

ASM HANDBOOK

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5

Surface Engineering



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Foreword

Improving the performance, extending the life, and enhancing the appearance of materials used for engineering components are fundamental--and increasingly important--concerns of ASM members. As the performance demands placed on materials in engineering applications have increased, the importance of surface engineering (cleaning, finishing, and coating) technologies have increased along with them.

Evidence of the growing interest in (and complexity of) surface engineering processes can be found in the expansion of their coverage in ASM handbooks through the years. The classic 1948 Edition of *Metals Handbook* featured a total of 39 pages in three separate sections on surface treating and coating. In the 8th Edition, surface technologies shared a volume with heat treating, and the number of pages jumped to over 350. The 9th Edition of *Metals Handbook* saw even further expansion, with a separate 715-page volume devoted to cleaning, finishing, and coating.

Surface Engineering, the completely revised and expanded Volume 5 of *ASM Handbook*, builds on the proud history of its predecessors, and it also reflects the latest technological advancements and issues. It includes new coverage of testing and analysis of surfaces and coatings, environmental regulation and compliance, surface engineering of nonmetallic materials, and many other topics.

The creation of this Volume would not have been possible without the early leadership of Volume Chairperson Fred A. Smidt, who passed away during the editorial development of the handbook. Two of his colleagues at the Naval Research Laboratory, Catherine M. Cotell and James A. Sprague, stepped in to see the project through to completion, and they have done an excellent job of shaping the content of the book and helping to ensure that it adheres to high technical and editorial standards. Special thanks are also due to the Section Chairpersons, to the members of the ASM Handbook Committee, and to the ASM editorial and production staffs. Of course, we are especially grateful to the hundreds of authors and reviewers who have contributed their time and expertise to create this outstanding information resource.

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Preface

In the 9th Edition of *Metals Handbook*, the title of this Volume was *Surface Cleaning, Finishing, and Coating*; for the new *ASM Handbook* edition, the title has been changed to *Surface Engineering*. A useful working definition of the term *surface engineering* is "treatment of the surface and near-surface regions of a material to allow the surface to perform functions that are distinct from those functions demanded from the bulk of the material." These surface-specific functions include protecting the bulk material from hostile environments, providing low- or high-friction contacts with other materials, serving as electronic circuit elements, and providing a particular desired appearance.

Although the surface normally cannot be made totally independent from the bulk, the demands on surface and bulk properties are often quite different. For example, in the case of a turbine blade for a high-performance jet engine, the bulk of the material must have sufficient creep resistance and fatigue strength at the service temperature to provide an acceptably safe service life. The surface of the material, on the other hand, must possess sufficient resistance to oxidation

and hot corrosion under the conditions of service to achieve that same component life. In many instances, it is either more economical or absolutely necessary to select a material with the required bulk properties and specifically engineer the surface to create the required interface with the environment, rather than to find one material that has both the bulk and surface properties required to do the job. It is the purpose of this Volume to guide engineers and scientists in the selection and application of surface treatments that address a wide range of requirements.

Scope of Coverage. This Volume describes surface modifications for applications such as structural components, in which the bulk material properties are the primary consideration and the surface properties must be modified for aesthetics, oxidation resistance, hardness, or other considerations. It also provides some limited information on surface modifications for applications such as microelectronic components, in which the near-surface properties are paramount and the bulk serves mainly as a substrate for the surface material.

The techniques covered may be divided broadly into three categories:

- Techniques to prepare a surface for subsequent treatment (e.g., cleaning and descaling)
- Techniques to cover a surface with a material of different composition or structure (e.g., plating, painting, and coating)
- Techniques to modify an existing surface topographically, chemically, or microstructurally to enhance its properties (e.g., glazing, abrasive finishing, and ion implantation)

Two significant surface-modification techniques that are not covered extensively in this Volume are conventional carburizing and nitriding. Detailed information on these processes is available in *Heat Treating*, Volume 4 of the *ASM Handbook*.

The materials that are suitable for surface engineering by the techniques addressed in this Volume include metals, semiconductors, ceramics, and polymers. Coverage of the classes of surfaces to be engineered has been broadened in this edition, reflecting the trend toward the use of new materials in many applications. Hence, this Volume provides information on topics such as high-temperature superconducting ceramics, organic-matrix composites that are substituted for metals in many automotive parts, diamond coatings that are used for either their hardness or their electronic properties, and surfaces that are implanted on medical prostheses for use in the human body. While a number of new materials and processes have been added to the coverage of this Volume, every attempt has been made to update, expand, and improve the coverage of the established surface treatments and coatings for ferrous and nonferrous metals.

In this edition, a section has been added that specifically addresses the environmental protection issues associated with the surface treatment of materials. These issues recently have become extremely important for surface treatment technology, because many surface modification processes have the potential to create major environmental problems. For some technologies, such as cadmium and chromium plating, environmental concerns have prompted intensive research efforts to devise economical alternative surface treatments to replace the more traditional but environmentally hostile methods. This Volume presents the current status of these environmental protection concerns and the efforts underway to address them. This is a rapidly developing subject, however, and many legal and technological changes can be expected during the publication life of this Volume.

Organization. Depending on the specific problem confronting an engineer or scientist, the most useful organization of a handbook on surface engineering can be by technique, by material being applied to the surface, or by substrate material being treated. The choice of an appropriate technique may be limited by such factors as chemical or thermal stability, geometrical constraints, and cost. The choice of material applied to a surface is typically dictated by the service environment in which the material will be used, the desired physical appearance of the surface, or, in the case of materials for microelectronic devices, the electrical or magnetic properties of the material. The substrate material being treated is usually chosen for its mechanical properties. Although the surface modification technique and the material being applied to the surface can be changed, in many cases, to take advantage of benefits provided by alternative techniques or coatings, the choice of a substrate material is generally inflexible. For example, if the problem confronting the materials engineer is the corrosion protection of a steel component, the most direct approach is to survey the processes that have been successfully applied to that particular base material. Once candidate processes have been identified, they can be examined in more detail to determine their suitability for the particular problem.

To serve as wide a range of needs as possible, this Volume is organized by both treatment technique and base material. Wherever possible, efforts have been made to cross-reference the technique and material sections to provide the reader with a comprehensive treatment of the subject.

The first several sections are organized by technique, covering surface cleaning, finishing, plating, chemical coating, vapor deposition, ion implantation, and diffusion treatment. The first of the process-oriented sections, "Surface Cleaning," covers techniques for removing various types of foreign substances. In addition to the mature technologies that have been applied routinely for decades, this section describes a number of processes and innovations that have been developed recently, prompted by both technological demands and environmental concerns. The section "Finishing Methods" addresses processes used to modify the physical topography of existing surfaces. These processes also have a lengthy history, but they continue to evolve with the development of new materials and applications. New information has been added to this section on methods used to assess the characteristics of finished surfaces.

The section "Plating and Electroplating" describes processes used for electrolytic and nonelectrolytic deposition of metallic coatings. Coverage of these techniques has been significantly expanded in this edition to include a larger number of metals and alloys that can be plated onto substrate materials. This section also contains an article on electroforming, a topic that spans surface and bulk material production. The next section, "Dip, Barrier, and Chemical Conversion Coatings," contains articles on physically applied coatings, such as paints and enamels, as well as on coatings applied by chemical reactions, which are similar in many cases to plating reactions. The final technique-related section, "Vacuum and Controlled-Atmosphere Coating and Surface Modification Processes," covers techniques that apply coatings from the vapor and liquid phases, plus ion implantation, which modifies the composition near the surface of materials by injecting energetic atoms directly into the substrate. Several new technologies involving deposition of energetic atoms have been added to this section. Reflecting the rapid development of electronic materials applications since the last edition was published, articles have been added on processes specifically applicable to semiconductors, superconductors, metallization contacts, and dielectrics.

Following the technique-oriented sections, a new section has been added for this edition specifically to address methods for the testing and characterization of modified surfaces. This information is similar to that provided in *Materials Characterization*, Volume 10 of *ASM Handbook*, but it is extrapolated to surface-specific applications. Because of the functions performed by engineered surfaces and the limited thickness of many coatings, materials characterization techniques must be specifically tailored to obtain information relevant to these problems.

The next four sections of the book focus on the selection and application of surface modification processes for specific bulk or substrate materials. The section "Surface Engineering of Irons and Steels" is new to this edition and provides a convenient overview of applicable processes for these key materials. The articles in the section "Surface Engineering of Nonferrous Metals" provide updated information on the selection and use of surface treatments for widely used nonferrous metals. Reflecting the increased importance of a variety of materials to engineers and scientists and the integration of different classes of materials into devices, a section entitled "Surface Engineering of Selected Nonmetallic Materials" has been added to this edition.

The final section of this Volume, "Environmental Protection Issues," deals with regulatory and compliance issues related to surface engineering of materials. In recent years, concerns about the impact of many industrial processes on local environments and the global environment have joined economic and technological questions as significant drivers of manufacturing decisions. The surface engineering industry, with its traditional reliance on toxic liquids and vapors for many processes, has been especially affected by these concerns. Environmental protection in surface engineering of materials is a rapidly developing field, and this final section attempts to assess the current status of these issues and give some bases for predicting future trends.

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Classification and Selection of Cleaning Processes

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Introduction

CLEANING PROCESSES used for removing soils and contaminants are varied, and their effectiveness depends on the requirements of the specific application. This article describes the basic attributes of the most widely used surface cleaning processes and provides guidelines for choosing an appropriate process for particular applications.

The processing procedures, equipment requirements, effects of variables, and safety precautions that are applicable to individual cleaning processes are covered in separate articles that follow in this Section of the handbook. Additional relevant information is contained in the articles "Environmental Regulation of Surface Engineering," "Vapor Degreasing Alternatives," and "Compliant Wipe Solvent Cleaners" in this Volume. Information about considerations involved in cleaning of specific metals is available in the Sections

Cleaning Process Selection

In selecting a metal cleaning process, many factors must be considered, including:

- The nature of the soil to be removed
- The substrate to be cleaned (i.e., ferrous, nonferrous, etc.)
- The importance of the condition of the surface to the end use of the part
- The degree of cleanliness required
- The existing capabilities of available facilities
- The environmental impact of the cleaning process
- Cost considerations
- The total surface area to be cleaned
- Effects of previous processes
- Rust inhibition requirements
- Materials handling factors
- Surface requirements of subsequent operations, such as phosphate conversion coating, painting, or plating

Very few of these factors can be accurately quantified, which results in subjective analysis. Frequently, several sequences of operations may be chosen which together produce the desired end result. As in most industrial operations, the tendency is to provide as much flexibility and versatility in a facility as the available budget will allow. The size and shape of the largest predicted workpiece is generally used to establish the cleaning procedure, equipment sizes, and handling techniques involved.

Because of the variety of cleaning materials available and the process step possibilities, the selection of a cleaning procedure depends greatly on the degree of cleanliness required and subsequent operations to be performed. Abrasive blasting produces the lowest degree of cleanliness. Solvent, solvent vapor degrease, emulsion soak, alkaline soak, alkaline electroclean, alkaline plus acid cleaning, and finally ultrasonics each progressively produces a cleaner surface. In addition to these conventional methods, very exotic and highly technical procedures have been developed in the electronics and space efforts to produce clean surfaces far above the normal requirements for industrial use.

Cleaning Media. Understanding the mechanics of the cleaning action for particular processes can help guide the selection of an appropriate method.

Solvent cleaning, as the name implies, is the dissolution of contaminants by an organic solvent. Typical solvents are trichloroethylene, methylene chloride, toluene, and benzene. The solvent can be applied by swabbing, tank immersion, spray or solid stream flushing, or vapor condensation. Vapor degreasing is accomplished by immersing the work into a cloud of solvent vapor; the vapor condenses on the cooler work surface and dissolves the contaminants. Subsequent flushing with liquid solvent completes the cleaning process. Temperature elevation accelerates the activity.

One major drawback of solvent cleaning is the possibility of leaving some residues on the surface, often necessitating additional cleaning steps. Another more significant disadvantage is the environmental impact of solvent cleaning processes. In fact, much effort is being expended on replacing solvent-based processes with more environmentally acceptable aqueous-based processes (see the article "Vapor Degreasing Alternatives" in this Volume).

Emulsion cleaning depends on the physical action of emulsification, in which discrete particles of contaminant are suspended in the cleaning medium and then separated from the surface to be cleaned. Emulsion cleaners can be water or water solvent-based solutions; for example, emulsions of hydrocarbon solvents such as kerosene and water containing emulsifiable surfactant. To maintain stable emulsions, coupling agents such as oleic acid are added.

Alkaline cleaning is the mainstay of industrial cleaning and may employ both physical and chemical actions. These cleaners contain combinations of ingredients such as surfactants, sequestering agents, saponifiers, emulsifiers, and chelators, as well as various forms of stabilizers and extenders. Except for saponifiers, these ingredients are physically active and operate by reducing surface or interfacial tension, by formation of emulsions, and suspension or flotation of insoluble particles. Solid particles on the surface are generally assumed to be electrically attracted to the surface. During

the cleaning process, these particles are surrounded by wetting agents to neutralize the electrical charge and are floated away, held in solution suspension indefinitely, or eventually are settled out as a sludge in the cleaning tank.

Saponification is a chemical reaction that splits an ester into its acid and alcohol moieties through an irreversible base-induced hydrolysis. The reaction products are more easily cleaned from the surface by the surface-active agents in the alkaline cleaner. Excessive foaming can result if the alkalinity in the cleaner drops to the point where base-induced hydrolysis cannot occur; the reaction of the detergents in the cleaner with oil on the work surface can make soaps, which causes the characteristic foaming often seen in a spent cleaner.

Electrolytic cleaning is a modification of alkaline cleaning in which an electrical current is imposed on the part to produce vigorous gassing on the surface to promote the release of soils. Electrocleaning can be either anodic or cathodic cleaning. Anodic cleaning is also called "reverse cleaning," and cathodic cleaning is called "direct cleaning." The release of oxygen gas under anodic cleaning or hydrogen gas under cathodic cleaning in the form of tiny bubbles from the work surface greatly facilitates lifting and removing surface soils.

Abrasive cleaning uses small sharp particles propelled by an air stream or water jet to impinge on the surface, removing contaminants by the resulting impact force. A wide variety of abrasive media in many sizes is available to meet specific needs. Abrasive cleaning is often preferred for removing heavy scale and paint, especially on large, otherwise inaccessible areas. Abrasive cleaning is also frequently the only allowable cleaning method for steels sensitive to hydrogen embrittlement. This method of cleaning is also used to prepare metals, such as stainless steel and titanium, for painting to produce a mechanical lock for adhesion because conversion coatings cannot be applied easily to these metals.

Acid cleaning is used more often in conjunction with other steps than by itself. Acids have the ability to dissolve oxides, which are usually insoluble in other solutions. Straight mineral acids, such as hydrochloric, sulfuric, and nitric acids, are used for most acid cleaning, but organic acids, such as citric, oxalic, acetic, tartaric, and gluconic acids, occupy an important place in acid cleaning because of their chelating capability.

Phosphoric Acid Etching. Phosphoric acid is often used as an etchant for nonferrous metals (such as copper, brass, aluminum, and zinc) to enhance paint adhesion. A detergent-bearing iron phosphating solution is often ideal for this sort of combined cleaning and etching approach.

Molten salt bath cleaning is very effective for removing many soils, especially paints and heavy scale. However, the very high operating temperatures and high facility costs discourage widespread use of this process.

Ultrasonic cleaning uses sound waves passed at a very high frequency through liquid cleaners, which can be alkaline, acid, or even organic solvents. The passage of ultrasonic waves through the liquid medium creates tiny gas bubbles, which provide a vigorous scrubbing action on the parts being cleaned. Although the mechanism of this action is not completely understood, it yields very efficient cleaning. It is ideal for lightly soiled work with intricate shapes, surfaces, and cavities that may not be easily cleaned by spray or immersion techniques. A disadvantage of ultrasonic cleaning processes is the high capital cost of the power supplies and transducers that comprise the system. Therefore, only applications with the most rigorous cleaning requirements are suitable for this technique.

Substrate Considerations. The selection of a cleaning process must be based on the substrate being cleaned as well as the soil to be removed. Metals such as aluminum and magnesium require special consideration because of their sensitivity to attack by chemicals. Aluminum is dissolved rapidly by both alkalis and acids. Magnesium is resistant to alkaline solutions with pH values up to 11, but is attacked by many acids. Copper is merely stained by alkalis, yet severely attacked by oxidizing acids (such as nitric acid) and only slightly by others. Zinc and cadmium are attacked by both acids and alkalis. Steels are highly resistant to alkalis and attacked by essentially all acidic material. Corrosion-resistant steels, also referred to as *stainless steels*, have a high resistance to both acids and alkalis, but the degree of resistance depends on the alloying elements. Titanium and zirconium have come into common use because of their excellent chemical resistance. These two metals are highly resistant to both alkalis and acids with the exception of acid fluorides which attack them rapidly and severely.

Table 1 summarizes the comparative attributes of the principal cleaning processes.

Table 1 Comparative attributes of selected cleaning processes

Rated on a scale where 10 = best and 1 = worst

Attribute	Hand wiping	Immersion	Emulsion	Batch spray	Continuous conveyor	Ultrasonic
Handling	2	7	7	5	9	7
Cleanness	4	3	5	7	7	10
Process control	3	6	6	8	9	9
Capital cost	7	8	7	5	4	1
Operating cost	5	8	8	7	6	6

Types of soil may be broadly classified into six groups: pigmented drawing compounds, unpigmented oil and grease, chips and cutting fluids, polishing and buffing compounds, rust and scale, and miscellaneous surface contaminants, such as lapping compounds and residue from magnetic particle inspection. These six types of soil are dealt with separately in the order listed.

Removal of Pigmented Drawing Compounds

All pigmented drawing lubricants are difficult to remove from metal parts. Consequently, many plants review all aspects of press forming operations to avoid the use of pigmented compounds. Pigmented compounds most commonly used contain one or more of the following substances: whiting, lithopone, mica, zinc oxide, bentonite, flour, graphite, white lead (which is highly toxic), molybdenum disulfide, animal fat, and soaplike materials. Some of these substances are more difficult to remove than others. Because of their chemical inertness to acid and alkali used in the cleaners and tight adherence to metal surfaces, graphite, white lead, molybdenum disulfide, and soaps are the most difficult to solubilize and remove.

Certain variables in the drawing operation may further complicate the removal of drawing lubricants. For example, as drawing pressures are increased, the resulting higher temperatures increase the adherence of the compounds to the extent that some manual scrubbing is often an essential part of the subsequent cleaning operation. Elapsed time between the drawing and cleaning operations is also a significant factor. Drawing lubricants will oxidize and loosely polymerize on metal surfaces over time, rendering them even more resistant to cleaning.

Table 2 indicates cleaning processes typically selected for removing pigmented compounds from drawn and stamped parts such as Parts 1 through 6 in Fig. 1.

Table 2 Metal cleaning processes for removing selected contaminants

Type of production	In-process cleaning	Preparation for painting	Preparation for phosphating	Preparation for plating
Removal of pigmented drawing compounds^(a)				
Occasional or intermittent	Hot emulsion hand slush, spray emulsion in single stage, vapor slush degrease ^(b)	Boiling alkaline blow off, hand wipe	Hot emulsion hand slush, spray emulsion in single stage, hot rinse, hand wipe	Hot alkaline soak, hot rinse (hand wipe, if possible) electrolytic alkaline, cold water rinse
		Vapor slush degrease, hand wipe		



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Type of production	In-process cleaning	Preparation for painting	Preparation for phosphating	Preparation for plating
		Acid clean ^(c)		
Continuous high production	Conveyorized spray emulsion washer	Alkaline soak, hot rinse alkaline spray, hot rinse	Alkaline or acid ^(d) soak, hot rinse, alkaline or acid ^(d) spray, hot rinse	Hot emulsion or alkaline soak, hot rinse, electrolytic alkaline, hot rinse
Removal of unpigmented oil and grease				
Occasional or intermittent	Solvent wipe	Solvent wipe	Solvent wipe	Solvent wipe
	Emulsion dip or spray	Vapor degrease	Emulsion dip or spray, rinse	Emulsion soak, barrel rinse, electrolytic alkaline rinse, hydrochloric acid dip, rinse
	Vapor degrease	Phosphoric acid etch	Vapor degrease	
	Cold solvent dip		Alkaline spray	
	Alkaline dip, rinse, dry or dip in rust preventative			
Continuous high production	Automatic vapor degrease	Automatic vapor degrease	Emulsion power spray, rinse	Automatic vapor degrease, electrolytic alkaline rinse, hydrochloric acid dip, rinse ^(e)
	Emulsion, tumble, spray, rinse, dry		Vapor degrease	
			Acid clean ^(c)	
Removal of chips and cutting fluid				
Occasional or intermittent	Solvent wipe	Solvent wipe	Solvent wipe	Solvent wipe
	Alkaline dip and emulsion surfactant	Alkaline dip and emulsion surfactant	Alkaline dip and emulsion surfactant ^(f)	Alkaline dip, rinse, electrolytic alkaline ^(g) , rinse, acid dip, rinse ^(h)
	Stoddard solvent or trichlorethylene	Solvent or vapor	Solvent or vapor	
	Steam			
Continuous high production	Alkaline (dip or spray) and emulsion surfactant	Alkaline (dip or spray) and emulsion surfactant	Alkaline (dip or spray) and emulsion surfactant	Alkaline soak, rinse, electrolytic alkaline ^(g) , rinse, acid dip and rinse ^(h)





Type of production	In-process cleaning	Preparation for painting	Preparation for phosphating	Preparation for plating
Removal of polishing and buffing compounds				
Occasional or intermittent	Seldom required	Solvent wipe	Solvent wipe	Solvent wipe
		Surfactant alkaline (agitated soak), rinse	Surfactant alkaline (agitated soak), rinse	Surfactant alkaline (agitated soak), rinse, electroclean ⁽ⁱ⁾
		Emulsion soak, rinse	Emulsion soak, rinse	Alkaline spray
Continuous high production	Seldom required	Surfactant alkaline spray, spray rinse	Surfactant alkaline spray, spray rinse	Surfactant alkaline soak and spray, alkaline soak, spray and rinse, electrolytic alkaline ⁽ⁱ⁾ , rinse, mild acid pickle, rinse
		Agitated soak or spray, rinse ⁽ⁱ⁾	Emulsion spray, rinse	

- (a) For complete removal of pigment, parts should be cleaned immediately after the forming operation, and all rinses should be sprayed where practical.
- (b) Used only when pigment residue can be tolerated in subsequent operations.
- (c) Phosphoric acid cleaner-coaters are often sprayed on the parts to clean the surface and leave a thin phosphate coating.
- (d) Phosphoric acid for cleaning and iron phosphating. Proprietary products for high-and low-temperature application are available.
- (e) Some plating processes may require additional cleaning dips.
- (f) Neutral emulsion or solvent should be used before manganese phosphating.
- (g) Reverse-current cleaning may be necessary to remove chips from parts having deep recesses.
- (h) For cyanide plating, acid dip and water rinse are followed by alkaline and water rinses.
- (i) Other preferences: stable or diphase emulsion spray or soak, rinse, alkaline spray or soak, rinse, electroclean; or solvent presoak, alkaline soak or spray, electroclean.
- (j) Third preference: emulsion spray rinse

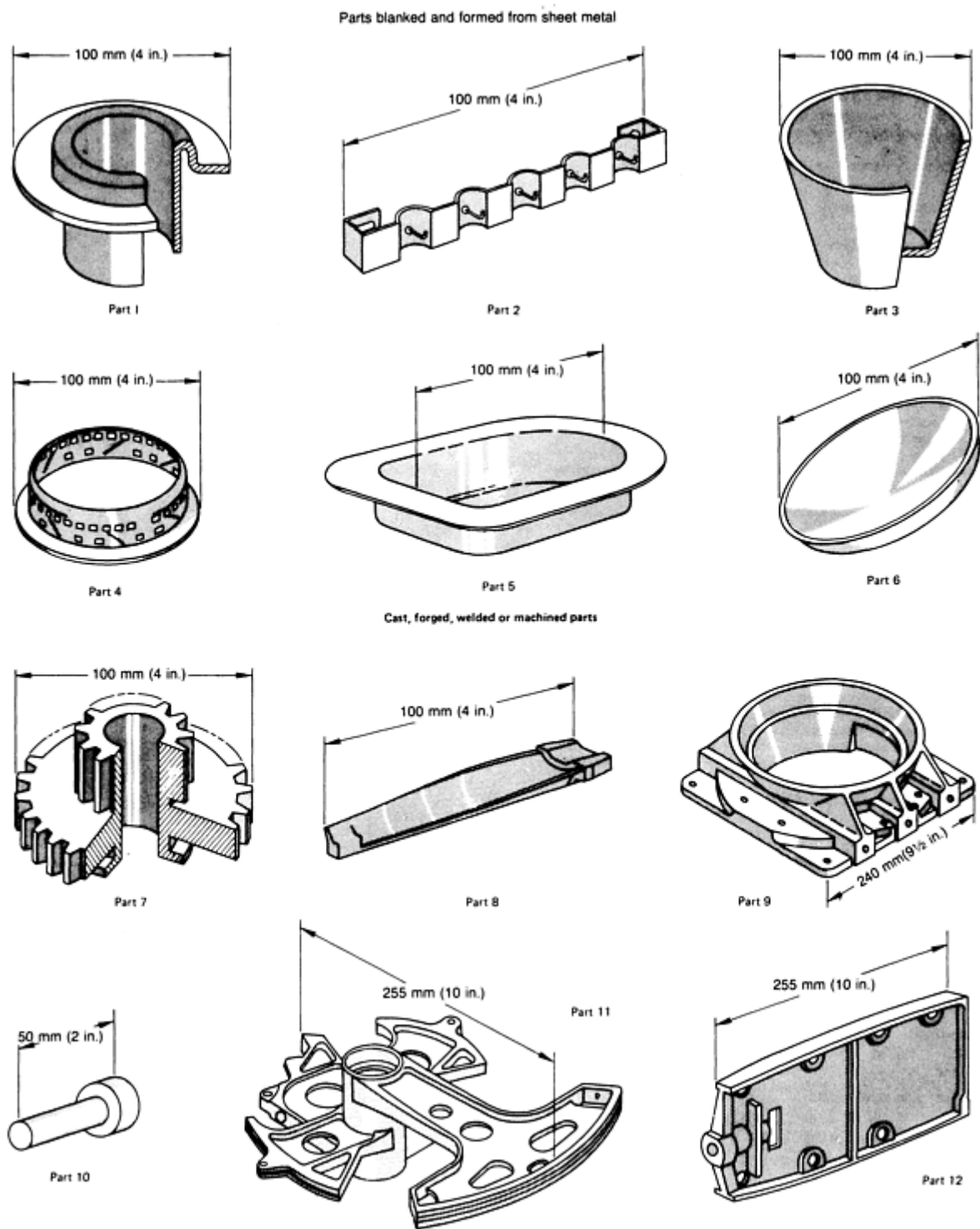


Fig. 1 Sample part configurations cleaned by various processes. See text for discussion.

Emulsion cleaning is one of the most effective methods for removing pigmented compounds, because it relies on mechanical wetting and floating the contaminant away from the surface, rather than chemical action which would be completely ineffective on such inert materials. However, emulsions alone will not do a complete cleaning job, particularly when graphite or molybdenum disulfide is the contaminant. Emulsion cleaning is an effective method of removing pigment because emulsion cleaners contain organic solvents and surfactants, which can dissolve the binders, such as stearates, present in the compounds.

Diphase or multiphase emulsions, having concentrations of 1 to 10% in water and used in a power spray washer, yield the best results in removing pigmented compounds. The usual spray time is 30 to 60 s; emulsion temperatures may range

from 54 to 77 °C (130 to 170 °F), depending on the flash point of the cleaner. In continuous cleaning, two adjacent spray zones or a hot water (60 to 66 °C, or 140 to 150 °F) rinse stage located between the two cleaner spraying zones is common practice.

Cleaning with an emulsifiable solvent, a combination of solvent and emulsion cleaning, is an effective technique for removing pigmented compounds. Emulsifiable solvents may either be used full strength or be diluted with a hydrocarbon solvent, 10 parts to 1 to 4 parts of emulsifiable solvent. Workpieces with heavy deposits of pigmented compound are soaked in this solution, or the solution is slushed or swabbed into heavily contaminated areas. After thorough contact has been made between the solvent and the soil, workpieces are rinsed in hot water, preferably by pressure spray. Emulsification loosens the soil and permits it to be flushed away. Additional cleaning, if required, is usually done by either a conventional emulsion or an alkaline cleaning cycle.

Most emulsion cleaners can be safely used to remove soil from any metal. However, a few highly alkaline emulsion cleaners with pH higher than 10 must be used with caution in cleaning aluminum or zinc because of chemical attack. Low alkaline pH (8 to 9) emulsion cleaners, safe on zinc and aluminum, are available. Emulsion cleaners with a pH above 11 should not be used on magnesium alloys.

Alkaline cleaning, when used exclusively, is only marginally effective in removing pigmented compounds. Success depends mainly on the type of pigmented compounds present and the extent to which they have been allowed to dry. If the compounds are the more difficult types, such as graphite or white lead, and have been allowed to harden, hand slushing and manual brushing will be required for removing all traces of the pigment. Hot alkaline scale conditioning solutions can be used to remove graphite and molybdenum disulfide pigmented hot forming and heat treating protective coatings. The use of ultrasonics in alkaline cleaning is also highly effective in removing tough pigmented drawing compounds.

The softer pigmented compounds can usually be removed by alkaline immersion and spray cycles (Table 2). The degree of cleanness obtained depends largely on thorough mechanical agitation in tanks or barrels, or strong impingement if a spray is used. A minimum spray pressure of 0.10 MPa (15 psi) is recommended.

Parts such as 1 to 6 in Fig. 1 can be cleaned effectively by immersion or immersion and spray when the parts are no longer than about 508 mm (20 in.) across. Larger parts of this type can be cleaned more effectively by spraying. Operating conditions and the sequence of processes for a typical alkaline cleaning cycle are listed in Table 3. This cycle has removed pigmented compounds effectively from a wide variety of stampings and drawn parts. Energy saving low-temperature solventized-alkaline cleaners are available for soak cleaning. Similarly low-temperature electro-cleaners also are effectively employed in industry, operating at 27 to 49 °C (80 to 120 °F).

Table 3 Alkaline cleaning cycle for removing pigmented drawing compounds

Process sequence	Concentration		Time, min	Temperature		Anode current		Remarks
	g/L	oz/gal		°C	°F	A/dm ²	A/ft ²	
Alkaline soak clean								
Barrel ^(a)	65 to 90	9 to 12	3 to 5	Boiling	Boiling	...	...	...
Rack ^(b)	65 to 90	9 to 12	3 to 5	Boiling	Boiling	...	...	...
Hot water rinse, immersion, and spray								
Barrel ^(a)	...	...	3 ^(c)	43	110	...	...	Spray jet if barrel is open type

Process sequence	Concentration		Time, min	Temperature		Anode current		Remarks
	g/L	oz/gal		°C	°F	A/dm ²	A/ft ²	
Rack ^(b)	...	...	2 ^(c)	43	110	...	...	Spray rinse, immerse, and spray rinse
Electrolytic alkaline clean								
Barrel ^(a)	55 to 65	7 to 9	2	82 to 99	180 to 210	4 to 6	40 to 60	...
Rack ^(b)	65 to 90	9 to 12	2	82 to 99	180 to 210	4 to 6	40 to 60	...
Hot water rinse, immersion, and spray^(d)								
Barrel ^(a)	...	...	3 ^(c)	43	110	...	...	Spray jet if barrel is open type
Rack ^(b)	...	...	2 ^(c)	43	110	...	...	Spray rinse, immerse, and spray rinse
Cold water rinse, immersion, and spray^(e)								
Barrel ^(a)	...	...	2 ^(c)	...	...	...	...	Spray jet if barrel is open type
Rack ^(b)	...	...	1 ^(c)	...	...	...	...	Spray rinse, immerse, and spray rinse

(a) Rotate during entire cycle.

(b) Agitate arm of rack, if possible.

(c) Immersion time.

(d) Maintain overflow at approximately 8 L/min (2 gal/min).

(e) Clean in cold running water.

Electrolytic alkaline cleaning is seldom used as a sole method for the removal of pigmented compounds. Although the generation of gas at the workpiece surface provides a scrubbing action that aids in removal of a pigment, the cleaner becomes contaminated so rapidly that its use is impractical except for final cleaning before plating (Table 2).

Copper alloys, aluminum, lead, tin, and zinc are susceptible to attack by uninhibited alkaline cleaners (pH 10 to 14). Inhibited alkaline cleaners (pH below 10), which have reduced rates of reaction, are available for cleaning these metals. These contain silicates and borates.

Acid Cleaning. Acid cleaners, composed of detergents, liquid glycol ether, and phosphoric acid have proved effective in removing pigmented compounds from engine parts, such as sheet rocker covers and oil pans, even after the pigments have dried. These acid compounds, mixed with water and used in a power spray, are capable of cleaning such parts without hand scrubbing.

A power spray cycle used by one plant is given in Table 4. A light blowoff follows the rinsing cycle. Parts with recesses should be rotated to allow complete drainage. This cleaning procedure suitably prepares parts for painting, but for parts to be plated, the acid cleaning cycle is conventionally followed by electrolytic cleaning which is usually alkaline, but sometimes done with sulfuric or hydrochloric acid. Phosphoric acid cleaners will not etch steel, although they may cause some discoloration.

Table 4 Power spray acid cleaning for removing pigmented compounds

Steel parts cleaned by this method are suitable for painting, but electrolytic cleaning normally follows if parts are to be electroplated; solventized, phosphoric acid-based, low-temperature (27 to 49 °C, or 80 to 120 °F) products are successfully used for power spray cleaning.

Cycle	Phosphoric acid		Solution temperature		Cycle time, min
	g/L	oz/gal	°C	°F	
Wash	15-19	2-2.5	74-79	165-175	3-4

Aluminum and aluminum alloys are susceptible to some etching in phosphoric acid cleaners. Chromic acid or sodium dichromate with either nitric or sulfuric acid is used to deoxidize aluminum alloys. Nonchromated deoxidizers are preferred environmentally. Ferric sulfate and ferric nitrate are used in place of hexavalent chromium. However, nonchromated deoxidizers tend to produce smut on the workpiece, especially 2000- and 7000-series alloys, when the deoxidizer etch rate is maintained (normally with fluoride) above 0.003 µm/side per hour (0.1 µin./side per hour). For more information on removing smut from aluminum, see the article "Surface Engineering of Aluminum and Aluminum Alloys" in this Volume.

Vapor degreasing is of limited value in removing pigmented compounds. The solvent vapor will usually remove soluble portions of the soil, leaving a residue of dry pigment that may be even more difficult to remove by other cleaning processes. However, modifications of vapor degreasing, such as slushing, spraying, ultrasonic, or combinations of these, can be utilized for 100% removal of the easier-to-clean pigments, such as whiting, zinc oxide, or mica.

The latter practice is often used for occasional or intermittent cleaning (Table 2). However, when difficult-to-clean pigments such as graphite or molybdenum disulfide are present, it is unlikely that slush or spray degreasing will remove 100% of the soil.

Vapor degreasing of titanium should be limited to detailed parts and should not be used on welded assemblies that will see later temperatures in excess of 290 °C (550 °F) because degreasing solvents are known to cause stress-corrosion cracking of titanium at these temperatures. Subsequent pickling in nitric-fluoride etchants may relieve this concern.

Solvent cleaning, because of its relatively high cost, lack of effectiveness, rapid contamination, and health and fire hazards, is seldom recommended for removing pigmented compounds, except for occasional preliminary or rough cleaning before other methods. For example, parts are sometimes soaked in solvents such as kerosene or mineral spirits immediately following the drawing operation to loosen and remove some of the soil, but the principal effect of the operation is to condition parts for easier cleaning by more suitable methods, such as emulsion or alkaline cleaning.

Removal of Unpigmented Oil and Grease

Common shop oils and greases, such as unpigmented drawing lubricants, rust-preventive oils, and quenching and lubricating oils, can be effectively removed by several different cleaners. Selection of the cleaning process depends on production flow as well as on the required degree of cleanliness, available equipment, and cost. For example, steel parts in a clean and dry condition will rust within a few hours in a humid atmosphere. Thus, parts that are thoroughly clean and dry must go to the next operation immediately, be placed in hold tanks, or be treated with rust preventatives or water displacing oils. If rust preventatives are used, the parts will probably require another cleaning before further processing. Accordingly, a cleaner that leaves a temporary rust-preventive film might be preferred.

Table 2 lists cleaning methods frequently used for removing oils and greases from the 12 types of parts in Fig. 1. Similar parts that are four or five times as large would be cleaned in the same manner, except for methods of handling. Variation in shape among the 12 parts will affect racking and handling techniques.

Advantages and disadvantages of the cleaners shown in Table 2, as well as other methods for removing common unpigmented oils and greases, are discussed in the following paragraphs.

Emulsion Cleaning. Emulsion cleaners, although fundamentally faster but less thorough than alkaline cleaners, are widely used for intermittent or occasional cleaning, because they leave a film that protects the steel against rust. Emulsion cleaners are most widely used for inprocess cleaning, preparation for phosphating, and precleaning for subsequent alkaline cleaning before plating (Table 2).

Vapor degreasing is an effective and widely used method for removing a wide variety of oils and greases. It develops a reproducible cleanliness because the degreasing fluid is distilled and filtered.

Vapor degreasing has proved especially effective for removing soluble soil from crevices, such as rolled or welded seams that may permanently entrap other cleaners. Vapor degreasing is particularly well adapted for cleaning oil-impregnated parts, such as bearings, and for removing solvent-soluble soils from the interiors of storage tanks.

Solvent cleaning may be used to remove the common oils and greases from metal parts. Methods vary from static immersion to multistage washing. Eight methods of solvent cleaning listed in increasing order of their effectiveness are as follows:

- Static immersion
- Immersion with agitation of parts
- Immersion with agitation of both the solvent and the parts
- Immersion with scrubbing
- Pressure spraying in a spray booth
- Immersion scrubbing, followed by spraying
- Multistage washing
- Hand application with wiper

A number of solvents and their properties are found in the articles on vapor degreasing and solvent cleaning in this Volume. Solvent cleaning is most widely used as a preliminary or conditioning cleaner to degrease both the time required in and contamination of the final cleaner.

Shape of the part influences the cycle and method selected. For example, parts that will nest or entrap fluids (Parts 3 and 6 in Fig. 1) are cleaned by dipping in a high-flash naphtha, Stoddard solvent, or chlorinated hydrocarbon for 5 to 30 s at room temperature. Time depends on the type and amount of soil. Parts that are easily bent or otherwise damaged, such as Part 2 in Fig. 1, are now sprayed for 30 s to 2 min at room temperature. Complex parts, such as Part 9 in Fig. 1, are soaked at room temperature for 1 to 10 min.

Acid Cleaning. Acid cleaners such as the phosphoric acid-ethylene glycol monobutyl ether type are efficient in the removal of oil and grease. Also, they remove light blushing rust and form a thin film of phosphate that provides temporary protection against rusting and functions as a suitable base for paint (Table 2).

Acid cleaners are usually used in a power spray washer. The cycle shown for removing pigmented compounds in Table 4 also removes unpigmented compounds.

Although acid cleaners are comparatively high in cost, they are often used on large ferrous components, such as truck cabs, before painting. Acid cleaners will etch aluminum and other nonferrous metals.

Alkaline Cleaning. Alkaline cleaners are efficient and economical for removing oil and grease and are capable of cleaning to a no-water-break surface. They remove oil and grease by saponification or emulsification, or both. The types that saponify only are quickly exhausted.

Mineral, lard, and synthetic unpigmented drawing compounds are easily removed by alkaline cleaners. Silicones, paraffin, and sulfurized, chlorinated, oxidized, or carbonized oils are difficult, but can be removed by alkaline cleaners. Alkaline cleaners will etch aluminum and other nonferrous metal parts unless inhibitors are used, and aqueous solutions of alkaline cleaners cannot be tolerated on some parts or assemblies. On assemblies comprised of dissimilar metals, this presence of alkaline solution in crevices may result in galvanic corrosion, and even a trace of alkali will contaminate paint and phosphate coating systems; therefore, rinsing must be extremely thorough. However, very hot rinsing will promote flash drying and flash rusting of work. Parts should be kept wet between stages, and delays before subsequent processing should be kept to a minimum. Cold water rinsing is recommended.

Electrolytic alkaline cleaning is effective as a final cleaning process for removing oil and grease from machined surfaces when extreme cleanness is required. It is almost always used for final cleaning before electroplating of items such as precision steel parts (fitted to ± 0.0076 mm, or ± 0.0003 in.) in refrigeration and air conditioning equipment. Electrolytic alkaline cleaning provided a cleanness of 0.0005 g/10 parts on the small plate assembly (Part 13) in Fig. 2, and of 0.003 g/10 parts on the 165 mm (6.5 in.) diameter part (Part 14). This degree of cleanness was obtained by using a conveyor system and the following cycle:

1. Soak in alkali, 45 to 60 g/L (6 to 8 oz/gal) at 77 to 88 °C (170 to 190 °F) for 1 to 2 min. Energy saving, solventized-alkaline low-temperature soak cleaners, suitable for ferrous and nonferrous metals are available. Similarly, low-temperature electrocleaners are also used. Both operate at 27 to 49 °C (80 to 120 °F).
2. Alkaline clean with reverse current, using current density of 5 A/dm² (50 A/ft²), same time, concentration, and temperature as in step 1. Avoid making the part cathodic when cleaning high-strength steels or titanium to avoid hydrogen embrittlement.
3. Rinse in cold water containing chromic acid for rust prevention.
4. Rinse in cold water containing ammonia.
5. Rinse in hot water containing 0.1% sodium nitrate.
6. Dry in hot air.
7. Place parts in solvent emulsion prior to manganese phosphate coating.

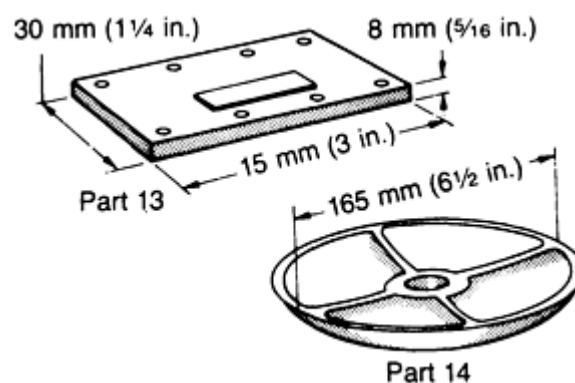


Fig. 2 Parts for refrigerators or air conditioners that are cleaned using electrolytic alkaline processes

Removal of Chips and Cutting Fluids from Steel Parts

Cutting and grinding fluids used for machining may be classified into three groups, as follows:

- Plain or sulfurized mineral and fatty oils (or combination of the two), chlorinated mineral oils, and sulfurized chlorinated mineral oils.
- Conventional or heavy-duty soluble oils with sulfur or other compounds added and soluble grinding oils with wetting agents.
- Chemical cutting fluids, which are water-soluble and generally act as cleaners. They contain soaps, amines, sodium salts of sulfonated fatty alcohols, alkyl aromatic sodium salts of sulfonates, or other types of soluble addition agents.

Usually, all three types of fluids are easily removed, and the chips fall away during cleaning, unless the chips or part become magnetic. Plain boiling water is often suitable for removing these soils, and in some plants, mild detergents are added to the water to increase its effectiveness. Steam is widely used for in-process cleaning, especially for large components. Table 2 indicates cleaning processes typically used for removing cutting fluids to meet specific production requirements.

Emulsion cleaning is an effective and relatively inexpensive means of removing all three types of cutting fluids. Attendant fire hazard is not great if operating temperatures are at least 8 to 11 °C (15 to 20 °F) below the flash temperature of the hydrocarbon used. Parts may be cleaned by either dipping or spraying. Many parts are immersed and then sprayed, particularly parts with complex configurations, such as Part 9 in Fig. 1.

It has often proved economical to remove a major portion of the soil by alkaline cleaning first and then to use an emulsion surfactant, an emulsion containing surface-activating agent. This sequence prevents the possible contamination of painting or phosphating systems with alkaline solution.

Most emulsion cleaners can be safely used for removing these soils from nonferrous metals. Only the emulsions having pH values higher than 10 are unsafe for cleaning nonferrous metals.

Alkaline Cleaners. Alkaline cleaners are effective for removing all three types of cutting and grinding fluids. Alkaline cleaning is usually the least expensive process and is capable of delivering parts that are clean enough to be phosphate coated or painted. Inhibited alkaline cleaners are required for removing cutting and grinding fluids from aluminum and zinc and their alloys.

Electrolytic alkaline cleaning, which invariably follows conventional alkaline cleaning for parts that are to be plated, is also recommended for removing cutting fluids when extra cleanness is required. For example, Parts 7 and 9 in Fig. 1 would be cleaned electrolytically before scaleless heat treating.

Vapor degreasing will remove cutting fluids of the first group easily and completely, but fluids of the second and third groups may not be completely removed and are likely to cause deterioration of the solvent. Water contained in these soluble fluids causes the hydrolysis of the degreasing solvent and produces hydrochloric acid, which will damage steel and other metals. Vapor degreasing solvents have inhibitors to reduce corrosion by stabilizing the pH. A potential fire hazard exists when water or moisture and aluminum chips are allowed to accumulate in a vapor degreaser.

If vapor degreasing is used to remove water-containing soils, perchloroethylene may be the preferred solvent because its higher boiling point (120 °C or 250 °F) causes most of the water to be driven off as vapor. However, prolonged immersion at 120 °C (250 °F) may also affect the heat treated condition of some aluminum alloys. Used exclusively, the vapor phase will not remove chips or other solid particles. Therefore, combination cycles, such as warm liquid and vapor, are ordinarily used. An air blowoff also aids in removing chips.

Solvent cleaning by soaking (with or without agitation), hand wiping, or spraying is frequently used for removing chips and cutting fluids. Solvents preferentially remove cutting fluids of the first group. Solvent cleaning is commonly used for cleaning between machining operations, to facilitate inspection or fixturing.

Acid Cleaning. Phosphoric or chromic acid cleaners used in a power spray or soak cleaning when followed by pressure spray rinsing are effective in removing most types of cutting fluids. However, they are expensive and are seldom used for routine cleaning. In some applications, acid cleaners have been used because they also remove light rust from ferrous metals and oxide and scale from aluminum alloys.

Removal of Polishing and Buffing Compounds

Polishing and buffing compounds are difficult to remove because the soil they deposit is composed of burned-on grease, metallic soaps, waxes, and vehicles that are contaminated with fine particles of metal and abrasive. Consequently, cleaning requirements should be considered when selecting polishing and buffing compounds. Compounds used for obtaining buffed and polished finishes may be classified by cleaning requirements:

- **Liquids:** mineral oils and oil-in-water emulsions or animal and vegetable oils with abrasives
- **Semisolids:** oil based, containing abrasives and emulsions, or water based, containing abrasives and dispersing agents
- **Solids:** greases containing stearic acid, hydrogenated fatty acid, tallow, hydrogenated glycerides, petroleum waxes, and combinations that produce either saponifiable or unsaponifiable materials, in addition to abrasives

Table 2 lists preferred and alternate methods for removing polishing and buffing compounds from sheet metal parts. However, some modification may be required for complete removal of all classes of these soils. Characteristics of polishing compounds and their effects on cleaning for the three broad classifications of soil are described in the following paragraphs.

Liquid compositions are oil based and flow readily, leaving a thin film of oil that contains particles of metal and abrasive on the work. Under extreme heat and pressure, some oils polymerize and form a glaze that is difficult to remove.

Mineral oils are usually unsaponifiable and are not readily removable by conventional alkaline cleaners. Solvent wiping, alkaline, or emulsion cleaning, using surfactant cleaners containing surface-activating agents, are more effective in removing residues from mineral oils.

Most animal and vegetable oils can be saponified at a slow rate. These oils are insoluble in water, but can be removed by soaking or spraying in hot alkaline solutions (82 °C, or 180 °F). Spraying is preferred because it removes adhering particles more effectively. Surfactants are suitable also, but their higher cost cannot always be justified.

Semisolid compounds are mixtures of liquid binders and abrasives that contain emulsifying or dispersing agents to keep the abrasive in suspension. When subjected to heat and pressure, these compounds usually form a heavy soil on the surface and may cake and fill in depressions and corners. Such compounds vary from unsaponifiable to completely saponifiable. Hand wiping with solvent or emulsion cleaner is effective in removing these compounds. Impingement from power washers usually removes most of the soil, regardless of the cleaner used. If power washers are not available, soak in agitated solutions containing surfactants, followed by a thorough rinsing, for satisfactory results.

Solid Compounds. The oil phases of solid compounds are easily removed, but the remaining residues cling tenaciously to metal surfaces and must be dislodged by scrubbing action. Power washers are the most effective. Most agitated surfactant cleaners are also effective, but the agitation must be strong enough to dislodge the soils.

Removal Methods

Solvent cleaning is effective for precleaning but is more costly than alkaline or emulsion methods. Cleaning with chlorinated solvents in a mechanical degreaser or brushing or spraying with petroleum solvents quickly removes most of the gross soil after buffing or polishing.

Emulsion Cleaning. Emulsion cleaners containing one part of emulsion concentrate to 50 to 100 parts of water, and operated at 54 to 60 °C (130 to 140 °F) are effective for removing mineral oils and other unsaponifiable oils from polished work. To effectively remove semisolid compounds, the temperature must be raised to 66 to 71 °C (150 to 160 °F) and the concentration increased to one part concentrate to 10 to 20 parts water. Agitation helps dislodge soil from corners or grooves. Table 5 describes cleaning cycles for removing polishing and buffing compounds. Thickened emulsion cleaners may be applied with an airless spray pump. Allow 5 to 10 min dwelling time before cold water rinsing. Emulsion cleaners applied manually at ambient temperature are suitable for many applications, especially for buffed aluminum parts.

Table 5 Emulsion cleaning cycles for removing polishing and buffing compounds

All workpieces were rinsed using water spray.

Type of compound	Temperature		Time, min	Concentration, emulsion to water	Agitation
	°C	°F			
Oil	66-71	150-160	3-5	1:10-20	Soak
Semisolid	54-60	130-140	3-5	1:50-100	Solution movement
Solid	71-82	160-180	1 $\frac{1}{2}$	1:20-50	Spray wash

Note: All emulsion cleaned parts should be subsequently cleaned by alkaline soaking and electrolytic alkaline cleaning before

Removal of solid soils or those containing grit requires the use of higher temperature (71 to 82 °C, or 160 to 180 °F) and increased concentration (one part concentrate to ten parts water). If the soil is heavy, caked, or impacted in corners, a spray washer is required, and the proper ratio of concentrate to water is between 1 to 20 and 1 to 50 (Table 5).

All emulsion methods must be followed by a thorough water spray rinse. The cleaner will loosen and remove most of the soil, but only a strong water spray can remove the remainder. Warm water is preferred, but cold water can be used. A rust inhibitor additive may be required in the rinse after emulsion cleaning to control flash rusting.

In spray equipment, concentration must be controlled to avoid foaming or breaking the emulsion. When soil removal requires a critical concentration, a foam depressant may be added to the cleaner. Polishing compounds containing soap or soap-forming material will cause excessive foaming during agitation, which may reduce the efficiency of the cleaner and the washer. The performance of emulsion cleaners can sometimes be improved by using them in conjunction with alkaline solutions, particularly in spray washers. Alkaline cleaning compounds at a concentration of about 4 g/L ($\frac{1}{2}$ oz/gal) may be used, but the surface being cleaned will still have an oily film after rinsing.

Although the preceding information is applicable primarily to ferrous metal parts, it can be applied also to brass and to zinc-based die castings. The following is a cycle that proved successful for removing polishing and buffing soil from zinc-based die castings in high-volume production:

1. Preclean by soaking for 4 min in diphasic cleaner, using kerosene as the solvent; temperature, 71 °C (160 °F); concentration, 1 to 50; plus a 75 mm (3 in.) layer of kerosene. Parts are sprayed with a solution as they are being withdrawn from the tank.
2. Fog spray rinse.
3. Alkaline spray cleaner, 7.5 g/L (1 oz/gal), 71 °C (160 °F), for 1 $\frac{1}{2}$ min.
4. Alkaline soak cleaner, 30 to 45 g/L (4 to 6 oz/gal), 71 °C (160 °F), for 4 min.
5. Spray rinse.
6. Transfer to automatic plating machine or electrolytic alkaline cleaning.

Alkaline cleaning, or one of its modifications, is an effective and usually the least expensive method for removing soils left by polishing and buffing. Mineral oils and other saponifiable oils are difficult to remove by soak cleaning. Oil that floats to the surface redeposits on the work unless the bath is continually skimmed. Agitation of the bath to minimize oil float and proper rinsing of parts as there are withdrawn from the tank minimizes the retention of oil on the part.

Removing liquid or solid compounds that contain abrasives requires agitation. Most soak cleaners foam if agitated sufficiently to dislodge hardened soil from recesses or pockets. A mildly agitated surfactant cleaner, followed by a strong water spray, can loosen these soils (Table 2).

Operating conditions for soak, spray, and electrolytic alkaline cleaning methods for removing polishing and buffing compounds are listed in Table 6. When the soil is charged with abrasive, alkaline cleaners must be renewed more frequently to prevent the accumulation of dirt that will clog screens and nozzles.

Table 6 Alkaline cleaning for removing polishing and buffing compounds

Soak and spray cleaning are followed by electrolytic cleaning if parts are to be electroplated; electrolytic cleaning is usually preceded by soak or spray cleaning.

Method of cleaning	Concentration		Temperature		Time, min
	g/L	oz/gal	°C	°F	
Soak ^(a)	30-90	4-12	82-100	180-212	3-5
Spray ^(b)	4-15	$\frac{1}{2}$ -2	71-82	160-180	1-2
Electrolytic ^(c)	30-90	4-12	82-93	180-200	1-3

Note: Use great care in cleaning brass and zinc die cast, because these materials are easily attacked at high concentration, temperature, and current density of alkaline cleaners. Anodic cleaning is best, using a concentration of 30 to 45 g/L (4 to 6 oz/gal) at a temperature

(a) For removing light oils, semisolid compounds, and solid compounds if not impacted or burned on work; must be followed by a strong spray rinse.

(b) For removing light mineral oils, semisolids, and solids if impacted or caked on work; followed by a rinse.

(c) For removing light oil films and semisolids. Solids are difficult to remove, especially if combined with grit or metal particles.

Electrolytic alkaline cleaning provides a high level of agitation close to the work surface because of the gas generated and is an effective method for removing polishing and buffing residues. Electrocleaners can be easily contaminated by polishing and buffing compounds as well as steel particles which may be attracted to the work and cause surface roughness during plating. Precleaning is necessary. Parts on which mineral oil has been used as a polishing compound should always be precleaned before being electrocleaned. Use of both heavy duty alkaline soak cleaners and electrocleaners is often necessary to provide a water-break-free surface necessary for good plating quality and adhesion. The presence of large amounts of animal or vegetable oils or fatty acids and abrasives in the polishing and buffing compounds will react with free caustic and form soaps in the electrocleaner and shorten its life.

Acid Cleaning. Acid cleaners are chemically limited in their ability to remove polishing and buffing compounds. Soaps and other acid-hydrolyzable materials present in these compounds are decomposed by acid cleaners into insoluble materials, which precludes the use of acid cleaners in most instances.

Acid cleaners can be used alone for the more easily removed polishing and buffing compounds, such as fresh and unpolymerized liquids. In these applications, the acid cleaner must be used at the maximum operating temperature recommended for the specific cleaner in conjunction with the maximum agitation obtainable by spraying or scrubbing.

Acid cleaners may be desirable for removing acid-insensitive soils in special instances such as: where slight surface attack (short of pickling) is needed for dislodging particles or smut, and in conjunction with alkaline or alkaline emulsion cleaners, when successive reversal of pH proves to be advantageous. A light pickle in dilute hydrochloric, hydrofluoric, or sulfuric acid may be added to the cleaning sequence to remove fine metal particles, tarnish, or light scale to activate the surface for electroplating.

Removal of Rust and Scale

The seven basic methods used for removing rust and scale from ferrous mill products, forgings, castings, and fabricated metal parts are:

- Abrasive blasting (dry or wet)
- Tumbling (dry or wet)
- Brushing
- Acid pickling
- Salt bath descaling
- Alkaline descaling
- Acid cleaning

The most important considerations in selecting one of the above methods are:

- Thickness of rust or scale
- Composition of metal
- Condition of metal (product form or heat treatment)
- Allowable metal loss
- Surface finish tolerances
- Shape and size of workpieces
- Production requirements
- Available equipment
- Cost
- Freedom from hydrogen embrittlement

Combinations of two or more of the available processes are frequently used to advantage.

Abrasive blast cleaning is widely used for removing all classes of scale and rust from ferrous mill products, forgings, castings, weldments, and heat treated parts. Depending on the finish requirements, blasting may be the sole means of scale removal, or it may be used to remove the major portion of scale, with pickling employed to remove the remainder. Glass bead cleaning (blasting) is used for cleaning threaded or precision parts, high-strength steel, titanium, and stainless steel.

Tumbling is often the least expensive process for removing rust and scale from metal parts. Size and shape of parts are the primary limitations of the process. Tumbling in dry abrasives (deburring compounds) is effective for removing rust and scale from small parts of simple shape, such as Part 10 in Fig. 1. However, parts of complex shape with deep recesses and other irregularities cannot be descaled uniformly by tumbling and may require several hours of tumbling if that method is used. Adding descaling compounds rather than deburring compounds often decreases the required tumbling time by 75%.

Brushing is the least used method of descaling parts, although it is satisfactory for removing light rust or loosely adhering scale. It is better suited for workpieces formed from tubing than for castings or forgings.

Pickling in hot, strong solutions of sulfamic, phosphoric, sulfuric, or hydrochloric acid is used for complete removal of scale from mill products and fabricated parts. However, pickling is declining in use as a single treatment for scale removal. With increasing frequency, pickling, at acid concentrations of about 3% and at temperatures of about 60 °C (140 °F) or lower, is being used as a supplementary treatment following abrasive blasting or salt bath descaling. Use of

deoxidizing aluminum alloys in room-temperature chromic-nitric-sulfuric acid solutions to remove heat treat scale is common practice.

Electrolytic pickling, although more expensive than conventional pickling, can remove scale twice as fast and may prove economical where the time is limited. In an automatic plating installation, electrolytic pickling removes light scale and oxidizes during the time allowed in the pickling cycle and eliminates a preliminary pickling operation. For this purpose, a solution of 30% hydrochloric acid is used at 55 °C (130 °F) and 3 to 6 V for 2 to 3 min. Cathodic current is used.

Sulfuric acid formulas also are used electrolytically. A cycle for removing light scale from spot-welded parts is a solution of 10% sulfuric acid at 82 °C (180 °F) and 3 to 6 V for 5 to 20 s.

The main objection to electrolytic pickling is high cost. In addition to the requirement for more elaborate equipment, all workpieces must be racked.

Salt bath descaling is an effective means of removing or conditioning scale on carbon, alloy, stainless, and tool steels, heat-resisting alloys, copper alloys, nickel alloys, titanium, and refractory metals. Several types of salt baths either reduce or oxidize the scale. Various baths operate within a temperature range of 400 to 525 °C (750 to 975 °F).

Except in the descaling of pure molybdenum, molten salt baths are seldom used alone for scale removal. Usually, salt bath descaling and quenching are followed by acid pickling as a final step in removing the last of the scale. The supplementary pickling is done with more dilute acids at lower temperatures and for shorter times than are used in conventional pickling. A solution of 3% sulfuric acid at a maximum temperature of about 60 °C (140 °F) is commonly used for pickling after salt bath descaling. Other acids are used at comparable concentrations. Metal loss and the danger of acid embrittlement are negligible in this type of pickling.

Alkaline descaling or alkaline derusting is used to remove rust, light scale, and carbon smut from carbon, alloy, and stainless steels and from heat-resisting alloys. Alkaline descaling is more costly and slower in its action than acid pickling of ferrous alloys, but no metal is lost using the alkaline method, because chemical action stops when the rust or scale is removed. Alkaline descaling also allows complete freedom from hydrogen embrittlement. Alkaline etch cleaning of aluminum alloys is less expensive than acid pickling solutions for descaling, removing shot peen residue, removing smeared metal prior to penetrant inspection, chemical deburring, and decorative finishing of nonclad surfaces.

A number of proprietary compounds are available. They are composed mainly of sodium hydroxide (60% or more) but also contain chelating agents.

Immersion baths are usually operated from room temperature to 71 °C (160 °F), but can be used at 93 to 99 °C (200 to 210 °F) with concentrations of about 0.9 kg (2 lb) of compound to 4 L (1 gal) of water. Required immersion time depends on the thickness of the rust or scale.

The rate of removal of oxide can be greatly increased by the use of current in the bath, either continuous direct or periodically reversed. In one instance, an electrolyzed bath descaled steel parts in $1 \frac{1}{2}$ min, as compared to 15 min for a nonelectrolytic bath doing the same job. However, parts must be racked for electrolytic descaling, increasing cost because of the additional equipment, increased power requirement, and decreased bath capacity.

The addition of about 0.5 kg (1 lb) of sodium cyanide per 4 L (1 gal) of water increases the effectiveness of electrolyzed baths. However, when cyanide is used, the bath temperature should be kept below 54 °C (130 °F) to prevent excessive decomposition of the cyanide. One manufacturer descales heat treated aircraft parts in an alkaline descaling bath, using direct current and cyanide additions. Another manufacturer descales similar work in an alkaline bath operated at 82 to 93 °C (180 to 200 °F) with a lower concentration of descaling compound, 60 to 90 g/L (8 to 12 oz/gal), and no cyanide. The latter bath is operated at a current density of 2 to 20 A/dm² (20 to 200 A/ft²) and with periodic current reversal (55 s anodic, followed by 5 s cathodic). Alkaline permanganate baths are also used for descaling. Proprietary products available are used at about 120 g/L (1 lb/gal), 82 to 93 °C (180 to 200 °F), 30 min or longer, depending on scale thickness and condition

Despite the high cost of alkaline descaling baths, they can be economical. Because alkaline descaling baths are compounded for detergency as well as derusting, chemical cleaning and derusting are accomplished in one step.

Paint, resin, varnish, oil, grease, and carbon smut are removed along with rust and scale. Thus, in a single operation, work is prepared for phosphating, painting, or electroplating. If parts are to be plated, the cost of electrolytic descaling may be comparable to that of the nonelectrolytic process, because in either case workpieces must be racked before final cleaning and plating. An electrolytic descaling bath may serve as the final cleaner.

Alkaline descalers are used for applications on critical parts such as turbine blades for jet engines where risk of hydrogen embrittlement, loss of metal, or etched surfaces cannot be tolerated. Alkaline descaling may also be chosen for parts made of high-carbon steel or cast iron, because acid pickling will leave smut deposits on these metals. Because of the time required, alkaline descaling is seldom used for removing heavy scale from forgings.

Acid Cleaning. Acid cleaners more dilute than acid pickling solutions are effective for removing light, blushing rust, such as the rust that forms on ferrous metal parts in storage under conditions of high humidity or short-time exposure to rain. Acid deoxidizing solutions specifically designed for use on aluminum remove oxides and should be used before electroplating or chemical coating. Various organic acid-based solutions, such as citric acid, are used to remove rust from stainless steels, including the 400 series and the precipitation hardening steels.

The following examples illustrate the considerations that influence the choice of process for removing rust and scale. Additional criteria for selection of process are included in Table 7, which compares advantages and disadvantages of abrasive blast cleaning, pickling, and salt bath descaling.

Table 7 Advantages and disadvantages of the three principal processes for removing scale and rust from steel parts

Advantages

Abrasive blast cleaning

- A variety of equipment and abrasives is available
- Does not interfere with properties established by heat treatment
- Size of workpiece is limited only by available equipment
- A wide variety of shapes can be blasted
- All metals can be safely blasted
- Adaptable to either intermittent low or continuous high production

Pickling

- Formulations can be adjusted to meet individual requirements in removing scale from various ferrous and nonferrous alloys
- Equipment required is simple and relatively inexpensive
- Materials are relatively low in cost, and process control usually is not difficult
- Adaptable to products of virtually any size or shape
- Installations can be adapted to either low or high, intermittent or continuous production
- Temperatures used will not affect properties of heat treated steel

Salt bath descaling

- Reduction or oxidation of the scale is almost instantaneous after workpieces reach bath temperature
- No loss of metal and no danger of hydrogen embrittlement
- Preliminary cleaning is unnecessary unless there is so much oil on the work that a fire hazard is involved as workpieces enter the bath
- Different metals can be descaled in the same bath
- Workpieces of complex shape can be processed, although special handling may be required to obtain complete removal of salt
- Processing temperature may provide useful stress relieving
- For some heat-resisting and refractory metals, molten salt is the only satisfactory method
- Will not damage sensitized stainless steels, whereas acid pickling would be harmful

Disadvantages

Abrasive blast cleaning

- Some of the metal will be abraded from workpieces, especially from corners
- May alter dimensions of machined parts or damaged corners
- If sufficiently drastic to remove scale, process may cause more surface etching or roughness than can be tolerated

Complex configurations will not receive equal blasting on all surfaces without special handling, which may be too costly

Pickling

Potential source of hydrogen embrittlement in some metals such as carbon and alloy steels of high carbon content, especially if these materials have been heat treated to high strength levels

Up to 3% of the metal may be lost in pickling--particularly significant for the more costly metals such as stainless steels or heat-resisting alloys

Fume control and disposal of spent acids are major problems

Process is likely to deposit smut on cast iron

Excessive pitting may occur in the pickling of cast steels and irons

Salt bath descaling

Not economical for intermittent production, because high operating temperatures necessitate special heating and handling equipment, and because the bath must be kept molten between production runs

The required water quenching may cause cracking or excessive warping of complex workpieces

The process is not suitable for metals (such as some grades of stainless steel) that precipitation harden at the temperature of the salt bath

Operating temperature of the bath can cause carbide precipitation in unstabilized stainless steels

Properties of heat treated workpieces may be impaired if their tempering temperature is below that of the salt bath

Subsequent acid cleaning is usually required to neutralize remaining salts, complete the descaling, and brighten the finished product

Example 1:

Barrel or vibratory tumbling is probably the most economical method for removing scale or rust from steel parts like Part 10 in Fig. 1, if they are no larger than about 50 to 75 mm (2 to 3 in.). For similar but larger parts, abrasive blasting is usually a better choice.

However, if such parts are close to finished dimensions and these dimensions are critical, a nonabrasive method of cleaning should be chosen. If parts are made of low-carbon steel and are not heat treated, pickling in inhibited hydrochloric or sulfuric acid is satisfactory and less expensive, and hydrogen embrittlement is not a factor. However, if such parts are made of high-carbon (or carburized) steel and are heat treated, acid pickling would be hazardous and alkaline descaling would be preferred.

Example 2:

The gear illustrated as Part 7 in Fig. 1 is made of 8620 steel, carburized, and hardened to about 56 to 58 HRC. Although the part is processed in a controlled atmosphere, a descaling operation is required. Abrasive blasting with fine steel grit or chilled iron shot (SAE G40 or S170) proved the most economical method for cleaning large tonnages of such parts used in the manufacture of trucks, tractors, and similar vehicles. Acid pickling was precluded because of hydrogen embrittlement, and descaling in molten salt was unsuitable because of the softening effect of the high-temperature bath.

Conventional abrasive blasting may deleteriously affect the dimensions of precision gears or pinions. In these special applications, alkaline descaling or wet blasting with a fine abrasive, such as glass beads, under carefully controlled conditions, is indicated.

Example 3:

The turbine blade shown as Part 8 in Fig. 1 is made of type 403 stainless steel. If such parts are made in continuous production, molten salt bath descaling would be the preferred cleaning method. If production is intermittent, the molten salt method would be too costly, and alkaline descaling would be more practical. Abrasive blasting is unsuitable for this application because of close dimensional requirements; pickling cannot be used because of metal loss and the risk of hydrogen embrittlement.

Example 4:

Scale resulting from welding of the low-carbon steel component shown as Part 12 in Fig. 1 could be removed satisfactorily and economically by either abrasive blasting or acid pickling. Because the part is phosphated and painted, surfaces are not critical. Acid pickling would probably be preferred, because it would make more uniform contact with all areas without the need for special handling. Even if a large quantity of parts were to be cleaned, salt bath cleaning would

not be used, because the water quench from about 425 °C (800 °F) would cause excessive warpage. The cost of alkaline descaling in an aqueous solution would not be justified for this class of work.

Example 5:

Normally, abrasive blasting would be the preferred method for removing rust and scale from a rough ferrous metal casting like Part 11 in Fig. 1. Chilled iron shot or steel abrasives are usually the most economical abrasives for this purpose.

Pickling is seldom used for descaling castings, such as cast iron, because smut is deposited and must be removed by another cleaning operation. Severe pitting is also likely to result.

Salt baths have been successfully used for descaling ferrous castings, but there is danger of cracking and excessive distortion for configurations such as Part 11.

Removal of Residues from Magnetic Particle and Fluorescent Penetrant Inspection

Successful removal of the iron oxide particles deposited on ferrous parts during magnetic particle inspection requires complete demagnetization of the part. After demagnetization, emulsion cleaning is an effective and practical means of removing both the iron oxide residues and oil. Fluorescent pigments used for similar inspection of aluminum parts can be removed with hot alkaline cleaners.

For low-to-moderate production, an efficient procedure consists of immersing parts in a light, undiluted, oil-based emulsion cleaner at room temperature or slightly above. Parts are then drained to remove excess cleaner and rinsed in water, using either agitation or forced spray at room temperature or slightly above. For higher-volume production, power washers are successful. Parts can be handled singly or in baskets or carriers.

Parts with complex configurations such as Part 9 in Fig. 1, fine threads, or serrations are difficult to clean thoroughly. As-cast or as-forged surfaces also cause the magnetic oxide particles to cling tenaciously. However, immersion in a cleaning emulsion with sufficient agitation or the use of a power washer, with properly placed nozzles and with suitable handling equipment, will clean almost any part. All oxide particles must be removed before the part is dried, or hand wiping or brushing will be required.

A type of emulsion cleaner that incorporates a rust preventative is usually preferred, because it provides protection until the next operation is performed. If rust-preventive films are objectionable in the next operation, they can be removed easily with alkaline cleaners.

Special Procedures for the Removal of Grinding, Honing, and Lapping Compounds

Residues remaining on parts after honing or grinding are usually mixtures of metallic and abrasive particles with oil-based or water-based cutting fluids. Thus, the methods recommended earlier in this article for the removal of chips and cutting fluids are applicable also for the removal of grinding residues in a majority of instances.

Lapped parts are usually more difficult to clean than honed or ground parts. Lapping residues are composed of extremely fine particles of various abrasives, minute metal particles, semi-solid greases and oils, and some graphite. Even if graphite is not a part of the original lapping compound, it accumulates from the wear of cast iron laps. Allowing compounds to dry increases cleaning difficulty. In many instances, methods used for removing polishing and buffing compounds are applicable also for removing lapping compounds. However, parts that are precision ground, honed, or lapped present special cleaning problems because: such parts are commonly used in precision machinery, and consequently the degree of cleanness required is higher than for most commercial work; they are frequently intricate in design (an example in Part 15 in Fig. 3); and they are commonly susceptible to damage and frequently require special handling.

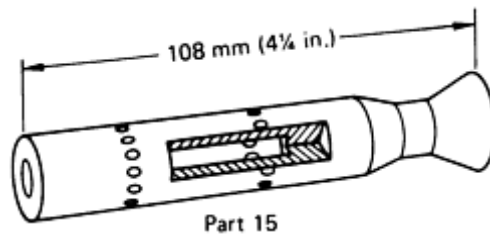


Fig. 3 Part for fuel control mechanism that requires special modification of solvent cleaning to remove grinding and lapping compounds

An extremely high degree of cleanness without damage is required on some expensive delicate parts (e.g., fuel injection equipment). Ultrasonic cleaning with alkaline solution, followed by spray with alkaline and immersion/spray rinsing is ideal for this application. Ultrasonic cleaning is rapidly replacing the old pressure solvent spray/agitated immersion technologies, which were only partially effective. Parts which normally took an hour or more to clean using solvent cleaning processes are now effectively cleaned in just a few minutes of ultrasonic cleaning. Other inherent advantages of this approach are that it is nondestructive to the parts; it uses more environmentally friendly cleaning solutions, and it is much safer with respect to the explosion dangers that are characteristic of many solvent cleaning technologies. As always, the primary drawback to ultrasonic cleaning is the comparative high up-front capital cost.

Room-Temperature Cleaning

Room-temperature or cold cleaners are aqueous solutions for removing soil without the aid of heat other than that resulting from pumping and circulating the solution or being transferred from the surrounding atmosphere. The operating range of such cleaners is usually from 21 to 46 °C (70 to 115 °F). For additional information, see the article "Alkaline Cleaning" in this Volume.

Cold alkaline cleaners, such as the silicate or phosphate types (orthosilicate or tetrasodium pyrophosphate), are chiefly used for cleaning where heat is not available, where heated solutions are not permitted, or when heating the parts above about 46 °C (115 °F) is not desirable. In a cold process for iron phosphating, for example, parts that have been cleaned in a heated solution and have not cooled sufficiently before entering the phosphate solution will yield an unacceptable phosphate coat. In some applications, an unheated cleaning solution is preferred in order to facilitate the checking of part dimensions at room temperature without the delay involved in cooling the parts after cleaning. This procedure is used for cam shafts, honed cylinder walls, and valve-guide holes in engine heads. One automotive plant utilizes a cold alkaline cleaner for removing soil from engine blocks in a power washer at the rate of 300 per hour. In another application, carburetor parts are cleaned at a rate of 600 to 700 per hour. Table 8 provides several detailed examples of the application of cold alkaline cleaners.

Table 8 Examples of application of room-temperature alkaline cleaners

Part	Surface from last operation	Relative of original amount of soil on part	Residual soil on part after cleaning, mg
Aluminum alloy piston	Ground	Heavy, up to 0.75 g per part	0.1
Pinion gear, ferrous	Ground and lapped	Heavy	0.1
Ring gear, ferrous	Ground and lapped	Heavy	0.1

Part	Surface from last operation	Relative of original amount soil on part	Residual soil on part after cleaning, mg
Engine heads, ferrous	Fully machined	Heavy	1.5
Engine intake manifold, ferrous	Fully machined	Heavy	10
Carburetor throttle body, ferrous	Fully machined	Medium to heavy	0.5
Automatic transmission pump, ferrous	Fully machined	Medium to heavy	6

Cold cleaners may also reduce costs by using simpler equipment, eliminating the expense of energy for heating, and reducing maintenance requirements.

Cold acid cleaners, such as monosodium phosphate containing a detergent, are also available. Their chief use is for cleaning immediately before iron phosphating, where the advantage of a lower pH is significant. These acid cleaners have a pH of about 6 and thus impart a surface compatible with the iron phosphate bath, which has a pH of 4.5 to 5.5.

Some proprietary products now offer simultaneous cleaning and iron phosphating at room or low temperatures. In a few other isolated applications, cold acid cleaners perform satisfactorily, but in most instances heated solutions are much more efficient.

Ultrasonic Cleaning

Ultrasonic energy can be used in conjunction with several types of cleaners, but it is most commonly applied to chlorinated hydrocarbon solvents, water, and water with surfactants. Ultrasonic cleaning, however, is more expensive than other methods, because of higher initial cost of equipment and higher maintenance cost, and consequently the use of this process is largely restricted to applications in which other methods have proved inadequate. Areas of application in which ultrasonic methods have proved advantageous are:

- Removal of tightly adhering or embedded particles from solid surfaces
- Removal of fine particles from powder-metallurgy parts
- Cleaning of small precision parts, such as those for cameras, watches, or microscopes
- Cleaning of parts made of precious metals
- Cleaning of parts with complex configurations, when extreme cleanness is required
- Cleaning of parts for hermetically sealed units
- Cleaning of printed circuit cards and electronic assemblies

Despite the high cost of ultrasonic cleaning, it has proved economical for applications that would otherwise require hand operations.

Part size is a limitation, although no definite limits have been established. The commercial use of ultrasonic cleaning has been limited principally to small parts. The process is used as a final cleaner only, after most of the soil is removed by another method. Ultrasonic cleaning, in some cases, has resulted in fatigue failure of parts. Proper racking and isolation from tank wall will often solve this problem.

Surface Preparation for Phosphate Coating

Because the chemical reaction that results in the deposit of a phosphate coating depends entirely on good contact between the phosphating solution and the surface of the metal being treated, parts should always be sufficiently clean to permit the phosphating solution to wet the surface uniformly. Soil that is not removed can act as a mechanical barrier to the phosphating solution, retarding the rate of coating, interfering with the bonding of the crystals to the metal, or, at worst, completely preventing solution contact. Some soils can be coated with the phosphate crystals, but adherence of the coating will be poor, and this will in turn affect the ability of a subsequent paint film to remain continuous or unbroken in service.

Soils such as cutting oils, drawing compounds, coolants, and rust inhibitors can react with the substrate metal and form a film that substantially changes the nature of the coating. Precautions must be taken to avoid carryover of cleaning materials into phosphating tanks. This is particularly true for alkaline cleaners, which can neutralize the acid phosphating solutions, rendering them useless. Additional information can be found in the article "Phosphate Coatings" in this Volume.

Surface Preparation for Painting

Surface preparation has a direct effect on the performance of paint films. The best paint available will fail prematurely if applied to a contaminated or improperly prepared surface. The surface will also influence the final appearance of the paint film. Surface irregularities may not be hidden by the paint, but they may instead be reflected as apparent irregularities of the paint film. The principal surface contaminants that are deleterious to the performance of paint films include oil, grease, dirt, weld spatter, alkaline residues, rust, mill scale, water, and salts such as chlorides and sulfides.

Mechanical and chemical cleaning operations may be used in combination to meet a rigid requirement of surface cleanliness. For example, on scale-bearing steel intended for an application involving exposure to chemical environments, complete removal of all oil, grease, rust, mill scale, and any other surface contaminants is mandatory. Nonferrous alloys such as aluminum require chemical conversion pretreatment plus chromated primers for maximum life and corrosion protection.

Further discussion can be found in the article "Painting" in this Volume.

Surface Preparation for Electroplating

Preparation for plating is one of the most critical of all cleaning operations, because maximum adhesion of the plated coating to the substrate is the major requirement for quality work. Maximum adhesion depends on both the elimination of surface contaminants in order to induce a metallurgical bond whenever possible and the generation of a completely active surface to initiate plating on all areas. In addition to pickling or other descaling operations, adequate cleaning requires multistage cycles, usually comprised of the following steps: (1) precleaning with a solvent to remove most of the soil; (2) intermediate cleaning with alkaline cleaners; (3) electrocleaning to remove the last traces of solids and other contaminants that are especially adherent; (4) acid treatment and surface conditioning to remove light oxide films formed during previous cleaning processes and to microetch the surface; and (5) electrolytic (anodic) desmutting to remove any smut formed during acid pickling of heat treated high-carbon steel parts. Low-carbon steels do not require this desmutting step. Anodic electrocleaning also offers oxidation or conditioning of scale. The oxidized or softened scale is easily removed in subsequent acid pickling. The types of cleaning usually employed in the above steps are:

- **Precleaning:** cold solvent, vapor degreasing, emulsifiable solvent, solvent emulsion spray, or alkaline spray with or without solvent emulsion
- **Intermediate alkaline cleaning:** soak cleaning with 30 to 90 g/L (4 to 12 oz/gal) of cleaner at 82 °C (180 °F) to boiling, spray cleaning with 4 to 15 g/L (0.5 to 2 oz/gal) at 66 to 82 °C (150 to 180 °F), and barrel cleaning with 7.5 to 45 g/L (1 to 6 oz/gal) at temperatures below 82 °C (180 °F)
- **Electrocleaning:** cathodic, anodic, or periodic-reverse
- **Acid treatment:** practice is highly specific for the metal being processed
- **Anodic desmutting:** necessary to remove carbon smut

ASTM recommended practices for cleaning various metals prior to plating are given below:

A 380	Descaling and cleaning of stainless steel surfaces
B 183	Preparation of low-carbon steel for electroplating
B 242	Preparation of high-carbon steel for electroplating
B 252	Preparation of zinc-based die castings for electroplating
B 253	Preparation of and electroplating on aluminum alloys
B 254	Preparation of and electroplating on stainless steel
B 281	Preparation of copper and copper-based alloys for electroplating
B 319	Preparation of lead and lead alloys for electroplating
B 480	Preparation of magnesium and magnesium alloys for electroplating
B 322	Cleaning metals before electroplating

Process sequences and operating details in surface preparation for electroplating are presented in articles in this Volume on cadmium plating, finishing of stainless steel, finishing of aluminum alloys, finishing of copper alloys, finishing of magnesium alloys, and finishing of titanium alloys. The procedures used for preparing the surfaces of high-carbon and low-alloy steels, low-carbon steel, and zinc-base die castings are discussed below.

Steels may be cleaned and otherwise prepared for electroplating according to the procedures outlined by the flow charts in Fig. 4 and operating conditions in Table 9. The preparation of low-carbon steel for electroplating consists essentially of cleaning to remove oil and caked-on grease, pickling to remove scale and oxide films, cleaning to remove smut left on the surface, and reactivating the surface for plating.

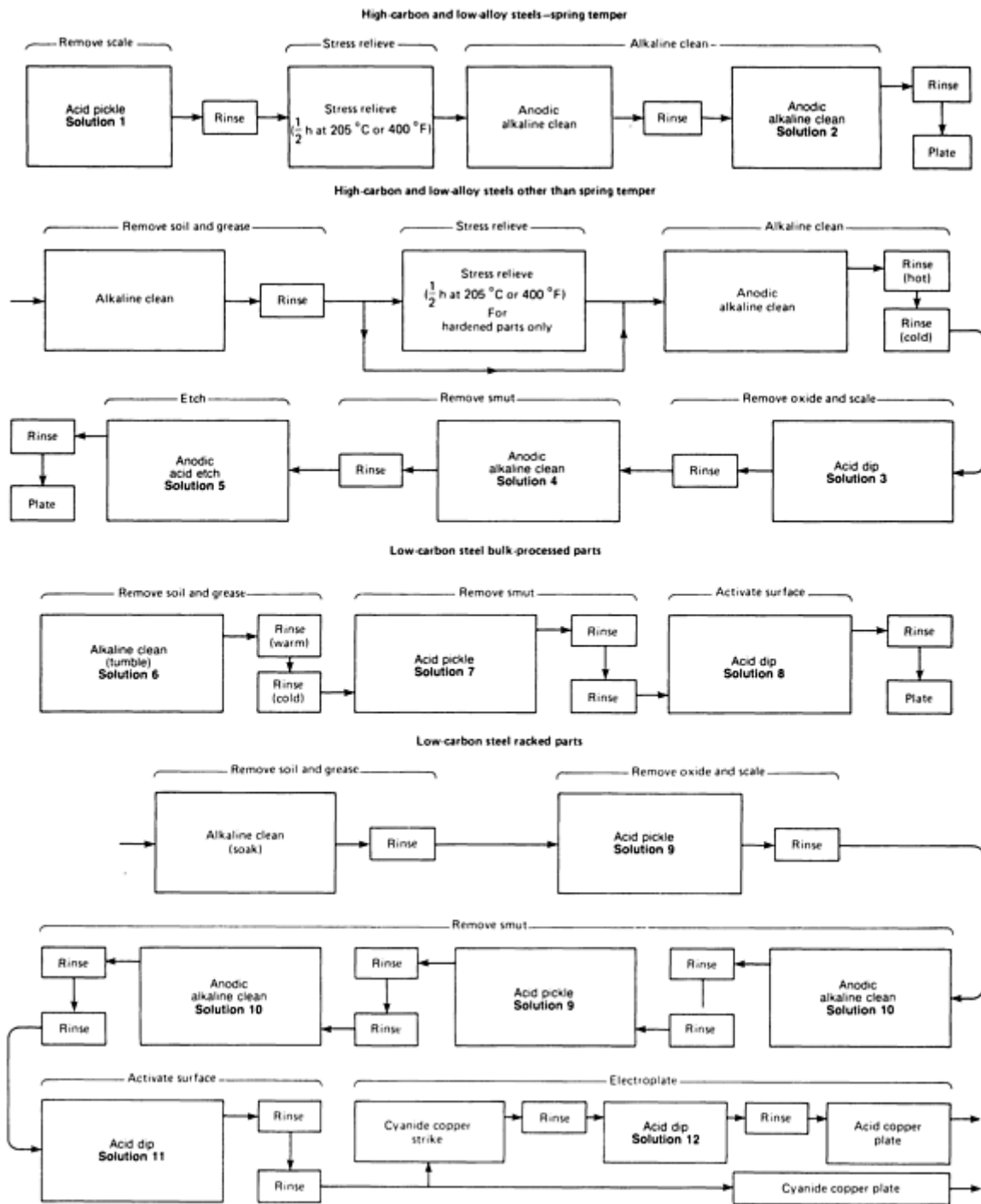


Fig. 4 Process flow charts for preparation of steels for electroplating. See Table 9 for operating conditions.

Table 9 Solutions and operating conditions for preparation of steels for electroplating

See Fig. 4.

Solution no.	Type Solution	of	Composition	Amount	Operating temperature		Cycle time, s
					°C	°F	
High-carbon and low-alloy steels, spring tempter							

1	Acid pickle	HCl HNO ₃	20-80 1-5 vol%	vol%	Room temperature	(a)
2	Anodic alkaline cleaner ^(b)	NaCN	20-45 g/L (3-6 oz/gal)	49-54	120-130	30-60
High-carbon and low-alloy steels other than spring temper						
3	Acid dip	HCl	1-10 vol%		Room temperature	(a)
4	Anodic alkaline cleaner ^(b)	NaCN	20-45 g/L (3-6 oz/gal)		Room temperature	30-60
5	Anodic acid etch ^(c)	H ₂ SO ₄	250-1005 g/L (33.5-134 oz/gal)	30 max	86 max	60 max
Low-carbon steel bulk-processed parts						
6	Alkaline cleaner ^(d)	Alkali	30-60 g/L (4-8 oz/gal)	82-99	180-210	60-120
7	Acid pickle	HCl	25-85 vol%		Room temperature	5-15
8	Acid dip	H ₂ SO ₄	4-10 vol%		Room temperature	5-15
Low-carbon steel racked parts^(e)						
9	Acid pickle	HCl	25-85 vol%		Room temperature	(a)
10	Anodic alkaline cleaner ^(f)	Alkali	60-120 g/l (8-16 oz/gal)	93-99	200-210	60-120
11	Acid dip	H ₂ SO ₄	4-10 vol%		Room temperature	5-15
12	Acid dip	H ₂ SO ₄	1 vol%		Room temperature	5-10

(a) Minimum time for removal of scale.

(b) Current density, 1.5 to 2.0 A/dm² (15 to 20 A/ft²).

(c) Current density, 1.50 A/dm² (150 A/ft²).

(d) Tumble, without current.

- (e) Cycles for copper plating included in chart are applicable to all steels here, except that for high-carbon and low-alloy steels, a cyanide copper strike precedes cyanide copper plating.
- (f) Current density, 5.0 to 10.0 A/dm² (50 to 100 A/ft²)

Plating on low-carbon steels represents the bulk of industrial plating. The steps generally used before plating low-carbon steels are:

1. Vapor degrease, if necessary
2. Alkaline soak clean
3. Water rinse
4. Descale, if necessary
5. Water rinse
6. Alkaline electroclean
7. Water rinse
8. Acid activate
9. Water rinse
10. Plate, as required

These steps are a general guideline and should not be construed as firm recommendations. The actual required cycle would depend on extent of grease and oil contamination, type of scale, and facilities available for the plating operation. Some of the options available to the plater are:

- Emulsion cleaning may be used in place of vapor degreasing. In this case, additional water rinsing is required.
- Anodic electrocleaning is preferred over cathodic cleaning which can cause smut on parts because of plating of polar soils in the cleaner. Electrocleaners are generally used at 60 to 75 g/L (8 to 10 oz/gal) and at 8.0 to 10.0 A/dm² (80 to 100 A/ft²). Temperature will depend on the type of cleaner. Low-temperature cleaners operate at 27 to 49 °C (80 to 120 °F); high-temperature cleaners operate at 82 to 93 °C (180 to 200 °F).
- If parts are not excessively dirty, soak cleaning can be used instead of electrocleaning. Specially compounded alkaline cleaners are sometimes used to remove slight amounts of oxides. Elevated temperatures are recommended for all alkaline cleaning.
- Alkaline cleaners are difficult to rinse. Carryover of residues can produce staining, skip plating, or loss of adhesion. Warm water is recommended in the first rinse along with good agitation. Two or more countercurrent (cascade) rinses are highly desirable both from the standpoint of good rinsing and conservation of water. If both alkaline soak cleaning and alkaline electrocleaning are used, the two cleaning steps should be separated with a thorough rinse.
- Plating is initiated on an active surface. A wide variety of activators is available, and most are acidic in nature. Hydrochloric, sulfuric, or fluoboric acids are commonly used.
- Water rinse after activation is critical to avoid contaminating the sensitive plating solution. Countercurrent rinsing with two or more rinse tanks is desirable.
- High-carbon and low-alloy steels are susceptible to hydrogen embrittlement.
- Proprietary inhibited acid pickles are available for the effective removal of scale and rust with reduced danger of hydrogen embrittlement and base metal attack.

Unless the acids used contain inhibiting agents, the acid treatments for surface preparation must be very mild and of short duration. If electrolysis is necessary, it should be used with anodic current. This is especially significant for spring-temper parts and parts that have been case hardened. Mechanical methods of descaling can often eliminate the need for pickling.

During the anodic etch, a high acid content, low solution temperature, and high current density will minimize smut formation. Carryover of water into the anodic etching solution should be held to a minimum, and long transfer times after the anodic etch should be avoided.

Cold rolled steel that has been subjected to deep drawing and certain prepickled hot rolled steels with glazed brownish-colored surfaces may be exceedingly difficult to clean. For these materials, a solution of 25 to 85 vol% nitric acid has proved effective.

Paint Stripping

Infrequently, parts have to be stripped and repainted. Possibly there is a problem with appearance; the wrong paint or color may have been used. Tools, fixtures, and automatic spray line fixtures must be periodically cleaned of old paint buildup as well. Some paints are easier to strip than others, and some paint stripping methods are incompatible with some metals. A hot alkaline cleaning bath, which is a part of a metal process line, should not be used as a paint stripping tank. Even if the cleaning bath works, the bath quality would be degraded and uncontrolled impurities introduced. Paint cannot be effectively removed from a soiled part, so any part should first be cleaned. Table 10 compares various stripping methods and lists appropriate financial considerations. Selection of strippers is summarized in Table 11. In paint stripping, two processes are widely used, hot stripping and cold stripping.

Table 10 Methods of stripping paint

Method	Facility	Cost factors
Immersion	One or more tanks, water rinse capability required	Slow removal rate, low labor, costly facility, disposal cost
Spray or brush-on	Area, ventilation, rinse capability required	Slow removal rate, higher labor, lesser cost facility, disposal cost
Abrasive	Sand or shot blast facility	Slow removal, high labor, may use existing facility, disposal cost
Molten salt	Specialized facility for steel only	Rapid removal rate, costly facility, low labor, very efficient, lower disposal cost, fume collection required

Table 11 Selection of strippers for removing organic coatings

Type of organic finish to be removed	Approved metal substrates	Means of application	Approved strippers and methods	Operating temperature		Remarks
				°C	°F	
Epoxy primer epoxies polyurethanes	All ^(a)	Spray or brush on	Proprietary phenolic chromated methylene chloride	10-38 ^(b)	50-100 ^(b)	Good ventilation and protective clothing. Must be approved for high-strength steels
All others	Steel	Immersion	Low viscosity ^(c)	10-38 ^(b)	50-100 ^(b)	Good ventilation and protective clothing
	All ^(a)	Spray or brush on	High viscosity ^(c)	10-38 ^(b)	50-100 ^(b)	Must be approved for high-strength steels

All	Steel ^(d)	Immersion	Proprietary molten salt	As specified by vendor		2-5 min follow with water quench and rinse. Smoke and fume control required
Primers, wax, overspray, and temporary coatings	All	Wipe or squirt on	Butyl cellosolve methyl isobutyl ketone, ethyl alcohol xylene, toluene	Room temperature ^(e)		Xylene and toluene are normally only effective on waxes and some temporary coatings
All except epoxy based	All	Immersion	Caustic stripper	10-38 ^(b)	50-100 ^(b)	Water base 10-12 pH
Epoxy	All	Dry abrasive blast	MIL-G-5634 Type III	Room temperature		Adjust pressure to part fragility
	Aluminum	Immersion	Chromic acid solution, 360-480 g/L (3-4 lb/gal)	74 ± 3	165 ± 5	Maximum allowable immersion time is 15 min. Water rinse parts as soon as possible on removal from solution.
			Chromic acid plus nitric acid solution			CrO ₃ 360-480 g/L (3-4 lb/gal), HNO ₃ 5% total volume
All	Aluminum	Immersion	Nitric acid solution 50-78% HNO ₃	34 ± 6	110 ± 10	Maximum allowable immersion time, 20 min

Note: Heavy metals plus stripping chemicals require appropriate means of disposal to meet EPA regulations.

(a) Except steel heat treated above 1500 kPa (220 psi).

(b) Optimum temperature range: 18 to 29 °C (65 to 85 °F).

(c) Proprietary: phenolic, chromated, methylene chloride.

(d) Except heat treated steel.

(e) Do not exceed 32 °C (90 °F)

Hot stripping uses high caustic level and high temperatures. Alkaline paint strippers contain caustic soda, sodium gluconate, phenols, or cresols. The bath is used at 80 to 95 °C (180 to 200 °F). Depending on the type of paint and coating thickness, stripping can be done in 30 min to 6 to 8 h. Hot stripping is slow, but economical and environmentally safe. Hot alkaline paint strippers will attack brass, zinc, and aluminum. These strippers are safe for steel and copper.

Cold stripping, as the name indicates, is done without any heating. The stripping bath consists of powerful organic solvents, such as methylene chloride; also organic acids, such as phenols or cresols. Many of the organic solvent strippers available in the market contain two layers. The heavier bottom layer is the organic solvent layer, in which the actual paint stripping takes place. The lighter top layer is the aqueous layer which prevents the evaporation of the highly volatile organic solvents from the bottom layer.

Cold solvent stripping, when applicable, is fast. The process, however, is very expensive and waste disposal could be a problem. Unlike hot strippers, the organic cold strippers can be used on all base metals such as steel, copper, aluminum, brass, and zinc.

Newer paint stripping technologies strive to combine advantages of both the hot and cold stripping techniques. These paint strippers, called *diphase* or *multiphase* strippers, allow hot alkaline stripping and solvent-based stripping to occur in the same tank via formation of a stable paint stripping emulsion. The emulsion stripper is best run hot with high agitation to keep the emulsion stable. This process is often able to strip paint that cannot be stripped by either hot alkaline or cold solvent methods, and it is comparatively fast.

Glass Bead Cleaning

Glass bead cleaning is a low energy, nonpolluting method for use with both small and delicate parts as well as large turbines and engines. Glass bead air systems equal or surpass the finish quality provided by liquid abrasive slurry. Other benefits include no measurable amount of metal removed from close tolerance surfaces (fine threaded screws) and noncontamination of work surfaces with wide range of bead sizes (170 to 400+ grit). Glass bead cleaning has been successfully applied to a wide diversity of uses such as: preparation of surfaces for painting, plating, brazing, welding, bonding; finishing of castings; production of matte finish on metal, glass, and plastics for decorative purposes; reclamation of tools such as files and saws; stripping of paint; and removal of solder from electrical assemblies.

Air pressures recommended for this procedure range from 70 to 415 kPa (10 to 60 psi). An angle of 40 to 60° for nozzle to work direction should be used to minimize bounce back and reduce bead consumption because of breakage. The selection of bead size should be based on the smallest particle that will give the desired surface. This provides the maximum number of impacts per pound. Working distances of 100 to 200 mm (4 to 8 in.) from nozzle to work will provide greatest impact (velocity) with the best pattern.

Pollution Control and Resource Recovery

The increasing cost of waste disposal has a great impact on process cost and should be considered in selecting cleaning processes. Treatment of waste within the plant should be considered to reduce cost, reduce liability, permit reuse of the raw material, and improve process control. A good example of closed-loop recycling is the distillation purification of vapor degreasing solvent. The federal EPA has established compliance guidelines, but state and local regulations are often more stringent. For more information, see the article "Environmental Regulation of Surface Engineering" in this Volume.

Safety

In the use of any metal cleaning process, there are possible safety, health, and fire hazards which need to be considered. The degree of hazard is dependent upon such factors as the specific materials and chemicals involved, the duration of employee exposure, and the specific operating procedures.

Information is presented in Table 12 on the types of hazards which may be associated with each cleaning process and the general control measures which would be used for each hazard.

Table 12 Safety and health hazards of cleaning processes

Cleaning process	Hazard/air contaminant	Control measures	OSHA/NFPA references
Abrasive blasting	Silica dust/total dust exposures	Local exhaust ventilation	(29 CFR)
		Respiratory protection	1910.94(a)
		Goggles or face shield	1910.95

Cleaning process	Hazard/air contaminant	Control measures	OSHA/NFPA references
	Noise exposures	Noise exposures	1910.133
		Hearing protective devices	1910.134
	Skin abrasion	Leather protection garments	1910.1000
			Table Z-3
Acid cleaning	Acid gas or mist exposure	Local exhaust ventilation	1910.94(L)
		Respiratory protection	1910.133
		Goggles or face shield	1910.134
	Skin contact	Impervious gloves and garments	1910.1000
			Table Z-1
Alkaline cleaning	Alkaline mist exposure	Local exhaust ventilation	1910.94(d)
		Respiratory protection	1910.133
		Goggles or face shield	1910.134
	Skin contact	Impervious gloves and garments	1910.1000
			Table Z-1
Emulsion cleaning	Petroleum or chlorinated hydrocarbons	Local exhaust ventilation	1910.94(d)
		Respiratory protection	1910.132
	Alkaline mist exposures	Local exhaust ventilation	1910.133
			1910.134
			1910.1000

Cleaning process	Hazard/air contaminant	Control measures	OSHA/NFPA references
			Tables Z-1, Z-2
Emulsion cleaning	Alkaline mist exposures	Respiratory protection	
		Goggles or face shield	
	Skin contact	Impervious gloves and garments,	
Pickling	Acid gas or mist exposures	Local exhaust ventilation	1910.94(d)
		Respiratory protection	1910.133
		Goggles or face shield	1910.134
	Skin contact	Impervious gloves and garments	1910.1000
			Table A
Salt bath descaling	Burns	Heat resistant gloves and garments	1910.132
		Face shield	1910.133
	Toxic gases	Local exhaust ventilation	1910.134
		Respiratory protection	1910.1000
			Table Z-1
	Fire/explosion	Proper facility design, construction, maintenance	NFPA 86C, Chapter 11
		Proper controls for tank	
		Proper work procedures	
Solvent cleaning	Petroleum or chlorinated hydrocarbon exposure	Local exhaust ventilation	1910.94(d)
			1910.132

Cleaning process	Hazard/air contaminant	Control measures	OSHA/NFPA references
			1910.133
		Respiratory protection	1910.134
			1910.1000
	Skin contact	Impervious gloves and garments	Tables Z-1, Z-2
Tumbling	Noise exposure	Noise enclosure for equipment	1910.95
		Hearing protective devices	
Vapor degreasing	Chlorinated hydrocarbon exposure	Condenser cooling system and appropriate thermostats	1910.94(d)
		Minimize dragout	
		Local exhaust ventilation	
	Solvent decomposition products	Eliminate hot surfaces above 400 °C (750 °F) in the vicinity	
		Eliminate sources of ultraviolet radiation in the vicinity	
		Proper monitoring of solvent for acid buildups to prevent exothermic decomposition	

The Occupational Safety and Health Administration has established in its General Industry Standards (29 CFR 1910) regulations pertaining to a variety of safety and health hazards. Those sections of the standards which may apply to each cleaning process are referenced in Table 12. Because of the unusual fire hazard associated with salt bath descaling, an applicable chapter of the NFPA standards has also been referenced.

Tests for Cleanliness

The final evaluation of the effectiveness of a cleaning process should come from a performance test. Eight well-known methods of determining the degree of cleanness of the work surface are discussed below.

Water-break test is a simple test, widely used in industry. It consists of dipping the work into clean water to reveal a break in the water film in the soiled area. However, because the test depends on the thickness of the applied water film, a factor which cannot be controlled, false results can be obtained because of bridging of residues. A mild acid dip before testing for water break has been found advantageous.

Nielson method requires that ten soiled panels be processed individually to determine the time required for each to be cleaned. Panels are checked by the water-break test and then by the acid copper test. In the acid copper test, the ferrous panel is immersed in a copper sulfate solution (typical composition, 140 g [5 oz] of copper sulfate and 30 cm³ [1 fl. oz.]

of sulfuric acid per gallon of water). On clean surface areas, copper will be deposited by chemical activity, forming a strongly adherent, semibright coating that is free of spots.

An average of the times required to clean the ten panels is taken as a measure of the effectiveness of the cleaning solution.

Atomizer Test. In the atomizer test, panels are cleaned, acid dipped, dried, placed in a vertical position, and sprayed with an atomizer containing a blue dye solution. Just before the droplets begin to run, the spray is stopped and the panel is placed in a horizontal position. Heat is applied to freeze the pattern. The cleaning index is the percentage of the total area that appears clean. This is determined by placing a grid over the panel, estimating the cleaning for several random squares, and then averaging for the reported value. The atomizer test is 10 to 30 times as sensitive as the water-break test.

Fluorescent method requires soiling with a fluorescent oil, cleaning, and inspecting under ultraviolet light. It is very slow and is less sensitive than the water-break and atomizer tests.

Weight of residual soil is also an evaluation of cleanness. The cleaned panel is washed with ether, the washings are evaporated, and the residue is then weighed. A modified method is to clean, dry, and weigh the test panel, then soil, clean, dry, and reweigh it. The increase in weight represents the amount of residual soil present.

Wiping method is a qualitative test. A panel is coated with pigmented soil, cleaned, and then wiped with a white cloth or paper. The presence of soil on the cloth or paper indicates poor cleaning.

In the residual pattern method, cleaned panels are dried at 49 °C (120 °F) for 20 min. After drying, the presence of a stained area indicates residual soil and incomplete cleaning.

Radioisotope tracer technique requires that radioactive atoms be mixed with the soil. Panels are coated uniformly with the soil, and their radioactivity is determined. The panels are then subjected to various cleaning cycles, after which their radioactivity is again determined. The cleaning ability of each of the various cycles can be evaluated by the amount of radioactivity remaining on the panels. This is the most sensitive test; however, dealing with radioactive materials requires an AEC license, trained personnel, and special types of equipment.

Alkaline Cleaning

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Introduction

ALKALINE CLEANING is a commonly used method for removing a wide variety of soils from the surface of metals. Soils removed by alkaline cleaning include oils, grease, waxes, metallic fines, and dirt. Alkaline cleaners are applied by either spray or immersion facilities and are usually followed by a warm water rinse. A properly cleaned metal surface optimizes the performance of a coating that is subsequently applied by conversion coating, electroplating, painting, or other operations. The main chemical methods of soil removal by an alkaline cleaner are saponification, displacement, emulsification and dispersion, and metal oxide dissolution.

Alkaline Cleaner Composition

Alkaline cleaners have three major types of components: builders, which make up the bulk of the cleaner; organic or inorganic additives, which promote better cleaning or affect the rate of metal oxide dissolution of the surface; and surfactants.

Builders are the alkaline salts in an alkaline cleaner. Most cleaners use a blend of different salts chosen from:

- Orthophosphates, such as trisodium phosphate
- Condensed phosphates, such as sodium pyrophosphate and sodium tripolyphosphate
- Sodium hydroxide
- Sodium metasilicate
- Sodium carbonate

- Sodium borate

The corresponding (and more expensive) potassium versions of these salts are also commonly used, especially in liquid cleaner formulations. The choice of salts for a given cleaner is based on the metal being cleaned, the cleaning method, performance requirements, and economics. Table 1 shows a few common formulations for specific combinations of metals and cleaning methods.

Table 1 Alkaline cleaning formulas for various metals

Constituent	Formula, wt%, for cleaning:					
	Aluminum		Steel		Zinc	
	Immersion	Spray	Immersion	Spray	Immersion	Spray
Sodium hydroxide	...	...	38	50	...	...
Sodium carbonate	55	18	36	17	10	20
Sodium metasilicate, anhydrous	37	...	12	...	15	10
Sodium metasilicate, hydrated	...	60	...	...	...	...
Tetrasodium pyrophosphate	...	20	9	20	20	65
Sodium tripolyphosphate	...	...	...	...	50	...
Trisodium phosphate	...	...	...	10	...	...
Fatty acid esters	1	...	3	0.6	...	...
Ethoxylated alkylphenol	...	...	2	0.2	...	...
Ethoxylated alcohol	...	2	...	2	...	5
Sodium lauryl sulfonate	5	...	...	...	5	...

Phosphates are of great importance in the builder packages of alkaline cleaners. A key function of phosphates is their ability to complex with hard water salts. By "softening" these hard water salts, they eliminate the formation of flocculate precipitation caused by calcium, magnesium, and iron. Phosphates are also effective as dispersants for many types of soils. Additionally, they provide alkalinity and prevent large changes in the pH of the cleaning solution.

Silicates are also versatile as builders for cleaners. They provide alkalinity, aid detergency, and most importantly, protect metals such as aluminum and zinc from attack by other alkaline salts. However, silicates are difficult to rinse away and therefore may cause trouble in subsequent plating operations.

Carbonates are an inexpensive source of alkalinity and buffering. They are useful in powdered cleaners as adsorbents for liquid components. Hydroxides are relatively inexpensive and are the strongest form of alkalinity available.

Borates provide strong buffering at a moderately alkaline pH. They have been used extensively in the cleaning of aluminum. Borates provide a degree of metal inhibition and aid detergency.

Additives are organic or inorganic compounds that enhance cleaning or surface modification. Chemical compounds such as glycols, glycol ethers, corrosion inhibitors, and chelating agents should be considered additives.

- *Glycols and glycol ethers* are solvents that remove certain oily soils.
- *Corrosion inhibitors* can be incorporated into a cleaner to help decrease the occurrence of oxidation of the metal surface during water rinsing.
- *Chelating agents* are specialized chemicals for counteracting the negative effects of hard water salts and metal ions.

Some widely used chelating agents are sodium gluconate, sodium citrate, tetrasodium ethylenediaminetetraacetic acid (EDTA), trisodium nitrilotriacetic acid (NTA), and triethanolamine (TEA).

Surfactants are organic and are the workhorses of alkaline cleaners. They are key in displacing, emulsifying, and dispersing many of the soils found on a metal surface. Surfactants lower the surface tension of the cleaner at the metal surface, allowing it to cover the surface uniformly. There are four major types:

- *Anionic* (e.g., sodium alkylbenzene sulfonate)
- *Cationic* (e.g., quaternary ammonium chloride)
- *Amphoteric* (e.g., alkyl substituted imidazoline)
- *Nonionic* (e.g., ethoxylated long chain alcohol)

These major types differ in the type of charge found on the individual surfactant molecule, which has both a water-soluble portion and an oil-soluble portion. In anionic surfactants, the water-soluble portion of the molecule is negatively charged. Cationic surfactants have a positively charged entity. Amphoteric surfactants have both a positively and a negatively charged entity on each molecule. Nonionic surfactants are free of any charge; they are neutral.

For spray cleaners, nonionic surfactants are used almost exclusively, because in general this is the only type that can provide both low foaming and good cleaning ability. For immersion cleaning, anionic or nonionic surfactants are most often used. Alkaline immersion cleaners can use any of the four types, because the foaming properties of surfactants do not cause a problem. Amphoteric surfactants behave like anionic surfactants when used in an alkaline medium, so it is usually more cost-effective to use an anionic surfactant directly. Cationic surfactants are rarely used in the alkaline cleaning of metal because they are the weakest cleaners. In addition, certain cationics react with the metal surface and form a counterproductive film.

Cleaning Mechanisms

Cleaning is accomplished using saponification, displacement, emulsification and dispersion, and metal oxide dissolution. When a particular part is cleaned, any one or more of these mechanisms may be at work.

Saponification is limited to the removal of fats or other organic compounds that react chemically with alkaline salts. Fatty compounds, both animal and vegetable, react with the alkaline cleaner salts in the cleaning solution to form water-soluble soaps. The soap formed may be either beneficial or detrimental to the performance of the cleaner.

Displacement is the lifting of oily soils from a surface by the action of surfactants. By their chemical nature, surfactants have an affinity for metal surfaces that is stronger than the oil's affinity. The surfactant in the cleaning solution lifts the oil from the surface and replaces it with itself. Once the oil is in solution, dispersion and emulsification phenomena act on it.

Dispersion and emulsification hold oily materials in solution. These two mechanisms have the same goal: to allow mutually insoluble liquids, such as oil and water, to stay together.

Emulsification is the use of a surfactant as a connector to keep oil and water together as if they were one unit. As stated above, one portion of a surfactant molecule is water soluble, and this allows it to move freely in water-based cleaners. The oil-soluble portion of the surfactant molecule allows it to hold on to oil-soluble molecules. In a typical water-based cleaner, the surfactant captures and holds oil in solution.

Dispersion is the ability of the cleaner to break oil down into tiny droplets and prevent it from regrouping (reassembling). Both the surfactants and the alkaline salts of the cleaning solution aid in keeping the oil dispersed.

Metal Oxide Dissolution. Surface oxide dissolution is the direct reaction of the alkaline cleaner salts on the metal surface. Metal oxide dissolution targets the removal of undesirable oxides and inorganic contaminants (e.g., light mill scale, corrosion products, and superficial oxides) from a metal surface. The type of metal being cleaned and the concentration, composition, and temperature of the cleaner all play a role in the speed and degree of metal dissolution. The rate should be controlled to minimize the loss of base metal beneath the oxide. Excessive base metal removal will result in localized corrosion and pitting of the surface.

Rinsing

A good water rinse is essential for good cleaning. The temperature of the water rinse may be hot, warm, or cold, but regardless of the temperature the solution should be kept clean. Warm water is usually the best for rinsing. Cold rinses are less efficient than warm rinses, while hot rinses may promote the rapid formation of an oxide film commonly known as "flash rust."

The water rinse should contain no more than 3% of the concentration of the cleaner solution. For example, if the cleaner is prepared at 30 g/L (4 oz/gal), the rinse water should contain no more than 0.9 g/L (0.12 oz/gal). The water rinse is mainly responsible for removing residual cleaner, but it may also remove a small amount of soil. Water rinsing can be done by either immersion, spray, or a combination.

Method of Application

Immersion Cleaning. When an alkaline cleaner is applied by immersion, the parts to be cleaned are immersed in the solution and allowed to soak. As the alkaline cleaner acts on the parts, convection currents (due to heating or mechanical agitation) help to lift and remove soils from the metal surface. The efficiency of removal by the soak cleaner is greatly enhanced by agitation.

There are several approaches to immersion cleaning:

- *Barrel cleaning*, in which small parts are agitated inside a barrel that rotates in the cleaner solution
- *Moving conveyor cleaning*, in which solution flow is created as parts are dragged through the cleaner
- *Mechanical agitation*, in which the cleaner is circulated using pumps, mechanical mixers, or ultrasonic waves
- *Mechanical contact*, in which the cleaner is applied with external forces such as brushes or squeegees

Spray Cleaning. The effectiveness, low cost of equipment, and high degree of flexibility associated with spray cleaning has made this method popular for many years. Specialized methods of spray cleaning include *steam cleaning*, in which the cleaning solution is injected into a stream of high-pressure steam, and *flow cleaning*, in which the cleaning solution is flooded onto the part at high volume but at relatively low pressure.

Spray cleaning is accomplished by pumping the cleaning solution from a reservoir through a large pipe ("header"), through a series of smaller pipes ("risers"), and finally out of spray nozzles onto the part to be cleaned (Fig. 1). The