1
Selecting Surface-treatment Technologies

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1.1
Introduction

Nowadays, modern production processes require inherent state-of-the-art surface technologies. Furthermore, rising standards of technical products are creating the perception that surface technologies are often the central impetus needed for meeting product specifications. Design engineers thus face two essential tasks: On the one hand, part specifications need to be transformed into properties of materials and surfaces. On the other hand, selected materials technologies have to be integrated in corresponding process chains. Apart from the required part specifications, production costs and ecological aspects are important issues.

Not only production standards but also economic conditions lead to increasing significance of surface technologies. Considering the two substantial domains of surface technology, tribology and corrosion, macroeconomics experts estimate that tribological damage causes a loss of approx. 1% of the German gross national product (GNP). The economic effect of corrosion damage is even higher, approaching approx. 3.5–4.2% of the GNP. Surface technologies therefore have to be considered as one of the key technology fields in production engineering.

Here, one possible method for selecting surface-treatment processes that satisfy existing requirements of specific parts is introduced. In addition, a variety of surface-treatment processes are compared with respect to possible fields of application and characteristics specific to the individual processes.

1.2
Requirements on Part Surfaces

Systematic selection of suitable surface treatments is always based on acquiring a complete set of requirements on the part surface with respect to intended operating conditions. According to Haefer [3], the surface is responsible for all me-

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chanical, thermal, chemical, and electrochemical interactions with the environment. This leads to the main functions that need to be fulfilled by technical surfaces:

- corrosion resistance
- wear resistance
- defined tribological behaviour
- optical behaviour
- decorative behaviour
- matched interface behaviour (e.g. for joining purposes).

In addition, especially highly specialised products may demand specific functions. Parts used in micro-technology for example can require special electromagnetic properties of surfaces.

Ultimately, requirements on part surfaces are determined by the particular load conditions under which the final product operates. Figure 1.1 illustrates the main kinds of load conditions subdivided into volume and surface loads.

Wear and corrosion are the main stresses that have to be controlled by surface technology in the realm of mechanical engineering. Incorrect materials selection as well as unsuitable or missing protective layers lead to manifold damages, some of which are shown in Figs. 1.2 and 1.3.

In many cases, appropriate surface treatment can either prevent or at least delay such damages. However, adjusting part surface characteristics carefully is essential in order to handle overall operating conditions.

Surface technology focuses on reacting adequately to the specific kinds of load and stress. For this, the materials properties of part surfaces are systematically modified or produced, particularly by means of:

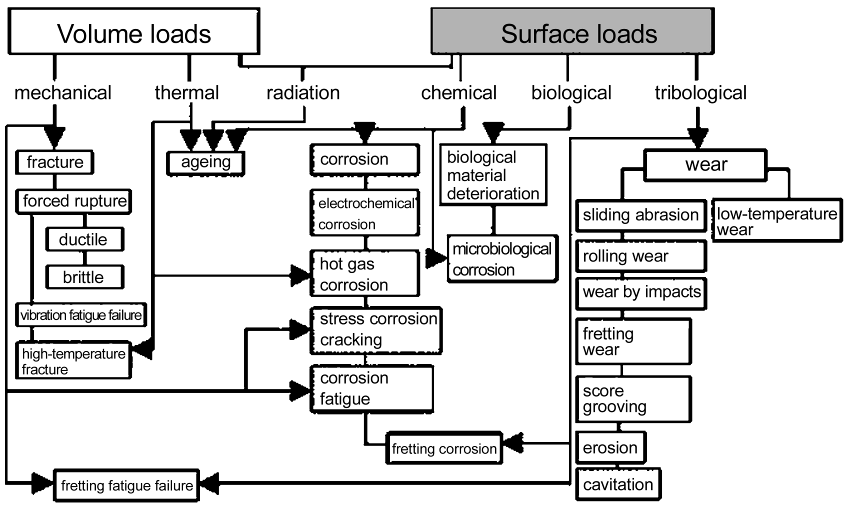

Fig. 1.1 Main volume and surface loads on parts.

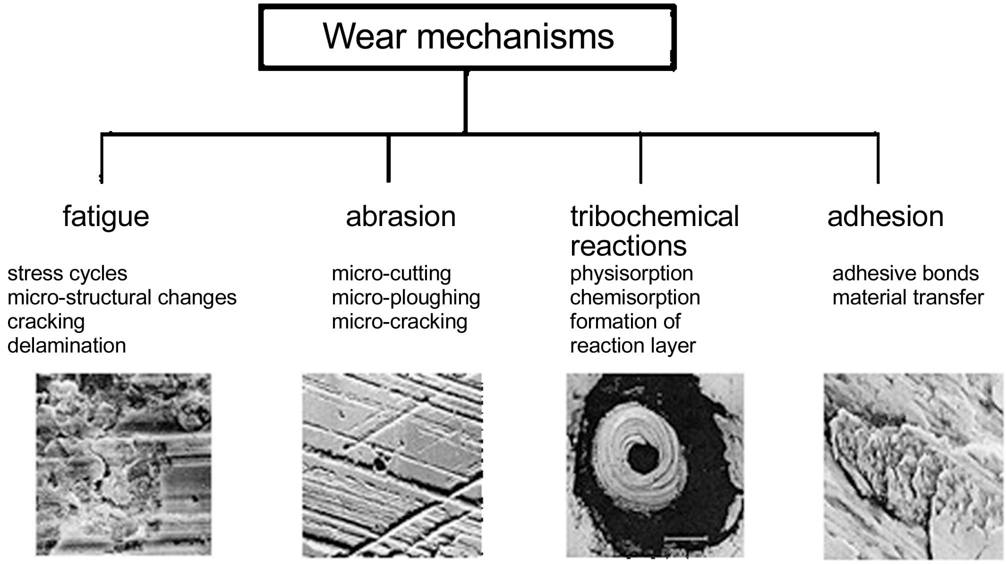

Fig. 1.2 Wear phenomena.

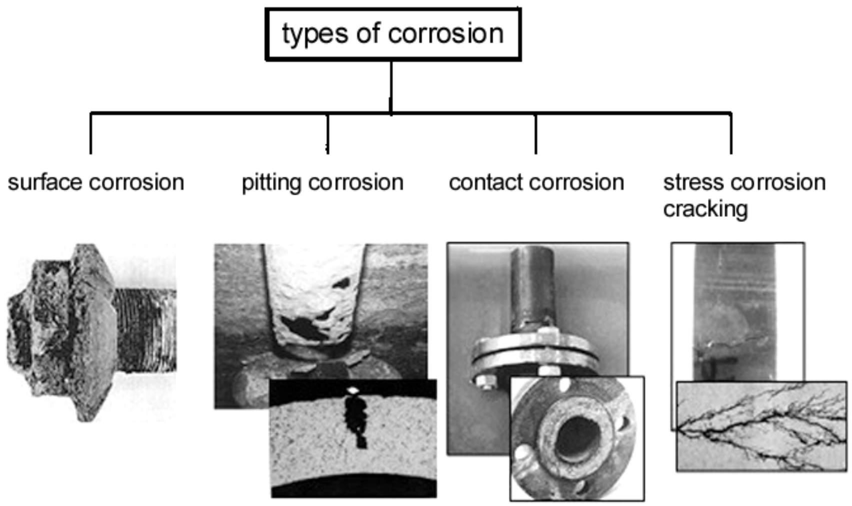

Fig. 1.3 Corrosion phenomena.

- applying a protective coating to the workpiece
- modifying the surface zone of the workpiece.

Typical coating processes are chemical vapour deposition (CVD), physical vapour deposition (PVD), thermal spraying, build-up brazing and welding, as well as cladding and dip coating. Surface-modification processes, on the other hand, include thermo-chemical diffusion processes, thermal surface hardening, implantation methods, and mechanical surface-hardening processes.

1.3 Selecting Coating and Surface Technologies

Designing a suitable surface treatment from a given combination of loads is challenging. Not only is it often difficult to precisely and thoroughly understand the operating conditions of a part, but very large variety of possible materials and materials technological processes have to be considered. Estimates indicate that the number of materials used in materials technology is in the range of 40 000–80 000. Moreover, including surface technologies, about 1000 different processes are used. In contrast, the mean vocabulary of a Central European spans approx. 5000 words. Quite obviously, the process of selecting an appropriate coating or surface treatment requires a systematic approach. The selection process needs to be implemented at an early stage of product development. It is necessary that developers already consider surface requirements during concept phases, directly after taking down customer and market demands. Based on the given operating conditions, four fundamental aspects should be clarified systematically [1, 6]. The following facets and questions need to be considered carefully:

1) Function:
   - What are the functional characteristics of the part surface?
   - What kind of requirements exist?
2) Purpose:
   - What needs to be maximised?
   - What needs to be minimised?
3) Limitations:
   - Which constraints and boundary conditions have to be met? e.g.
   - from a technical point of view
   - from an economic point of view
   - considering design-to-cost concepts
   - considering design for environment concepts
   - considering life-cycle costs
4) Options:
   - What options exist?

This systematic approach basically represents the general framework of the requirement catalogue concluded from the set of loads and stresses. Subsequently, individual materials and surface technologies need to be analysed and assessed against this background. This search and evaluation should be performed in an equally systematic approach. Figure 1.4 illustrates an example of a systematic analysis sheet. Here, individual coating materials and processes can be rated with respect to selected properties, prerequisites, and restrictions. The listed se-

material /process	prerequisites / restrictions	feasible	rating
coating			
wear properties			
hardness / strength			
corrosion resistance			
impact resistance			
coating thickness			
adhesion			
cohesion			
porosity			
residual stresses			
structure / property correlations			
process			
shape of part			
dimensions of part			
deposition rate			
coating process temperature			
strength reducing process characteristics			
costs			
environmental issues			

Rating matrix sample

Fig. 1.4 Example of a rating matrix for evaluating coating materials and/or processes against the background of a desired property catalogue.

lection of properties within the rating matrix as well as the corresponding prerequisites and restrictions originate from the formerly compiled catalogue of requirements.

The approach presented here describes a workable method of correlating a catalogue of requirements with appropriate surface technologies. Certainly, the quality of results is determined and limited by the requirement catalogue developed in phase one. Furthermore, this methodology requires comprehensive knowledge of available materials and processes, a frequently limiting factor due to the already mentioned manifold process varieties and materials.

1.4
Processes for Surface Modification and Coating

Giving a detailed overview of the different surface modification and coating processes would go far beyond the scope of this chapter. Therefore, a general summary of the most important process classes is presented, along with their indi-

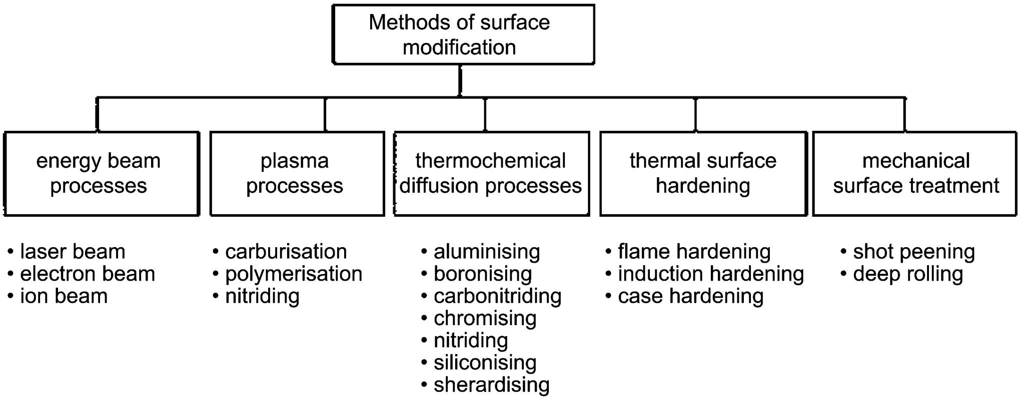

Fig. 1.5 Classification of surface-modification processes.

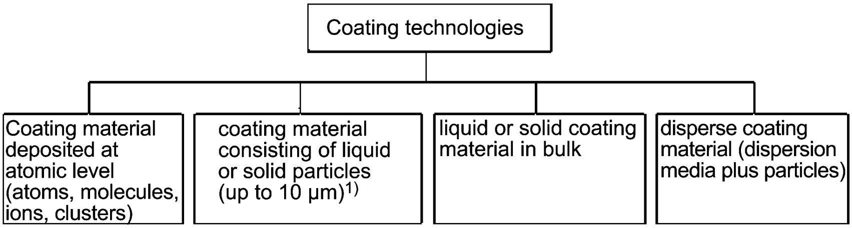

Fig. 1.6 Classification of coating technologies.

vidual assets and drawbacks. Figure 1.5 shows the systematic classification of surface-modification processes.

Selected process technologies are presented in Table 1.1, including basic advantages and disadvantages [5].

Unlike surface-modification processes, coating involves covering the surface of a workpiece with a well-bonded layer of shapeless material. A possible classification of coating technologies is given in Fig. 1.6.

Bond strength to the substrate material primarily determines the quality of a coating. This macroscopic property is controlled by:

- materials combination
- type of interface zone
- microstructure and process conditions
- substrate type and pre-treatment.

A strong atomic bond in the contact zone is most favourable, provided that internal stresses within the coating are not too high and no long-term degradation occurs within the coating/substrate composite. Coating process and material combinations determine whether mechanical, chemical, or electrostatic bonds prevail, or whether diffusion occurs. Thus, preparation of the workpiece is a

Table 1.1 Selected process technologies for surface modification.

Advantages	Process technologies	Disadvantages
+ inexpensive + selective treatment possible + depth 1–10 mm	**Hardening** by means of induction flame laser, electron beam TIG (tungsten-inert gas)	– limited to steel, Co, 3–0.6% – distortion possible
+ applicable to many types of steel + well-controlled coating properties	**Carburisation** • diffusion of C (up to 0.8%) into surface including hardening • variety of different C-carriers	– distortion – cooling cracks
+ less distortion of surface compared to hardening and carburisation	**Carbonitriding** • compare above, additional nitrogen • low-temperature process	– slow process
+ less distortion of surface + high elevated temperature hardness	**Nitriding** • N-diffusion, formation of surface nitrides	– slow process
+ good resistance against adhesive wear + allows oxidising for corrosion protection	**Nitrocarburising** – cf. nitriding	– modifies thin surface zone
+ high hardness	**Boronising** • boron diffusion for boride formation • also applicable for Co-, N-, Ti-alloys	– distortion (high process temperatures) – brittle – low corrosion resistance
+ inexpensive	**Sherardising** • Zn-diffusion with subsequent chromatising	– no wear protection
+ good corrosion protection + less vibration fatigue + increased resistance against stress-corrosion cracking and corrosion fatigue	**Shot peening** for plastic deformation of workpiece surface	– modifies thin surface zone – low increase in hardness
see above	**Deep rolling** comparable with shot peening	– expensive
+ can create high surface hardness values + good wear and corrosion protection	**Plating, metallising** (e.g. Cr, V, Nb, Si-containing diffusion coatings) large variety of processes	– high process temperatures (distortion)

crucial factor in obtaining good coating adhesion. Apart from removing contamination, pre-treatments activate the substrate surface and therefore substantially influence the bond between coating and substrate. Typical mechanisms of surface activating are:

- creating defects in the substrate
- increasing surface energy
- removing oxide layers.

Table 1.2 summarises different coating technologies in common use and includes important process characteristics [4, 6].

Table 1.2 Selected coating technologies.

Advantages	Technologies	Disadvantages
+ high hardness values + good corrosion resistance + reduces friction in contact with steel	**Electrochemical deposition** (e.g. Cr) up to 0.5 mm coating thickness	– coating of complex geometries is difficult – danger of hydrogen embrittlement – environmental problems
+ low-temperature process + very high corrosion protection + suitable for most metal substrates and many non-conducting materials + uniform coating thickness even on complex geometries	**Chemical (electroless) deposition** from electrolyte solution (e.g. NiB, NiP)	– expensive – additional heat treatment necessary
+ very high hardness values + good adhesion	**CVD, chemical vapour deposition** chemical vapour deposition at high temperatures	– distortion – coating of sharp-edged geometries is difficult – disposal of aggressive gaseous waste
+ dense coatings with high adhesion + low coating process temperature + allows deposition of pure elements, compounds and alloys	**PVD, physical vapour deposition** – evaporation – cathode sputtering	– low growth rate of coating – expensive vacuum process – restrictions in terms of part geometry
+ large variety of materials + good adhesion + properties well controllable by choice of materials and process	**Thermal spray processes**	– residual porosity – deposition efficiency of coating process (overspray)
+ very high adhesion + large parts coatable + inexpensive	**Build-up welding**	– coating materials limited – impact on substrate material
+ very high adhesion + coating of complex geometries	**Build-up brazing** powdery hard material and brazing filler metal with binding agent protective gas process	– coating materials limited

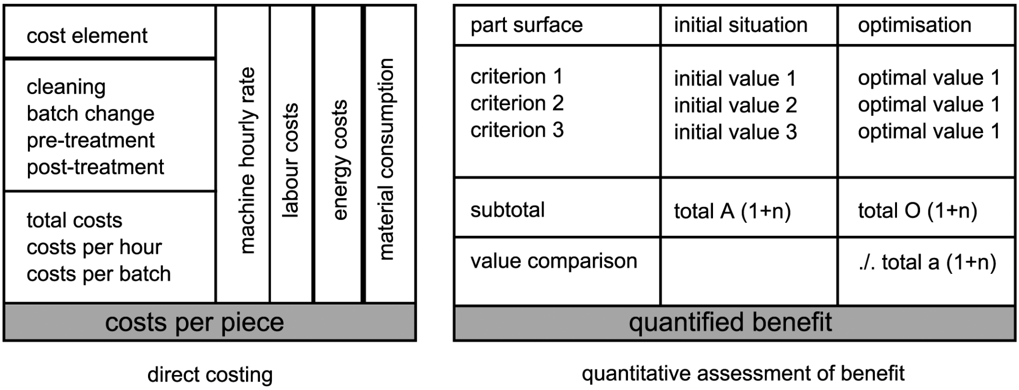

Fig. 1.7 Procedure for determining costs per piece and customer benefit for surface-technology processes.

1.5 Economic Assessment of Surface-treatment Technologies

Next to selecting coatings from a technological point of view, the costs of available surface-treatment processes need to be taken into account. Considering all relevant cost elements associated with individual process steps by means of direct costing is necessary. As presented in Fig. 1.7, analysis yields individual costs per piece and thus allows comparing different surface-treatment processes. Furthermore, specific customer benefit of a surface technology can be an additional determining factor during economic assessment [2].

Inevitably, this task is more of a challenge than pure cost assessment because customer benefit is hard to quantify. The fundamental idea is to compare the two situations before and after optimisation using a quantitative approach. Once this method delivers quantified benefits associated to different surface treatments it represents an additional economic assessment tool. Process and material selection can thus use a supplementary criterion along with technical and economic ratings. The quantitative assessment of customer benefit can also be used to reduce complications of market launch for new surface-treatment processes.

1.6 Summary and Conclusions

Selecting an appropriate technology to produce a certain combination of surface characteristics is a very complex process. It involves systematic correlation of specifications with attainable surface properties. Usually, the selection process includes economic and ecological evaluations.

Surface technologies are gaining importance as integral parts of manufacturing chains. While surface treatments nowadays are often carried out as separate or post-processes, integration into process chains is on the advance. Aimed primarily at reduced production time, integration creates synergies as well. For instance, coating sheet metal with initially poor conductivity can ease subsequent electromagnetic forming steps. Also, part geometry close to final contour can be produced using enhanced process control during coating. These examples show that integration of surface treatment technologies and manufacturing process chains is essential along with developing new coating processes and materials.

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