

EVALUATION OF 20,000 PSI WATER JETTING
FOR SURFACE PREPARATION OF STEEL PRIOR
TO COATING OR RECOATING

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INTRODUCTION

The coatings industry has long perceived water blasting as a process which has no abrasive effect on steel and other hard surfaces. This perception has not kept up with the development of new understanding of jet technology at 20,000 psi (137.8 MPa) and how it applies to surface preparation.

For years, waterjetting at high pressures has been used in mining, drilling, and cutting operations for such diverse applications as blasting holes through concrete, hard rock, and coal, to cutting plastic shoe soles. The application of water blasting in steel surface preparation for painting or recoating has been limited largely to cleaning operations at lower pressures or the use of sand and water mixtures to facilitate higher production rates and achieve "white metal" blasts.

Water cleaning and blasting is recognized as a process to remove loose surface contaminants. Water cleaning, at pressures below 10,000 psi, is used to remove barnacles from hulls without significant damage to existing paint. Criticism of this cleaning technique arises when more adherent (and porous) rust layers and contaminants are left on the surface to trap water droplets, an undesirable situation which leads to long drying times. Sand-water mixtures successfully clean the surface but generate a considerable amount of sludge. Moreover, the paint applicator is faced with the difficult task of making sure that all solid particles are removed from the surface before applying any paint.

More owners and applicators are becoming aware that dry abrasive blasting may not completely remove pinpoint sources of corrosion initiation sites. These sites are particularly insidious as they usually go undetected by normal field site evaluation. The results can be very expensive. For example, at the April, 1983, NACE meeting in Houston, the Exxon speaker described recoating a storage tank three times within a short time span. The metal was rusting beneath the paint. Each time all precautions were taken to insure a good white metal blast and proper environmental conditions during coating. Finally they decided to detect soluble iron (11) salts on the surface with potassium ferricyanide paper. It took four consecutive blasts to white metal to clean the corrosion cells from the surface. Only then could the tank be painted.

During the past year, development of a newly designed pump, hose, and nozzle system has provided new capabilities to water blasting without the introduction of solids. Water blasting at 20,000 psi has moved from the laboratory stage and is now practical for field applications. Some aspects of the development force a review of the very concepts of surface cleaning and preparation. This new technology proves to be particularly useful in cleaning older steel and surfaces which have become contaminated.

New on the side of safety is the hose design for the 20,000 psi water jetting technique which has a burst strength of 55,000 psi providing a 2.5:1 safety factor. The nozzle is specially designed to form the jet stream into a controlled fan pattern so that deep cutting of the metal does not occur. The thrust design on the gun is modified so that a 150 pound person can handle the cleaning operations. With this holistic development approach, water blasting at 20,000 psi is manageable on field sites and is relatively safe. It cannot be overemphasized that the equipment used in our study was the product of extensive design analysis and testing. The energy inherent in a 20,000 psi water jet system requires thoroughly proven equipment capabilities to achieve safe operations. Using the newly designed system, operators can safely handle 20,000 psi water blasting with the requirement of ear plugs to reduce the noise level.

In these field studies, water blasting pressures of 7,000 psi, 10,000 psi, and 20,000 psi were compared on different sections of the same metal pieces. The visual amount of cleaning on the uncoated rusty steel specimen was striking. At 7,000 psi, we could not achieve an acceptable commercial gray surface even with longer dwell times. At 10,000 psi, it was difficult and slow to remove adherent black oxide products. At 20,000 psi, we could get to a gray surface in a relatively short time. This later proved to be clean of microscopic solid and chemical contaminants.

This cleaning is not merely a matter of gradual change. At 20,000 psi, the energy transferred to the surface is approximately four times the energy transferred at 10,000 psi. Seemingly, the acoustical energy (shock wave energy) of the 20,000 psi jet exceeds the bonding energy of even the most adherent coating. Elastomeric coatings, enamel paint, red oxide, and eighteen to twenty-four inches of polypropylene are immediately blasted from metal surfaces. The absolute cleanliness is greater for a given amount of time. This makes it difficult to establish comparative production rates. A cleaning operation which is acceptable for 7,000 and 10,000 psi blast operations becomes trivial at 20,000 psi. Immediately the anticipations for cleaning become more stringent.

When characterizing metal surfaces, Coastal uses special storage conditions which allow localized cells to develop (if they are present initially) along with optical microscopic examination up to 100x magnification. Above 100x magnification, we use a Scanning Electron Microscope (SEM) equipped with Energy Dispersive X-ray Analysis (EDAX) so the elements on the surface and inside crevices can be located. EDAX allows us to detect all the elements except hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, and neon. The SEM gives a greater depth of field and reduces sample preparation requirements. Fourier Transform Infrared Spectroscopy (FTIR) and Raman Spectroscopy is used to augment the information about particular species such as phosphate, nitrate, carbonate, organic films, or specific iron oxides along with the elemental analysis of EDAX. EDAX quickly tells us if sulfur is present over the entire surface or at particular sites; FTIR and Raman Spectroscopies tell us if the sulfur is present as sulfate.

FIELD CASE I

Heavily rusted (80-90% surface area), pitted 1018 new steel plate was cleaned at 7,000 psi, 10,000 psi, and 20,000 psi. Loose rust and debris were removed from the surface as fast as the nozzle could be moved manually in a sideways sweeping motion. The nozzle was held two to three inches from the surface to maximize the area cleaned per pass while maintaining good energy transfer. The cleaning effectiveness is related roughly to the square of the distance from the nozzle to the surface. At all pressures, the lower indentation or pits in the metal were cleaned to a bright shiny surface. The appearance of the steel plate, after a defined cleaning time of three minutes, was an upper layer of adherent black oxide speckled with very clean shiny pits.

Additional sweeping at 7,000 psi did not remove the tightly adherent black oxide. However, at 10,000 psi, the surface oxide could be cleaned off slowly to a uniform dull gray appearance. *Figure 1* is a cross section of the uncleaned new steel under the original corrosion products. *Figure 2* is a partially cleaned surface (10,000 psi). The black oxide, which was tightly bonded to the good metal, is now being lifted from the surface. A surface view using the SEM showed fractures in the oxide layer. This oxide layer is about half the thickness of the original corrosion.

Observations at 20,000 psi were substantially different. At 20,000 psi, the adherent corrosion layer could be removed completely. SEM showed a very clean, open surface which follows the contours of the original metal. *Figure 3*. The microstructure of the metal shows that the small "tits" of metal are standing out and not bent over. This same plate was blasted with silica sand and glass beads to white metal. In a few days, in storage, these white metal surfaces had become shadowed but did not exhibit localized corrosion. The cross-section of the sand blasted surface (*Figure 4*) shows a pocket fold in the metal formed when two spikes of steel have come together. Painting over this surface would leave an air site for underlying corrosion initiation. The cross-section of the metal blasted with glass beads did not show any of these folds, but rather a smooth, almost sinusoidal shape. It contained channels which had almost been closed, but not completely. A coating on this surface would bridge over the channel inlet but would leave air trapped in the channel.

When the metal was blasted at 20,000 psi, the surface profile anchor pattern of the 1018 steel plate was relatively unchanged except for removal of the brittle black oxide. The uncleaned steel had a measured anchor pattern of 0.0074 inch (0.0052 - 0.0107); the 20,000 psi surface was 0.0044 inch (0.0015 - 0.0052) with occasional depressions of 0.009 inch; the sand-blasted surface was 0.0050 inch (0.0012 - 0.0094); the glass bead blasted surface was 0.0047 inch (0.0016 - 0.0091). Skid marks on the metal plates remained well defined on the water blasted surfaces and were erased on the abrasive cleaned surfaces.

Figure 1 130 x

- 0.00394 inch (Amm)
Uncleaned 1018 steel.
Rusty, new steel,

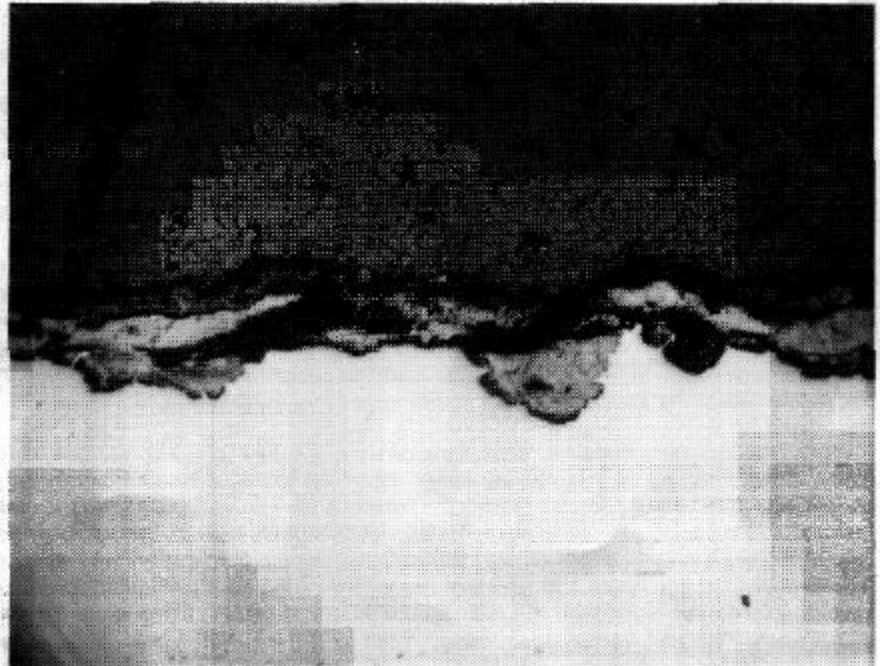


Figure 2 130 x

- 0.00394 inch (Amm) 1018 steel cleaned at 10,000 psi. Partially cleaned surface. Top corrosion is lifting from surface.

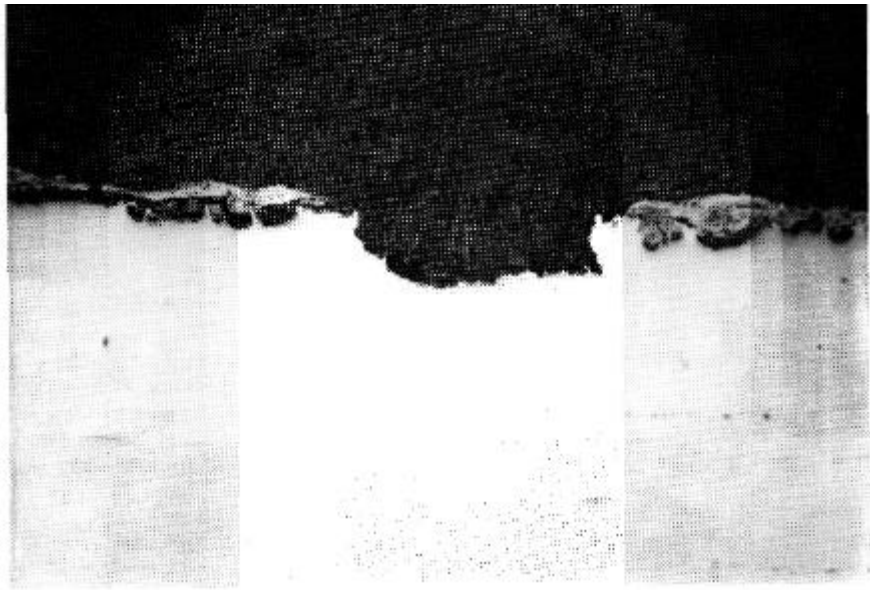


Figure 3 130 x

- 0.00394 inch (.1mm) 1018 steel cleaned at 20,000 psi. Partially cleaned surface. Visual standard - near white.

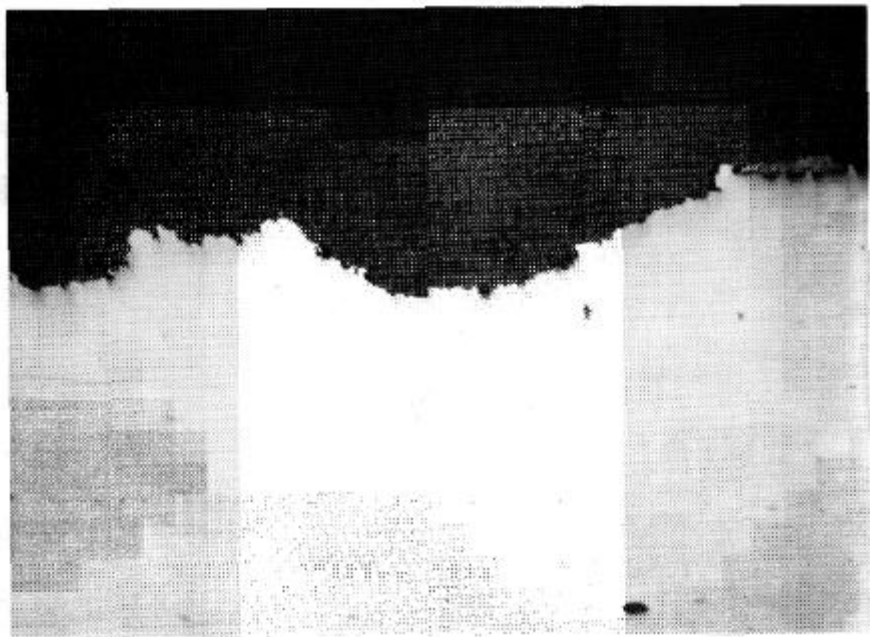
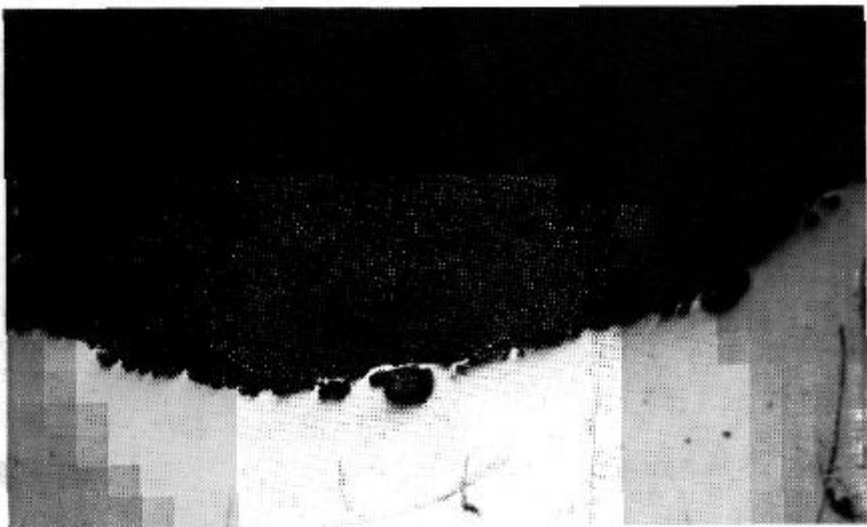


Figure 4 130 x

- 0.00394 inch (Amm) 1018 steel blasted with sand. Visual standard - white metal.



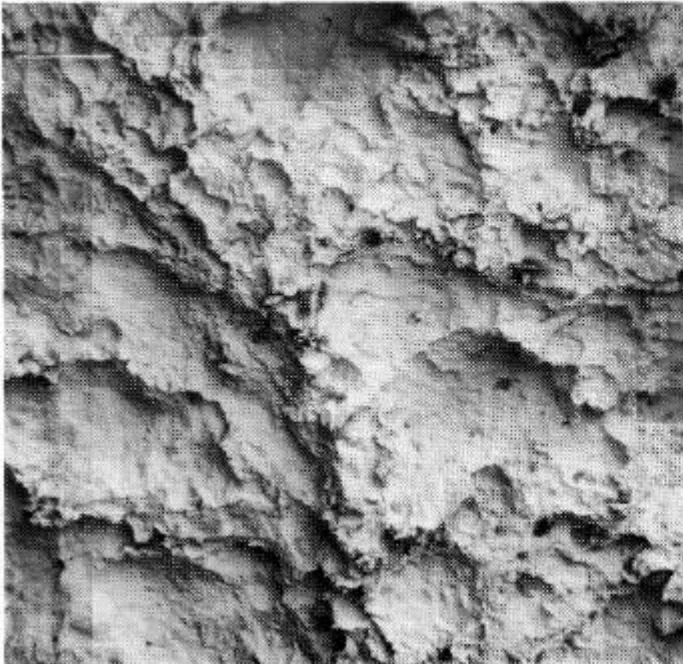
FIELD CASE 11

A U channel approximately 2 inches per side was completely covered with heavy rust 1/4 to 3/8 inches thick. *Figure 5* is a cross-section of the uncleaned surface showing the adherent rust. This channel was blasted to white metal with glass beads and with sand. Within a day, the white surface was covered (80-90%) with dark local corrosion spots. The use of ferricyanide indicator showed the presence of ferrous salts on the surface. This was confirmed with EDAX during the SEM survey. Spot traces of silica, chlorine, and sulfur were found on the surface. The cross-section (*Figure 6*) of the surface cleaned with the glass beads clearly shows the dark rust which has now formed on the surface from the colorless iron salts. One can also see the flattened lip of metal protecting a local corrosion cell. This type of defect would not have been found with standard field inspection. If this surface had been coated the same day it was blasted with abrasive materials, even though it would have passed all visual criteria for white metal, these chemical contaminants would have led to premature paint problems.

The same U channel blasted with 20,000 psi water is now quite clean (*See Figures 7, 8, and 9*). Blasting at 7,000 and 10,000 psi did not remove the rust even though it was fairly loose. The 7,000 psi surface remained covered with black oxide; the 10,000 psi surface was closer to a commercial gray.

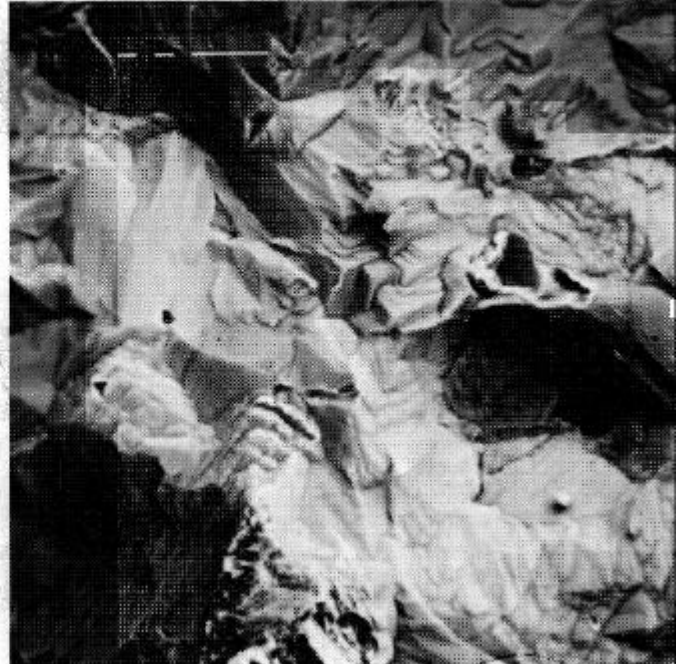
The blast water was fresh, but uninhibited, and the metal surface of the U channel developed a golden hue as the water was drying. Surfaces which were force-dried after water blasting retained their clean, shiny appearance. During the SEM survey of the "golden" surfaces, small isolated patches of patches of surface material could be found on the cross sections (*Figure 7*). EDAX did not detect any chlorine or sulfur sites. Dark local corrosion spots did not develop during storage. The dried surfaces are very clean and should be ideal for coating. The "tits" of metal are quite open.

Figure 8 130 x



Surface view
0.00394 inch (Amm)

Figure 9 1040 x



Surface view
0.000394 inch (.01mm)
Very clean.

Figure 5 130 x

- 0.00394 inch (Amm) Unclean U Channel.
Immediate gray is rust layer.

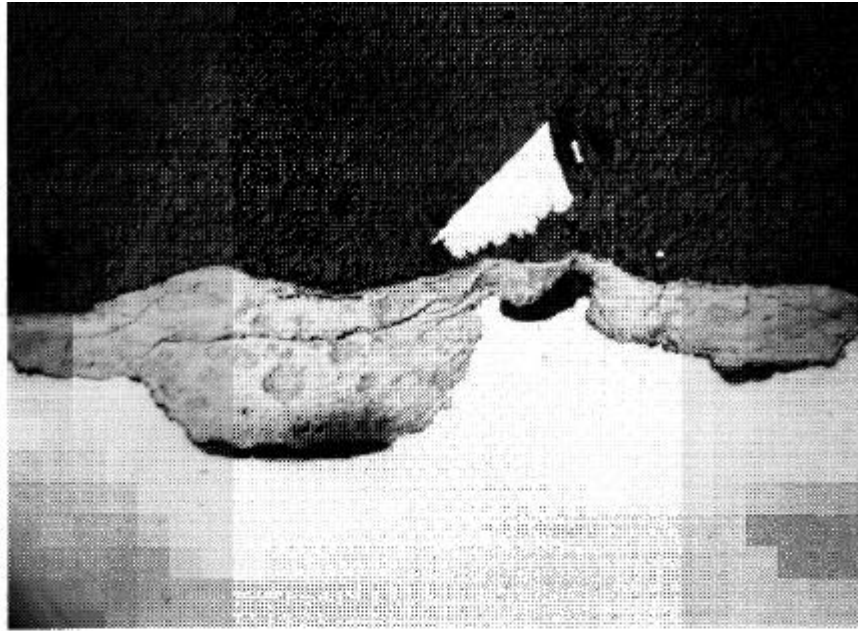


Figure 6 130 x

- 0.00394 inch (.1 mm) U channel cleaned to
white metal with silica glass beads. Localized
corrosion cells became apparent overnight.

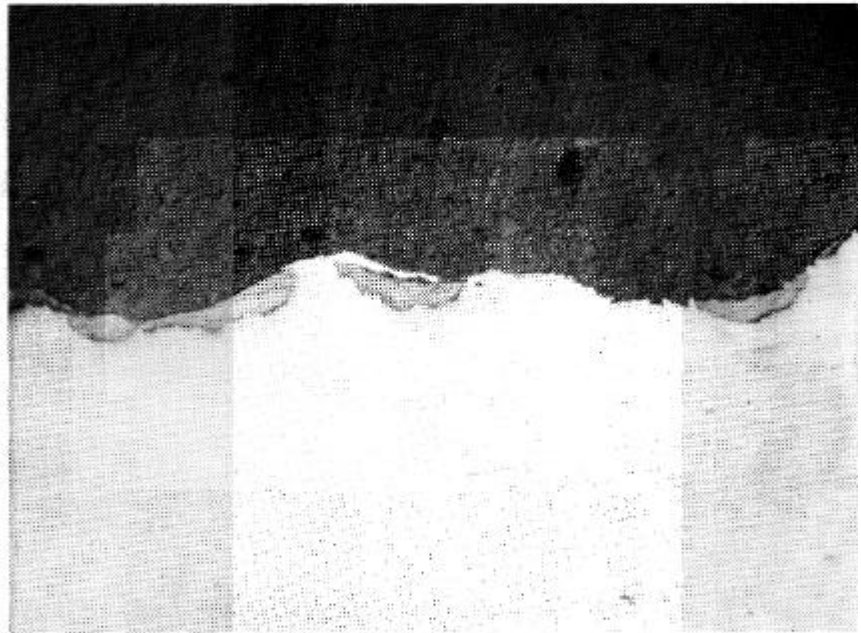
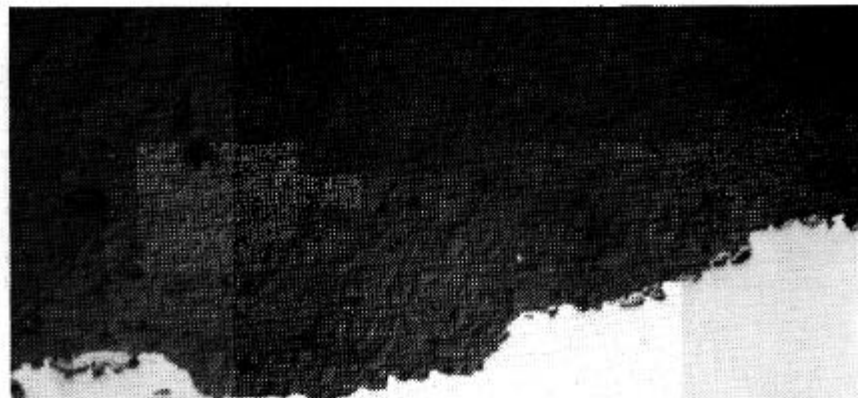


Figure 7 130 x

- 0.00394 inch (Amm) U channel cleaned with
20,000 psi water blasting.



FIELD CASE III

In 1982, CSAI examined steel plate, reputed to be ASTIVI A 441, which had problems in metallurgy, chemical contamination, and bad mill practices. The steel was blasted with steel shot repeatedly to white metal and rerusted within hours to a dark splotchy pattern. Other steel plates from the same source were responding normally with an overall light corrosion. The top view of a freshly blasted surface (*Figure 10*) did show a few black corrosion products but did not look abnormal. However, the cross-sections (*Figures 11 and 12*) revealed the corrosion cells were located within the top 0.002 inches and were being hidden by flattened lips of metal. The steel shot was working the surface but not actually removing the steel. In addition, the outer steel was completely decarburized so that the corrosion rate was high.

If the surfaces were painted before the splotchy pattern had time to develop and with subsequent thermal drying of the paint in a controlled oven, the splotchy pattern appeared through the gray paint in a matter of a few weeks of outdoor storage. The industrial paint was not able to control the localized corrosion cells.

The use of 20,000 psi water blasting with a rust inhibitor added to the water did remove the corrosion cells and clean the metal to gray without immediate rerusting. (*See Note*) Lower pressure at 10,000 psi cleaned the pits in the metal but did not entirely remove the adherent black oxide layer.

This metal plate also had thin rolled layers of steel where the rollers had contaminants and banded layers of manganese sulfide fiber inclusions parallel to the surface. The steel tended to delaminate and corroded in sheets. The use of 20,000 psi did not explode the steel along these weak interfaces while cleaning the corrosion at the plateaus.

In summary, the 20,000 psi water blasting technique appears to be the only way to clean this steel in one step. Abrasive dry blasting alone will not clean the corrosion cells and blasting at lower pressures does not remove enough adherent oxide.

GENERAL DISCUSSION

CSAI has evaluated the relative effectiveness of storing blasted steel surfaces in closed containers with commercial desiccants and vapor phase corrosion inhibitors. We have found that if the surface is truly clean and free of localized corrosion cells, our proprietary vapor phase corrosion inhibitors will hold a surface free from rust for two to three years. However, if there exists any local chemical corrosion cells such as isolated pockets of connate water or salts in old metal or where a finger has touched the cleaned surface, dark spots of rust which are visible to the naked eye, will appear on the surface in a matter of a few hours. This spotted corrosion pattern is distinctly different in appearance from general surface corrosion of steel.

The dry abrasive blasting was performed in a blast cabinet. Elaborate care was taken to remove the abrasive from the surface and to handle the field specimen by the edges. SEM surveys always showed particulate remnants of the abrasives (EDAX defined the silicon) even though the surfaces were cleaned much more thoroughly than on field sites. These particles would usually go undetected in field inspections as they were not seen with a Surface Profile Comparator.

There is growing evidence that when sand hits the surface at a site where there is a trapped water droplet, some of the silicate is solubilized at the impact site and remains there. Chemical contaminants on the dry blast material must be avoided.

The contact points on the water-cleaned steel are quite sharp. Small samples were cushioned in paper wipes to prevent damage during transportation. Lint fibers, which were very difficult to remove, were observed in the SEM surveys.

In all cases, the steel could be blasted at 20,000 psi to a dull gray appearance which, by standard field examination, would be classified as near white. The light shiny appearance associated with white metal could not be achieved. However, microscopic examination proved the surfaces met the cleanliness criteria of white metal. This dull appearance will always be associated with water blasted surfaces as the many contact points of metal diffuse the light coming to the eye. Solid abrasive techniques flattened these surfaces and inherently produced a shiny, lighter appearance.

Surfaces blasted with uninhibited water quickly flash rusted to a uniform light golden color unless the surface was forced dried or the water was inhibited. During storage, there was no evidence of the local dark corrosion sites associated with contaminants as was found in the older steels cleaned with dry abrasives. This lack of localized corrosion was true for both inhibited and uninhibited water blasting.

Figure 10 100 x

- 0.00394 inch (.1mm) Surface View of A441 Steel.
Shot blasted to white metal. Dark Spots are corrosion
products.

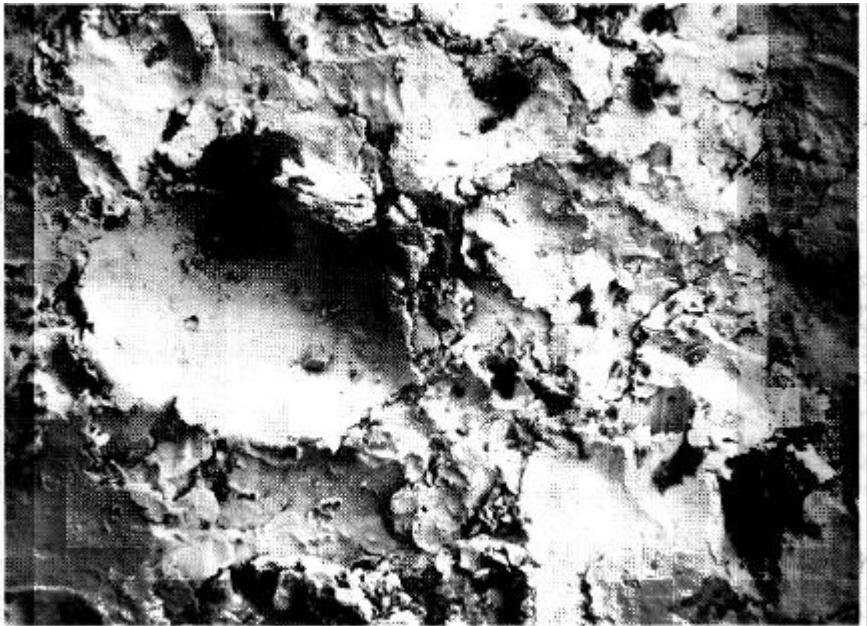


Figure 11 266x

- 0.00394 inch (.1mm) Steel cleaned to white metal
twice with steel shot. View of corrosion cell hidden
under lip of crater.

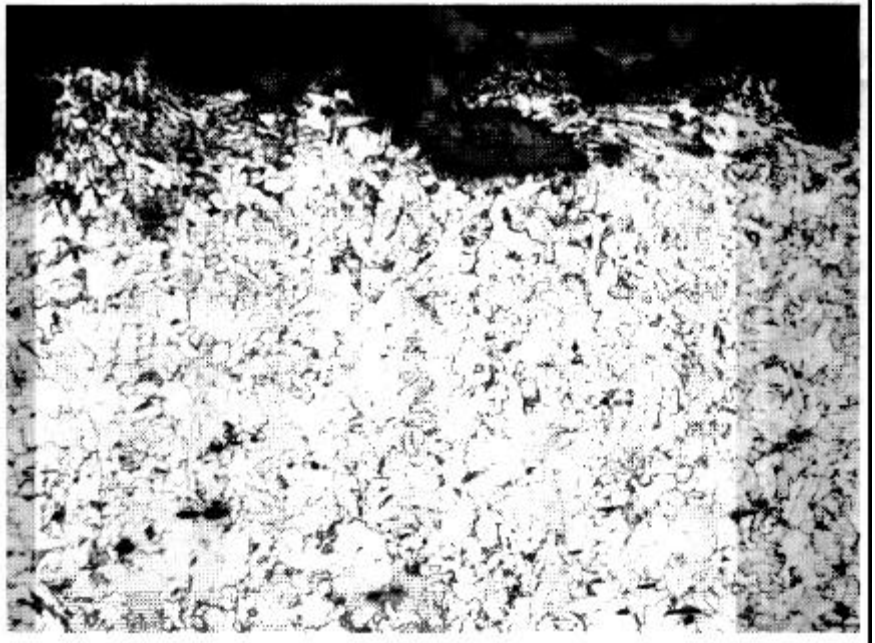


Figure 12 100 x

- 0.00394 inch (.1mm) Steel cleaned to white metal
three times with steel shot. The metal surface is being
worked without being cleaned.



INHIBITORS

In order to keep the steel surface from immediately flash rusting during the water dry ingti me, the surface must be forced dried with heat or an inhibitor added to the water. The flash rusting is light and uniform; good, industrial grade coatings should be able to be applied over the flash rust without difficulty.

To keep the steel surfaces from flash rusting, a nitrite-phosphate inhibitor was added to the freshwater (See Note). This inhibitor not only stopped the rusting, it turned the surface steel-gray during the microscopic examination. Studies using SEM, EDAX, and FTIR indicate the steel surface may be lightly phosphated. The surface profile is still quite open.

These inhibited steel surfaces have been coated with inorganic zinc silicate, vinyl, and hard boil mastic paint systems and are currently in long-term testing with comparative sand-blasted surfaces to determine compatibility with paint systems. After 500 hours, there were no paint failures traceable to the inhibitor. This is not unexpected, as the inhibitor has been used with lower pressure water blasting on steel without subsequent premature paint failures.

PRODUCTION RATES

Published production rates are available for water blasting at 10,000 psi (Table 1). Practical production rates for this new 20,000 psi water blasting under different conditions are being gathered in actual field situations.

The 20,000 psi water blasting technique is two to three times faster than 10,000 psi in achieving the same degree of cleanliness. With the new 20,000 psi system, it is possible to achieve near white to white metal conditions (SSPC-SP 10 and SSPC-SP 5) while the 10,000 psi and lower pressures are limited practically to a commercial gray blast condition (SSPC-SP 6).

In Case 1, dry abrasive blasting was approximately twice as fast as the 20,000 psi water blast. In Case 11, the water blast was three to four times faster than the dry blast; and in Case 111, dry abrasive blast was simply not able to clean the corrosion cells. The water blast not only removed the rust in Cases 11 and III, it also removed the corrosion cells.

When 20,000 psi water blast was used to clean a coal scrubber plate coated with elastameric polyurethane, the production rate to commercial gray was approximately six times that of dry abrasive. It also removed the sulfur contaminants which had migrated to the metal wall. The adhesion of polyurethane to the steel was above 700 psi when measured with an Elcometer Adhesion Tester. The surface profile on this steel which had initially been sand blasted to a 0.005 inch remained the same. The contour looked like a sand blasted pattern except that cletrital material in the valleys had been removed. The same phenomena was observed when some Tator panels (1020 steel) which had been rusted in salt chambers were cleaned with the 20,000 psi water blast. The anchor pattern was unchanged from the original sand blast pattern; the top view looked like a sand blast pattern except detritus was absent.

Production rates are affected by operator skill and condition of the steel surface. Regardless of the surface conditions, production rates are enhanced when the operator gains additional experience with 20,000 psi blasting. New metal with tightly adhering mill scale requires the highest level of skill to produce a clean surface with an acceptable anchor pattern. Older, more corroded or previously coated surfaces require the least skill for excellent results. This is the reverse of abrasive blasting, where poor surface conditions require the highest levels of operator skill. In view of the fact that poor surfaces are the most encountered field conditions, 20,000 psi water jet blasting would seem to be highly favorable.

Table 1
Some Waterblast Cleaning Rates at 10,000 psi (Square Feet/Hour)
Water Only

1. Uncoated Steel, flat surfaces greater than 60% of surface covered with tightly adhering rust and pitting.	150-450
1. Uncoated. Steel, small size members having less than 1 square foot per lineal foot. Greater than 60% of surface covered with tightly adhering rust and pitting.	75-150
1. Coated steel, flat surface. Finish coat of paint thoroughly weathered with almost all primer showing. Approximately 60% surface covered with tightly adhering rust. Some surface pitting & paint blistering.	350-550
2. Heavily corroded surface rust scale, irregular shape	125

References:

1. National Association of Corrosion Engineers Recommended Practice RP-01-72
2. Steel Structures Painting Manual, Volume 1, Good Painting Practice p. 66

SUMMARY

The new 20,000 psi water blasting technique opens the possibility to clean coated and uncoated metal surfaces without the addition of solid abrasives. The technique virtually eliminates the problems of hidden local corrosion cells. This includes corrosion pockets which are formed when metal folds over the surface, corrosion pits in the metal which cannot be reached by the surface attack of abrasives, and colorless chemical salt solutions such as iron chlorides.

The mechanism of 20,000 psi cleaning is now better understood. Indentations in the surface are being cleaned first and then the upper surface. This material removal is complementary to abrasive blasting which cleans the brittle upper surface layers preferentially and doesn't reach into pits.

In fact, this water blasting technique does not remove material by abrasion or scraping it away with friction. But 20,000 psi water blasting does disrupt the interface between different materials and can remove some of the steel surface.

The primary application of this technique will be in maintenance programs rather than new steel with tightly adherent mill scale. Conformance of the water blast to curved surfaces is excellent but, because of the deflection at a curved surface, it is difficult for the operator to see what is happening at inside corners. The technique should not be used where there are very thin pieces of metal sheet or where there are wires.

The layered corrosion problem found in Case III is becoming more prevalent as more old steel is being reworked. Water blasting is ideal for cleaning the layered corrosion.

Coastal has also found corrosion problems caused by discontinuities in the steel chemical composition itself. This forms an internal electro-chemical potential difference within the steel piece; one area acts as the anode and another area, the cathode. Eventually this results in corrosion under the paint. Surface preparation and coating cannot remove that internal cell.

Proper equipment is mandatory for operator safety. Any use of field improvised or unproven commercial equipment is discouraged as it may result in serious injury. Hearing protection is mandatory.

Our field studies are yielding production rates and evaluating the relative effectiveness of various inhibitors. The compatibility of one inhibitor containing nitrite and phosphate with paint systems has been proven. Long-term evaluation is still underway. Adherence of paint systems over the light flash rusting is included in this long-term evaluation as in many maintenance programs, particularly on older equipment, it is not economically feasible to specify a near white blast.

Note: The *inhibitor (Partek 104, Butterworth Inc.)* was *injected into the fresh water stream at a rate of 1100 ppm.*

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