

APPENDIX T

MINING





Gravel yard



Backhoe



Open-pit mining



Earth mover

MINING

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SUMMARY

Corrosion in the mining industry is not considered a significant issue. Interviews with several mining engineers indicated that equipment wear and tear was the primary concern in maintaining the equipment. Although various forms of corrosion could be identified in mining machinery, corrosion is not considered to be a life-limiting factor for this equipment. Maintenance painting is, however, heavily relied upon to control corrosion, and it is estimated that an average of \$93 million is spent annually on maintenance painting for the coal mining industry.

In the few instances where corrosion has been considered to be a problem, the mining industry has relied heavily on past experience and the knowledge of equipment suppliers to quickly resolve any issues so that production is not interrupted. Engineers with corrosion knowledge and expertise are not kept on staff; however, if circumstances require additional help, corrosion consultants are hired.

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SECTOR DESCRIPTION

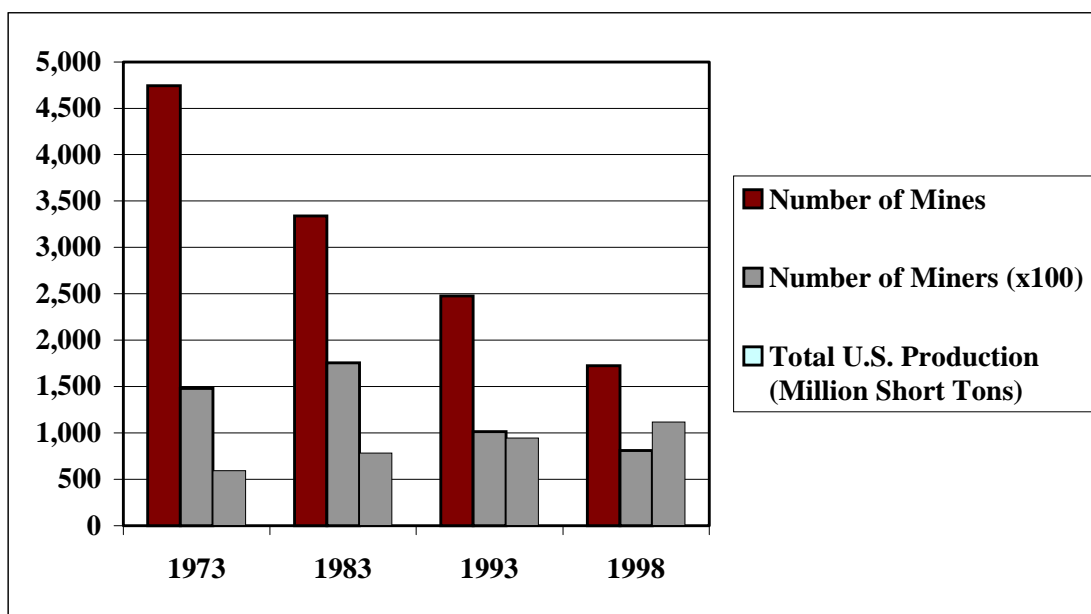
The United States mines and processes coal and more than 2,500 known minerals.⁽¹⁾ Each American relies on more than 21,000 kg (46,000 lb) of mined materials, including 3,400 kg (7,500 lb) of coal energy per year.⁽²⁾

The mining, mineral processing, and extractive metallurgy industries possess the ingredients for an extremely corrosive environment. Water, grinding media, dissimilar materials, oxygen, wide pH range, and the presence of many corrosive species in solution contribute to the corrosion-related difficulties that the mining industry deals with on a continuous basis.

This sector report includes information on the mining of metallic materials, industrial minerals (non-fuel, non-metal), and coal. Industry statistics and corrosion issues within the industry are discussed below.

Mining Industry Statistics

Total mining production in the United States was estimated at \$59.3 billion in 1998.⁽²⁾ Figure 1 shows that the trend of the mining industry over the past 25 years is to use fewer employees in fewer mines, but with greater production.⁽³⁾



1 short ton = 2,000 lb = 0.9072 metric tons

Figure 1. U.S. trends for the mining industry from 1973 to 1998.⁽³⁾

The total mining production values in 1998 for metals, industrial minerals, and coal are shown in figure 2. Industrial minerals such as dimension stone, clay ceramic, refractory minerals, and chemical and fertilizer minerals comprised more than 48 percent of the total mining production in U.S. dollars, while coal comprised 33.2 percent and metals 18.7 percent. The quantities and values of specific metals mined are shown in table 1.

In 1998, U.S. exports of principal minerals and products, excluding mineral fuels, totaled \$31.4 billion, while imports totaled \$65.4 billion.⁽⁵⁾

It is estimated that \$2.1 billion of processing equipment to support the mining industries are developed and shipped annually.⁽¹⁾

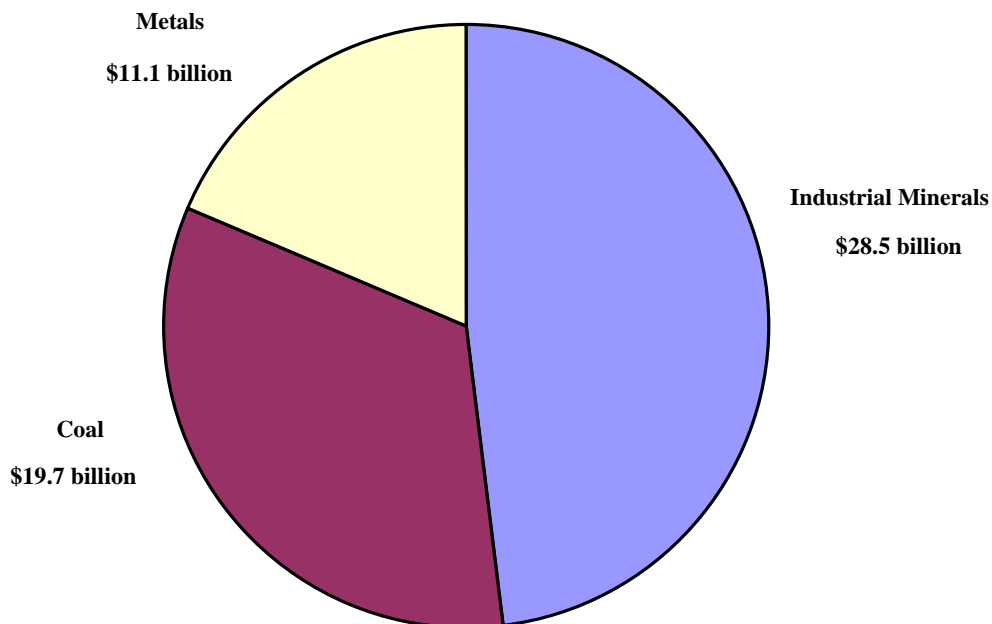


Figure 2. Total mining production values for the United States in 1998, as reported by the U.S. Geological Survey.⁽⁴⁾

Table 1. 1998 Metal production in the United States, as reported in March 2000 by the U.S. Geological Survey.⁽⁵⁾

MINERAL	QUANTITY (metric tons)	VALUE (\$ x million)
Beryllium concentrates	6,080	*
Copper	1,860,000	3,220
Gold	366	3,480
Iron ore, usable	63,200,000	1,970
Iron oxide pigments, crude	46,100	7.3
Lead	481,000	480
Magnesium metal	106,000	344
Nickel ore	-	-
Palladium	10.6	98.6
Platinum	3.24	38.8
Rare-earth metal concentrates	5,000	14.4
Silver	2,060	339
Zinc	722,000	819
Antimony, bauxite, manganiferous ore, mercury, molybdenum, titanium, tungsten, vanadium, zirconium	-	590
TOTAL	-	\$11,400

*No value reported.

Corrosion in the Mining Industry

Corrosion within the mining industry can be characterized as corrosion enhanced by abrasion. It is also difficult for corrosion engineers to plan for corrosion because mine atmospheres and waters are unique and vary widely from one mine to another; therefore, each mine experiences relatively different corrosion-related problems.

Aerobic and anaerobic microorganisms present in mining water also contribute to the extremely corrosive environments.⁽⁶⁾ Aerobic species produce sulfuric acid, making the environment very acidic. Anaerobic microorganisms reduce sulfate and sulfides by using available hydrogen and producing hydrogen sulfide (H₂S).

Although corrosion does exist in the mining industry, the industry does not consider it to be a serious issue. Engineers from several mining companies who were interviewed could not provide any information on instances where corrosion problems were a critical issue. Past experiences and equipment suppliers provide these process engineers with enough information to keep the mining industry processing its metallic minerals, industrial minerals, and coal.

Maintenance painting is heavily relied upon to prevent corrosion. American Electric Power⁽⁷⁾ estimated that it spends between \$0.5 million and \$1 million annually for maintenance painting in order to produce approximately 8.2 million metric tons (9 million short tons) of coal. Correlating this to the 1.0142 billion metric tons of coal (1.1176 billion short tons) that were produced nationwide in 1998,⁽⁴⁾ it can be estimated that between \$62 million and \$124 million (average \$93 million per year) was spent on maintenance painting for the coal mining industry.

While mine engineers are not involved in serious corrosion issues, literature on the subject lists several areas of major concern due to personnel safety and continuation of production. These areas are listed below.

AREAS OF MAJOR CORROSION IMPACT

The corrosive environment of the mining industry limits the life span of the processing equipment and as a result, decreases production and endangers the lives of employees within the mine. Examples of mining equipment that undergo corrosion are discussed below.

Wire Rope

Wire ropes are used extensively in the mining industry to help hoist equipment. Mine workers also depend on this rope for their safety. Wire rope undergoes both corrosion and abrasion, which will degrade the mechanical properties of the wire and, thus, reduce its load-bearing capability and cause it to fail.

A statistical study of mine-hoist wire ropes showed that 66 percent of the ropes exhibited the greatest strength loss in the portion of the rope in contact with the shaft environment during its service life.⁽⁸⁾ The Mine Safety and Health Administration (MSHA) of the U.S. Department of Labor requires that wire ropes in service be visually examined for structural damage, corrosion, and improper lubrication or dressing.⁽⁹⁾ MSHA also requires performance of careful nondestructive testing (NDT) every 6 months and sites one instance where a contractor reported that four ropes were in acceptable condition for use in an elevator shaft. However, less than 6 weeks later, one of the four 12.7-mm- (0.5-in-) diameter ropes broke and another was severely corroded with several broken wires.⁽¹⁰⁾

Wire ropes within the mining industry are routinely replaced every 18 to 36 months, depending on environmental conditions and use over time. These wire ropes are mainly made of carbon steel; however, due to their susceptibility to corrosion and wear, stainless steel and synthetic fiber ropes are becoming more widely used instead.⁽⁶⁾

Roof Bolts

In the mining industry, roof bolts provide support in underground mines by tying the lower layer to a stronger layer located above the main roof. In the United States, more than 120 million low-carbon steel roof bolts are used per year and are a major area of concern with regard to corrosion because a failure of the roof bolt is hazardous and could result in the loss of lives.⁽⁶⁾ In sulfide mines, roof bolts have been reported to fail within 1 year due to sulfide stress corrosion cracking

Pump and Piping Systems

Corrosion within pump and piping systems is another critical issue in the mining and mineral processing industries. The most common form of corrosion is uniform attack; however, pitting, crevice corrosion, intergranular corrosion, dealloying, galvanic corrosion, and cavitation are each possible, depending on the processing environment.

Erosion-corrosion in the milling process is another critical issue. Particulates are often carried in a corrosive medium through pipes, tanks, and pumps. The presence of these particulates erodes and removes the protective film of the metal and exposes the reactive alloy to high flow velocity, thus accelerating the corrosion mechanism.

Mining Electronics

According to the Connaisseur Corporation Pty. Ltd.,⁽³⁾ the effects of corrosion in electrical and electronic systems in modern mines are often overlooked; however, the harsh environment of the mining industry often causes electrical equipment to fail after a short period of time.

Acid Mine Drainage

When pyrite and other sulfide minerals are oxidized by exposure to oxygen and water, ferrous ions and sulfuric acid are produced. The ferrous ions further react to form hydrated iron oxide and more acidity. This acid formation lowers the pH of the water, making it unable to support many forms of aquatic life and to become corrosive to surrounding structures. The acid mine drainage can cause corrosion problems in structures such as pipes, well screens, dams, bridges, water intakes, and pumps. In 1993, a survey by the U.S. Forest Service estimated that 8,050 to 16,100 km (5,000 to 10,000 mi) of domestic streams and rivers are impacted by acid drainage.⁽¹¹⁾

In comparison, in 1995, the Pennsylvania Department of Environmental Protection reported that 3,902 km (2,425 mi) of stream in Pennsylvania did not meet EPA-mandated in-stream water quality standards due to mineral extraction.⁽¹²⁾ This significant amount affected streams in Pennsylvania, compared with the nationally estimated amount, can be explained by the fact that this state has a relatively large portion of the U.S. coal industry.

CORROSION CONTROL METHODS

Material selection is the most important general form of corrosion prevention. Choosing the correct material based on the environment decreases the amount of corrosion and lengthens the life span of the equipment. While material selection is the most important general approach to corrosion prevention, several other methods of corrosion protection are used in the mining industry. They include protective coatings, corrosion inhibitors, and electrochemical techniques such as cathodic protection.

CORROSION MANAGEMENT

Corrosion-related issues in the mining industry are dealt with immediately when problems arise that can cause a slowdown in production. As corrosion-related issues develop, the mining industry relies almost entirely on past experience and vendor input to assist with a quick remedy to the problem. Corrosion engineers are not common in mines. When major corrosion problems are encountered, mining companies will contract the help of external contractors or corrosion consulting firms.⁽¹³⁾

CASE STUDY

Example of Cost Analysis of Organic Coatings

Andrew⁽¹⁴⁾ performed a cost-benefit analysis for both the initial and long-term costs associated with four organic coating systems used in the mining industry. Alkyd, vinyl, and epoxy coatings were each analyzed with various forms of surface preparation (e.g., surface blasting or no surface blasting) and coating thicknesses. It is recognized that the values presented in this case study are merely estimates and should not be extrapolated beyond the current example; however, the presented method to compare systems is a valid approach to analyze long-term costs.

Organic coatings will react differently depending on the environment to which they are exposed.⁽¹⁵⁾ Alkyd resins are oil-based coatings that have excellent adhesion to poorly prepared surfaces, but are not chemically resistant. They are mainly used for dry exterior uses. Vinyl coatings are easily recoated, are low in toxicity, but are highly volatile. They are mainly used under conditions where equipment is frequently exposed to either saltwater or fresh water and acidic chemicals. Epoxies are similar to alkyds, but are more chemically resistant and correspondingly more expensive. They are used in applications that involve exposure to fresh water, saltwater, or chemicals such as mineral spirits, lower alcohols, glycols, etc.

The surface preparation and thickness of the coating also play important roles in the amount of corrosion protection provided. Abrasive blasting produces a surface anchor pattern, which allows for better adhesion between the substrate and the coating. The thickness of the coating will also determine the amount of protection that the coating will provide. The thicker the coating, the longer it will last.

The initial costs, maintenance costs (touch-up versus replacement), and maintenance frequency of four painting systems with the different organic coatings, surface preparations, and coating thicknesses are estimated by Andrew⁽¹⁴⁾ (see table 2). These cost estimates are relative with respect to the variable “P”, which is the basic cost of the carbon steel item for which corrosion protection is required.

The two-coat, 100- μ m (4-mil) alkyd coating system with no abrasive blasting has the lowest initial cost, but must be touched-up annually and be replaced every 2 years. As the abrasive blasting is performed and the coating thickness increases, the initial cost increases. However, the maintenance frequency decreases.

Table 2. Cost analysis of four coating systems.⁽¹⁴⁾

COATING SYSTEM	INITIAL COST	MAINTENANCE COST		MAINTENANCE FREQUENCY	
		TOUCH-UP	REPLACEMENT	TOUCH-UP	REPLACEMENT
2-coat alkyd/no blasting 100 µm (4 mil)	0.2P	0.1P	0.3P	Yearly	Every 2 years
3-coat vinyl/no blasting 175 µm (7 mil)	0.5P	0.3P	0.6P	Every 2 years	Every 4 years
3-coat vinyl/with blasting 175 µm (7 mil)	0.7P	0.3P	0.6P	Every 3 years	Every 6 years
3-coat epoxy/with blasting 250 µm (10 mil)	0.9P	0.4P	1.1P	Every 4 years	Every 8 years

Note: “P” is the basic cost of the carbon steel item requiring corrosion protection.

Table 3 evaluates the estimated costs and maintenance frequencies of the four coating systems over a 20-year period. The three-coat, 175-µm (7-mil) vinyl coating with abrasive blasting is the most cost-effective, while the same system with no abrasive blasting is the most expensive due to the necessary maintenance. Figure 3 shows this data in graphical form.

Table 3. Cost evaluation of four coating systems over a 20-year period.⁽¹⁴⁾

COATING SYSTEM	INITIAL COST	MAINTENANCE COST	TOTAL COST (20 YEARS)
2-coat alkyd/no blasting 100 µm (4 mil)	0.2P	4.0P	4.2P
3-coat vinyl/no blasting 175 µm (7 mil)	0.5P	4.3P	5.0P
3-coat vinyl/with blasting 175 µm (7 mil)	0.7P	2.6P	3.4P
3-coat epoxy/with blasting 250 µm (10 mil)	0.9P	3.4P	4.3P

Note: “P” is the basic cost of the carbon steel item requiring corrosion protection.

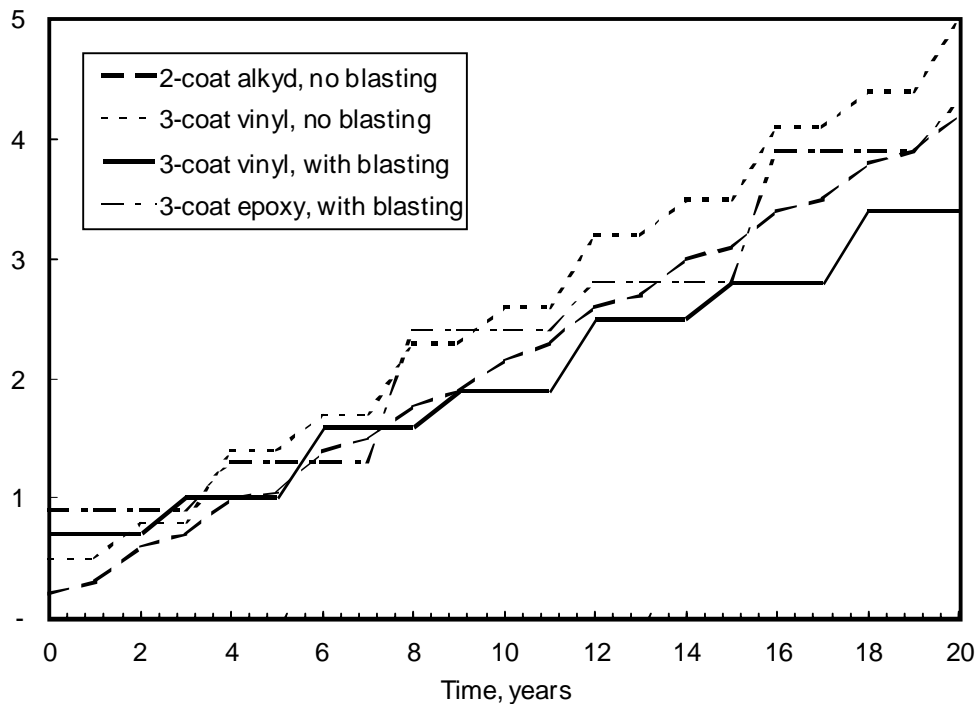


Figure 3. Comparison of relative cumulative costs for four typical painting systems.⁽¹⁴⁾

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