2. <u>CONTAMINATION</u>

All types of contamination that separate coatings from their intended substrates should be removed. However, complete removal is not practical in many cases and coatings will inevitably be applied over some contaminants. This is not a problem where the remaining contamination is firmly adherents and will have no detrimental affect if left in place, which may be the case with remaining traces of old paint or primer. Unfortunately most contaminants are weakly bonded to the substrate, or they are themselves harmful and can cause corrosion of the substrate and coating breakdown.

The removal of contamination is particularly important for modern high build spray applied high performance coatings, such as those used for cargo tanks, because they are normally based on high molecular weight resins and thus are high in viscosity. This gives them poor surface wetting characteristics. This means that there is less opportunity for the high viscosity material to flow into the contamination and down onto the primary surface. Older type, lower performance coatings are often more surface tolerant in this respect.

The types of substrate contamination most frequently encountered in shipyards are described below:

2.1 <u>MILLSCALE</u>

Most steel used for shipbuilding and shiprepair has been hot rolled and therefore has various amounts of millscale on its surface. On heavy plates it can be as much as 250 microns thick.

The millscale is formed in the rolling mill, when oxygen in the furnace atmosphere combines with the hot metal to form oxides on the steel surface. Most of this oxide is broken off during the rolling process, but more oxide is formed by the latent heat of the steel after it has been rolled and this remains on the surface as a tight adherent blue/grey colored film.

Millscale is not uniform in consistency, see Figure 5. The outer layer is primarily ferric oxide Fe_2O_3 which is 30% oxygen by weight. Underneath this is the layer that contains the majority of the scale and this is primarily magnetite Fe3O4, which is about 28% oxygen. Nearer the metal itself the scale is mainly ferrous oxide FeO which is about 22% oxygen and then there is a mixed oxygen metal layer of scale binder FeO+Fe. It is this scale binder which grit blasters find the most difficult to remove and which causes them the most problems, however, it **can** be removed by thorough blasting.
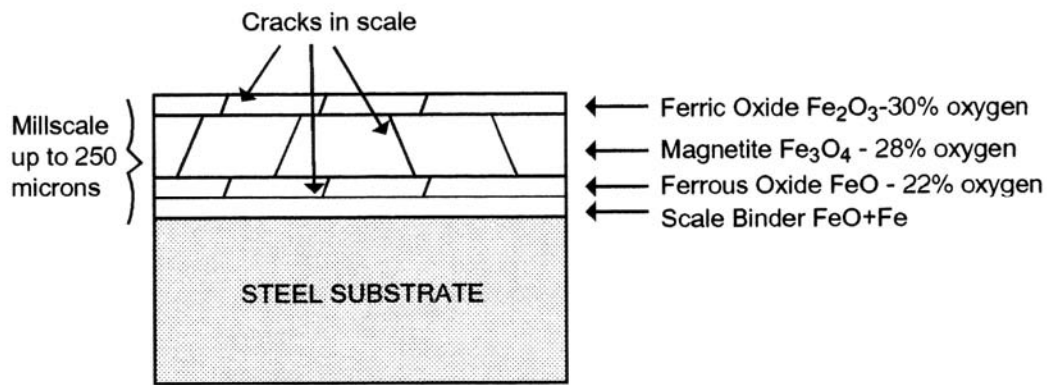
Figure 5 – Millscale

It is vital that millscale is removed from steel that is destined for service in an aqueous environment such as in a ballast tank, or the outside shell of a ship. The reason for this is straightforward. Millscale is composed principally of Fe_3O_4 or magnetite. When magnetite is in direct metallic contact with steel in the presence of an electrolyte, such as sea water, a galvanic corrosion cell is formed, with the steel as the anode and the magnetite as the cathode. There is a fixed driving voltage between the two of about
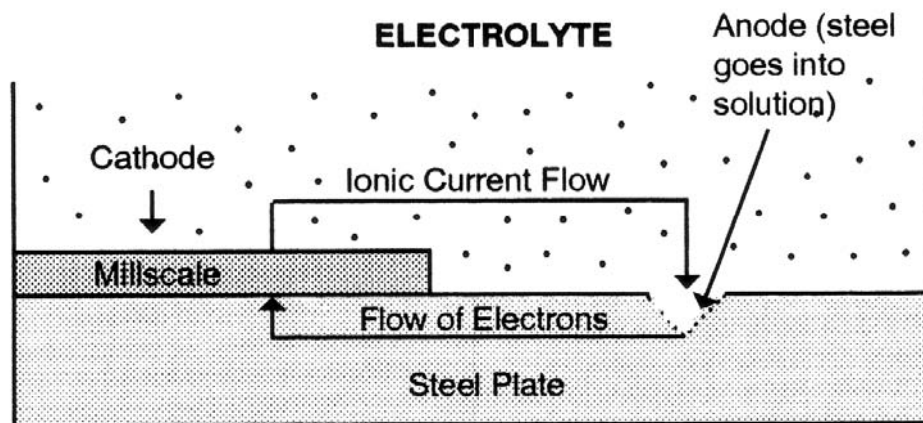0.4 volts. See Figure 6.

Figure 6 – Galvanic Corrosion Cell between Millscale
and Steel

In the circuit shown above, electrons leave the anodic area and flow through the steel to the cathodic area, with the circuit being completed by an ionic current flow through the electrolyte. This results in the steel going into solution (i.e. corroding) at the anode, with the consequent loss of metal and pitting. The degree of metal loss and the severity of the pitting are dependent upon current flow and relative size of anode and cathode as follows:

1. Metal loss is directly proportional to current flow. For example, 1 amp flowing for 1 year would dissolve about 10 kg of steel. However, the size of the current which flows in a circuit is governed by Ohms Law, $I = E/R$

   Where   I = Current E = Driving Voltage (fixed at 0.4 volts in this case) R = Total circuit resistance (the greater part of this resistance being in the electrolyte).
   Obviously metal loss will be greater in a low resistance electrolyte such as salt water,

than it will be in a high resistance electrolyte such as oil.

2. The relative size of the anode and cathode dictate the severity of the pitting. If a very small anode, such as a small area of exposed steel, is protecting a very large cathode such as a large area of millscale, then pitting can be extremely rapid.

In fact localized pitting of the steel can sometimes be severe enough to penetrate the plate and cause a structural failure. Some American 'Liberty' ships built during the Second World War actually sank between the launching and fitting out period for exactly this reason.

If paint is applied over millscale, the corrosion process described above can still occur, because coatings are permeable to both moisture and oxygen. The coating itself will act as a high electrical resistance in the corrosion circuit and slow the process down, but it will not stop it entirely. Actual breaks in the coating will allow very rapid corrosion and pitting, so the removal of millscale is critical.

Millscale itself is quite brittle and it will crack on cooling and flexing when the plate is handled. It also expands and contracts at a different rate to mild steel, so it tends to crack and fall off naturally if the plate is left outside to weather. Flame cleaning which exploits this differential expansion principle can also be used for millscale removal. Weathering was the traditional method of removal in the shipbuilding industry, but modern production techniques have meant that steel plates are no longer allowed to weather and millscale is generally removed by abrasive blasting in a wheelabrator and shop priming plant. Heavy metallic abrasives which clean by impact energy are normally used in these plants, prior to the plate being coated with shop primer.

You may encounter other methods of millscale removal, including open abrasive blasting, chipping and even pickling, but whatever method is employed it is important that millscale is thoroughly removed.

If you are uncertain whether the corrosion products left on a steel plate are millscale or some other form of rust, you can check this on-site by the use of a small magnet. Magnetite, as the name suggests will be attracted to the magnet, other forms of rust will not.

2.2 RUST CONTAMINATION

Rust is a generic term used to describe all types of iron or steel corrosion products ranging from thick heavy scale to light gingering. They are the most commonly encountered contaminants on steel surfaces and they can be difficult to thoroughly remove. However, the severity of the contamination problem is highly dependent upon the type of corrosion product encountered.

Simple ferric oxide Fe_2O_3, which is a light tan-brown color and occurs as flash rusting on steel which has been high pressure fresh water washed or hydroblasted, is an inert material. It may affect coating adhesion if it is loose, but it will not cause further chemical reactions with the steel or the coating. This type of contamination can be removed by wire brushing or abrasive blasting.

Unfortunately most 'rust' encountered on ships will be hydrated iron oxide containing soluble sulphate and chloride salts which have been formed from a contaminated atmosphere or from sea water. These salts are not usually on the surface of the rust, but are near the interface with the steel, where they are highly reactive and cause continuing corrosion of the steel surface itself. Removal of this type of rust contamination can be carried out by a variety of manual, mechanical and blasting methods, but the only practical way to remove the salts which remain in the pits of the steel is to wash with high pressure fresh water.

Once rust contamination has been removed, you may notice that areas which have previously rusted tend to rust preferentially again in the same area. This is because the original electrochemical corrosion process will have permanently altered the grain structure and grain boundaries of the steel in its vicinity. It will have created new cathodic and anodic areas. Consequently corrosion will reoccur in the anodic areas fairly quickly if the atmosphere is humid and it will be accelerated if salt is still present on the steel.

2.3 SALT CONTAMINATION

The salts which create the greatest contamination and corrosion problems are sulphates and chlorides. Sulphates are more common in industrial environments and come from air pollution. They are not as aggressive as chlorides, but they can cause particular problems on ships decks, down wind of funnels. On the other hand almost all surfaces in a marine environment will be exposed to chloride contamination from the sea and salt spray. On steel surfaces the chlorine ion and water form a ferrous chloride solution which is not only conductive aiding the electrochemical corrosion reaction, but is in itself a strong corroding of the steel surface. The ferrous chloride molecule further oxidizes to form ferric chloride which is a hygroscopic salt that draws moisture from humidity in the air, creating a ferric chloride solution on the steel surface, again aiding the corrosion reaction.

Even only a few molecules of either ferrous or ferric chloride remaining on the surface, or in the bottom of a corrosion pit tend to form a concentrated iron chloride solution. This will lead to corrosion of the steel, turning the contaminated areas through a color change from dark green to light yellow then to the more familiar brown and black.

A salt contaminated surface, particularly old pitted steel, which has been grit blasted two or three times can still show this type of corrosion. 'Flashing up' will give the appearance of a clean surface but it will not remove the salts entirely. Coating over this type of contaminated surface can lead to failure, because the salts will draw water through the coating by osmosis, causing loss of adhesion and blistering.

As mentioned above, the solution to this problem is to high pressure fresh water wash contaminated areas after blasting to remove the salts from the pits and then to reblast to remove flash rusting, if necessary. Water jetting (hydro blasting), using high or ultra high pressure water, instead of grit blasting will also very effectively remove salts from contaminated substrates.

Measurement of salt levels on substrates, abrasives and in fresh water used for washing is becoming increasingly important for both ship-owners and International Paint. In addition, the International Standards Organization(ISO) and bodies such as the SSPC (Steel Structures Painting Council) issue standards for permissible levels of residual salt and methods of measurement. International Paint have their own salt contamination procedures and the on-site measurement of substrate and abrasive salt levels will form a routine part of your job for all cargo and ballast tank coating work.

1. Methods of Salt Measurement
Several techniques and methods are available for measuring surface salt levels on-site.
There are simple indicator tests which cause test papers to change color in the presence of chloride ions, and there are the more accurate quantitative methods which involve obtaining some saline solutions for measurement with conductivity meters.

2. Permissible Salt Levels
Permissible salt levels vary depending upon coating type and service environment. For cargo and ballast tank coatings permissible salt levels are given in the relevant coating application procedure. However, as a rule of thumb, levels of around 10 micrograms/ cm^2 are acceptable for ballast tank coatings and 5-10 micrograms/ cm^2 are accepted for most cargo tank coatings.

2.4   Oil and Grease Contamination

Oil and grease are common materials in all marine, shipbuilding and shiprepair environments and they are a serious source of substrate contamination, because they are virtually impossible to paint over with successful results.

Most organic coatings have fairly low surface free energies, or surface tension properties and do not have much difficulty 'wetting' metal and metal oxide surfaces, which have much higher energies. Unfortunately oil contamination reduces the free energy of the metal surface to below the energy of most coatings. This means that the coatings cannot displace the oil and 'wet' the surface.

Older, low performance coatings, such as oil based red lead paint, have lower surface energies than modern coatings, and they do have some chance of adhering to an oil contaminated surface. But where high performance coatings are to be applied it is **essential** to remove oil or grease contamination by following proper degreasing procedures.

2.5   Water and Moisture Contamination

Although there are some moisture tolerant coatings that can absorb a small amount of water into the structure of the coating itself, they are special cases. For most coatings, water or moisture contamination will form an immiscible or barrier layer between the coating and substrate and prevent adhesive bonding between the two. Water will also prevent intercoat adhesion if it is present on painted surfaces and, of course, it will create rust contamination on bare steel.

Water is probably the most common type of substrate contamination that you will encounter and it is very difficult to prevent. However, it is naturally removed by evaporation. You should not allow painting when surfaces are wet or are likely to become wet, so it is fortunate that moisture contamination can be easily observed.

2.6   Dust and Grit Contamination

Dust and grit contamination can occur through natural environmental processes, but in shipyards it is most likely to arise from blast cleaning and other surface preparation operations.

This type of contamination will effectively nullify local adhesion of the coating to the substrate, because the contamination itself is not bonded to the substrate. In addition, grit particles in the paint film may act as the focal point for blister formation and eventual coating breakdown.

Dust naturally accumulates on horizontal surfaces and the interior of structural cavities. Special inspections must be carried out to ensure such surfaces are adequately cleaned and free from dust prior to painting. Dusty surfaces must therefore be cleaned in line with normal procedures. This can involve blowing down the outside hull, or brushing and vacuum cleaning inside tanks.

You may occasionally be asked in tank coating situations to carry out this test to the ISO 8502-3 standard. This standard specifies the type of pressure sensitive tape that must be used, the method of applying it, and most usefully gives a visual assessment of the contamination that is detected.

2.7   Defects in Steelwork

Although they are not strictly regarded as contaminants, surface defects in steelwork contribute to coating failure and they have to be rectified as part of the surface preparation process.

In newbuilding situations, steelwork preparation should be viewed as a critical part of the construction programme. Failure to do this work properly will inevitably lead to coating breakdown, with claims from the ship-owner against both the shipyard and the coating manufacturer. (If you can imagine extensive coating breakdown on weld seams and sharp edges in large cargo tanks, with consequent cargo contamination, you have an idea of the size of the claims and the difficulties of putting the work right). Unfortunately the responsibility for carrying out steelwork inspections and rectification work may not be clearly defined in some shipyards. Obviously the Steelwork Fabrication Department and the Painting Department have some responsibility for carrying out inspections and rectifying defects. Ideally the Fabrication Department should do their work before grit blasting, with the Painting Department carrying out a further inspection after grit blasting, because some defects will only show up after grit blasting. You may be involved in both types of inspection, but your primary concern, as always is to either accept or reject these surfaces as suitable for painting with International Paint's products. Preparation of welds, cut edges and surface imperfections is described in ISO 8501-3. The most common types of steelwork defects are described below:

2.7.1   Surface Laminations and Shelling

These defects will probably be exposed after grit blasting when they will tend to stand up above the surface. See Figure 7. No coating system can properly coat or protect laminations, so they have to be removed by grinding or disc sanding.
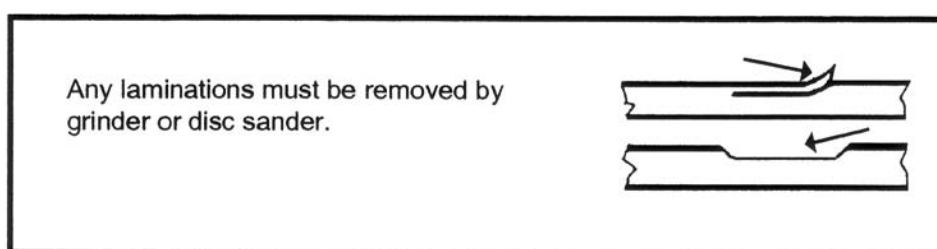

Any laminations must be removed by grinder or disc sander.

Figure 7- Plate Laminations

2.7.2　Cracks and Deep Crevices

This type of defect can contain entrapped moisture which will create corrosion cells. Defects should be ground out unless they are too deep, in which case they should be filled by welding and then ground smooth.

2.7.3　Inclusion

All surface inclusions in steel plates including millscale not removed in the wheelabrator process, should be removed by chipping and grinding, then the surface can be weld filled and ground smooth if necessary.

2.7.4　Sharp Edges

Wet paint will tend to flow away from sharp edges leaving a thin dry film which is likely to break down, therefore all sharp edges, including gas cut edges should be smoothed by grinding. See Figure 8. Smoothing to a radius of between 2-3mm is normally recommended for sharp edges.
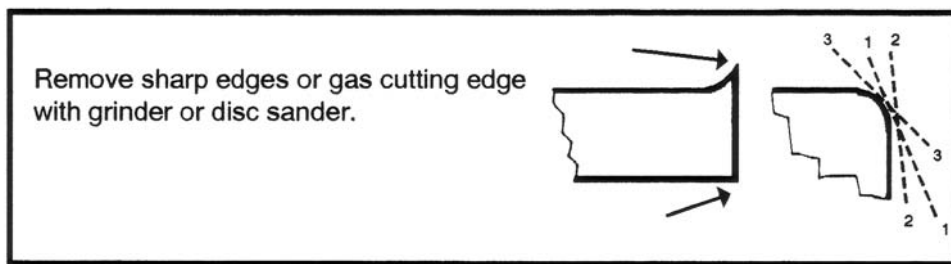

Figure 8 – Sharp Edges

2.7.5　Weld Spatter

Weld spatter may cause coating failure, either because it is sharp and irregular, or because it is loosely adherent to the substrate. It should therefore be removed by grinding, chipping or scraping. See Figure 9.
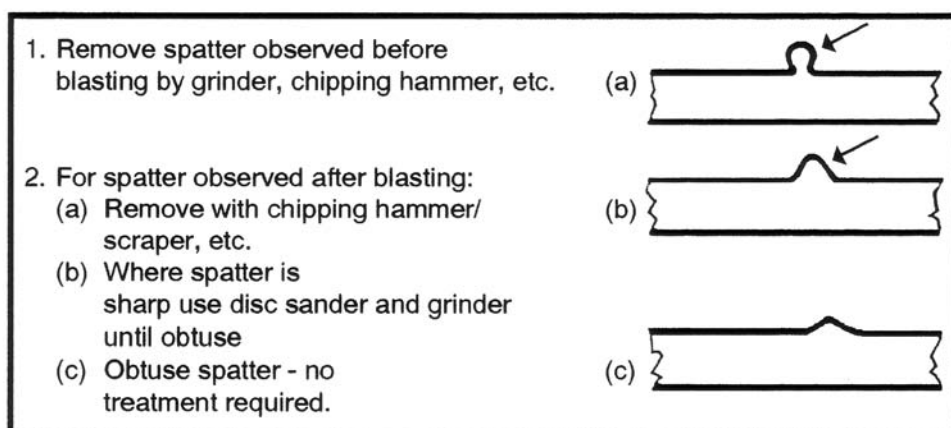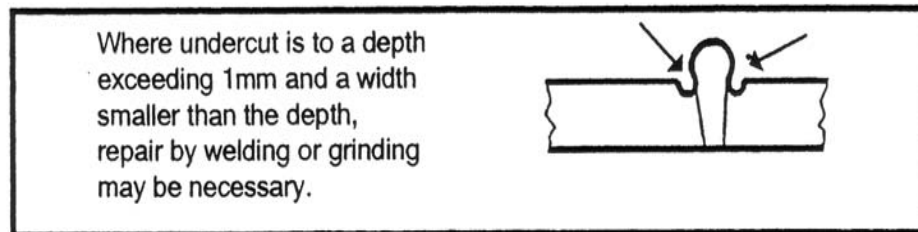

Figure 9 – Weld Spatter

2.7.6 Weld Porosity

It is not possible to effectively coat weld porosity. Corrosion cells will form in the defects, leading to coating breakdown. Porosity defects should be filled with weld metal and then ground smooth.
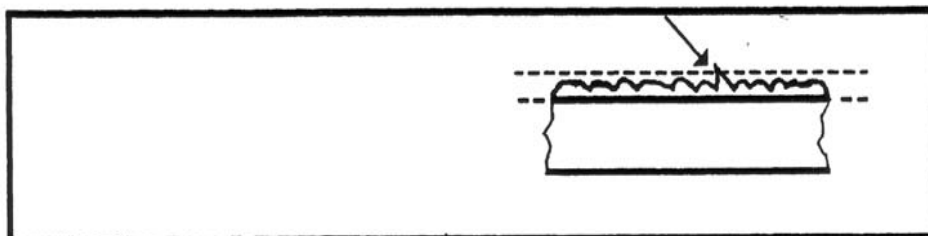
2.7.7 Weld Undercut

Welding undercut can be difficult to coat and can lead to coating failure. Substantial undercut therefore should be repaired by grinding and filling. See Figure 10.

Where undercut is to a depth exceeding 1mm and a width smaller than the depth, repair by welding or grinding may be necessary.

2.7.8 Jagged Manual Welding Seams

Automatic welding seams are normally smooth and should not present a coating problem, but manual welds may have sharp edges or irregularities which can cause coating breakdown. Irregularities must be removed by grinding. See Figure 11.

2.7.9 Missed Welds and Stitch Welding

Missed welds and far more common than might be imagined. Defective areas should have been found and rectified before coating operations begin, but they may have been overlooked in awkward or hidden areas.

It is impossible for a coating to fill the gap between two plates that have not been fully welded together. Corrosion will take place in this area with resultant coating breakdown. The best way of treating these defects is to have the welding operations completed. Filling with epoxy fillers is a poor alternative.

Stitch welding is a technique which deliberately leaves open gaps between sections of weld and it therefore builds corrosion problems into the ship. It is a design fault as far as coatings are concerned and is best dealt with by being abandoned at the design stage. It can be remedied on site by filling in the gaps with weld metal or, as a last alternative, with epoxy filling compounds.

2.7.10 Weld Slag and Welding Flux Residues

Weld slag is brittle solidified weld flux. It penetrates the voids of the weld and may also spread to surrounding areas. Due to it's alkalinity it must be completely removed, or it may react with oil based binders and encourage corrosion products beneath the coating system. It can be removed by chipping or blasting.

In addition to the weld slag, fume and oxide deposits caused by welding can be found adjacent to the weld which can seriously affect coating adhesion. It is normal practice to thoroughly remove welding residues by wire brushing, grinding or blasting.

Most of the surface defects described above are normally removed by grinding. You should bear in mind that grinding can also remove the surface profile and produce a smooth finish which may not in itself be suitable for coating. This depends upon the grinding tool used to remove the defect. In some cases it may be necessary to re-prepare these areas in order to reestablish a surface profile.