

# Contents

Foreword	1	Decorative Cast Iron	56
<b>Part I: A Historical Survey of Metals</b>	<b>3</b>	Stairs and Elevators	56
<b>Chapter 1. Introduction</b>	<b>5</b>	Lintels and Grilles	62
<b>Chapter 2. Lead</b>	<b>8</b>	Verandas and Balconies	64
Roofing and Related Items	8	Railings, Fences, and Cresting	64
Lead-coated Metals	9	Street Furniture and Lighting	64
Window Cames	10	Fountains and Statues	66
Sculpture	11	Tombs	72
Paint	11	Rolled Sheet Iron and Steel	72
<b>Chapter 3. Tin</b>	<b>12</b>	Steels	74
Pure Tin	12	Structural Steel	74
Tinplate	12	Stainless Steel	79
Tinplate Roofing and Related Items	12	Copper-Bearing Steels	79
Decorative Uses	13	<b>Chapter 8. Aluminum</b>	<b>84</b>
<b>Chapter 4. Zinc</b>	<b>15</b>	<b>Part II: Deterioration and Methods of</b>	
Pure Zinc Roofing and Related Items	15	<b>Preserving Metals</b>	<b>89</b>
Zinc-coated Metals	15	<b>Chapter 9. Preservation of Architectural Metals</b>	<b>90</b>
Decorative Uses	15	<b>Chapter 10. Causes of Metal Deterioration and Failure</b>	<b>92</b>
Paint	21	Corrosion	92
<b>Chapter 5. Copper and Copper Alloys</b>	<b>22</b>	Uniform Attack	92
Copper	22	Pitting	92
Roofing and Related Items	23	Selective Attack	92
Decorative Uses	24	Stress Corrosion Cracking	92
Bronze	27	Corrosion Erosion	92
Brass	31	Galvanic Corrosion	92
<b>Chapter 6. Nickel and Nickel Alloys</b>	<b>35</b>	Oxygen Concentration Cell	93
Nickel Silver	35	Atmospheric Corrosion	93
Monel Metal	39	Corrosive Agents	93
<b>Chapter 7. Iron and Iron Alloys</b>	<b>42</b>	Mechanical Breakdown	93
Wrought Iron	42	Abrasion	93
Decorative Wrought Iron	42	Fatigue	93
Structural Wrought Iron	44	Creep	95
Cast Iron	50	Fire	95
Structural Cast Iron	50	Overloading	95
Columns	50	Weathering	95
Building Fronts	51	Connection Failure	95
Domes and Cupolas	56	<b>Chapter 11. General Preservation Methods</b>	<b>97</b>
Lightcourts and Skylights	56	Introduction	97

Proper Design.....	98	<b>Chapter 16. Nickel and Nickel Alloys;</b>	
Control of the Environment.....	98	<b>Preservation and Repair.....</b>	<b>128</b>
Dehumidification.....	98	Identification.....	128
Cathodic Protection.....	98	Nickel.....	128
Corrosion Inhibitors.....	98	Nickel Silver.....	128
Protection with Applied Coatings.....	98	Monel Metal.....	128
Cleaning.....	99	Causes of Deterioration.....	128
Mechanical Repairs.....	99	Methods of Preservation and Repair.....	128
Patching.....	99	<b>Chapter 17. Iron and Iron Alloys;</b>	
Splicing.....	99	<b>Preservation and Repair.....</b>	<b>130</b>
Reinforcing.....	100	Identification.....	130
Duplication and Replacement.....	100	Iron.....	130
<b>Chapter 12. Lead; Preservation and Repair.....</b>	<b>101</b>	Wrought Iron.....	130
Identification.....	101	Cast Iron.....	130
Causes of Deterioration.....	101	Steel.....	130
Methods of Preservation and Repair.....	102	Galvanized Steel.....	130
<b>Chapter 13. Tin; Preservation and Repair.....</b>	<b>104</b>	Stainless Steel.....	130
Identification.....	104	Causes of Deterioration.....	131
Causes of Deterioration.....	104	Iron and Steel.....	131
Methods of Preservation and Repair.....	104	Cast Iron.....	131
Priming and Painting.....	105	Wrought Iron.....	131
Replacement.....	105	Steel.....	131
<b>Chapter 14. Zinc; Preservation and Repair.....</b>	<b>111</b>	Galvanized Iron and Steel.....	131
Identification.....	111	Stainless Steel.....	131
Causes of Deterioration.....	111	Copper-Bearing Steel.....	135
Methods of Preservation and Repair.....	113	Methods of Preservation and Repair.....	135
<b>Chapter 15. Copper and Copper Alloys;</b>		Cleaning and Coatings.....	135
<b>Preservation and Repair.....</b>	<b>118</b>	Paint Coatings.....	136
Identification.....	118	Plating and Glazes.....	140
Copper.....	118	Repairs.....	140
Bronze.....	118	Replacement.....	142
Brass.....	118	Substitute Materials.....	142
Causes of Deterioration.....	118	Stainless Steel.....	147
Copper.....	118	<b>Chapter 18. Aluminum; Preservation and Repair.....</b>	<b>149</b>
Bronze and Brass.....	119	Identification.....	149
Methods of Preservation and Repair.....	125	Causes of Deterioration.....	150
Copper.....	125	Methods of Preservation and Repair.....	151
Bronze and Brass.....	125	Notes.....	154
		<b>Selected Bibliography.....</b>	<b>157</b>

## Identification

**Nickel** is an inactive, corrosion resistant, metal, silvery or off-white in color, which resembles iron in strength and toughness and copper in its resistance to oxidation and corrosion.<sup>61</sup> Nickel is ferromagnetic and can be hot or cold rolled, forged, bent, extruded, spun, punched, and deep drawn. For architectural purposes, nickel is used in the form of alloys such as nickel silver, Monel, and stainless steel. Nickel has also been used to plate brass and nickel silver.

Coating of nickel and nickel alloys can be applied for decorative or protective reasons to other metals such as aluminum, beryllium-copper, brass, copper, iron, magnesium. Monel and other nickel alloys, lead-base alloys, steel, tin, and zinc.<sup>62</sup> Electroplating is the most common method of applying the coating, although methods using chemical reactions, pressure welding by hot rolling and spraying or vapor-deposition are becoming more common.<sup>63</sup>

**Nickel silver**, originally called "German silver," is a class of nickel alloys, none of which contain any silver. Rather, it gets its name from its silver-white color and its ability to take a high polish. Its composition is similar to brass with nickel added. There were many companies that made nickel silver, each with a slightly different formula and trademark. The proportions varied from 5 to 30% nickel, 10 to 35% zinc, 50-80% copper, and small quantities of tin and lead when cast.

Nickel silver is ductile, hard, and moderately strong. Some nickel silvers have the strength of mild steel and their structural use is limited only by cost. The metal can be cast, forged, rolled, drawn, extruded, and machined; and nickel silver parts can be hard and soft soldered<sup>64</sup> and spot-, arc-, and fusion-welded.

**Monel** metal is a registered trademark name for an alloy of approximately two-thirds nickel and one-third copper with small amounts of iron, manganese, silicon, and carbon. It is similar in appearance to nickel and can either take high polish or be left with a matte finish.

Monel is harder to work than iron. It can be forged, cast, welded, annealed, soldered, brazed, spun and drawn,<sup>65</sup> but it cannot be extruded.<sup>66</sup> Monel has a low coefficient of expansion comparable to that of concrete.<sup>67</sup> It thus resists fatigue cracking caused by thermal expansion and contraction. The high rigidity of Monel permits its transfer or movement to expansion joints without

buckling the metal.

Nickel is one of the three main ingredients of *chrome-nickel steel*, commonly known as stainless steel. It will be discussed in detail in chapter 17 on iron and steel.

## Causes of Deteriorated

Nickel resists corrosion by salt water, strong alkalis, and most acids, except nitric acid.<sup>68</sup> In nickel components, galvanic corrosion can be avoided by using a base metal or alloy close to nickel in the galvanic series (that is, stainless steel) and by insuring that the nickel coating is thick, nonporous, and continuous.<sup>69</sup> Nickel silver resists corrosion, especially outdoors where it acquires a soft brown or greenish patina that protects the metal from further corrosion. Monel metal is attacked by some acids, alkalis, and salts.<sup>70</sup> When Monel oxidizes, it forms a silver-gray to greenish-brown protective patina (figure 156). Nickel silver and Monel used indoors can usually be cleaned with a mild (non-ionic) detergent and a wetting agent. Outdoors, nickel silver and Monel with natural patinas are usually cleaned in the same manner as other copper alloys (see bronze and brass).<sup>71</sup>

It is often difficult to differentiate the "white metals" (see part I, chapter 6), as nickel, nickel silver, Monel, stainless steel, and aluminum were often called. Most buildings containing white metals were built in the 20th century. Building records often exist that will identify the metal and perhaps even the specific nickel content and fabricator. If records do not exist or evidence is conflicting, the physical remains may be the only source of information. The procedures in "Simple Tests Identify White Metals" (see bibliography) may be dangerous because they involve the use of different acids and may damage the building if not performed correctly in an inconspicuous spot. Only a professional, such as a chemist, metallurgist, metal conservator, or corrosion engineer trained in the use of these materials, should perform these tests.<sup>72</sup>

## Methods of Preservation and Repair

Nickel can be brazed, soldered, and welded by metallic arc, electric resistance, oxyacetylene, and atomic hydrogen processes. In soldering nickel, acid flux solder should be used. For use with Monel, prepared "cut acid" soldering fluxes consisting of zinc and hydrochloric acid<sup>73</sup> are available. To prevent corrosion, every trace

of the flux must be removed after the soldering is completed.

For Monel metal roofing and sheathing, only fastenings and nails of Monel or other nickel alloys should be used to prevent galvanic corrosion.

Where the nickel plating has worn away or been damaged, the only solution is to replate the base metal with a new coating of nickel. To replate an architectural element, it must first be removed from the building and thoroughly cleaned.<sup>74</sup> Care must be taken not to damage the object when disassembling it. After removal, it can be given an electro-coating of copper to clean or smooth out the surface. The element is then immersed in an electrolytic solution of nickel salts where the element acts as the cathode and the nickel in the solution acts as an anode. Nickel is deposited on the element from the electrolyte. The thickness of the nickel coating can be controlled by the strength of the electrolyte and the amount of time the element is immersed in it.



**Figure 156. Oxidation of Monel.** *These exterior doors on the Headquarters of the United Mine Workers of America in Washington, D.C., have a greenish-brown patina of oxidation and an accumulation of dirt and fingerprints. Although the patina is protective, it is not attractive, and detracts from the overall appearance of the building. The push bars are brass with chrome plating which has worn through. To restore the doors to their original appearance, they should be cleaned and polished; and the push bars should be removed, cleaned, polished, replated, and reinstalled. (David W. Look)*

## Identification

**Iron** is a gray-white metal, which in its pure form is relatively soft, tough, malleable, ductile, magnetic, and high in tensile strength. It oxidizes rapidly when exposed to a damp atmosphere and is readily attacked by most acids. When alloyed with small amounts of carbon to form steel, it can be hardened by heating and *sudden cooling*, or made more workable by heating and *slow cooling*.<sup>75</sup> Historically, iron in a number of alloy forms has been used for architectural purposes. These alloys include cast iron, wrought iron, various types of steels, iron, and steel sheet metals, and stainless steel.

**Wrought Iron** is defined as a commercial iron consisting of slag (iron silicate) fibers entertained in a ferrite matrix.<sup>76</sup> It is almost pure iron with less than 1 percent (usually 0.02 to 0.03%)<sup>77</sup> carbon. The slag content varies between 1 and 4% (usually about 2.5%). The slag exists in a purely physical association, that is, it is not alloyed;<sup>78</sup> this gives wrought iron its characteristic laminated structure. The fundamental differences between wrought iron and steel are in their compositions and methods of processing. Steel is cast at a white heat into ingot; wrought iron is removed from the furnace at a lower temperature in a semi-molten plastic condition together with slag, then is formed into bars with most of the slag hammered out.<sup>79</sup> The presence of slag in the composition of wrought iron distinguishes it from steel. Wrought iron also contains less carbon and manganese and usually more phosphorus than steel.<sup>80</sup>

Wrought iron is relatively soft, malleable, tough fatigue-resistant, and easily worked by forging, bending, rolling, and drawing. Until steel was available, wrought iron was used structurally for beams and girders as it had strength in both tension and compression. During the late 19th and early 20th centuries, it was not unusual to find a mixture of cast-iron columns and wrought iron or steel beams in the same building. Currently very little wrought iron is being produced.

**Cast Iron** is an alloy with a high carbon content (at least 1.7% and usually 3.0 to 3.7%)<sup>81</sup> that makes it more resistant to corrosion than either wrought iron or steel. In addition to carbon, cast iron contains varying amounts of silicon, sulfur, manganese, and phosphorus.

While molten, cast iron is easily poured into molds, making it possible to create nearly unlimited decorative and structural forms. Unlike wrought iron and steel, cast

iron is too hard and brittle to be shaped by hammering, rolling, or pressing.<sup>82</sup> However, because it is more rigid and more resistant to buckling than other forms of iron, it can withstand great compression loads.<sup>83</sup> Cast iron is relatively weak in tension, however, and fails under tensile loading with little prior warning.

The characteristics of various types of cast iron are determined by their composition and the techniques used in melting, casting, and heat treatment. Metallurgical constituents of cast iron that affect its brittleness, toughness, and strength include ferrite, cementite, pearlite, and graphite carbon.<sup>84</sup> Cast iron with flakes of carbon is called gray cast iron. The "gray fracture" associated with cast iron was probably named for the gray, grainy appearance of its broken edge caused by the presence of flakes of free graphite, which account for the brittleness of cast iron. This brittleness is the important distinguishing characteristic between cast iron and mild steel.<sup>85</sup>

Compared with cast iron, wrought iron is relatively soft, malleable, tough, fatigue-resistant, and readily worked by forging, bending, and drawing. It is almost pure iron, with less than 1% (usually 0.02 to 0.03%) carbon. Slag varies between 1% and 4% of its content and exists in a purely physical association, that is, it is not alloyed. This gives wrought iron its characteristic laminated (layered) or fibrous structure.

Wrought iron can be distinguished from cast iron in several ways. Wrought-iron elements generally are simpler in form and less uniform in appearance than cast-iron elements, and contain evidence of rolling or hand working. Cast iron often contains mold lines, flashing, casting flaws, and air holes. Cast-iron elements are very uniform in appearance and are frequently used repetitively. Cast-iron elements are often bolted or screwed together, whereas wrought-iron pieces are either riveted or forge-molded (heat welded) together.

Mild steel is now used to fabricate new hand-worked metal work and to repair old wrought-iron elements. Mild steel is an alloy of iron and is not more than 2% carbon, which is strong but easily worked in block or ingot form. It is not as resistant to corrosion as either wrought iron or cast iron.

**Steel** is an alloy of iron and carbon that contains not more than 2% carbon, and is malleable in block or ingot form. Steels may include phosphorus, sulfur, oxygen, manganese, silicon, aluminum, copper, titanium, molybdenum, and nickel. The properties of steels vary greatly

in relation to their chemical compositions and the types of heat treatment and mechanical working used in their manufacture.<sup>86</sup> Characteristic affected by these differences include strength, hardness, ductility, resistance to abrasion, weldability, machinability, and resistance to corrosion.

The classification of steel is based on its carbon content, as shown in the following comparison:<sup>87</sup>

- Low carbon steel—up to 0.2% carbon
- Mild steel—up to 0.25% carbon
- Medium carbon steel—0.25 to 0.45% carbon
- High carbon steel—0.45 to 2% carbon

In the late 1880s, steel began to overtake wrought iron in structural systems, and became dominant in the 20th century. A grade of medium carbon steel is used for most structural applications today, while high-strength alloy steels are available for specialized installations.

**Galvanized Steel** consists of sheet steel with a zinc coating, which makes it highly resistant to corrosion.<sup>88</sup> (See chapter 14 on zinc for further information on preservation treatments.)

**Stainless Steel** is defined as a steel containing sufficient chromium, or chromium and nickel, to render it highly resistant to corrosion. The composition of stainless steel must be over 50% iron and 11.5% chromium, with the remaining constituents including nickel, columbium, molybdenum, phosphorus, selenium, silicon, sulfur, titanium, and zirconium.<sup>89</sup> Stainless steel is malleable, is hardened by cold working, and is resistant to oxidation, corrosion, and heat. It has characteristics of high thermal expansion and low heat conductivity, and can be forged, soldered, brazed, and welded. Chromium-nickel stainless steel (for example 18-8—18% chromium and 8% nickel) is termed austenitic. It non-magnetic, but ferritic chromium stainless steel is magnetic.

Four stainless steel alloys most commonly used in architectural work are AISI Types 302, 304, 316, and 430.<sup>90</sup> The 300 series alloys are austenitic chromium nickel steels. Type 302 is an austenitic alloy containing 18% chromium and 8% nickel. It has been widely used in building exteriors for many years. It is highly resistant to atmospheric corrosion, very strong and hard, available in many forms, and fabricated easily by all standard techniques. Type 304 is a low carbon variation of Type 302 having similar properties but improved weldability. It has largely replaced Type 302 in architectural applications and is the type most readily available in many forms. Type 316 contains more nickel than Types 302 or 304, as well as 2% to 3% molybdenum, added to improve corrosion resistance. It is often used in locations exposed to severe marine environments or the extremely corrosive industrial atmospheres.

Type 430 is a ferritic chromium alloy which is somewhat less resistant to corrosion than the 300 series of austenitic alloys. It has been found suitable for interior applications and for exterior applications which receive frequent maintenance.

## Causes of Deterioration

**Iron and Steel** (when unprotected) oxidize rapidly when exposed to moisture and air, except for some of

the corrosion-resistant alloy steels and stainless steels (figure 157). The oxidation of iron and steel is a highly destructive process (figure 158). The product of this oxidation is rust, which initially consists of a mixture of ferrous and ferric hydroxides ( $\text{FeO}$ ), and later becomes a hydrated ferric oxide ( $\text{Fe}_2(\text{OH})_3$ ) with some traces of a carbonate.<sup>91</sup> The minimum relative humidity necessary to promote rusting is 65%, but this figure can be lower in the presence of pollutants.<sup>92</sup> When salts are present, they act as electrolytes, accelerating the corrosion of iron and steel and making it more complicated. Once a rust film occurs, its porosity acts as a reservoir for any liquid present,<sup>93</sup> which also tends to accelerate corrosion. If simple oxidation is not arrested, its rate will accelerate until the metal is completely destroyed.

Iron and steel are also corroded by the following: sea water, salt air, acids, soils, gypsum plasters, magnesium oxychloride cements,<sup>94</sup> ashes and clinkers, and some sulfur compounds. Corrosion is accelerated where architectural details provide pockets and crevices to catch and hold these corrosive agents (figure 156).

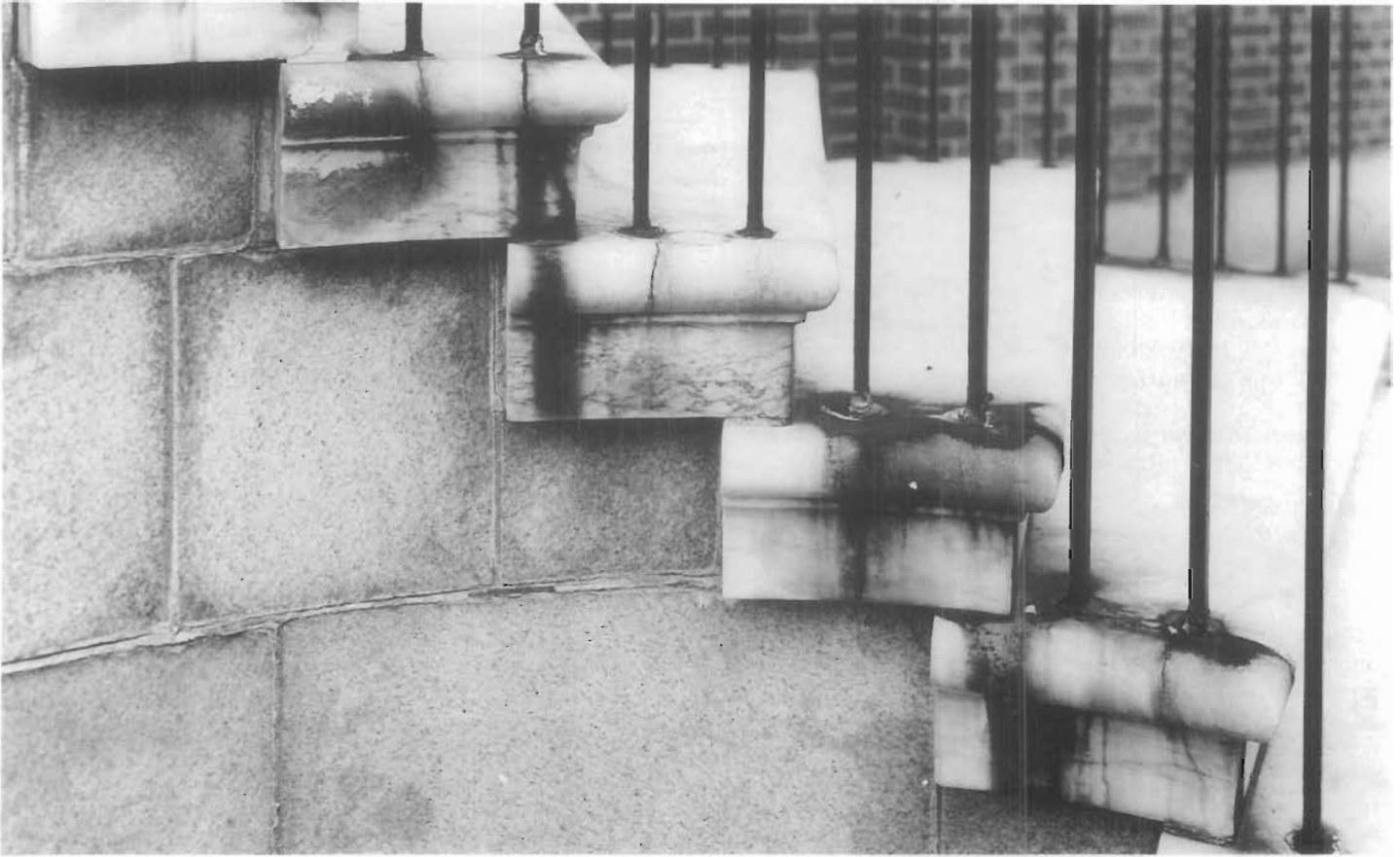
Galvanic corrosion will occur in varying degrees when iron and steel are exposed to cupro-nickels, aluminum bronzes, gun metals, copper (see figures 145 and 146), brasses, lead, soft solders, stainless steels, and chromium.<sup>95</sup>

**Cast Iron** develops a kind of protective scale on its surface, thus it is slightly more resistant to corrosion than ordinary steel. However, although it generally has some resistance to corrosion, cast iron should be kept painted to prevent rusting (figure 160).

A form of deterioration that is unfortunately fairly common is caused by inappropriate repairs. These not only disfigure a building (figure 161) but also decrease its architectural integrity.

Graphitization of cast iron, a less common problem, occurs in the presence of acid precipitation or seawater. As the iron corrodes, the porous graphite (soft carbon) corrosion residue is impregnated with insoluble corrosion products. As a result, the cast-iron element retains its appearance and shape but is weaker structurally.<sup>96</sup> Graphitization occurs where cast iron is left unpainted for long periods or where caulked joints have failed and acidic rainwater has corroded pieces from the backside. Testing and identification of graphitization is accomplished by scraping through the surface with a knife to reveal the crumbling of the iron beneath. Where extensive graphitization occurs, usually the only solution is replacement of the damaged element.

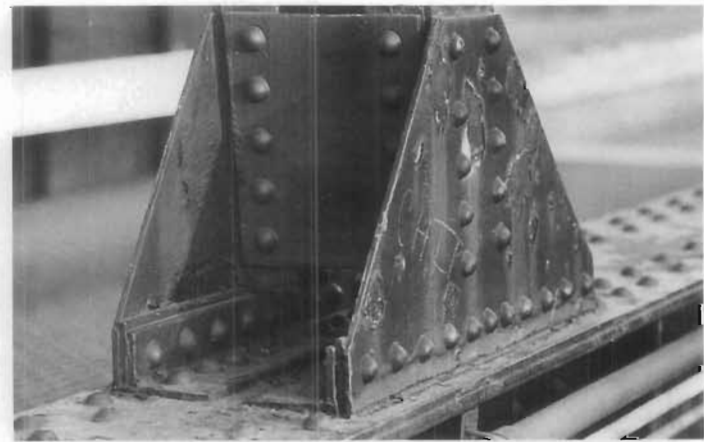
Castings may also be fractured or flawed as a result of imperfections in the original manufacturing process, such as air holes, cracks, and cinders (caused by the "freezing" of the surface of the molten iron during casting because of improper or interrupted pouring).<sup>97</sup> Brittleness is another problem occasionally found in old cast-iron elements. It may be a result of excessive phosphorus in the iron, or of chilling during the casting process. A number of nondestructive tests using, for example, fluorescent fluids and ultraviolet lamps, have been developed to detect these potential defects.<sup>98</sup>



**Figure 157. Stone Damage from Rust.** In the 1950s the stairs of Library Hall in Philadelphia were reconstructed. Since wrought iron was not available for the railing, steel was substituted. The design of the railing was poorly detailed. The bottoms of the balusters were fitted into stone steps. Not only did the rusting stain the steps, it cracked the stone because of the expansion in volume of the steel during rusting. (Jack E. Boucher)



**Figure 158. Advanced Corrosion of Rolled Iron.** This column base of a New York Central Railroad pedestrian overpass has not been well maintained and has rusted beyond repair. Such exposed ironwork should be painted regularly to keep it from contact with air and moisture. Note the characteristic way that wrought-iron rust exfoliates, or flakes off in layers. (John G. Waite)



**Figure 159. Defective Original Design Detail.** Corrosion of the connection between the girder and the built-up truss members has occurred on the former Delaware and Hudson Railroad Bridge, 1884, over the Hudson River between Troy and Green Island, New York, because the connection served as a pocket to trap rain and snow in an area difficult to maintain and protect. This connection is almost impossible to maintain without modification in the design. The connection should be sandblasted, primed immediately, and painted. Since the bottom of the vertical truss member is boxed in, which prevents painting with a brush, the inside of this member could be spray painted. (John G. Waite)



**Figure 160. Cast-iron Corrosion, Fracture, and Missing Pieces.** (a) The massive newel posts of the stair railings on the entrance of 637 I Street, NW in Washington, D.C., are hollow and are made up of several pieces screwed and bolted together. The newel post to the right side of the stairs is substantially intact. (b) The finial of the left newel post is missing. Note the threaded rod in the center of the newel post used for assembly. Inside the railing, loose rust has collected to a depth of about a half inch. Water seeped into the hollow rail and froze, resulting in the crack. (David W. Look)





Table II. Galvanic Series in Sea Water.

ACTIVE END (-)	Magnesium Magnesium Alloys Zinc Galvanized Steel
	Aluminum 1100
	Aluminum 6053 Alclad
	Cadmium
	Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)
	Mild Steel Wrought Iron Cast Iron
	13% Chromium Stainless Steel Type 410 (Active)
	18-8 Stainless Steel Type 304 (Active)
	18-12-3 Stainless Steel Type 316 (Active)
	Lead-Tin Solders Lead Tin
	Muntz Metal Manganese Bronze Naval Brass
	Nickel (Active) 76 Ni-16 Cr-7 Fe alloy (Active)
	60 Ni-30 Mo-6 Fe-1 Mn
	Yellow Brass Admiralty Brass Aluminum Brass Red Brass Copper Silicon Bronze
	70:30 Cupro Nickel G-Bronze M-Bronze Silver Solder Nickel (Passive) 76 Ni-16 Cr-7 Fe Alloy (Passive) 67 Ni-33 Cu Alloy (Monel)
	13% Chromium Stainless Steel Type 410 (Passive) Titanium
	18-8 Stainless Steel Type 304 (Passive) 18-12-3 Stainless Steel Type 316 (Passive)
(+) NOBLE or PASSIVE END	Silver  Graphite Gold Platinum

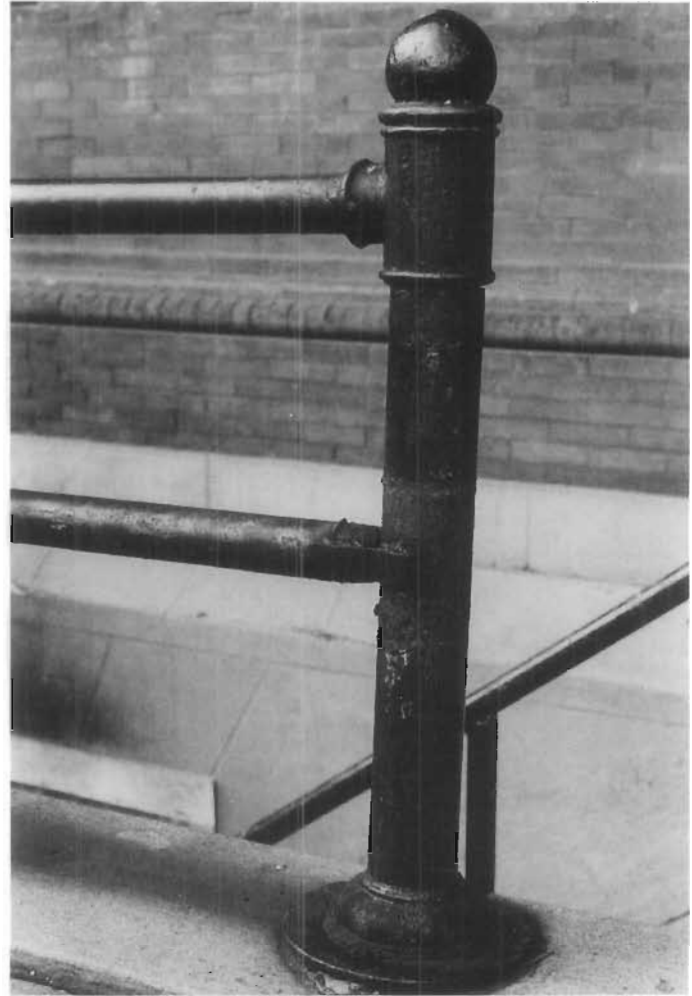


Figure 161. Inappropriate Repairs of Cast Iron. A simple cast-iron pipe railing guards the areaway of the Old Pension Building in Washington, D.C. The collar on the newel post to receive the bottom rail is missing (it probably cracked off from the pressure of expanding rust and/or ice). Unfortunately, a strap was welded to each side instead of repairing or reproducing the collar. (David W. Look)

Table II. Galvanic Series in Sea Water.

There is always an electrical potential difference between two different metals. Any time there are two dissimilar metals in electrical contact, the metal closer to the top of this table (most active) will act as an *anode* and will eventually be consumed by corrosion. The metal closer to the bottom of the table will act as a *cathode* and will be protected by the galvanic action. At the *anode*, positively charged atoms, called *positive ions*, separate from the metal and go into solution in the electrolyte such as ionized water. These positive ions travel through the electrolyte and "plate out" (deposit) on the cathode and release H<sub>2</sub> or reduce O<sub>2</sub> thus giving it an excess positive charge. The negatively charged particles, *electrons*, flow through the two metals (or conductors) as an electrical current to the cathode to neutralize the excess positive charge. (From American Society for Testing and Materials. Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance—G82-83.)

**Wrought Iron** generally rusts more quickly than cast iron, however the corrosion can be more readily measured and the degree of deterioration ascertained.<sup>97</sup> However, wrought iron is resistant to progressive (severe) corrosion, primarily because of the slag content<sup>100</sup> which acts as a barrier to corrosion.

**Steel** can resist rusting, but this varies from alloy to alloy. Those alloys containing chromium, nickel, or both, are far more resistant to corrosion than other alloys (see stainless steel). Both tests and experience have shown that high-strength low-alloy steels are more resistant to atmospheric corrosion than ordinary mild steel. Unlike cast iron, steel generally has poor resistance to corrosion from fresh water and sea water. The rate of corrosion increases as the temperature of the water surrounding a steel member rises<sup>101</sup> and as the water movement accelerates.

**Galvanized Iron and Steel** can resist corrosion, but this is dependent on the type and thickness of the protective zinc coating, the type and thickness of additional protective coatings, and the kind of corrosive environment to which it is exposed. Galvanized steel can generally be used in direct contact with most wood, as long as it is not cedar, oak, sweet chestnut, and redwood, all of which produce acids. Just the contact of moist wood (any species) against the metal can cause an O<sub>2</sub> concentration cell. Galvanized iron and steel can be used with concrete, mortar, lead, tin, zinc, and aluminum.<sup>102</sup> Galvanic corrosion occurs, however, when it is in contact with any of the other metals. Like most types of iron and steel, galvanized steel is also corroded by acids and chemical fumes (see chapter 14).

**Stainless Steels** have a high resistance to heat, oxidation, and corrosion. Chromium and chromium-nickel stainless steels are among the few metals that remain substantially unaltered in appearance after being exposed to the atmosphere.<sup>103</sup> Stainless steels resist corrosion from hydrogen sulfide and sulfur dioxide, and have good resistance to water and to some soils; thus, they often retain their natural finishes.

The high corrosion resistance of stainless steels is dependent on the presence of a thin, complex, protective film.<sup>104</sup> The *passivation* (resistance to rust) of the stainless steel occurs readily in environments containing oxygen. When corrosion does occur, it is usually localized.<sup>105</sup> As with all metals, the presence of chlorides increases the susceptibility of attack; therefore, stainless steel can be lightly corroded by mortar and pitted by a salt environment.<sup>106</sup> Galvanic action can occur when some stainless steel comes in contact with aluminum, aluminum alloys, steel, zinc, and to a lesser extent copper.<sup>107</sup>

**Copper-bearing Steels** have a copper content of just 0.1% and are markedly more resistant to atmosphere corrosion than ordinary steel.<sup>108</sup> Known as copper-bearing steel, these steels form a protective oxide coating or "skin" of a uniform deep over brown color which can wash down over other building materials leaving a rust stain. "Corten" and "Mayari R" are two trade names of copper-bearing steel. Problems with excessive corrosion have been found to occur when copper-bearing steels are used in a saline environment such as near sea water.

## Methods of Preservation and Repair

Iron and steel architectural components are most commonly protected from oxidation by paints. Other protective methods include electroplating of nearby harmful metals and humidity control. The U.S. Navy has been successful in preventing rust on ships in the mothball fleet by using "sealed zones" and enclosures over steel components where the relative humidity is kept below 30%.<sup>109</sup> In the future, similar techniques may be used temporarily for architectural applications such as the "mothballing" of large, abandoned industrial sites or of individual metal components (figure 162).

In the repair of historic iron and steel structures, the introduction of details that provide crevices or pockets to catch and hold water should be avoided wherever possible (figure 159). If it is necessary to retain such details for historical reasons, they should be carefully cleaned periodically and protected against oxidation. Structural arrangements that prevent the free circulation of air should be avoided, and hollow sections should be hermetically sealed if at all possible. Sharp corners and edges should be modified and rounded contours used to prevent mechanical damage to the metal and the breakdown of protective coatings. Sheltered surfaces, such as the underside of eaves where evaporation of moisture is inhibited, should receive additional protective coatings.

A number of finishes are commonly used to protect iron and steel architectural components, including plating with another metal, and coating with plastics, concrete, vitreous enamels, and paints. If these coatings have only partially broken down, simple recoating is in order, such as a coating paint. If the paint shows minor flame cleaning and chemical methods. The selection of an appropriate technique depends upon how much paint failure and corrosion has occurred, the fineness of the surface detailing, and the type of new protective coating to be applied. Local environmental regulations may restrict the options for cleaning and paint removal methods, as well as the disposal of materials.

Many of these techniques are *potentially dangerous* and should be carried out only by experienced and qualified workers using proper eye protection, protective clothing, and other workplace safety conditions. Before selecting a process, test panels should be prepared on the iron to be cleaned to determine the relative effectiveness of various techniques. The cleaning process will most likely expose additional coating defects, cracks, and corrosion that have not been obvious before (figure 164).

There are a number of techniques that can be used to remove paint and corrosion from cast iron:

**Hand scraping, chipping, and wire brushing** are the most common and least expensive methods of removing paint and light rust from cast iron. However, they do not remove all corrosion or paint as effectively as other methods. Experienced craftsmen should carry out the work to reduce the likelihood that surfaces may be scored or fragile detail damaged.

**Low-pressure grit blasting** (commonly called abrasive cleaning or sandblasting) is often the most effective approach to removing excessive paint build-up or substan-

tial corrosion (figure 163). Grit blasting is fast, thorough, and economical, and it allows the iron to be cleaned in place. The aggregate can be iron slag or sand; copper slag should not be used on iron because of the potential for electrolytic reactions. Some sharpness in the aggregate is beneficial in that it gives the metal surface a "tooth" that will result in better paint adhesion. The use of a very sharp or hard aggregate and/or excessively high pressure (over 100 pounds per square inch) is unnecessary and should be avoided. Adjacent materials, such as brick, stone, wood, and glass, must be protected to prevent damage. Some local building codes and environmental authorities prohibit or limit dry sandblasting because of the problem of airborne dust.

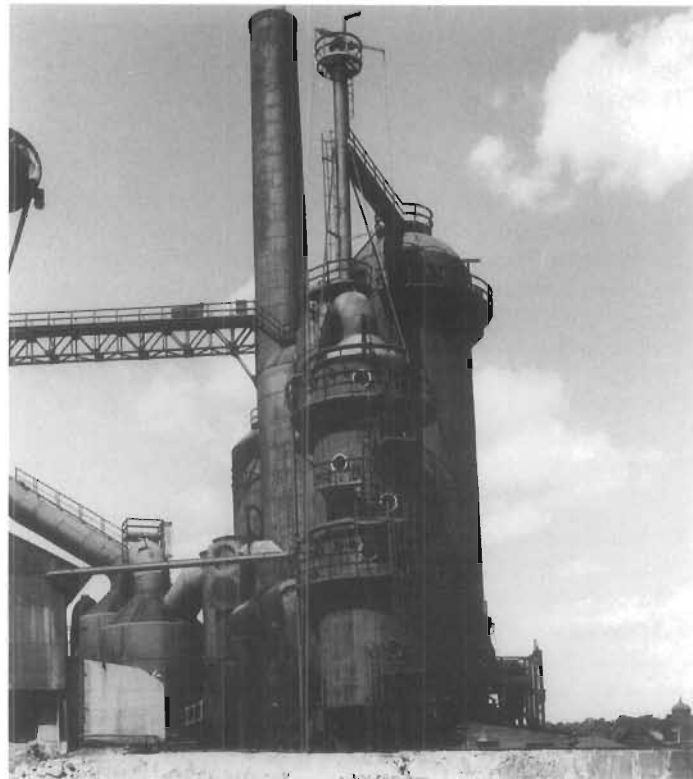
**Wet sandblasting** is more problematic than dry sandblasting for cleaning cast iron because the water will cause instantaneous surface rusting and will penetrate deep into open joints. Therefore, it is generally not considered an effective technique. Wet sandblasting reduces the amount of airborne dust when removing a heavy paint build-up, but disposal of effluent containing lead or other toxic substances is restricted by environmental regulations in most areas.

**Flame Cleaning** of rust from metal with a special multi-flame head oxyacetylene torch requires specially skilled operators, and is expensive and potentially dangerous.<sup>110</sup> However, it can be very effective on lightly to moderately corroded iron. Wire brushing is usually necessary to finish the surface after flame cleaning.

**Chemical rust removal**, by acid pickling, is an effective method of removing rust from iron elements that can be easily removed and taken to a shop for submerging in vats of dilute phosphoric or sulfuric acid. This method does not damage the surface of iron, providing that the iron is neutralized to pH level 7 after cleaning. Other chemical rust removal agents include ammonium citrate, oxalic acid, or hydrochloric acid-based products.<sup>111</sup>

**Chemical paint removal** using alkaline compounds, such as methylene chloride or potassium hydroxide, can be an effective alternative to abrasive blasting for removal of heavy paint build-up. These agents are often available as slow-acting gels or pastes. Because they cause burns, protective clothing and eye protection must be worn. Chemicals applied to a non-watertight facade can seep through crevices and holes, resulting in damage to the building's interior finishes and corrosion to the backside of the iron components. If not thoroughly neutralized, residual traces of cleaning compounds on the surface of the iron can cause paint failures in the future.<sup>112</sup> For these reasons, field application of alkaline paint removers and acidic cleaners is not generally recommended.

Following any of these methods of cleaning and paint removal, the newly cleaned iron should be painted immediately with a corrosion-inhibiting primer before new rust begins to form. This time period may vary from minutes to hours depending on environmental conditions. If priming is delayed, any surface rust that has developed should be removed with a clean wire brush just before priming, because the rust prevents good bonding



**Figure 162. Unpainted Steel.** *The Republic Steel Corporation in Troy, New York, could not meet the new environmental quality standards and shut down its 1920s steel blast furnace which was built for the Burden Iron Company. It had never been painted because steel at very high temperatures does not rust. When the heat was turned off, the steel rusted rapidly. (John G. Waite)*

between the primer and the cast-iron surface and prevents the primer from completely filling the pores of the metal.

**Painting** is the most common treatment for controlling the corrosion of iron and steel components. Before removing paint from historic architectural iron or steel, a microscopic analysis of samples of the historic paint sequencing is recommended. Called paint seriation analysis, this process must be carried out by an experienced architectural conservator. The analysis will identify the historic paint colors, and other conditions, such as whether the paint was matte or gloss, whether sand was added to the paint for texture, and whether the building was polychromed or marbled. Traditionally many cast-iron elements were painted to resemble other materials, such as limestone or sandstone. Occasionally, features were faux-painted so that the iron appeared to be veined marble.

Thorough surface preparation is necessary for the adhesion of new protective coatings. All loose, flaking, and deteriorated paint must be removed from the iron or steel, as well as dirt and mud, water-soluble salts, oil, and grease. Old paint that is tightly adhered may be left on the surface of the metal if it is compatible with the



**Figure 163. Cleaning Cast Iron.** The facade of the Zions Cooperative Mercantile Institute (ZCMI) Store was sandblasted to locate the screws and bolt connections and thereby discover the method of assembly and disassembly. The cast iron should not be heavily sandblasted (down to the bare metal) unless that entire section of the facade is being dismantled. As pieces are being removed, they should be primed immediately to avoid rusting. If the building is not to be dismantled, it is best to remove only the loose paint with a wire brush, being careful not to damage caulked joints and connection holes. Any bare cast iron should be spot primed. (Steven T. Baird, AIA)

proposed coatings. The retention of old paint also preserves the historic paint sequence of the building and avoids the hazards of removal and disposal of old lead paint.

It is advisable to consult manufacturer's specifications or technical representatives to ensure compatibility between the surface conditions, primer and finish coats, and application methods.

For the paint to adhere properly, the metal surfaces must be absolutely dry before painting. Unless the paint selected is specifically designed for exceptional conditions, painting should not take place when the temperature is expected to fall below 50 degrees Fahrenheit within 24 hours or when the relative humidity is above 80%; paint should not be applied when there is fog, mist, or rain in the air. Poorly prepared surfaces will cause the failure of even the best paints, while even moderately priced paints can be effective if applied over well-prepared surfaces.



**Figure 164. Exposure of Connections and Joints.** After the Wilmington Opera House was sandblasted, screw and bolt holes were visible. A cast-iron bracket such as this one may be made of as many as 10 pieces. (Steven T. Baird, AIA)

## Selection of Paints and Coatings

The types of paints available for protecting iron and steel have changed dramatically in recent years due to federal, state, and local regulations that prohibit or restrict the manufacture and use of products containing toxic substances such as lead and zinc chromate, as well as volatile organic compounds and substances (VOC or VOS). Availability of paint types varies from state to state, and manufacturers continue to change product formulations to comply with new regulations.

Traditionally, red lead had been used as an anti-corrosive pigment for priming iron and steel. Red lead has a strong affinity for linseed oil and forms lead soaps, which become a tough and elastic film impervious to water that is highly effective as a protective coating for iron. At least two slow-drying linseed oil-based finish coats have traditionally been used over a red lead primer, and this combination is effective on old or partially-deteriorated surfaces. Today, in most areas, the use of paints containing lead is prohibited, except for some commercial and industrial purposes, and the trend to eliminate lead-base paints altogether is likely to continue.

Today, alkyd paints are very widely used and have largely replaced lead-containing linseed-oil paints. They dry faster than oil paint, with a thinner film, but they do

Table III. Methods for Surface Preparation of Iron and Steel for Painting

Types of Cleaning	How Done	Characteristics of Cleaned Surface	Type of Paints Used With This Cleaning
Flame cleaning	Oxyacetylene flame consisting of a series of small, closely spaced flames that are very hot and projected at high velocity	Reduces ordinary rust to iron oxide and pops off loose mill scale; after flame cleaning the surface should be wire-brushed	Alkyd and phenolic vehicle paints, baked enamels
Iron phosphate	Metal is immersed in an alkali precleaner and then immersed in a patented solution containing ferric phosphate	Surface provides excellent adhesion for paint and retards rusting	Baked enamels
Pickling (phosphoric acid)	Metal is immersed in warmed dilute phosphoric acid with added rust inhibitors; does not need finishing	Removes all dirt, rust, and mill scale and gives the surface a protective film which retards rusting and is a good base for painting	Natural-drying-oil and resin vehicle paints
Pickling (sulfuric acid)	Metal is immersed in warmed dilute sulfuric acid with other chemicals which confine the action largely to rust and scale and is then rinsed	Removes all dirt, rust and mill scale and gives the surface a slight etching which helps adhesion of the paint	Vinyl, alkyd and phenolic vehicle paints, baked enamels
Rust removers	Applied by brush or spraying, the phosphate type forms a film and retards rusting	Generally used in maintenance painting and with on-site painting where slight rusting has occurred	All types of paint used for maintenance and on-site painting
Sand blasting and grit blasting	Sand or steel grit (crushed shot) in a range of No. 10 to No. 45 screen sizes and dry compressed air at 80 to 100 lb. per sq. in.	Removes all dirt, rust, tight mill scale and all other surface impurities; also roughens the surface, thus providing the best condition for adhesion of the paint	Coal-tar enamels and vinyl vehicle paints; baked enamels; also used for alkyd and phenolic vehicle paints
Solvent cleaning	Wiped with turpentine or mineral spirits	Removal of dirt, oil and grease	Oil-base paints
Wire brushing	Wire brushes operated either by hand or mechanically	Removes rust and loose mill scale but will not remove tight scale or rust. Too much wire-brushing gives a polished surface which has poor paint adhesion properties	Natural-drying-oil and resin vehicle paints

Table III. Methods of Surface Preparation of Iron and Steel for Painting

Good surface preparation is essential for good paint adhesion. This table was not custom tailored to historic preservation and includes most methods used by industry and building construction. It is intended as a guide to or listing of the various methods of paint, rust, dirt, and grease removal. Not all of these methods are practical or feasible on metal building components *in situ*, and even if they were, do not produce equal results. Do not select a method without reading the text. Selection of a method is determined by the location of the iron or steel component, the condition of the paint layer (if any), the amount of corrosion, the surrounding materials, type of exposure, convenience and cost of operation. Many of these methods are hazardous or dangerous and should be undertaken only with proper precautions and equipment both of which are not enumerated here because of a lack of space. For example, when sandblasting, care should be taken to protect the surfaces of the surrounding materials and the health and safety of the workers. Physical characteristics of the surface to be cleaned may eliminate certain methods, for example, cast iron and wrought iron can be sandblasted but sheet iron usually cannot. (From *Materials for Architecture: An Encyclopedia Guide* by C. Hornbostel, Copyrighted 1961 by Litten Educational Publishing, Inc. Reprinted by permission of Van Nostrand Reinhold Company, p. 357.)

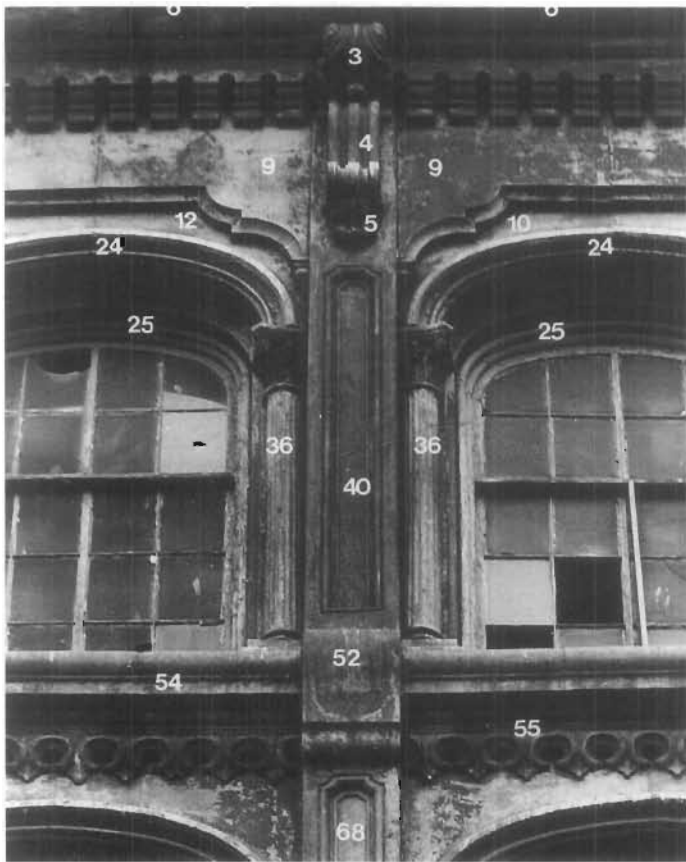
Table IV. Types of Paint Used for Painting Metal

Type of Paint	Surface Preparation and Pretreatment	Priming Coat *	Intermediate Coat * (Undercoat)	Finish Coat	Major Use on Iron and Steel
Alkyd vehicle	"Commercial" blast cleaning, pickling, flame cleaning, no pretreatment required	Red-lead alkyd varnish primer *	Same as priming coat except tinted with carbon black or lamp black to a contrasting color (in relation to priming coat) *	Aluminum alkyd, black alkyd, white or tinted alkyd paint	For the exterior exposed to severe weather conditions; for the interior where mild chemical exposure, high humidity and infrequent condensation exist
Coal-tar	Blast cleaning to white metal; surface to be cleaned and prime coat immediately applied	Coal-tar enamel primer applied hot	None	Coal-tar enamel applied hot	For the exterior where iron and steel are to be installed underground or in and under water
		Coal-tar enamel	Coal-tar paint	Coal-tar paint	Same as coal-tar enamel except not as good for foundations in and under water
Oil-base vehicle	Solvent cleaning, wire brushing; no pretreatment necessary	Red-lead oil-base primer *	Same as priming coat except tinted with carbon black or lamp black to a contrasting color (in relation to coat) *	Aluminum varnish or black, white or tinted oil-base paint	For the exterior exposed to normal weather conditions; for the interior where moderately corrosive conditions exist
Phenolic vehicle	"Commercial" blast cleaning; pickling, flame cleaning; no pretreatment necessary	Red-lead mixed-pigment phenolic varnish primer *		Aluminum phenolic, black phenolic, white or tinted phenolic paint	For the exterior where iron or steel is immersed in fresh water or exposed to high humidity and condensation; for the interior only where conditions are the same as the exterior
Vinyl vehicle	"Commercial" blast cleaning, pickling; after cleaning surface to be pretreated with basic zinc chromate vinyl butyral washcoat	Vinyl red-lead primer *	Same as priming coat except tinted with lamp black to a contrasting color *	Aluminum vinyl, black vinyl, or vinyl-alkyd paint in white, black, red, yellow or orange	For the exterior where iron or steel is immersed in salt or fresh water or exposed to high humidity and condensation; for the interior where flame resistance, mildew resistance, corrosion resistance and easy maintenance are necessary

Table IV. Types of Paint Used for Painting Metal

The table lists each basic type of paint to be used on metals, the surface preparation, primer, undercoat, finish coat, and major use on iron and steel. It was intended for use on new construction. The preparation and layers of paint may have to be modified to meet existing conditions. The primer, undercoat, and finish coat of paint should be purchased from the same company to insure their compatibility. The intermediate coat can be the same as the finish coat but tinted to a contrasting color, (From *Materials for Architecture: An Encyclopedic Guide* by Hornbostel, Copyrighted 1961 by Litton Educational Publishing, Inc. Reprinted by permission of Van Nostrand Reinhold Company, p. 356)

**\*Note: Although red lead makes an excellent primer for metals, paints that contain lead are prohibited in most areas of the United States, except for some commercial and industrial purposes. Iron-oxide and zinc rich primers have very good properties for protecting metals and are commonly available for most paint formulations. See text of chapter for a more thorough discussion of paints.**



**Figure 165. Sequence of Dismantling.** Once the bolts and screws have been located, the parts can be numbered. The numbers on the photograph indicate to the contractor the order of disassembling the cast-iron facade, which is the reverse order of its original erection. (Steven T. Baird, AIA)

not protect the metal as long.<sup>113</sup> Alkyd rust-inhibitive primers contain pigments such as iron oxide, zinc oxide, and zinc phosphate. These primers are suitable for previously painted surfaces cleaned by hand tools. At least two coats of primer should be applied, followed by alkyd enamel finish coats.

Latex and other water-based paints are not recommended for use as primers on iron or steel because they cause immediate oxidation if applied on bare metal. Vinyl acrylic latex or acrylic latex paints may be used as finish coats over alkyd rust-inhibitive primers, but if the primer coats are imperfectly applied or are damaged, the latex paint will cause oxidation of the iron or steel. Therefore, alkyd finish coats are recommended.

High-performance coatings, such as zinc-rich primers containing zinc dust, and modern epoxy coatings, can be used on iron or steel to provide longer-lasting protection. These coatings typically require highly clean surfaces and special application conditions which can be difficult to achieve in the field on large buildings.

One particularly effective system has been to coat commercially blast-cleaned iron with a zinc-rich primer, followed by an epoxy base coat, and two urethane finish coats. Some epoxy coatings can be used as primers on clean metal, especially those that are zinc rich, or applied to previously painted surfaces in sound condition.

Epoxies are particularly susceptible to degradation under ultraviolet radiation and must be protected by finish coats which are more resistant. There have been problems with epoxy paints which have been shop-applied to iron or steel where the coatings have been nicked prior to installation. Field touching-up of epoxy paints is very difficult, if not impossible. This is a concern since iron exposed by imperfections in the base coat will be more likely to rust and more frequent maintenance will be required.

A key factor to take into account in selection of coatings is the variety of conditions on existing and new materials on a particular building or structure. One primer may be needed for surfaces with existing paint; another required for newly cast, chemically stripped, or blast-cleaned iron or steel; and a third suitable for flashings or substitute materials—each surface primer followed by a compatible finish coat.

### Application Methods

Brushing is the traditional and most effective technique for applying paint to cast iron. It provides good contact between the paint and the metal, as well as the effective filling of pits, cracks, and other blemishes in the metal. The use of spray guns to apply paint is economical, but does not always produce adequate and uniform coverage. For best results, airless sprayers should be used by skilled operators. To fully cover fine detailing and reach recesses, spraying of the primer coat, used in conjunction with brushing, may be effective.

Rollers should never be used for primer coat applications on metal, and are effective for subsequent coats only on large, flat areas. The appearance of spray-applied and roller-applied finish coats is not historically appropriate and should be avoided on areas such as storefronts which are viewed at close range.

A number of types of paints used for iron and steel and their recommended uses are indicated in table IV. In addition to these paints, flaky or micaceous iron ore and aluminum provide a satisfactory coating, using an oil vehicle, without a priming coat.<sup>114</sup> Tar and bitumen paints are used for protecting iron and steel installed underground or underwater. However, these paints can break down when exposed to sunlight because they tend to flow in the summer heat and crack from the winter cold. When used, they usually are coated with a flaky aluminum paint.

Oils, greases, and waxes, reapplied at periodic intervals, have been widely used for the preservation of iron and steel in interior locations and in museums. Waxes may be used to protect the surfaces of some interior architectural elements such as chandeliers, cranes, firebacks, stoves, hardware, doors, and elevators. Some industrial ironwork was never painted because heat prevented rust and now need protection (figure 163).

**Plating and Glazing** is a common protective measure for iron and steel. The most common protective metals used for plating are lead, tin, and terne, zinc, nickel and Monel (see the appropriate sections for detailed information). Chromium aluminum, and cadmium are also used for plating.

Various plastics, applied by either brushing, dipping, spraying, or cladding, have been used recently for protecting steel.<sup>115</sup> Subsequent reduction in corrosion is dependent on the properties of the plastic, its adherence to the metal, and its porosity. Polyvinyl chloride (PVC) and epoxy resins are now applied under factory conditions to sheet steel; extruded PVC may be applied to steel window frames and pipes; and Neoprene (polymerized chloroprene) and Hypalon (a chloro-sulphanated polyethylene) are also used to protect steel architectural components.

Cast or sprayed concrete is another protective coating used on steel architectural components. This kind of protection has very limited use in the restoration of historic structures, but may be necessary to improve the fire rating of iron and steel structural members in rehabilitation of historic buildings. Under certain building codes, plas-



**Figure 166. Damaged Cast Iron.** This cast-iron perforated stoop in the 700 block of I Street, NW, in Washington, D.C., has fractured in several places because of differential settlement. As the right side of the stairs sank into the ground, the weight of the stoop was redistributed and induced shear, tensile, and torsion forces that were too great for the cast iron to resist. Differential settlement can also be caused by the upward and outward growth of a tree adjacent to a stoop and the downward settlement of a dead tree stump as it decays. No patching or repair work will be effective until the problem is corrected. The stoop should be disassembled and a new concrete foundation poured; the stoop can then be reassembled using welded fractured pieces and recast missing pieces. (David W. Look)

ter on metal lath, sprayed plaster, or fire-rated drywall will also provide the required fire rating.

A continuous, inorganic glaze of vitreous enamel, which is highly resistance to corrosion, can be applied to steel.<sup>116</sup> Corrosion resistance, especially to acids, can be increased by adding silica and titania; however, this type of coating must be applied under controlled, factory conditions. If the coating is chipped, it is no longer effective in protecting the steel. Like the use of concrete, this technique has limited use in the preservation of historic iron and steel structures which previously were not protected by such coatings.

**Repair** techniques for iron and steel are numerous. The worst enemy of iron and steel is water and the best protection is often caulking and painting. Just as a small chip or scratch in the paint on an automobile will allow rust to form and then progress under the paint, any break in the paint layer has the potential for serious damage. Information on the removal of rust and old paint and the priming and repainting of iron and steel has been given in the previous section.



**Figure 167. Welding Cast Iron.** Although cast iron is very difficult to weld, it can be done by a skilled welder. This is a detail of a weld on the cast-iron fence at the Gardiner-Pingree House in Salem, Massachusetts. "Ni-Rods" welding electrodes, made with a nickel alloy, have been used to weld cast iron since 1947. This weld should have been ground down after completion. (Lee H. Nelson)



Most architectural cast iron is made of many small castings assembled by bolts or screws (figure 165). Joints between pieces were caulked to prevent water from seeping in and causing rusting from the inside out. Historically, the seams were often caulked with white lead paste and sometimes backed with cotton or hemp rope; even the bolt and screw heads were caulked to protect them from the elements and to hide them from view. Although old caulking is sometimes found in good condition, it is typically crumbly from weathering, cracked from the structural settlement, or destroyed by mechanical cleaning (figure 164). It is essential to replace deteriorated caulking to prevent water penetration. For good adhesion and performance, an architectural-grade polyurethane sealant is preferred.

Water that penetrates the hollow parts of a cast-iron architectural element causes rust that may streak down over other architectural elements. The water may freeze, causing the ice to crack the cast iron. Cracks reduce the strength of the total cast-iron assembly and provide another point of entry for water. Thus, it is important that cracks be made weathertight by using caulks or fillers, depending on the width of the crack.

Filler compounds containing iron particles in an epoxy resin binder can be used to patch superficial, non-

structural cracks and small defects in cast iron. The thermal expansion rate of epoxy resin alone is different from that of iron, requiring the addition of iron particles to ensure compatibility and to control shrinkage. Although the repaired piece of metal does not have the same strength as a homogeneous piece of iron, epoxy-repaired members do have some strength. Polyester-based putties, such as those used on auto bodies, are also acceptable fillers for small holes.<sup>117</sup>

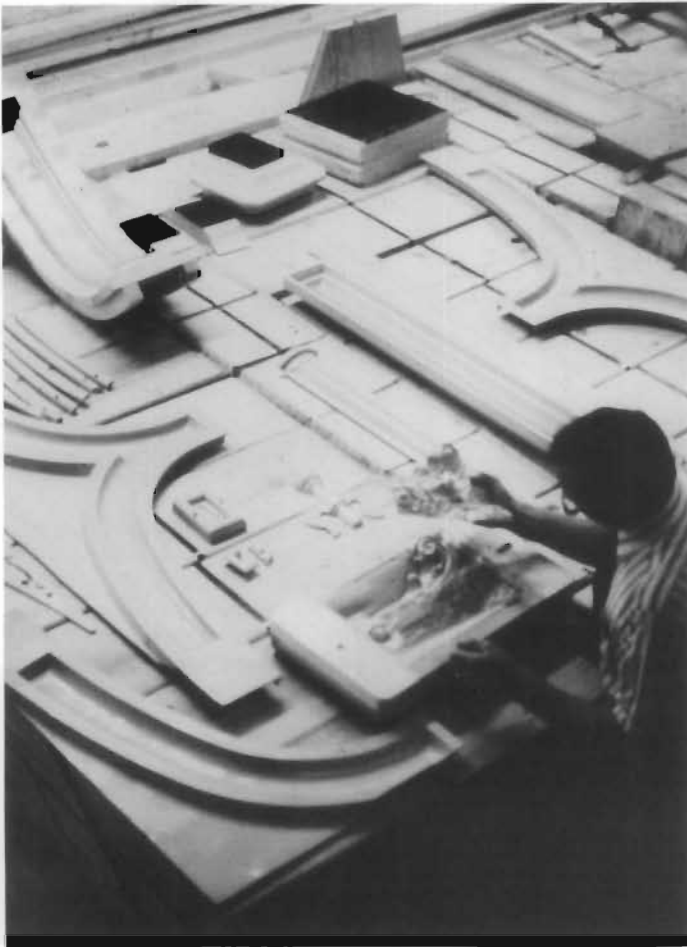
In rare instances, major cracks can be repaired by brazing or welding with special nickel-alloy welding rods (figure 164).<sup>118</sup> Brazing or welding of cast iron is very difficult to carry out in the field and should be undertaken only by very experienced welders.

In some cases, mechanical repairs can be made to cast iron using iron bars and screws or bolts. In extreme cases, deteriorated cast iron can be cut out and new cast iron spliced in place by welding or brazing. However, it is frequently less expensive to replace a deteriorated cast-iron section with a new casting rather than to splice or reinforce it. Cast-iron structural elements that have failed must either be reinforced with iron and steel or replaced entirely.

A wobbly cast-iron balustrade or railing can often be fixed by tightening all bolts and screws. Screws with



**Figure 168. Dismantled Cast-Iron Facades.** *The Edgar Laing Stores in New York City were erected by James Bogardus in 1849 and had one of the earliest cast-iron facades. The building was demolished in 1971 for an urban renewal project, but its cast-iron facade was carefully dismantled so it could be reerected on another site at a later date. Unfortunately, while the components were in storage, most of them were stolen and apparently sold for scrap. Dismantling of a building should be considered a measure of last resort, to be attempted after all other efforts to save a building in situ have failed. (Jack E. Boucher)*



**Figure 169. Wooden Patterns.** These patterns carved from white pine are inspected, and, if approved, sent to the foundry for making sand molds required for the individual castings. The patterns are made proportionally larger to compensate for the shrinkage of the casting. The percentage of shrinkage is different for cast iron, aluminum, fiberglass, et cetera; therefore, the material of the final casting must be determined before the pattern is carved. (Walter Smalling, Jr.)

stripped threads and seriously rusted bolts must be replaced. To compensate for corroded metal around the bolt or screw holes, new stainless steel bolts or screws with a larger diameter need to be used. In extreme cases, new holes may need to be tapped.

The internal voids of balusters, newel posts, statuary, and other elements should not be filled with concrete;<sup>119</sup> it is an inappropriate treatment that causes further problems (figure 143). As the concrete cures, it shrinks, leaving a space between the concrete and cast iron. Water penetrating this space does not evaporate quickly, thus promoting further rusting. The corrosion of the iron is further accelerated by the alkaline nature of concrete. Where cast-iron elements have been previously filled with concrete, they need to be taken apart, the concrete and rust removed, and the interior surfaces primed and painted before the elements are reassembled.



**Figure 170. Plastic Patterns.** Historically, most patterns for casting iron were carved from wood and pressed into sand to form molds. For the recasting of the iron shutters of the West Virginia Independence Hall, an attempt to use plastic patterns met with only limited success. How the original shutters, with their deeply undercut, beaded molding were cast in one piece is not known. To achieve the same effect in the restoration, the beaded molding of iron had to be cast separately and applied to the replicas. The patterns are mounted on plywood to give them enough rigidity so they may be hammered into the sand to form the molds. (West Virginia Independence Hall Foundation)

## Dismantling and Assembly of Architectural Components

It is sometimes necessary to dismantle all or part of a cast-iron structure during restoration, if repairs cannot be successfully carried out in place. Dismantling should be done only under the direction of a preservation architect or architectural conservator who is experienced with historic cast iron. Extreme care must be taken since cast iron is very brittle, especially in cold weather. If this work has to be carried out in the winter, care should be taken to avoid fracturing the cast-iron structural elements by uneven heating of the members.

Dismantling should follow the reverse order of construction and re-erection should occur, as much as possible, in the exact order of original assembly. Each piece should be numbered and keyed to record drawings.

When work must be carried out in cold weather, care needs to be taken to avoid fracturing the iron elements by uneven heating of the members.

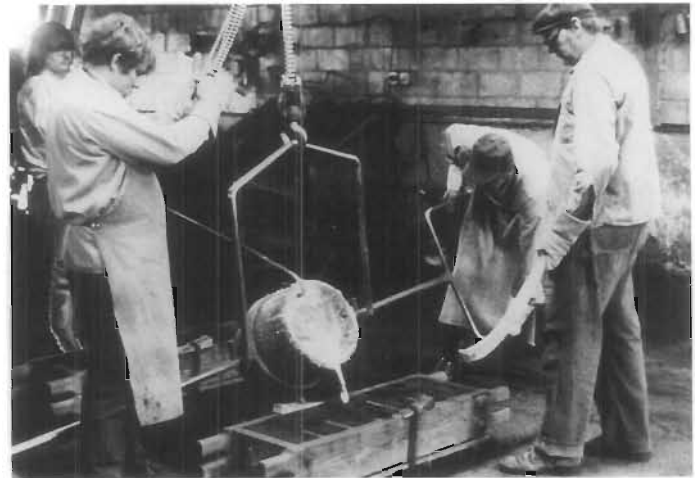
Both new castings and reused pieces should be painted with a shop-applied prime coat on all surfaces. All of the components should be laid out and pre-assembled to make sure that the alignment and fit are proper. Many of the original bolts, nuts, and screws may have to be replaced with similar fasteners of stainless steel.

After assembly at the site, joints that were historically caulked should be filled with an architectural-grade polyurethane sealant. Although the traditionally used white lead paste has the advantage of longevity, it is restricted in many areas.

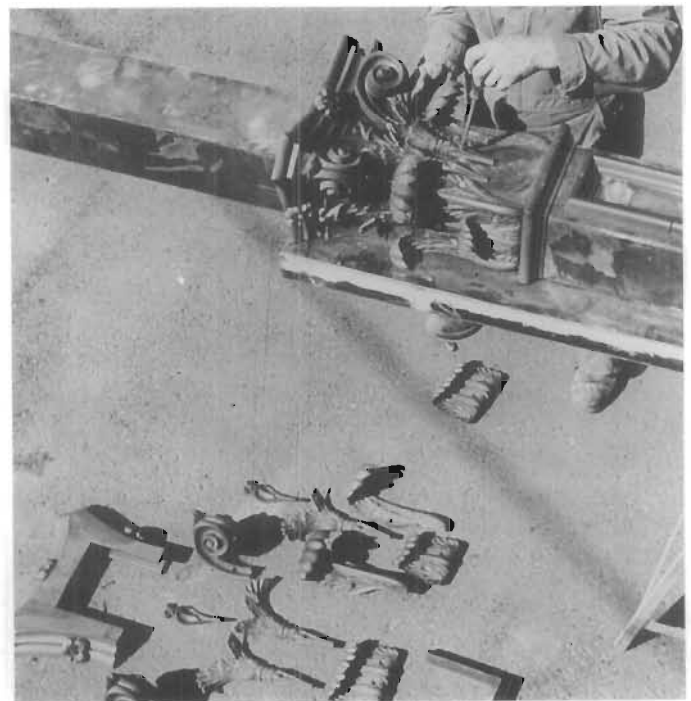
The Laing Stores in New York City (figure 168) were dismantled in a last-ditch preservation effort. The connecting nuts and bolts were corroded and had to be burned off with a torch. If this work has to be carried out in the winter, care should be taken to avoid fracturing the cast-iron structural elements by uneven heating



**Figure 171. Sand Mold.** The pattern has been pressed or hammered into the sand to form an impression or mold. Special casting flasks or boxes are used to hold the sand. Only one flask or box is required for an open mold which produces a casting with a flat top. To cast a piece with relief on both top and bottom requires two flasks stacked and bolted together. (Steven T. Baird)



**Figure 172. Casting Iron.** Molten iron is being poured into the sand molds. For open molds, the molten iron is just poured in from the open top. For closed molds, tunnels (called "sprues") are carved out of the wet sand to allow the molten metal to flow in and "risers" allow the air to escape. Once the casting has cooled to room temperature, the sand is removed from around the casting. The sprues and risers are cut off and any remaining irregularities or ragged edges (called "burrs") are ground smooth. (Walter Smalling, Jr.)



**Figure 173. Preassembly of Cast-Iron Components.** Before the cast-iron pieces are shipped from the foundry to the job site, the components are laid out and preassembled to insure proper fit. If the parts do not fit because of burrs, the pieces are machined to remove irregularities. If the parts still do not fit, the rejected parts are recast until all of the castings fit together. Some small ornamental parts may be left together, but most of the larger pieces are disassembled before shipping. All of the castings shown were necessary to produce a Corinthian pilaster. (Walter Smalling, Jr.)

of the members. The disassembled cast-iron facade was stored in a secure, dry shelter where the pieces could not be stolen or allowed to deteriorate.<sup>120</sup>

## Duplication and Replacement

The replacement of cast-iron components is often the only practical solution when such features are missing, severely corroded, or damaged beyond repair, or where repairs would be only marginally useful in extending the functional life of an iron element. Sometimes it is possible to replace small, decorative, non-structural elements using intact sections of the original as a casting pattern. For large sections, new patterns of wood or plastic made slightly larger in size than the original will need to be made in order to compensate for the shrinkage of the iron during casting (cast iron shrinks approximately 1/8 inch per foot as it cools from a liquid to a solid)<sup>121</sup> (figure 169).

Occasionally, a matching replacement can be obtained through the existing catalogs of iron foundries. Small elements can be custom cast in iron at small local foundries, often at a cost comparable to substitute materials. Large elements and complex patterns will usually require the skills and facilities of a large firm that specializes in replication.

## The Casting Process

Architectural elements were traditionally cast in sand molds (figure 171). The quality of the special sands used by foundries is extremely important; unlike most sands, they must be moist. Foundries have their own formulas for sand and its admixtures, such as clay, which makes the sand cohesive even when the mold is turned upside down.

A two-part mold (with a top and a bottom, or cope and drag) is used for making a casting with relief on both sides, whereas an open-top mold produces a flat surface on one side. For hollow elements, a third pattern and mold are required for the void. Because of the difficulty of supporting an interior core between the top and bottom sand molds during the casting process, many hollow castings are made of two or more parts that are later bolted, screwed, or welded together.

The molding sand is compacted into flasks, or forms, around the pattern. The cope is then lifted off and the pattern is removed, leaving the imprint of the pattern in the small mold. Molten iron, heated to a temperature of approximately 2700 degrees Fahrenheit, is pouted into the mold and then allowed to cool (figure 172). The molds are then stripped from the casting; the tunnels to the mold (sprues) and risers that allowed release of air are cut off; and ragged edges (called "burrs") on the casting are ground smooth.

The castings are shop-primed to prevent rust, and laid out and preassembled at the foundry to ensure proper alignment and fit (figure 173). When parts do not fit, the pieces are machined to remove irregularities caused by burrs, or are rejected and recast until all of the cast elements fit together properly. Most larger pieces then are taken apart before shipping to the job site, while some small ornamental parts may be left assembled.



**Figure 174. Erection of Cast-Iron Facade.** *To assemble the Main Street shop facade of the Wilmington Grand Opera House, many assembled sections and individual pieces were shipped to the job site where they were screwed and bolted together in their final positions. (Steven T. Baird)*



**Figure 175. Drilling Holes.** *Originally, screw and bolt holes were cast into the pieces of iron for new ironwork; however, for the restoration of existing cast-iron facades which may have settled over the years, the holes are sometimes drilled into the replacement parts at the job site to insure correct alignment. (Walter Smalling, Jr.)*

In addition to traditional wooden patterns, cast plastic patterns are now being tried. Like ice, which expands as it freezes, some plastics do not shrink when cast, but actually expand while setting (figure 170). This expansion can be used to compensate for later shrinkage of the cast iron or aluminum, but the amount of expansion plastic must be carefully matched to the amount of shrinkage of the cast metal in order for this to be effective.

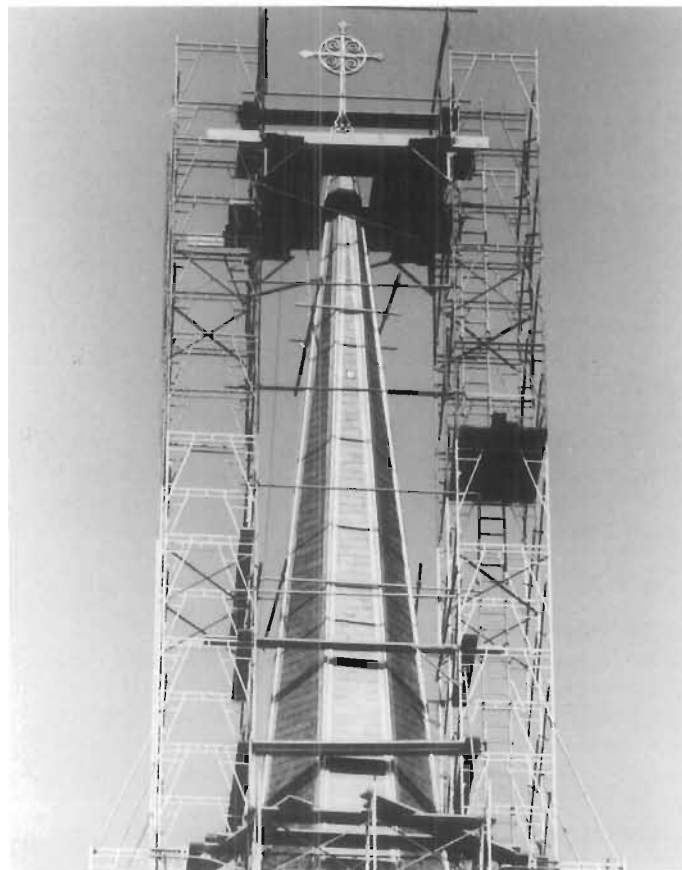
At the job site, the components are erected piece by piece (figure 174) and bolted or screwed together through holes cast in the parts. The new elements should be connected in the same manner as the original components. Bolt holes were originally cast into the pieces to aid trial assembly in the shop and final erection at the job site. With a new building most of the bolt holes will line up; however, with an old building that has settled, the bolt holes may not line up and minor adjustments may be necessary. Thus, in recasting missing or damaged pieces, bolt holes are not always cast into the pieces, but are often drilled on the job site to insure proper alignment (figure 175).

### Substitute Materials

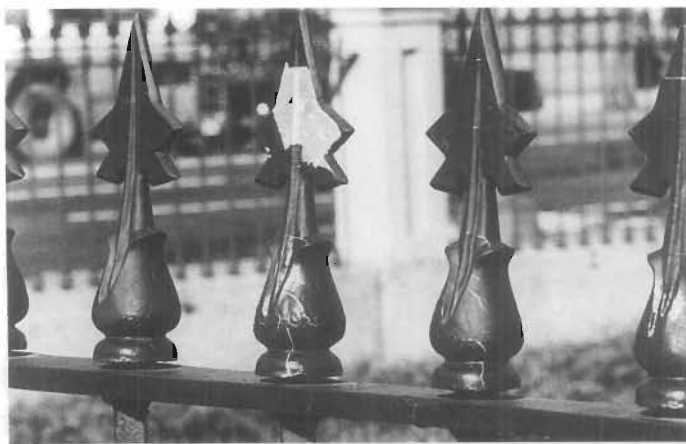
In recent years, a number of metallic and non-metallic materials have been used as substitutes for cast iron, although they were not used historically with cast iron. The most common have been cast aluminum, epoxies, reinforced polyester (fiberglass), and glass fiber-reinforced concrete (GFRC). Factors to consider in using substitute materials are addressed in the National Park Service's **Preservation Briefs 16, The Use of Substitute Materials on Historic Building Exteriors**, which emphasizes that "every means of repairing deteriorating historic materials or replacing them with identical materials should be examined before turning to substitute materials."

**Cast aluminum** has been used recently as a substitute for cast iron, particularly for ornately detailed decorative elements (figure 178). Aluminum is lighter in

weight, more resistant to corrosion, and less brittle than cast iron. However, because it is dissimilar from iron, its placement in contact with or near cast iron may result in galvanic corrosion, and thus should be avoided. Special care must be taken in the application of paint coatings, particularly in the field. It is often difficult to achieve a



**Figure 177. Reinforced Polyester Replica.** The original cross of St. Agnes Church, Cohoes, New York, was removed from the steeple in the 1890s to serve as a grave marker. The original wrought-iron steeple cross, still intact, was used as a model to cast a new cross of reinforced (fiberglass) polyester. Fiberglass was chosen as a substitute material because of the inaccessible location (top of the steeple) where maintaining wrought iron (painting) would be difficult and expensive and because from the street level no one would be able to detect the substitute materials. (John G. Waite)



**Figure 176. Aluminum Reproduction.** Cast aluminum is less brittle than cast iron and more impact resistant; therefore, it is more capable of resisting vandals or souvenir hunters. On the iron fence around the Treasury Building in Washington, D.C., the missing cast-iron spear tips were replaced with cast aluminum. Unfortunately, the paint adhesion has failed and the bare aluminum is visible. (John Myers)



durable coating after the original finish has failed. Because aluminum is weaker than iron, careful analysis is required whenever aluminum is being considered as a replacement material for structural cast-iron elements.

**Epoxies** are two-part, thermo-setting, resinous materials which can be molded into virtually any form. When molded, the epoxy is usually mixed with fillers such as sand, glass balloons, or stone chips. When mixed with sand or stone, it is often termed epoxy concrete or polymer concrete, a misnomer because no cementitious materials are included. Epoxies are particularly effective for replicating small, ornamental sections of cast iron. Since it is not a metal, galvanic corrosion does not occur. Epoxy elements must have a protective coating to shield them from ultraviolet degradation. They are also flammable and cannot be used as substitutes for structural cast-iron elements.

**Reinforced polyester**, commonly known as **fiberglass**, is often used as a lightweight substitute for historic materials, including cast iron, wood, and stone. In its most common form, fiberglass is a thin, rigid, laminate shell formed by pouring a polyester resin into a mold and then adding fiberglass for reinforcement. Like epoxies, fiberglass is non-corrosive, but is susceptible to ultraviolet degradation. Because of its rather flimsy nature, it cannot be used as substitute for structural elements, cannot be assembled like cast iron, and usually requires a separate anchorage system. It is unsuitable for locations where it is susceptible to damage by impact, and is also flammable.

**Glass fiber-reinforced concrete**, known as **GFRC**, is similar to fiberglass except that a lightweight concrete is

substituted for the resin. GFRC elements are generally fabricated as thin shell panels by spraying concrete into forms. Usually a separate framing and anchorage system is required. GFRC elements are lightweight, inexpensive, and weather resistant. Because GFRC has a low shrinkage coefficient, molds can be made directly from



**Figure 178. Aluminum Replacement of Minor Structural Elements of a Facade.** For minor structural members without great loads, aluminum can be used as a substitute material; however, the capacity of a cast-aluminum column must be designed or checked by a structural engineer and not just assumed to be adequate. When the Grand Opera House in Wilmington, Delaware, was restored, missing cast-iron columns on the first-floor storefronts (flanking center bay entrance, lower center of photograph) were cast in aluminum to match the missing pieces of the original cast iron. (John G. Waite)



**Figure 179. Use of Both Cast Aluminum and Fiberglass as Substitute Materials.** After the Mansard roof and dormers of the Wilmington Grand Opera House were destroyed by fire the top floor was rebuilt, but not according to the original design. During restoration of the facade, photographs showing the original Mansard roof and dormers were found, which enabled the re-creation of the missing parts of the facade. The oval windows were cast in aluminum; but the moldings and trim, which may have originally been sheet iron, were made of reinforced polyester. (Walter Smalling, Jr.)

historic elements. However, GFRC is very different physically and chemically from iron. If used adjacent to iron, it causes corrosion of the iron and will have a different moisture absorption rate. Also, it is not possible to achieve the crisp detail that is characteristic of cast iron.

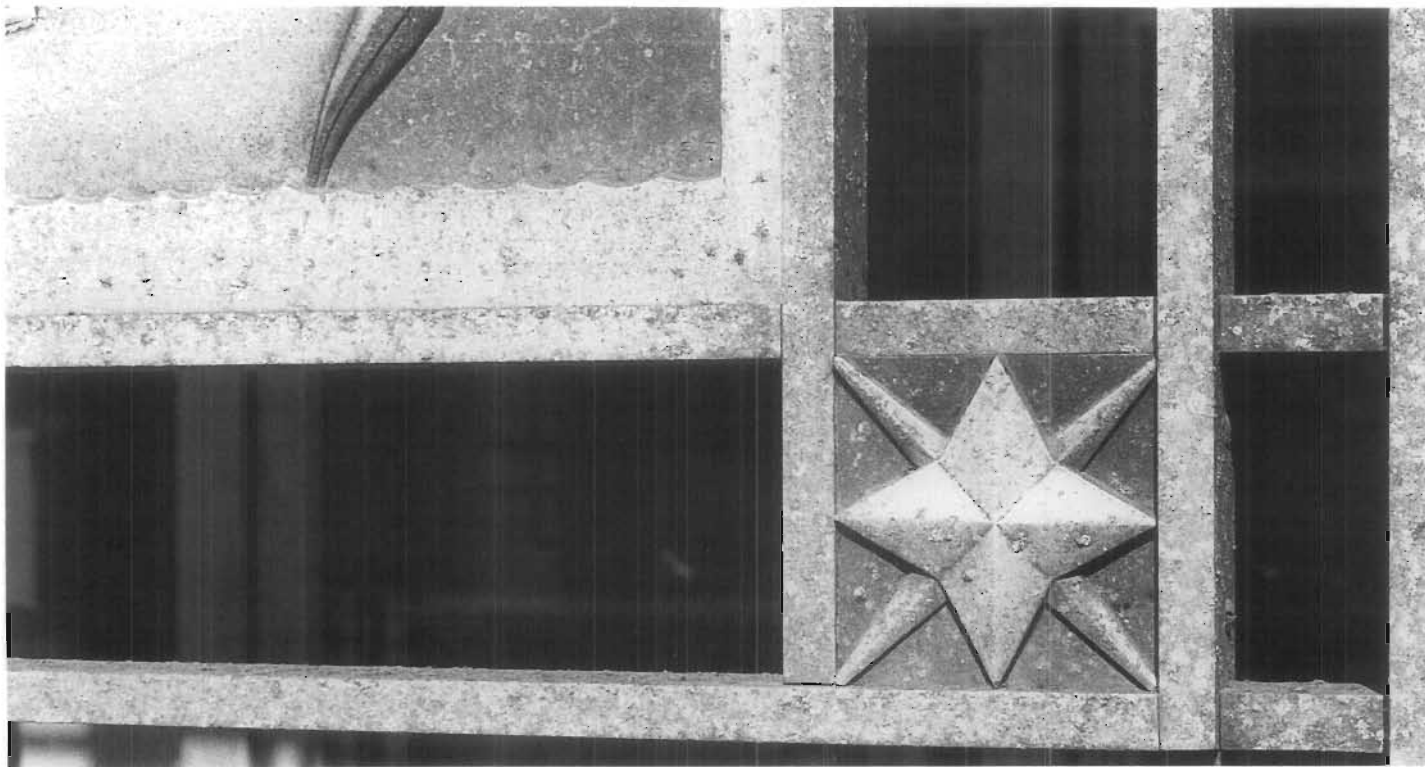
There are many other techniques for the selective repair and replacement of iron and steel architectural elements. If all or part of the assembly is structural and there is any doubt as to its load carrying capacity, it can be load tested. The safe load capacity reduced by an appropriate safety factor will give the maximum safe live load. If this is not adequate for the proposed use, the design can be reinforced or the use of the building or space revised. Once a building is partially opened up for restoration or rehabilitation work or inspection, it is usually possible to add plates, angles, channels, columns, and beams to strengthen or stiffen the design. It is not unusual to add wind bracing or other modifications to meet new code requirements such as those for seismic design.

The piercing of old iron and steel structural members with holes for new pipes or ducts should be avoided because such changes reduce the integrity of the elements and can help induce failure. Most mechanical improvements have a limited life expectancy because of de-

terioration and obsolescence; therefore, changes to accommodate mechanical equipment should be reversible. Because iron and steel produced in the 19th century had little quality control, the metal was seldom homogeneous and frequently contained faults. A hole in a member forces the load to be redistributed around the hole. This may throw the stresses onto a weaker area, which is inadequate to carry the load.

### Stainless Steel

To prevent corrosion (figure 180), stainless steel architectural elements should be washed regularly with warm water and a mild detergent to prevent the accumulation of dirt and other pollutants which can cause corrosion through creation of galvanic cells. Any encrustation of grime and dirt or stains can usually be removed with a commercial stainless steel cleaner. Although deterioration of stainless steel is seldom encountered, it may be physically damaged and require repairs, patching or replacement. Care should be taken to match the composition and finish of the original material with the replacement. If cast stainless steel is replaced, patterns must be made larger to allow for shrinkage which is 9/32 inch per foot.



**Figure 180. Corrosion and Pitting of Stainless Steel.** Although stainless steel was originally believed to be totally corrosion resistant, some types can corrode under certain conditions where the atmosphere is highly polluted. These stainless steel gates at the Federal Trade Commission in Washington, D.C. (see figure 108), have probably never been washed since they were hung and recessed into the facade of the building to protect them from the washing effect of rain. Under each bump of white corrosion, the surface of the metal is pitted. Dirt on the surface of stainless steel encourages corrosion at that particular location because the dirt holds moisture next to it. These doors should be cleaned with water and a non-ionic detergent and polished with a soft clean cloth and pumice powder. The gates should then be washed annually to remove surface dirt and wiped dry to avoid spotting. Corroded stainless steel may look like aluminum; in fact, these gates were recently described as aluminum in photographs in an exhibition on the Federal Triangle at the National Collection of Fine Arts Museum. Chemical tests were necessary to determine if the gates were indeed stainless steel as stated in the original specifications. (David W. Look)

# Chapter 18: Aluminum; Preservation and Repair

## Identification

Aluminum is light in weight—about one-half that of iron, copper, or brass. It is nonmagnetic and highly resistant to most environmentally caused corrosion, and has a melting point of 660°C, a moderately high coefficient of expansion, and a thermal and electrical conductivity surpassed only by silver and copper.<sup>122</sup> Aluminum is easily worked by most metal fabrication methods. In its purest form, it is very soft with a ductility comparable to that of lead.<sup>123</sup>

A number of aluminum alloys have been developed to improve certain properties. Nonheat-treatable alloys, which include 1 1/4% manganese and 2 to 7% magnesium, are of relatively high strength and are used for corrugated roofing and cladding.<sup>124</sup> Heat-treatable alloys contain varying proportions of aluminum, magnesium, silicon, and sometimes copper.<sup>125</sup> They have high strength and are therefore used for fasteners and for light structural members. The increased strength is obtained by a carefully controlled process of heat treatment. Aluminum alloys used for casting usually contain silicon, silicon and copper, or silicon and magnesium.<sup>126</sup>

Aluminum found in historic buildings may have a variety of surface treatments or finishes: nonfinished, anodized, chemical conversion coatings, painted (or lacquered), plated, porcelain enameled, or laminated.

“Nonfinished” is the term used for a bare aluminum surface with only its natural oxide patina which forms almost instantaneously upon exposure to air.<sup>127</sup> This film is thin, transparent, tough, tenacious, and to a great extent protective. Generally this type of bare finish is used on interior or exterior architectural elements where appearance is of no consequence; however, on historic buildings (1920-1950), the nonfinish is the most common type of finish used both indoors and outdoors. Although it is called a nonfinish, bare aluminum may have a variety of textures: it may be smooth, highly polished, or brushed; or it may be in a pattern formed by casting, extruding, or machining.

Anodized finishes are extra-thick (from 0.05 to over 1.5 mils) oxide films produced by electrochemical treatment.<sup>128</sup> This treatment is accomplished in an acid bath by passing an electrical current through the aluminum. The thickness of the anodized coating depends on the current and duration of the treatment. Quality of the anodized coating depends upon the temperature of the acid bath: the higher the temperature of the liquid, the

lower the quality of the coating. Since the electric current raises the temperature, the best quality of anodized aluminum is accomplished by refrigerating the liquid. The anodic coating can be transparent or integrally colored by adding pigments or dyes before it is sealed. Red, blue, and green aluminum produced with dyes in the 1950s have faded, often in a nonuniform manner, causing a blotched appearance. The gold, brown, grey, and black pigments used were more stable and have retained their original color. Today colored coatings are produced by varying the alloy content, which results in color on the surface (only) during the anodizing process. Any working of the metal and any texturing of the surface must be applied to the aluminum before anodizing. The anodized coating must be protected during the shipping and fabrication to avoid damage.

Chemical conversion coatings, formed by chemical processes only, are thinner and less abrasion resistant than anodic coatings and are often used as shop preparation before painting. When conversion coatings are the final finish (without paint), they may be clear or colored gold, gray, golden brown, green, or blue-green.<sup>129</sup>

Whether clear (lacquer) or pigmented (paint), various types of organic coatings can be applied in the factory over chemical conversion coatings, in the field over mechanically or chemically roughened surfaces, or over a suitable wash primer. This process was occasionally used in the 1930s on aluminum doors, frames, and radiator cabinets to create a wood grain finish.

Plated aluminum is achieved by electrodepositing a metal onto the aluminum surface. Chrome and nickel are the two most common metals to be plated on architectural aluminum. These platings are needed where heavy abrasion is anticipated, such as on stair railings. An intermediate layer of copper may be necessary to achieve a smoother surface or a mirror finish.

Porcelain or vitreous enameled (inorganic) finishes are baked-on ceramic coatings applied in the factory and seldom found in historic buildings.<sup>130</sup> Likewise, laminated finishes are fabricated by bonding wood, cloth, plastic, and so forth, onto the aluminum. Laminated finishes have been introduced only recently. The *Care of Aluminum*, published by the Aluminum Association, Inc., describes how to identify various coatings on aluminum.<sup>131</sup>



## Causes of Deterioration

Aluminum is resistant to most types of corrosion, including attack by sulfur compounds such as hydrogen sulfide and sulfur dioxide. It combines readily and quickly with oxygen to form a transparent, tightly adherent film of oxide which is relatively inert to further chemical action. Aluminum also resists attack by other atmospheric gases (figure 181), moisture, and many kinds of soils.

Corrosive agents that actively attack aluminum include alkalis, hydrochloric acid, lead-based paints, certain wood preservatives, and chlorides (figure 182). Wet lime mortar, Portland cement, plaster, and concrete will cause some surface corrosion of aluminum, but once cured, (and no longer alkaline), they have no further corrosive effect. Aluminum is often corroded where it comes into contact with damp, porous brickwork and stonework.<sup>132</sup> Although dry, seasoned lumber does not affect aluminum, unseasoned, damp oak, cedar, and redwood produce acids which attack the metal. Even water draining off a roof of unweathered wood shingles will corrode aluminum flashing. In addition, any wet wood in direct contact with aluminum will corrode it.

Aluminum is damaged by galvanic action caused by electrical contact with some other metals in a common electrolyte, especially copper; however, it does remain stable in the presence of zinc, cadmium, and magnesium.<sup>133</sup> Even though aluminum is generally compatible with nonmagnetic stainless steel, corrosion of the aluminum is still possible when the two metals come into electrical contact with an electrolyte, a condition that is more common in industrial environments.

The corrosion of aluminum roofs is accelerated by condensation when moisture forms on the underside of the membrane, or when water pools on the roof surface. Corrosion galvanic couples are encouraged by pools of standing water, especially where the rainwater is acidic.<sup>134</sup>

Although aluminum is generally corrosion resistant, aluminum roofing is very susceptible to damage by mechanical breakdown. Of the most commonly used roofing materials, aluminum is second only to copper in having a high coefficient of thermal expansion; aluminum roofing will suffer from fatigue caused by thermal expansion and contraction. Another critical problem



**Figure 181. Corrosion and Pitting of Aluminum.** *Designed by Carl Paul Jennewein, these cast-aluminum doors on the U.S. Justice Building in Washington, D.C., are pitted (see figure 114). Aluminum corrosion is white; however, surface dirt, grime, and pollution have collected on the corrosion products, forming small dark bumps. The pits are actually beneath the bumps and were formed as surface metal oxidized. Pitting is caused by a difference in potential of two or more points on the surface of the same metal and a local breakdown of the protective oxide film. It is encouraged by foreign particles, such as dirt and chlorides which hold moisture next to the surface. (David W. Look)*

with aluminum is its softness, which results in erosion of the metal as well as the protective patina of aluminum roofs and other exposed elements by abrasive agents.

Human error is another problem in dealing with aluminum. Sometimes the alloy specified for the job is not the best choice for the function or location, or the material used in fabrication is not the alloy specified (figure 183).

### Methods of Preservation and Repair

Aluminum architectural elements should be protected by a nonabsorptive, insulative coating to prevent direct contact with corrosive agents. Where aluminum touches masonry, it should be coated with a heavy-bodied bituminous paint, which in turn is covered with two coats of aluminum metal and masonry paint.<sup>135</sup> To protect aluminum from galvanic corrosion caused by contact with other metals, it should be electrolytically insulated by paint, mastics, or other nonconductive materials. To avoid electrolysis, aluminum roofing and flashings should be fastened only with aluminum nails and rivets, and aluminum architectural elements should be pro-

tected from rainwater run-off from copper roofs and gutters. When aluminum is painted for cosmetic reasons and there is no incompatibility with other building materials, it should be primed with zinc chromate and finish coats of compatible paint from the same manufacturer. Aluminum should *not* be painted with copper-containing antifouling paints, because they accelerate corrosion unless at least 4 mils of coating are used under the antifouling paint. This is done frequently on aluminum boats and ships.

Aluminum roofing and wall cladding systems must be carefully designed to accommodate thermal movements and to avoid fatigue damage. If fatigue cracking does occur, there is usually no choice other than to remove the improperly designed section.

Where aluminum elements have been damaged by abrasion or erosion, they can be protected from further damage by coatings of varnish, lacquer, or suitable paint, if the damage is not severe. If the damage is extensive, then the section must be replaced with new metal of a heavier gauge.

The book *Care of Aluminum*, mentioned earlier, discusses five categories of aluminum cleaners: 1) mild



**Figure 182. Corrosion and Severe Deterioration of Aluminum.** *The corrugated aluminum siding on a commercial building in Green Island, New York, has been severely deteriorated by the splashing of water and snow-melting salts. (John G. Waite)*

soaps and detergents and nonetching cleaners, 2) solvent and emulsion cleaners, 3) abrasive cleaners, 4) etching cleaners, and 5) special heavy-duty cleaners.<sup>136</sup> In cleaning aluminum, the most gentle methods should be tried first. More severe methods should be used only if milder methods are not effective, not just to save time.

Mild soaps and detergents and nonetching cleaners that are gentle enough to be applied with bare hands can be safely used on aluminum without spot testing first. However, some detergents that are too strong to be used with bare hands, such as automatic dishwasher detergents, should always be tested first. Some of these detergents can discolor nonfinished and anodized aluminum and can even bleach painted aluminum.<sup>137</sup>

Nonetching cleaners are acidic or alkaline solutions containing inhibitors that permit the cleaning of the metal without etching. Care should be exercised in their use. All cleaning solutions should be thoroughly rinsed from the surface and wiped dry to avoid water spotting. Although relatively mild, solvent and emulsion cleaners are used for removing dirt and stains that cannot be removed by milder cleaners. They can generally be used on bare, anodized, conversion coatings, and porcelain finished aluminum without spot tests, but product directions should always be followed exactly.<sup>138</sup>

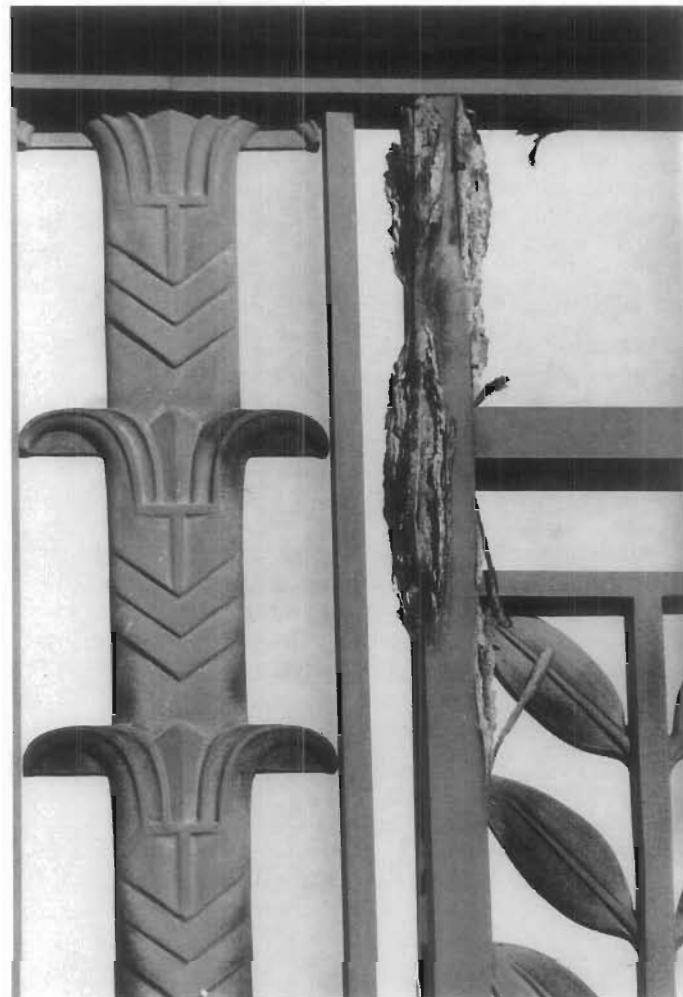
Abrasive cleaners include polishes, cleaners, cleaner-polishes, wax-cleaners, scouring powders, metal brighteners that contain abrasive particles, and may also include water, oil, wax, silicones, soap, acids, or alkali. These cleaners, which depend on vigorous rubbing action along with a chemical reaction, can remove most dirt, stains, and corrosion products from aluminum and will restore most weathered aluminum surfaces.

*Care of Aluminum* rates abrasive cleaners as moderate and heavy duty. Household cleaners with coarse abrasives should not be used on aluminum, except those with porcelain finishes. Even a very fine abrasive can dull a highly polished aluminum finish. Fine pumice powder and stainless steel wool (grades 0000 to 00) can be used with these cleaners, but regular steel wool may leave rust stains.<sup>139</sup>

Etching cleaners remove metal and can be used only on bare aluminum that is highly corroded or stained. Extreme caution should be used. These strong acid and alkali-based cleaners must be rinsed thoroughly and neutralized if necessary. Fine abrasives such as pumice powder and fine stainless-steel wool may be used with etched cleaners.<sup>140</sup>

Special cleaners are all other cleaners that require special power (other than hand) equipment, such as steam cleaners, rotary wirebrushes, and abrasive blasting.<sup>141</sup>

Decorative aluminum architectural elements (bare, anodized, and conversion coatings) are frequently found with a variety of tooled finishes including an embossed texture, a sandblasted texture, a wirebrushed or satin texture, and a buffed or polished finish. Although the best method of preserving the finish involves the application of a protective coating of varnish or lacquer to prevent dirt and grime from accumulating, it is sometimes necessary to restore the surfaces. For nonfinished or bare aluminum, the sandblasted surface can be restored by a light sandblasting; the wirebrushed surface



**Figure 183. Exfoliation Deterioration.** In Washington, D.C., at the Folger Shakespeare Library designed in 1932 by Paul Phillippe Cret, the aluminum alloy balcony railing began to exfoliate in layers, similar to rusting wrought iron. The corrosion product was grayish white and lifted up from the surface as if the metal had exploded. All of the cast ornamental sections were in relatively good condition; only the straight, bar stock was affected. The original specifications stated that the railing was to be an aluminum and chromium alloy. However, a recent laboratory report analyzed a four inch section cut from a sound piece of metal next to a corroded area and indicated that it was high-copper alloy (structural aluminum) fitting into the category of alloy 2017, which is not recommended for exposed outdoor use since it is not corrosion resistant. It is amazing that it lasted 47 years outdoors. All of the straight bar stock of the railing should be replaced with alloy 6063. The cast ornament could be cleaned and reused since they are obviously of more corrosion-resistant alloy and show no signs of deterioration. (David W. Look)

is restored by hand brushing with a finishing compound of ground pumice and water; and the buffed surface is restored by hand rubbing with pumice.<sup>142</sup> An anodized or conversion coating will be damaged by any of these methods. The repair and refinishing of these and other special finishes can only be done under factory conditions.

Bare finishes, anodized finishes, or conversion coatings should be protected by a coating of varnish or wax because there is usually no inexpensive way to restore a damaged anodized coating other than factory refinishing.<sup>143</sup> However, a portable hand-held anodizer was recently developed for the space program. Anodized aluminum elements should be washed at regular intervals to prevent the accumulation of dirt particles and other pollutants. If allowed to accumulate on the surface, dirt and grime will eventually break down the anodized coating.

Although not recommended for all repairs, the following techniques can be used to join aluminum elements: oxy-gas or acetylene welding, brazing, resistance welding, inert-gas-shielded arc processes, adhesive bonding, bolting, and riveting.<sup>144</sup>

Although welding is not difficult under field conditions, replacement is usually the most practical solution to the problem of a damaged structural architectural element or sheathing. Solder (a lead and tin mixture) should never be used for repairing a damaged aluminum roof because of potential galvanic action between the solder and aluminum. Aluminum roofing should be applied with riveted or other mechanical, nonsoldered and nonwelded connections.

## Conclusion

This report, initially published in 1980, is intended to provide updated guidance in the identification, preservation, and maintenance of historic metal building components. The historic preservation movement, begun in the 1960s, has only in recent years seriously utilized scientific conservation technology. As the preservation and reuse of historic buildings increased dramatically in the 1980s and into the last decade of the 20th century, however, some new technologies have become available for treating historic building materials, including metals. In the future, it may be possible to preserve *in situ* even more metal architectural elements that today can be preserved only by treatment in the laboratory. It is still as important as it was in 1980 that, when treating architectural metals, reversible methods be utilized so that the historic components will survive for the future when more effective technology may be available.

1. Material in this report expands John G. Waite's, "Architectural Metals: Their Deterioration and Stabilization," a lecture for the North American Regional Conference convened by the Rome International Centre Committee for Conservation and the International Centre Committee of the Advisory Council on Historic Preservation in Williamsburg and Philadelphia, September 10-16, 1972, *Preservation and Conservation: Principles and Practices* (Washington, D.C.: Smithsonian Institution Press, and Preservation Press, National Trust for Historic Preservation, 1976) pp. 213-242.
2. *Ibid.*, p. 213.
3. Glenn A. Greathouse and Carl J. Wessel, *Deterioration of Materials: Causes and Preventive Techniques* (New York: Reinhold Publishing Corp., 1954), p. 4.
4. W. D. Hoff; John W. Simpson; and Peter J. Horrobin, eds., *The Weathering and Performance of Building Materials* (New York: Wiley-Interscience, 1970), chapter on "Metals" edited by W. D. Hoff, pp. 186-187. Hereafter cited as "Metals."
5. F. L. LaQue and H. R. Copson, eds., *Corrosion Resistance of Metals and Alloys*, 2d ed. (New York: Reinhold Publishing Corp., 1963), pp. 7-37.
6. *Corrosion in Action* (New York: International Nickel Company, 1977), p. 19, and Jerome Kruger, *Corrosion: Facts for the Consumer* (Washington, D.C.: National Bureau of Standards Consumer Information Series 9, March 1978), p. 1.
7. *Ibid.*, pp. 11-18.
8. American Society for Testing and Materials. *Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance - G82-83* (Philadelphia: ASTM).
9. *Corrosion in Action*, p. 15.
10. LaQue and Copson, *Corrosion Resistance*, p. 46.
11. W. H. Munse, J. E. Stallmeyer, and F. P. Drew, *Structural Fatigue and Steel Railroad Bridges* (Chicago: American Railway Engineering Association, 1968), p. 2.
12. Greathouse and Wessel, *Deterioration of Materials*, p. 238.
13. *Ibid.*, p. 301.
14. Robert C. McMasters, ed., *Nondestructive Testing Handbook*, Vol. 1 (New York: Ronald Press Co., 1959), sec. 6-8.
15. Greathouse and Wessel, *Deterioration of Materials*, pp. 264-274.
16. *Ibid.*, p. 275.
17. These are other coatings. Ceramic coatings consist of inorganic glasses loaded with refractory or other materials to aid adhesion, decrease brittleness and liability to break off because of differences in temperature coefficients, and to often achieve decorative colors and texture. The use of this kind of corrosion protection for architectural metals which exist *in situ* is not common because the ceramic coating needs to be applied at red heat. See Greathouse and Wessel, *Deterioration of Metals*, pp. 280-286.
18. *Ibid.*, pp. 291-295.
19. Caleb Hornbostel, *Materials for Architecture: An Encyclopedic Guide* (New York: Reinhold Publishing Corp., 1961), p. 287.
20. Lyall Addleson, *Materials for Building*, Vol. 3 (London: Iliffe Books, 1972), p. 69.
21. Hornbostel, *Materials for Architecture*, p. 287.
22. *Lead in Modern Industry: Manufacture, Applications and Properties of Lead, Lead Alloys, and Lead Compounds* (New York: Lead Industries Association, 1952), p. 51.
23. Addleson, *Materials for Building*, p. 69.
24. *Ibid.*, p. 69.
25. Ulick R. Evans, *The Corrosion and Oxidation of Metals: Scientific Principles and Practical Applications* (London: Edward Arnold, Ltd., 1960), p. 518.
26. In the first case the copper nails, the more noble metal, are much smaller than the lead sheets and deterioration of the lead is only slight. In the second case the iron, the baser metal, is much larger than the lead waterproofing and the iron is almost always painted, so the deterioration of the iron is also slight.
27. Jack Bowyer, *History of Building* (London: Crosby Lockwood Staples, 1973), p. 115.
28. Donald W. Insall, *The Care of Old Buildings Today: A Practical Guide* (London: The Architectural Press, 1972), p. 98.
29. Robert M. Organ, "The Corrosion of Tin, Copper, Iron and Steel, and Lead," in *Preservation and Conservation: Principles and Practices* (Washington, D.C.: Smithsonian Institution Press and Preservation Press of the National Trust for Historic Preservation, 1976), p. 254.
30. Hornbostel, *Materials for Architecture*, p. 515.
31. Henry Leideheiser, Jr., *The Corrosion of Copper, Tin, and Their Alloys* (New York: John Wiley and Sons, Inc.), p. 326.
32. Hornbostel, *Materials for Architecture*, p. 515.
33. A formula for the traditional "inner's red" paint is 10 pounds of Venetian red, 1 pound red lead to 1 gallon of pure linseed oil; Frank E. Kidder and Henry Parker, *Kidder-Parker Architects' and Builders' Handbook*, 18th ed. (New York: John Wiley & Sons, Inc., 1956), p. 2001.
34. Revere Copper and Brass, Inc. *Examination of Corroded Lead Coated Copper Sheet: Austin-Hastings Company Incorporated, Cambridge, Massachusetts* (Rome, New York: Revere Copper and Brass Inc., Research and Development Center, 1964), p. 3.  
 "Due to the extremely small solubility of lead in copper, it is difficult to wet a copper surface with molten lead in applying a lead coat. To promote the wetting process, a few percent tin, soluble in both copper and lead, is added to the lead bath. The final product may then be considered as a three-layered composite consisting of the copper substrate, a copper-tin alloy layer, and the lead coat.  
 "Pinholes or voids in the coat as produced, gross inclusions in the coat, or abnormal corrosion of the coat all tend to expose the copper-tin alloy layer and the copper substrate to the corrodent. This condition may give rise to a galvanic corrosion all with the copper becoming anodic to the copper-tin alloy, resulting in accelerated pitting of the copper.  
 "This particular situation is somewhat aggravated in that the metal is exposed in a horizontal position. This allows rain water and condensed moisture, the electrolytes, to pool in the low spots and remain on the surface for periods much longer than those normally encountered on a pitched roof."
35. Hornbostel, *Materials for Architecture*, p. 592.
36. *Ibid.*

37. *Ibid.*, p. 596.
38. *Ibid.*
39. Ian A. Melville and Ian A. Gordon, *The Repair and Maintenance of Houses* (London: The Estates Gazette Limited, 1973), p. 534.
40. Ian A. Melville, Ian A. Gordon, and Peter Scott, *Structural Surveys of Dwelling Houses* (London: The Estate Gazette Limited, 1964), p. 29.
41. Hoff, "Metals," p. 206.
42. The discoloration caused by white storage stain or white rust can be avoided by dipping the sheets in dilute hydrochloric acid (remembering the zinc will dissolve in it), rinsing, and then dipping in a solution of dichromate, after which final rinsing and drying are necessary. *Ibid.*, p. 208; and Hornbostel, *Materials for Architecture*, p. 596.
43. Evans, *The Corrosion and Oxidation of Metals*, pp. 586-587.
44. Hornbostel, *Material for Architecture*, p. 177.
45. *Ibid.*, p. 105. This page contains additional information regarding the various types of brasses and their compositions.
46. *Ibid.*, p. 91.
47. *Ibid.*
48. *Ibid.*, pp. 91-92. These pages contain additional information regarding the various types of brasses and their compositions.
49. In the past, it was generally believed that the patina was basic copper carbonate but research in the 1930s determined that it was basic copper sulfate. See Donald H. Osburn and John M. Fochlich, "Coloring and Finishing of Copper Metals," *Construction Specifier* (October 1963), pp. 50-55.
50. Organ, "The Corrosion of Tin, Copper, Iron and Steel, and Lead," p. 248. Acetates are salts or esters of acetic acid (found in vinegar and some other organic acids).
51. *Ibid.*, p. 247.
52. H. J. Plenderleith and A. E. A. Werner, *The Conservation of Antiquities and Works of Art: Treatment, Repair, and Restoration*, 2nd ed. (New York: Oxford Press, 1971), pp. 246-250.
53. Hornbostel, *Materials for Architecture*, pp. 91-92.
54. *Kidder-Parker Architects' and Builders' Handbook*, p. 2018.
55. Joseph F. Long, P.E. Manager, Tin Research Institute, Inc., Columbus, Ohio, to John G. Waite, 23 June, 1972.
56. *Copper and Common Sense, Design Principles and Techniques of Sheet Copper Construction*, 6th ed. (New York: Revere Copper and Brass, Inc., 1961), p. 32.
57. *Kidder-Parker Architect's and Builders' Handbook*, p. 2018.
58. Harold L. Peterson, "Conservation of Metals," *History News* 23 (no. 2, Feb. 1968): p. 6.
59. Organ, "The Corrosion of Tin, Copper, Iron and Steel, and Lead," p. 249.
60. *Copper, Brass, Bronze Design Handbook: Architectural Applications* (New York: Copper Development Association, Inc., n.d.), p. 31.
61. Hornbostel, *Materials for Architecture*, p. 330.
62. *Ibid.*, p. 333.
63. *Ibid.*, p. 334.
64. Hard and soft solders are general terms that usually refer to temperature. Soft solders are all soldering alloys that melt below 840°F. and are usually composed of varying proportions of lead and tin. Hard solders are all soldering alloys that melt above 840°F. and are usually silver solders which contain varying percentages of silver, copper, tin, cadmium, nickel, and other metals, but never lead. Hard soldering is the same as brazing. The brazing filler metal (soldering alloy) has a melting point below the melting point of the metal pieces being joined. If the metal pieces being joined, often called the base metal (not to be confused with the baser metal in galvanic corrosion), is melted and fused with the filler metal, the process is welding. In brazing the metal pieces being joined are never melted and the filler metal is drawn into the joint by capillary action. For brazing nickel silver, the filler metal is 10-18 % nickel zinc, and the remainder, copper. *The Brazing Book* (New York: Handy & Harmon, 1977), p. 44.
65. Gerald K. Geerlings, *Metal Crafts in Architecture* (New York: Charles Scribner's Sons, 1929), p. 185.
66. Even at high temperatures, Monel metal is too strong to be extruded. *Practical Design in Monel Metal* (New York: International Nickel Company, Inc., 1931), pp. 9-10, and 25.
67. Hornbostel, *Materials for Architecture*, p. 320
68. *Ibid.*, p. 330.
69. *Ibid.*, p. 333.
70. Geerlings, *Metal Crafts in Architecture*, p. 185.
71. In general, nickel silver and Monel metal can be cleaned using the same methods as cleaning bronze since they all contain copper; however, chemicals should always be spot tested for desired results before general application. *Copper, Brass, Bronze Handbook: Architectural Application*, (New York: Copper Development Association, Inc., n.d.), p. 31; Peterson, "Conservation of Metals," p. 7.
72. "Simple Tests Identify White Metals: Reliable in Result, They Eliminate Guesswork by the Eye and Can be Carried Out With Inexpensive and Readily Available Equipment—Essential in Scrap Recovery, They Also Are Useful for Identification of Materials in Process and Storage," *Inco* 18 (no. 3, 1941): pp. 6-7. (Tests for the identification of nickel, Monel, nickel-silver, steel, cast iron, stainless steel, and Inconel).
73. Hornbostel, *Materials for Architecture*, p. 321.
74. *Ibid.*, p. 334.
75. *Ibid.*, p. 276.
76. LaQue and Copson, *Corrosion Resistance*, p. 305.
77. Addleson, *Materials for Building*, p. 64.
78. Hornbostel, *Materials for Architecture*, p. 285.
79. Addleson, *Materials for Building*, p. 64.
80. *Ibid.*
81. Geerlings, *Metal Crafts in Architecture*, p. 114.
82. Hornbostel, *Materials for Architecture*, p. 283.
83. Geerlings, *Metal Crafts in Architecture*, p. 45.
84. Hornbostel, *Materials for Architecture*, p. 283.
85. Addleson, *Materials for Building*, p. 64.
86. Hornbostel, *Materials for Architecture*, p. 448.
87. Addleson, *Materials for Building*, p. 64.
88. *Ibid.*, p. 66.
89. LaQue and Copson, *Corrosion Resistance*, p. 375.
90. *Metal Product Outline for Classifying Products Manufactured by NAAMM Member Companies* (Chicago: National Association of Architectural Metal Manufacturers, 1989, second edition), p. 10.
91. Plenderleith and Werner, *Conservation of Antiquities and Works of Art*, p. 281.
92. Organ, "The Corrosion of Tin, Copper, Iron and Steel, and Lead," p. 251.
93. *Ibid.*
94. Magnesium oxychloride cements were originally developed in 1867 by French chemist I. M. Sorel, the man who patented the galvanizing process in 1837. Historically, magnesium oxychloride cement was known as Sorel cement, or magnesite cement; today it is known as oxychloride cement. Philip Maslow, *Chemical Materials of Construction* (Farmington, Mich.: Structures Publishing Company, 1974), p. 132.
95. Addleson, *Materials for Building*, p. 63.
96. *Ibid.*, p. 64.
97. LaQue and Copson, *Corrosion Resistance*, p. 367-368.
98. McMasters, *Nondestructive Testing Handbook*, p. 6-1.
99. Hornbostel, *Materials for Architecture*, p. 285.
100. Addleson, *Materials for Building*, p. 64.
101. *Ibid.*, p. 66.
102. Hornbostel, *Materials for Architecture*, p. 461.
103. LaQue and Copson, *Corrosion Resistance*, p. 410.
104. Addleson, *Materials for Building*, p. 67.
105. *Ibid.*
106. Hornbostel, *Materials for Architecture*, p. 444.

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107. Addleson, *Materials for Building*, p. 67.
108. *Ibid.*, p. 65
109. Evans, *Corrosion and Oxidation of Metals*, p. 531.
110. F. Fansutt and J. C. Hudson, *Protective Painting of Structural Steel* (New York: MacMillan Co., 1957), p. 64.
111. Peterson, "Conservation of Metals," p. 4.
112. Organ, "The Corrosion of Tin, Copper, Iron and Steel, and Lead," p. 252.
113. Evans, *Corrosion and Oxidation of Metals*, p. 571.
114. *Ibid.*
115. Addleson, *Materials for Building*, p. 79.
116. *Ibid.*
117. Robert Ohlerking, "Cast Iron," *The Old House Journal* 8 (no. 2, Feb. 1980): p. 21.
118. "Ni-rod" welding electrodes used to weld cast iron lamp post. "Inco Echoes," *Inco* 17 (no. 2, 1947): p. 20.
119. Ohlerking, "Cast Iron," p. 21.
120. Dismantled Edgar Laing Stores facade components, erected by James Bogardus in 1849, were stolen while in storage; Margot Gayle and Frances Frieder, "Bogardus Building Badly Boosted," *Society of Industrial Archeology Newsletter* 3 (No. 4, July 1974): p. 1.
121. J. Scott Howell, "Architectural Cast Iron: Design and Restoration," *Association for Preservation Technology Bulletin* (vol. XIX, number 3, 1987), pp. 51-55.
122. Hornbostel, *Materials for Architecture*, p. 18-19.
123. Hoff, "Metals," p. 194.
124. *Ibid.*
125. *Ibid.*, p. 195.
126. *Ibid.*
127. *Care of Aluminum*, 4th ed. (Washington, D.C.: The Aluminum Association, Inc., and the Architectural Aluminum Manufacturers Association, Dec. 1977), p. 1.
128. *Ibid.*
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130. Hornbostel, *Materials for Architecture*, p. 29, 34-36.
131. *Care of Aluminum*, p. 3.
132. Hoff, "Metals," p. 204.
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