combination of wear mechanisms can usually be assessed. Wear mechanisms are discussed in Section 2 whilst some practical aspects of wear are discussed in Section 3. Table 6.1 provides a guide to the surface properties required for combating an identified wear mechanism.

4.1.6 Surface layer properties

(i) Type of layer required

Surface layers or coatings provided by the methods discussed in this Item can be divided into three categories according to their intended purpose (see Table 6.2).

(i) bearing surfaces,

(ii) lubricating films,

and (iii) expendable (short life) layers or coatings.

Bearing surfaces, whether provided by a treatment or a coating process or simply by the bulk material of a component, are intended to be permanent stable surfaces. Usually this implies that the depth of wear over the lifespan of the machine will not exceed the surface depth (treatment depth, coating thickness, allowable wear depth).

Lubricating films laid down by coating processes are, of course, solid films but are essentially mobile or low shear strength films allowing relative motion of the underlying “permanent” bearing surfaces. With such films there is always the possibility of material being expelled from the contact over a period of time. This is of no consequence where the film has been used as a running-in aid but where longer term protection of surfaces is required, continual replenishment of the film should be considered. In rolling bearings, for example, the cage might be constructed from a material impregnated with a solid lubricant.

Expendable layers or coatings are almost invariably used to aid running-in of bearing surfaces and as such are only required to be short life layers. Expendable coatings are distinguished from solid lubricating films, which can also be used to aid running-in, by the fact that they are usually not mobile films but wear away over their period of duty.

Solid lubricating films and expendable coatings are often known collectively as barrier films.

In some applications more than a single treatment may be required. For example, gear teeth may require a hard thick surface layer to resist fatigue wear and the large concentrated loads at the contact, together with a final barrier film of soft metal or a chemical conversion treatment, to resist scuffing during the running-in period.

(ii) Hardness

Typical hardness values for the materials most widely used to resist wear are given in Table 6.3. With non-homogeneous materials, such as cermets, abrasive wear resistance depends on the hardness of both the dispersed phase and the matrix but the exact relationship is not fully understood. Unless otherwise stated, macro-hardness values are given in Table 6.3 which represent, for such materials, an average hardness.

(iii) Impact resistance

The impact resistance of most wear resistant materials is low by normal engineering standards, but nevertheless differences in impact resistance between the various materials are significant in many applications. In general, impact strength varies inversely with hardness. In many cases tougher materials are preferable because failure by impact can be immediate and sometimes catastrophic.

(iv) Elevated temperatures

The maximum temperatures at which wear resistant materials can be used are listed in Table 6.3 and are determined by softening of the material or by excessive oxidation. For example, martensitic low alloy steels soften progressively above about 200°C and tungsten carbide oxidises rapidly when heated in air above about 550°C.

(v) Corrosion resistance

A qualitative indication of corrosion resistance is given in Table 6.3. In general, materials with a high chromium, cobalt or nickel content have good corrosion resistance. Aluminium oxide and chromium oxide are also inert in most environments. However, if coatings are porous *e.g.* sprayed coatings) or have micro-cracks *e.g.* electroplated chromium), corrosion resistant undercoats or resin impregnation must be used to prevent corrodents reaching the substrate.

(vi) Bond strength

An indication of the bond strength of some coatings is given in Table 6.4. In surface welding where the overlay is fused to the substrate, and in CVD where significant interdiffusion of overlay and substrate takes place, coatings that are virtually an integral part of the substrate can be produced. Perfect bonding is also possible with ion plating.

(vii) Porosity

In some applications a porous, lubricant-retaining coating may be required. Although electroplated chromium has nominally zero porosity (see Table 6.4) it is often given a post deposition chemical treatment to provide significant lubricant retaining properties. In other applications, porosity, particularly when open pored, will allow penetration by gases and liquids leading to corrosion. For corrosion resistance such coatings are either sealed with a resin (a solid lubricant such as PTFE can also be used) or applied over a corrosion resistant underlayer.

(viii) Thickness

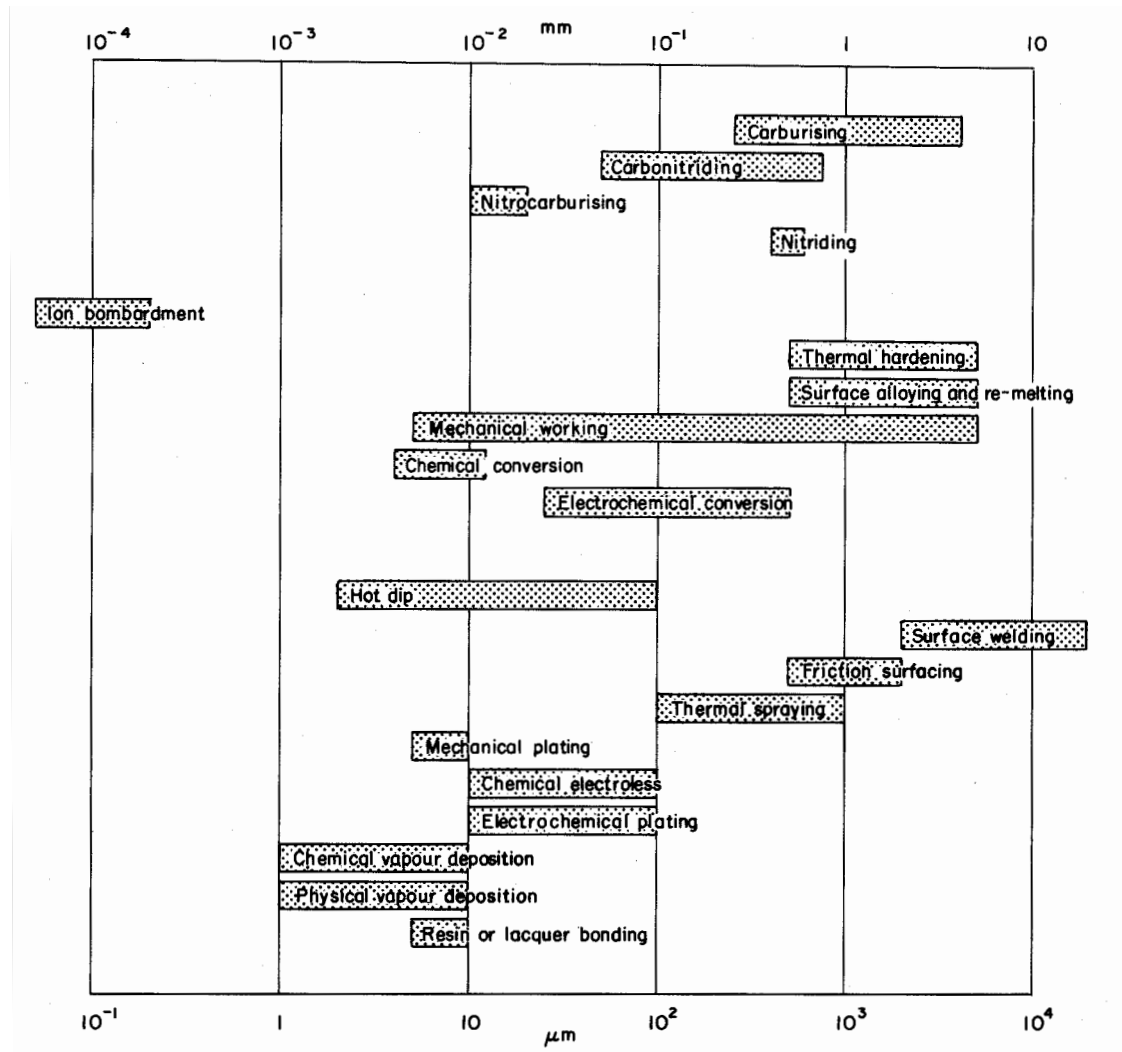
The allowable thickness of the surface layers produced by the various treatments is usually determined by the build up of excessive internal tensile stresses and sometimes by slow deposition rates. The thicknesses of the layers which are normally produced by the various processes are illustrated in Sketch 4.2.

4.1.7 Practicalities of treatments

Having satisfied the engineering and environmental requirements, a short list of possible treatments can be prepared. The final selection will be made by consideration of the practicalities, the availability and the economics of the competing treatments. Tables 7.1 to 7.7 and 8.1 to 8.10 give brief descriptions of each treatment and summarise their salient features.

(i) Component shape

Some treatments are unsuitable for use on complex shaped components. For example electrodeposits cannot be applied to components with sharp edges or blind cavities. Spraying processes are preferably carried out with the spray stream impinging at a high angle to the component surface. Most welding processes are also only applicable to relatively simply shaped components. Treatments carried out under low pressure (vacuum treatments) are essentially line of sight processes but electrical assistance will give some coverage of areas not directly exposed to the source. In contrast, chemical vapour deposition and electroless plating are noted for their ability to coat complex shaped components with a layer of uniform thickness.



Sketch 4.2 Comparative thicknesses/depths of treatments