# Duriron and Durichlor 51M

D/D 51M

Bulletin A/2l

# High Silicon Iron

## Introduction

High silicon iron has been serving the chemical process and related industries for over 85 years. The alloy's resistance to such a wide variety of corrosive chemicals has been claimed by many to be unmatched by any other commercially available metal or alloy. However, the single most important use of the high silicon iron alloy immediately after its discovery and to this day is in sulfuric acid applications.

Though produced only as castings, Duriron and its modifications, Durichlor 51M and Superchlor 77, are available in many forms of standard engineered equipment, including pumps, pump sleeves, ejectors, jets, pipe, fittings, anodes, strainers, and tank outlets. Tower sections, S-bend condensers, and concentrator dip tubes are normally produced only in the original Duriron alloy.

Flowserve is able to make special high silicon iron castings for customers as well. However, it should be emphasized that standard design practices for other metals and alloys do not usually apply to the high silicon irons. For this reason it is essential that Flowserve be consulted to determine if a particular design is practicable.

## History

The high silicon iron called Duriron was first produced in 1912. It found immediate and extensive use in handling corrosives and was especially valued for its long and reliable service under severe conditions. In fact, Duriron played a fundamental role in the effort to win World War I as it was essential to the containment of the acids for munitions production.

Despite the excellent corrosion resistance of Duriron, warm hydrochloric acid was an important exception in the list of chemicals to which the alloy was resistant. This shortcoming led to the development of a molybdenum bearing high silicon iron, dubbed Durichlor.

While Durichlor exhibited very good corrosion resistance to commercially pure hydrochloric acid, it lacked the resistance necessary when the acid contained iron or any other element that would form strongly oxidizing chlorides. The substitution of chromium for a small amount of the molybdenum resulted in a new alloy that retained the corrosion resistance of the full molybdenum bearing alloy, Durichlor, in pure hydrochloric acid, but now also was resistant to hydrochloric acid containing oxidizing chlorides. This alloy, designated Durichlor 51, possessed a much broader range of applicability than its predecessors in all types of hydrochloric acid services.

In the 1980's, additional modifications were made to Durichlor 51 to improve its mechanical properties. The alloy's name was changed to Durichlor 51M to reflect these modifications.

In 1977, in an effort to further improve the corrosion resistance of high silicon iron pump shafts, which tolerate less corrosion than other parts of the pump, the silicon content was increased. This alloy, called Superchlor 77, possesses the best resistance to hydrochloric acid of all the high silicon irons and is available only as cast pump sleeves.

## Chemical Composition

The basic difference between a high silicon cast iron and ordinary cast iron is the silicon level. Duriron and Durichlor 51M each have a nominal silicon content of 14.5%. Silicon is the element primarily responsible for imparting excellent corrosion resistance to these alloys, but it also is the element which most significantly affects the mechanical properties and casting design. The addition of chromium to Durichlor 51M results in improved resistance to oxidizing environments. Table I lists the chemical composition of Duriron and Durichlor 51M.

**Table I
Chemical
Composition**

| | Duriron ASTM A518 Grade 1 | Durichlor 51M ASTM A518 Grade 2 |
|---|---|---|
| Carbon | 0.65-1.10 | 0.75-1.15 |
| Manganese | 1.50 max. | 1.50 max. |
| Silicon | 14.20-14.75 | 14.20-14.75 |
| Chromium | 0.50 max. | 3.25-5.00 |
| Copper | 0.50 max. | 0.50 max. |
| Molybdenum | 0.50 max. | 0.40-0.60* |

*Molybdenum not required for anode applications.

## Mechanical and Physical Properties

The greatest hindrance to the widespread use of high silicon iron equipment has been its susceptibility to thermal and mechanical shock. Thus, the design engineer must weigh heavily the outstanding corrosion resistance against the limited mechanical properties when considering high silicon cast iron for any application.

For years, people have attempted to develop a ductile high silicon iron. While attempts to increase ductility without sacrificing corrosion resistance have failed, it was found that a substantial increase in tensile strength could be achieved through special ladle degassing treatment. This approach lead to the development of Durichlor 51M. See Table II for the mechanical and physical properties of high silicon cast iron.

Care should be taken to avoid subjecting equipment made of these alloys to shock or excessive strain and to eliminate sudden fluctuations in temperature. High silicon iron equipment can be successfully applied to elevated temperature service if proper precautions are observed. A rapid change in temperature may produce sufficient thermal shock to cause breakage. However, gradual temperature changes offer no service difficulties. Precautionary measures often taken to prevent thermal shock of high silicon iron include pre-heating by slowly introducing steam and using copper steam coils or steam blankets.

**Figure 1.
36" Diameter
Tower Sections**

It is quite common to use high silicon iron equipment in the manufacture of sulfuric acid, nitric acid, and explosives. In such applications, temperatures as high as 1000°F are encountered and high silicon iron towers as large as 48" in diameter are utilized. Figure 1 is an illustration of 36" diameter Duriron tower sections. It is not unusual to have as many as 20 to 30 of these tower sections assembled. In such applications, the design engineers and construction, operating, and maintenance personnel are well aware of the mechanical limitations of the alloy and make all the provisions possible to avoid breakage. The fact that Duriron has been used almost exclusively in this type application for many, many years is proof that when proper consideration is given to the characteristics of the alloy, an almost unlimited service life can be obtained.

In addition to being brittle, the high silicon irons are very hard, which necessitates grinding instead of machining for finished surfaces. Drilling of holes is extremely difficult and threads cannot be accurately produced.

**Table II
Mechanical and
Physical Properties**

| | Duriron and Durichlor 51M |
|---|---|
| Tensile Strength, psi (MPa) | 16,000 (110) |
| Compressive Strength, psi (MPa) | 100,000 (689) |
| Hardness, Brinell | 520 |
| Specific Gravity | 7.0 |
| Melting Point °F (°C) | 2300 (1260) |
| Thermal Conductivity, cgs | 0.125 |
| Mean Coefficient of linear thermal expansion, in/in/°F, 100-700°F x $10^{-6}$ (cm/cm/°C, 38-371°C x $10^{-6}$) | 7.8 (14.0) |

## Welding

The welding of simpler forms of Duriron, such as pipe, can be accomplished when proper precautions are carefully observed. For the average welding shop, it is not practicable to weld intricate shapes such as centrifugal pump casings or pump impellers. Stresses from preheating, welding, or cooling can cause the castings to crack. Before attempting to weld the high silicon irons, obtain instructions (Bulletin 113-1) from Flowserve Corporation. This bulletin gives proper precautions, method of welding, type flux needed, and other pertinent information regarding the recommended procedure.

## Specifications

Duriron and Durichlor 51M are produced to ASTM A518, grades 1 and 2, respectively. Superchlor 77 is not made to any applicable specification.

## Corrosion Resistance

These alloys are especially suitable for services which require good resistance to a variety of chemicals. Duriron and Durichlor 51M are used extensively for handling mineral acids in manufacturing explosives, petroleum refining, metal cleaning or pickling, electroplating, textile manufacture, paper making, beverage making, metal processing, paint and pigment manufacturing, sulfuric and nitric acid production, dye and color manufacturing, fertilizer production, sewage disposal and water treating plants, and many others.

Additionally, Duriron pipe and fittings are extensively used in hospitals, colleges, industrial chemical laboratories, and photo-engraving plants where a variety of different corrosive wastes are handled each day. Under these adverse conditions, many years of successful service can be expected with the pipe usually remaining in service as long as the building.

## Sulfuric Acid Resistance

Duriron and Durichlor 51M exhibit very good resistance to the entire range of sulfuric acid concentrations at all temperatures up to and including the normal boiling points. This high degree of resistance is unexcelled when compared to other commercially available metals and alloys, and is represented graphically by the isocorrosion diagram in Figure 2. This diagram depicts the resistance of Duriron for any combination of acid concentration and temperature. The curves are isocorrosion lines which delineate areas having corrosion rates less than 5 mils penetration per year (mpy) and between 5 and 20 mpy.

From this illustration, a low and acceptable corrosion rate can be expected for all concentrations to the boiling point. This resistance can be termed “excellent” for the majority of conditions since the corrosion rate is below 5 mpy. This is especially the case for the higher concentrations (above 60%) where the corrosion rates are nil even at boiling temperatures. It is in the intermediate concentration range that slightly higher rates of corrosion are observed, but despite these higher corrosion rates the resistance of Duriron is still considered good for chemical plant equipment. The maximum attack occurs in 30% boiling sulfuric acid where the rate is 20 mpy.

Duriron and Durichlor 51M are rapidly attacked in sulfuric acid concentrations over 100% (oleum or fuming acid). They should not be used for this service or any other containing free sulfur trioxide.

It is important to note that the corrosion resistance of Duriron and Durichlor 51M improves with time after the initial stages of exposure. Initially, the alloy will corrode at a very rapid rate, during which time a resistant film is being formed. After approximately 48 hours, a steady low rate is achieved and this will not change even under severe conditions. (See Figure 3.)

**Figure 2.**
**Resistance of Duriron to Sulfuric Acid**

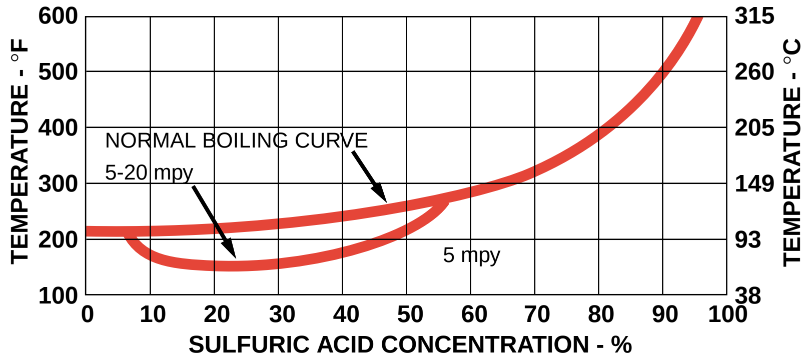



**Figure 3.**
**Effect of Time on Corrosion Rate of Duriron in Boiling 30% Sulfuric Acid**

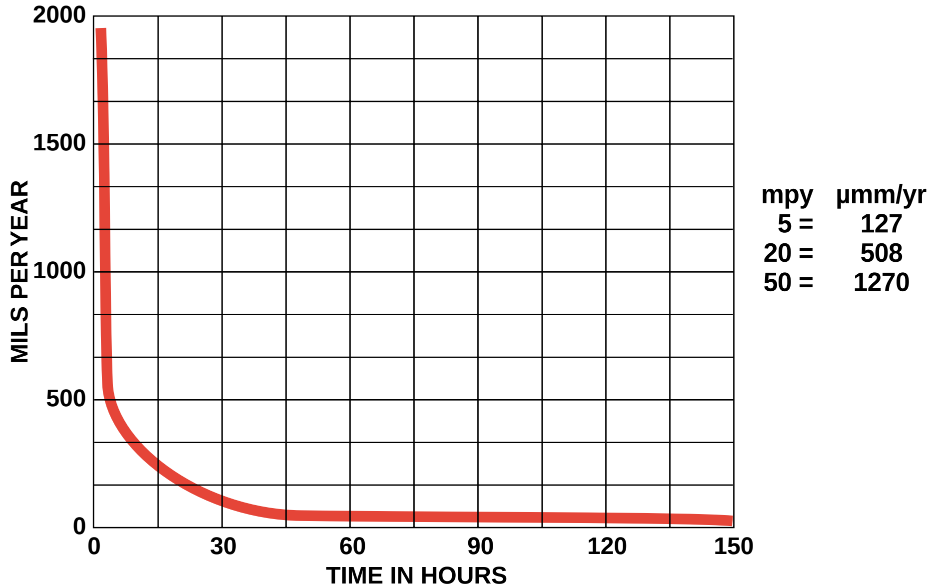
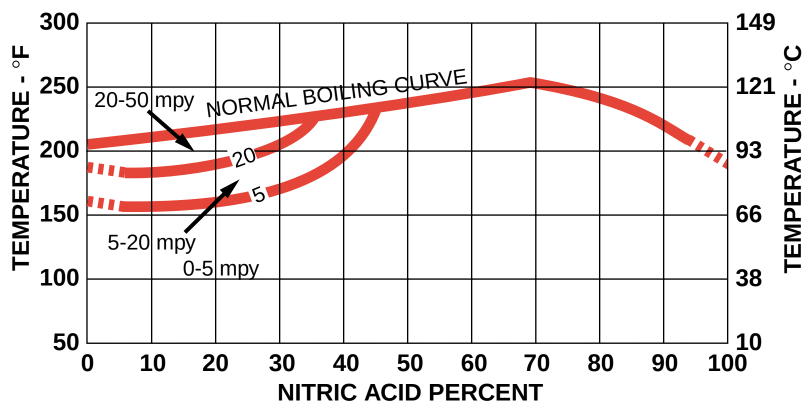



**Figure 4.**
**Resistance of Duriron to Nitric Acid**



Duriron and Durichlor 51M are used extensively in all phases of the chemical and metallurgical industries where sulfuric acid solutions are handled. For instance, high silicon iron is almost exclusively the material of construction for pumps used in the production of sulfuric acid by the chamber process. Corrosive conditions in the concentration of comparatively dilute acid solutions are normally handled by Duriron concentrator equipment. Other important uses of high silicon iron for sulfuric acid containing process liquors and slurries are: fertilizer plants, pickling solutions, explosive plants, ore digestion installations, electroplating and anodizing processes, and water treatment systems.

Additionally, high silicon iron is utilized in titanium dioxide pigment plants where severely erosive and corrosive conditions are encountered. Outstanding corrosion resistance and hardness account for the resistance of Duriron and Durichlor 51M to erosive and corrosive conditions which cause the destruction of less resistant materials. Duriron is superior to lead and the stainless steels, including Alloy 20, in many erosion-corrosion services involving sulfuric acid or slurries containing this acid. In every instance the stainless steel or lead were considered satisfactory from the corrosion standpoint, but failed due to erosion.

## Nitric Acid Resistance

High silicon iron equipment is used extensively in the manufacture of nitric acid. Duriron and Durichlor 51M show good to excellent resistance under all conditions. They are especially superior to stainless steels under severe conditions such as nitric acid concentrators where contact with strong, hot nitric acid corrodes the welded stainless steel equipment despite careful heat treatment after welding. Additionally, fuming nitric acid does not attack the high silicon irons.

Duriron and Durichlor 51M are suitable for use in all concentrations of nitric acid at normal temperatures. Increasing the temperature has very little effect on its corrosion resistance. Boiling nitric acid at concentrations above 50 percent has no effect on high silicon iron, although weak solutions do show a very slight attack. See Figure 4 for an isocorrosion diagram of Duriron in nitric acid.

The resistance of Duriron and Durichlor 51M to nitric acid solutions containing other constituents depends entirely on their resistance to the other constituents. These alloys are not recommended for nitric acid solutions containing fluorides or fluoride compounds.

A few examples of successful applications of high silicon iron equipment in nitric acid services follow:

1. Many chemical plants use Duriron equipment in the production of nitric acid by the sodium nitrate-sulfuric acid method. They use complete Duriron installations including denitrators, towers, condensers, and pipe.
2. In plants making nitric acid by the ammonia-oxidation process, High Silicon Iron equipment is used extensively in the form of pipe, condensers, pumps, tank outlets, towers, and packing (Raschig rings).
3. One chemical plant is using Duriron equipment on all concentrations of nitric acid at various temperatures including strong nitric at a very high temperature. They have not found any nitric acid applications for which Duriron is not suitable.

## Hydrochloric Acid Resistance

The comparatively low price of Durichlor 51M makes it an economical material to handle all concentrations of hydrochloric acid up to 80°F.

Most alloys that possess any degree of resistance to commercially pure hydrochloric acid are normally completely unsuitable when even small amounts of ferric chloride are present. In striking contrast, Durichlor 51M exhibits lower corrosion rates in up to 20% hydrochloric acid when ferric chloride and other oxidizing contaminants are present. However, above 20% hydrochloric acid, ferric chloride can accelerate the corrosion rate of Durichlor 51M. For instance, in commercially pure 20% hydrochloric acid at 175°F, Durichlor 51M would exhibit an excessively high corrosion rate and would not be suitable for these conditions. However, by the addition of as little as 0.02% ferric chloride the corrosion is inhibited to such an extent that Durichlor 51M is completely suitable. It is in ferric chloride containing hydrochloric acid solutions that Durichlor 51M possesses marked superiority over the now obsolete molybdenum-bearing high silicon iron, called Durichlor. Consequently, Durichlor 51M is suitable for many straight transfer and recirculation applications without fear of any deleterious concentration of ferric chloride.

Laboratory test data that accurately predicts the service life of Durichlor 51M for a given hydrochloric acid condition is extremely difficult to obtain. Durichlor 51M shows a high initial rate of attack in this acid until a state of "passivity" develops. In laboratory corrosion testing below 20% hydrochloric acid, this initial attack can provide sufficient iron contamination to cause the formation and accumulation of enough ferric chloride to render the results unreliable. In actual service th ferric chloride levels would not accumulate and adversely affect the corrosion rates of the high silicon iron. Hence, tests should be conducted in the actual process stream wherever possible.

## Other Media

The resistance of Duriron and Durichlor 51M to a long list of common corrosive chemicals has been included on page 8. The list is intended solely as a guide and should not be considered a specific recommendation for any particular operating condition. However, this list was derived from experience gained through 85 years of handling corrosive chemicals and reflects the practical aspects of corrosives handling. The descriptions "excellent resistance," "good resistance," and "poor resistance" have been used. "Excellent resistance" means negligible corrosion was observed or is expected. "Good resistance" means some corrosion occurs but experience with pumps and other equipment indicate that an economical service life may be expected. "Poor resistance" indicates these alloys are not satisfactory for use in the particular chemical indicated. Unless specified restrictions are cited, the statements pertain to all concentrations up to the normal boiling points.

Hydrofluoric acid or any solution containing fluoride compounds will rapidly attack the high silicon irons. Additionally, oleum or any other environment containing sulfur trioxide is detrimental to the high silicon irons. Similarly, sulfurous acid, sulfur dioxide, some sulfides, and sulfites rapidly corrode these alloys. Finally, hot, strong alkalies or alternating acid-alkaline conditions will also yield high corrosion rates.

Many factors influence the corrosion resistance of any alloy in service. The factors that must be given consideration are temperature, concentration, aeration, influence of inhibiting or accelerating contaminants, influence of recirculation, solids in suspension, velocity, continuity, or frequency of use, and equipment design. The influence of contaminants is probably the most important factor from a commercial standpoint, for while the majority of contaminants have no influence on corrosion, those that do, generally affect the conditions greatly.

Flowserve Corporation urges the proposed user of Duriron and Durichlor 51M to contact our nearest office, giving a complete description of the service with regard to the factors noted above. In this way our staff of engineers can study your problem and make recommendations based on their extensive experience in the field of corrosion and their knowledge of the high silicon iron alloys.

| | EXCELLENT RESISTANCE | | GOOD RESISTANCE | | POOR RESISTANCE | |
|---|---|---|---|---|---|---|
| | D | D51M | D | D51M | D | D51M |
| Acetaldehyde | ● | ● | | | | |
| Acetic Solvents | ● | ● | | | | |
| Acetic Acid | ● | ● | | | | |
| Acetic Anhydride | ● | ● | | | | |
| Acetone | ● | ● | | | | |
| Alcohol | ● | ● | | | | |
| Alum | ● | ● | | | | |
| Aluminum Chloride | | ● | ● | | | |
| Aluminum Sulfate | ● | ● | | | | |
| Amines | ● | ● | | | | |
| Ammonium Bicarbonate | ● | ● | | | | |
| Ammonium Chloride | | ● | ● | | | |
| Ammonium Fluoride | | | | | ○ | ○ |
| Ammonium Nitrate | ● | ● | | | | |
| Ammounium Persulfate | ● | ● | | | | |
| Ammonium Phosphate | ● | ● | | | | |
| Ammonium Sulphate | ● | ● | | | | |
| Aniline Dyes | ● | ● | | | | |
| Aniline Hydrochloride | | | | ● | | |
| Anodizing Solutions | | | ● | ● | | |
| Antimony Trichloride | | | ● | ● | | |
| Arsenic Acid | | | ● | ● | | |
| Barium Chloride | | ● | ● | | | |
| Barium Nitrate | ● | ● | | | | |
| Barium Sulfate | ● | ● | | | | |
| Benzene Sulfonic Acid | ● | ● | | | | |
| Benzoic Acid | ● | ● | | | | |
| Benzol | ● | ● | | | | |
| Boric Acid | ● | ● | | | | |
| Brine | ● | ● | | | | |
| Bromine | | | | | ○ | ○ |
| Butyric Acid | ● | ● | | | | |
| Cadmium Sulfate | ● | ● | | | | |
| Calcium Arsenate | ● | ● | | | | |
| Calcium Bisulfite | | | | | ○ | ○ |
| Calcium Chloride | ● | ● | | | | |
| Calcium Phosphate | ● | ● | | | | |
| Carbon Bisulfide | | | ● | ● | | |
| Carbonic Acid | ● | ● | | | | |
| Carbon Tetrachloride | | ● | ● | | | |
| Cellulose Acetate | ● | ● | | | | |
| Chlorinated Water | | ● | ● | | | |
| Chloracetic Acid | | ● | ● | | | |
| Chlorosulfonic Acid | | ● | ● | | | |
| Chromic Acid | ● | ● | | | | |
| Citric Acid | ● | ● | | | | |
| Copper Nitrate | ● | ● | | | | |
| Copper Sulfate | ● | ● | | | | |
| Cuprous Chloride | ● | ● | | | | |
| Ethylene Dichloride | | ● | ● | | | |
| Ethylene Glycol | ● | ● | | | | |
| Fatty Acids | ● | ● | | | | |
| Ferric Acetate | ● | ● | | | | |
| Ferric Nitrate | ● | ● | | | | |
| Ferric Sulfate | ● | ● | | | | |
| Ferrous Chloride | ● | ● | | | | |
| Ferrous Sulfate | ● | ● | | | | |
| Formaldehyde | ● | ● | | | | |
| Formic Acid | ● | ● | | | | |
| Gallic Acid | ● | ● | | | | |
| Glycerine | ● | ● | | | | |
| Hydrocarbons | ● | ● | | | | |
| Hydrofluoric Acid | | | | | ○ | ○ |
| Hydrofluosilicic Acid | | | | | ○ | ○ |
| Hydrogen Peroxide | | | ● | ● | | |
| Iodine | | | | | ○ | ○ |
| Lactic Acid | ● | ● | | | | |
| Lead Acetate | ● | ● | | | | |
| Lead Nitrate | ● | ● | | | | |
| Lead Sulfide | | | ● | ● | | |
| Lithopone | | | ● | ● | | |
| Magnesium Chloride | | ● | ● | | | |
| Magnesium Sulfate | ● | ● | | | | |
| Maleic Acid | | | ● | ● | | |
| Malic Acid | ● | ● | | | | |
| Manganese Chloride | | ● | ● | | | |
| Mercuric Nitrate | ● | ● | | | | |
| Mercuric Sulfate | ● | ● | | | | |
| Mercurous Sulfate | ● | ● | | | | |
| Mine Water | | | ● | ● | | |
| Mixed Acid | ● | ● | | | | |
| Nickel Chloride | ● | ● | | | | |
| Nickel Sulfate | ● | ● | | | | |
| Nicotine Sulfate | ● | ● | | | | |
| Nitrobenzene | ● | ● | | | | |
| Nitrous Acid | ● | ● | | | | |
| Oleic Acid | ● | ● | | | | |
| Oleum | | | | | ○ | ○ |
| Oxalic Acid | ● | ● | | | | |
| Perchloric Acid | ● | ● | | | | |
| Phenol | ● | ● | | | | |
| Phthalic Acid | ● | ● | | | | |
| Picric Acid | ● | ● | | | | |
| Potassium Bisulfate | ● | ● | | | | |
| Potassium Chloride | | ● | ● | | | |
| Potassium Nitrate | ● | ● | | | | |
| Potassium Sulfate | ● | ● | | | | |
| Pyridine Sulfate | ● | ● | | | | |
| Pyrogalic Acid | ● | ● | | | | |
| Pyroligneous Acid | ● | ● | | | | |
| Saicyclic Acid | ● | ● | | | | |
| Sodium Bicarbonate | ● | ● | | | | |
| Sodium Bichromate | | | ● | ● | | |
| Sodium Bisulfate | ● | ● | | | | |
| Sodium Chlorate | | ● | ● | | | |
| Sodium Chloride | | ● | ● | | | |
| Sodium Nitrate | ● | ● | | | | |
| Sodium Perchlorate | | ● | ● | | | |
| Sodium Phosphate | | | ● | ● | | |
| Sodium Sulfate | ● | ● | | | | |
| Sodium Sulfide | | | ● | ● | | |
| Sodium Sulfite | | | | | ○ | ○ |
| Sodium Thiosulfate | ● | ● | | | | |
| Stannous Chloride | | | ● | ● | | |
| Stearic Acid | ● | ● | | | | |
| Succinic Acid | ● | ● | | | | |
| Sugar Solutions | ● | ● | | | | |
| Sulfite Liquors | | | | | ○ | ○ |
| Sulfur | | | ● | ● | | |
| Sulfur Dioxide | | | | | ○ | ○ |
| Sulfurous Acid | | | | | ○ | ○ |
| Tannic Acid | ● | ● | | | | |
| Tanning Liquors | ● | ● | | | | |
| Tartaric Acid | ● | ● | | | | |
| Titanium Sulfate | ● | ● | | | | |
| Titanium Dioxide | ● | ● | | | | |
| Toluol | ● | ● | | | | |
| Trichloroethylene | ● | ● | | | | |
| Urine | ● | ● | | | | |
| Vegetable Juices | ● | ● | | | | |
| Vinegar | ● | ● | | | | |
| Vinegar Brines | ● | ● | | | | |
| Zinc Chloride | | ● | ● | | | |
| Zinc Sulfate | ● | ● | | | | |

● Normal resistance for most service conditions. ○ Duriron and Durichlor 51 should not be used for this corrosive. D = Duriron D51M = Durichlor 51M




Printed in U.S.A.
July 2002