EFFECT OF SURFACE PREPARATION ON CORROSION OF METALS AND ALLOYS

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At first look, it seems that surface condition can have a little or no practical influence on the performance of materials in service. In practice, however, its effect on common material properties those include mechanical, physical, tribological (friction, wear, hardness), metallurgical, corrosion, aesthetic, etc. is frequently experienced. Present article deals with the effect of surface defects, contaminants, products, surface cleaning methods, etc. on the corrosion properties and the performance of metals or alloys.

CORROSION PROPERTIES

corrosion Probability

Evan described a `drop method' to obtain the effect of surface roughness on corrosion probability. The proportion of drops producing rust were indicated to be a measure of corrosion probability. However, concrete conclusions could not be drawn on its basis except to realize the significance of surface condition for the corrosion occurring probability. Later on, other workers obtained some information by ruling `scratch' lines on the smooth thin nickel sheet, and counting the number of perforations per unit length. When sheet was subjected to chloride sulphate solution, the main surface remained uncorroded, but scratch line region suffered pitting resulting in perforation; the points of perforation were easily countable. However, this was also mentioned that the obtained results should not be taken as an absolute measure of corrosion probability.

Corrosion Distribution

In cases where the total corrosion rate is governed by an external factor, an attempt to enhance resistance by improving the surface is likely to confine and intensify the attack to small area. For example, corrosion of high grade (having no metallurgical heterogeneities) steel in a fairly concentrated salt solution is mainly fixed by the replenishment of oxygen at cathodic zones at the surface. In an experiment, a well prepared steel plate immersed in 0.1N KCl was found corroded along the cut edges, where the cutting stresses or the exposure of internal segregate might have favoured the attack. In next experiment cut edges were covered with a preventive coating but corrosion then started at numerous points on the face. It seems that the surface (large cathode) was protected in fist experiment by strong attack upon edges* (small anode). Thus the elimination of sensitive points on steel, whether they were due to cut edges, surface blemishes, sulphide inclusions, may not always improve the performance; if the total deterioration of metal is fixed, intensity of attack will increase with the decrease in the number of sensitive points. In the cases where the total attack is not fixed such as in atmospheric attack; a smooth surface finish and surface discontinuities, such as inclusions, are unlikely to affect corrosion. Often the tiny rust spots on iron are due to settlement of certain kind of dust and not due to surface condition.

There are some interesting cases where the surface polishing affects the role of metallurgical impurities, nature of attack, control measures etc. during corrosion. In a study conducted on steel in an inhibited salt solution (5% NaCl with Na_2CO_3), the polished surface was preferentially attacked at sulphide inclusion sites. However when surface was roughened (by abrasion) or scratched, the effect of inclusions ceased considerably, since there were alternate active points. In general, smooth surface is less prone to corrosion than coarser one and number of corrosion centres steadily increases with degree of coarsening. This fact is supported by electrochemical studies also. Polarization experiments made on SS 316 in sodium chloride solution have shown that the value of pitting and passivation potential increases with improvement in the surface smoothening as evident from the

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* In dilute solutions, where the low conductivity confines the mutual protective effects to short distances, there is attack at many points on the face, even when the cut edges are left unprotected.

following Table:

Surface Finish	Rest Pot. (mV)	Pitting Pot. (mV)	Repassivation Pot. (mV)
1 micron	-337	375	-60
p1200	-256	275	-205
p220	-344	125	-210

However, attack will be deep if occurs at smooth surfaces due to established reasons. Similarly, if inhibitors are added, the required dosage will be more for coarse surfaces but corrosion attack will be destructive on smooth surfaces if the dosage are not maintained above a certain level. Moreover, it is also established that a rough surface of steel when plated or electrodeposited with nickel will exhibit far more pores per unit area than smoother steel carrying the same amount of nickel.

SURFACE CLEANING FOR COATING AND CORROSION CONTROL

Protective barriers (coatings) have been successfully used in number of corrosive environments. These may be of metallic, inorganic and organic nature. Out of different coatings, organic ones including paints, varnishes, lacquers, etc. protect metals on large scale than any other method to combat steel corrosion. Further, steels are the most widely used materials in number of industrial, municipal, transport, marine, domestic, etc. applications due to outstanding strength and other engineering properties and low cost. However, these frequently require corrosion resistant coatings due to their high susceptibility to rusting. In view of the above, surface preparation has been discussed dominantly in the light of paint applications on steel components, however, some of them are employed in other important applications also, i.e., pre and post fabrication cleaning of chemical process equipments in industry, metallic coatings, etc. In most of the cases, poor paint performance, e.g., peel off, occurs due to poor application and inadequate surface preparation or pretreatments as shown in Photograph-1. Thus the surface preparation work lays the foundation for coating performance at the coating - metal interface.

Natural Surface Condition and Finishing Required for Painting

Metals are being formed or shaped on large scale by six specific processes, each producing a slightly different end condition and impurities at the surface, however, sufficiently resembling themselves in actual appearance that may be classified as:

i) Surface containing mill scale and oxides including hot rolled, forged, cast metals
ii) Surface free of mill scale and oxides including cold rolled, cold drawn, extended metals

In field, many users treat the metals with scales as `hot rolled' and those free of scales as 'cold rolled'.

The surface to which coating has to be applied must be sufficiently free of rusts, mill scales, dirt, oil, grease, old deteriorated paints, other contaminants, etc. This is required since, paint holds to the metal surface by two basic mechanisms: chemical attraction or `adhesion' and mechanical anchoring or `bonding'. Consequently, the finishing is desired to result in a clean, uniform and slightly roughened surface. Roughening provides a `tooth' or `anchor' (Photograph 2) for mechanical bonding and more surface area for adhesion.

Methods of Surface Preparation

The best finish for paint application is obtained with abrasive blast cleaning (also known as `sand blasting conventionally') which includes sand blast, grit blast and shot blast the steel surface. Other conventional surface preparation or cleaning techniques used prior to various coating or clean-up (of process equipments) operations are: pickling, solvent degreasing, detergent washing and other types chemical treatments; scraping and wire brushing; chiseling, chipping and hammering; grinding, polishing and buffing; flame cleaning (heating with a torch and scrap off dust and scale), electrochemical cleaning, etc. Besides, there are various pretreatments given to the surface of structures, pipes, equipments to prolong their life before coating or subjecting them to service. These may include wetting oil, wash primer, alkali treatments, phosphatizing, chromatising, cyaniding, nitrate passivation etc. A study on paint life showed 10.3 years for sand blasting, 9.6 years for pickling, 2.3 years for weathering and than hand cleaning. In practice, however, the selection of optimum surface preparation method depends upon economic considerations, effectiveness, required degree of finish (specific coating or medium) and other technical factors, i.e., the type of metal and paint system, alloy's self protection, existing surface condition, shape and size of component, physical accessibly to structure, environmental or chemical conditions, etc. In fact, methods are not mutually exclusive and sometimes used in combination also, for example, good surface preparation starts with preliminary degreasing to remove oil or grease since, these are not effectively removed by mechanical methods other than abrasive blasting. In the forthcoming paragraphs, an introduction of a few mechanical cleaning methods is being given due to lack of space. However, detailed information and guidelines are available in standards or literature published by ASTM (including A380-78, ASTM STP 538), NACE, structural steel paint corporation (SSPC), AISI, specialty steel producers, etc.

Hand tool cleaning may be used to remove loose mill scales, contaminants, nonadherent old paints but not for tight ones or deposits in pits and crevices. This is a slow operation and normally recommended for uncontaminated atmospheric exposures or, often used to remove heavy deposits before employing more through surface preparation methods such as power tool cleaning and abrasive blasting. The common tools are chipping and rust hammers, chisels, scrapers, wire and dust brushes, abrasive cloths or papers, etc. The SSPC has established a standard for hand cleaning (SP-2-63). Power tool cleaning is employed on steel structures where blast cleaning is impractical or uneconomical, and the coating systems used are those which tolerate the contaminants left behind after this cleaning. Mostly this is also chosen for uncontaminated atmospheric conditions. Power driven tools include pneumatic chippers, chisels, needle hammers, rotary brushes, grinding and polishing wheels, etc. The obtained surface may be excellent for painting if properly done as shown in Photograph-2(a). An arbitrary standard for cleanliness has been established by SSPC (SP-3-63).

Abrasive blast cleaning may be defined as cleaning through the impact of abrasive particles propelled (normally by jet action of compressed air) at high velocity against the surface to be cleaned. This method is convenient, fast, portable, suitable for different shapes, and is effectively used to remove all traces of oil or grease, adherent or hard scales, old paints, etc. from the surface and produces a desired cleaning and uniform roughening of the surface `anchor or tooth pattern' as shown in Photograph-2(b).The SSPC has developed four standards of surface preparation to get varying degree of surface cleanliness which have been accepted and recognized by professional organizations and industry. Following is the list in the descending order of cleanliness and cost:

1.	SSPC-SP 5-63	White metal blast cleaning
2.	SSPC-SP 10-63T	Near white blast cleaning
3.	SSPC-SP 6-63	Commercial blast cleaning
4.	SSPC-SP 7-63	Brush off blast cleaning

The first two are specified only for coatings in immersion service, while remained two are suitable for most of the atmospheric services. Sand is the most commonly used abrasive for air blast cleaning in the field due to its low cost and local availability but due to its high breakdown rate (10-40%) it may not be reused. The other common abrasives are: silica send, other natural abrasives (crushed flint, garnet sand), slags (byproduct of Pb and Cu ore reduction), metals (cast iron and steel shots and grit), nonmetallics (SiC, aluminium oxides), etc. The shapes of abrasives may be classified as:

Semisharp:	Common shape of sand and slag
Grit :	Angular; gouges the surface; high cutting efficiency
Shot :	Spherical; peens the surface pounds off brittle deposit and mill scale; may pound impurities into the surface

Grit and shot shapes usually apply to the metallic abrasives. Photograph-3 illustrates the type of surface obtained by their use. Nowadays, a mesh size range of 20-50 (US sieve series) is often selected to obtain an optimum profile height (1.5-2.5 mills) of the anchor patterns. There is one more method of blasting namely `glass bead blasting', but is used only for specific applications.

RESIDUAL EFFECTS OF CLEANING OPERATIONS

Metal forming processes, shipment mishandling and undesired media exposure, heating operations, e.g., hot bending, welding, stress relieving and other heat treatments, etc. produce scales (oxides) on the surface of respective steel or stainless steel component. For certain services, complete removal of scale is required and, therefore, methods like pickling, abrasive blasting, grinding etc. have to be essentially employed. When improperly done, each of these methods can result in damage or failure of structure. A few consequences of such operations are dealt in the coming discussion.

Pickling

Acids containing corrosion inhibitors are largely used as pickling agents. If the article is pickled with electrolytic method by making it cathode, the attack on the metal is greatly reduced. Cathodic action may, however, result in hydrogen embrittlement or blistering (Photograph-4 `a' and `b'), especially if acid contains a trace of arsenic, sulphides, etc. which hinders the union of hydrogen atoms (it can diffuse into metal) to form a molecule. If the article is made anode, hydrogen absorption is prevented but corrosion or roughening is increased.

On carbon and alloy steels, cleaning of whole surface is not achieved at the same time. An attempt to get a complete finish by prolong pickling results in severe pitting (Photograph-5), intergranular corrosion (IGC) attack (mainly on austenitic stainless steels, Photograph-6), and stress corrosion cracking (SCC) if trace of acids are retained in grooves, pits or pockets. An example of the SCC failure of a boiler tube is given in Photograph-7.

Grinding of Welds and Improper Cleaning for Repair Welds

Grinding:

There are many cases where grinding operations have resulted in localized corrosion and SCC of stainless steel, for example, a 316L vessel of a distillation unit (handling mixed industrial water having some chlorides) failed because of such attack. Photograph-8 shows hairline cracking and crevice corrosion in and around a vertical weld as a band, several inches wide, spanning both sides of the weld. The attacks took place in the region where grinding (for cleaning) was done after the welding work. SCC was attributed to residual tensile stresses and local sensitization (IGSCC) introduced into vessel plate by grinding work before and after welding. A 50 mm side branch connection (of the above mentioned vessel) also suffered severe localized corrosion due improper grinding (Photograph 9). Besides, it has been reported that the overemphasis on grinding during radiographic examinations of welds reduced the wall thickness of a process component 20% below the required minimum. This resulted in failure of equipment through cracking in heat affected zone.

Surface Cleaning for Repair Welds:
During the replacement of a section of the pressure reactors/piping or repair (in plant), removal of surface and intergranular contaminants, e.g., soft solders, etc. should be ensured. Photograph-10 illustrates IGC attack caused by penetration of copper into a boiler tube which had contained copper deposits along the inside surface prior to welding. The high heat of welding caused the copper to penetrate into the heat affected zone of the steel along the grain boundaries. However, intergranular penetration of steel by copper comparatively well known. Less well known is that soft solder is capable of penetrating steel in a similar manner, and the failure of a small pressure vessel used as propane container was attributed to this cause (Photograph-11). The soft solder was used to attach a name plate at the top of vessel near outlet valve and melted during mild fire hazard. Soft solder can penetrate (intergranularly) any steel surface which it wets at a temperature between its melting point and 400 degree celsius.

Abrasive Blasting

In one case, shot cleaning was done on inside of feedwater preheater tubing of a boiler. The increased tensile stresses on the outside of the tubing caused by the impact of the shot particles has produced corresponding tensile stresses on the inside of the light wall tubing (about 1/8" wall) amounting to 8,500 to 17,000 psi. The resulting corrosion occurring only in tubing containing water is associated with high oxygen concentration. The attack involved pitting corrosion and IGC with significant oxidation present in the cracks. The attack was attributed to be a sort of oxygen SCC. However contrary to the above discussed failure case, abrasive blasting sometimes helps in reducing the possibility of corrosion under stressed (SCC) and fatigue (corrosion fatigue) condition. This benefit is achieved indirectly by `shot peening effect' during shot blasting which induces compressive tensile stresses on the wall of the pressure vessels or pipelines. In brief, most of the coarsening and groove, notch, crevices making finishing operations are corrosion promoting (except when especially created for paint applications).

OTHER SURFACE DEFECTS

This is essential to properly remove surface products, contaminants, irregularities before subjecting to service environment. Such defects may include embedded iron, grease, rust and deposits, slags, welding flux, weld spatters, debris, dirt and sediments, crayon and paint marks, adhesive tapes, etc. If not carefully avoided, these may result serious corrosion problems resulting in catastrophic failures of the component.

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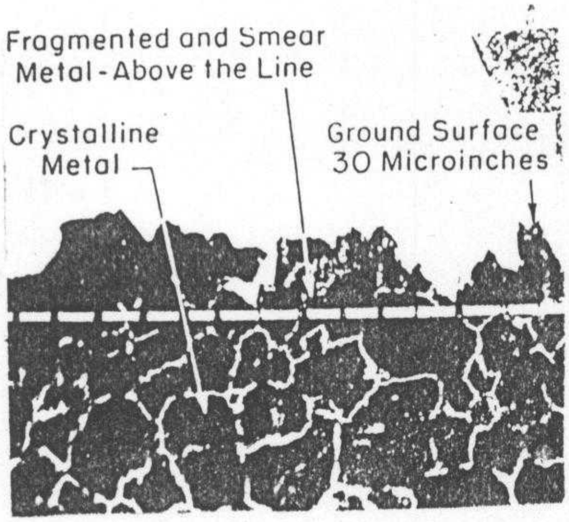
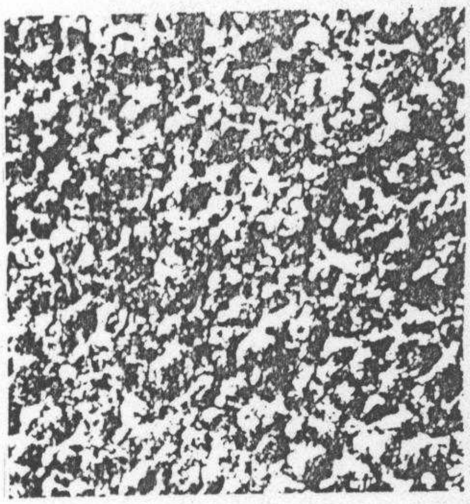
1(a)

1(b)


Fragmented and Smear
Metal - Above the Line
Crystalline
Metal
Ground Surface
30 Microinches

2(a)



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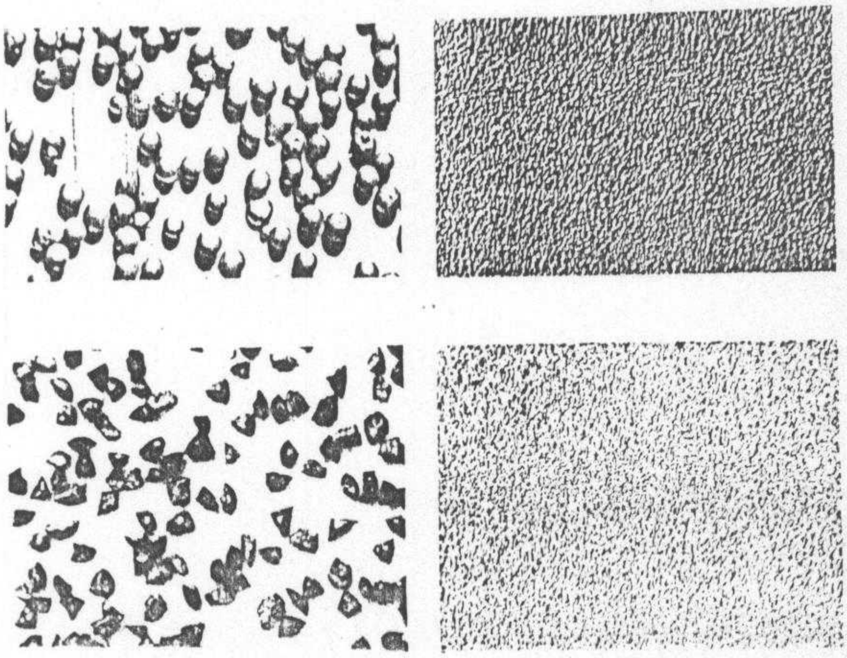

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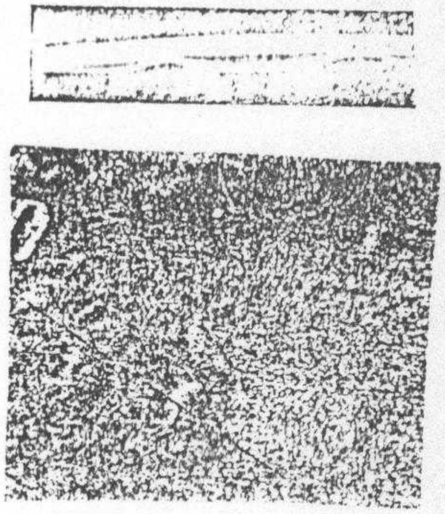
4 (a)



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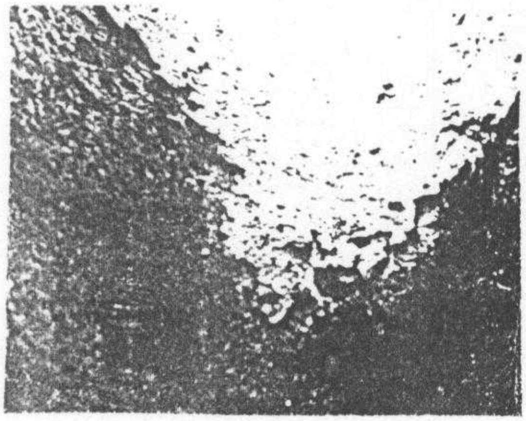

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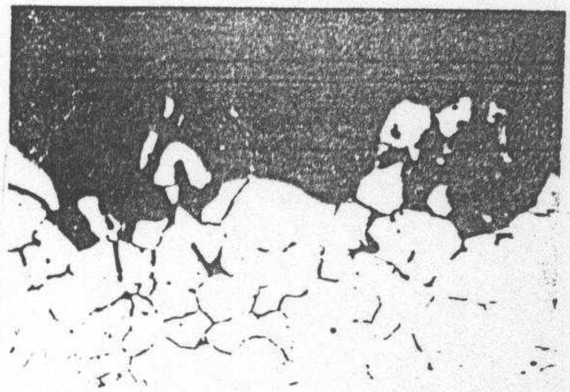

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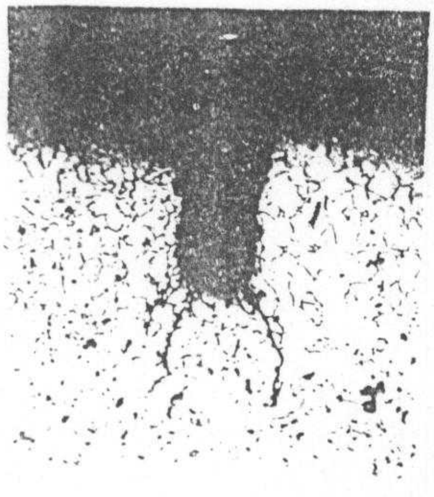

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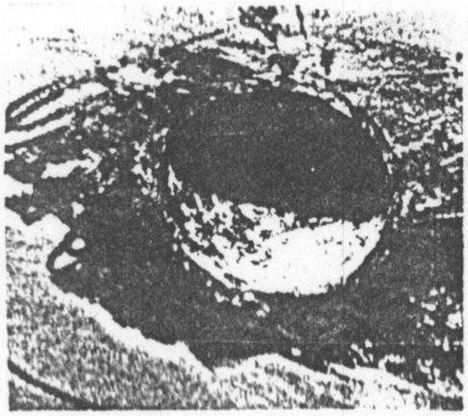

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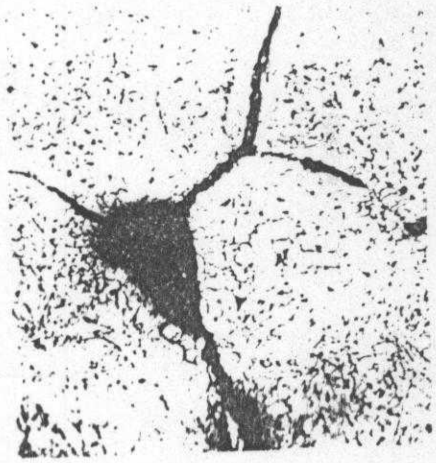

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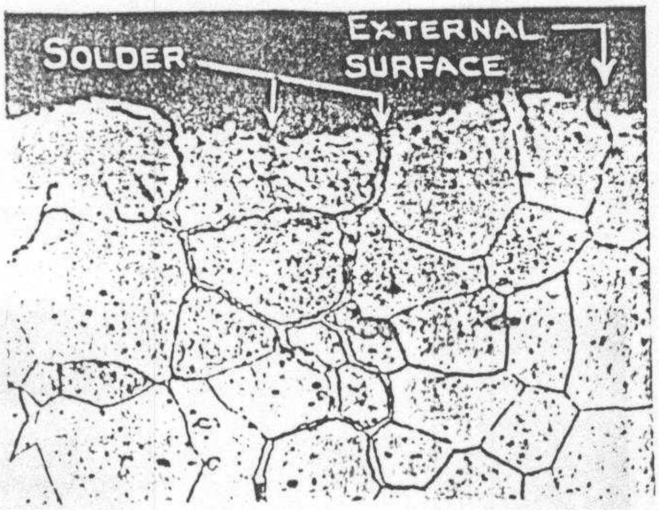

11.