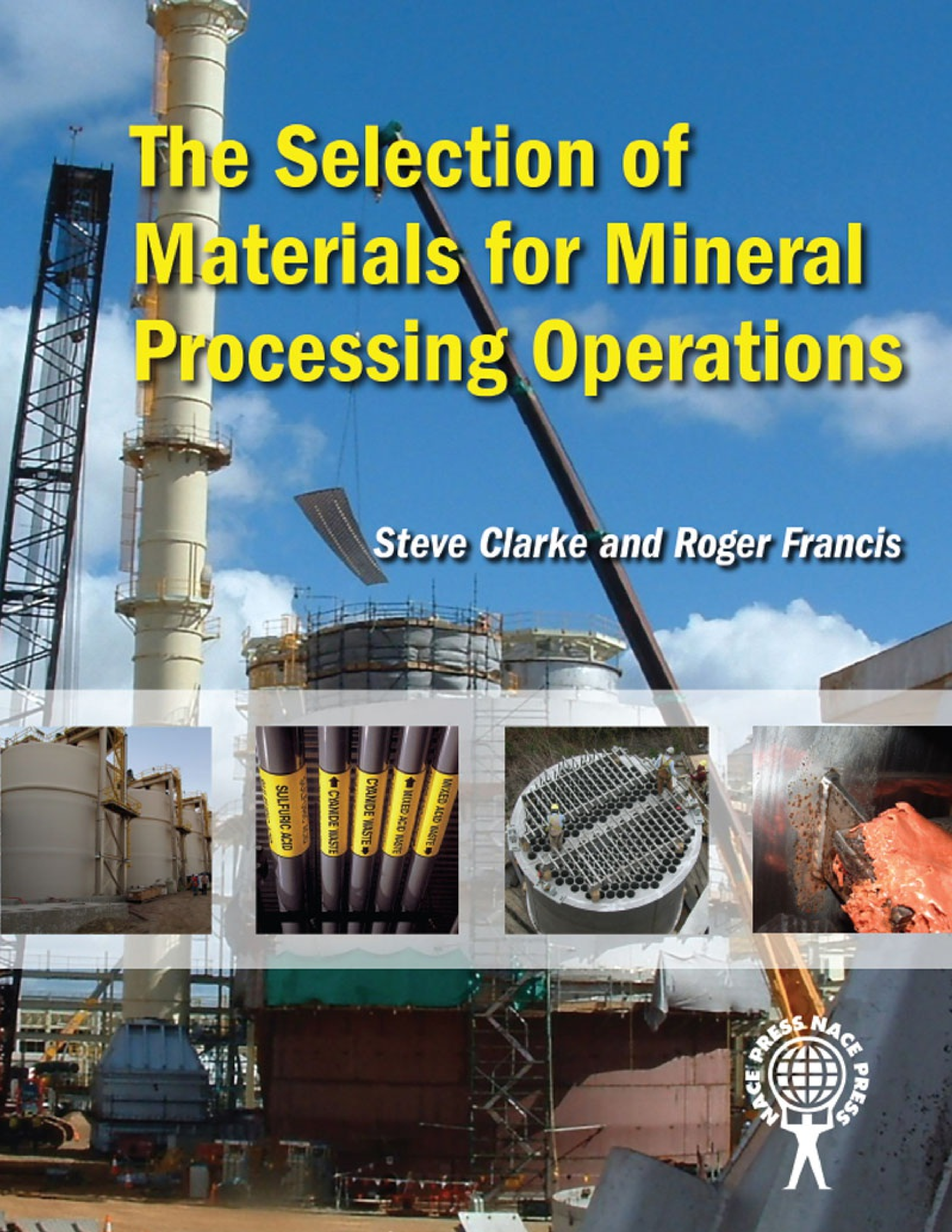
The Selection of Materials for Mineral Processing Operations

Steve Clarke and Roger Francis



NACE PRESS

The Selection Of Materials For Mineral Processing Operations

by Steve Clarke and Roger Francis

ISBN: 978-1-57590-314-9

Cover design by Ian Francis

NACE International
15835 Park Ten Place
Houston, TX 77084
USA
Phone: +1-281-228-6200
Fax: +1-281-228-6300
Web: nace.org

NACE INTERNATIONAL
The Worldwide Corrosion Authority

PREFACE

We have both been involved for many years in looking at failures or helping to select materials for arduous duty in chemical and mineral processing plants around the world, involving a wide range of materials. What has struck us repeatedly is that many projects and mine sites do not have a materials/corrosion engineer. This can mean that some strange materials choices have been made and these choices are quite often low cost in the short term but incredibly expensive in the longer term. This usually involves the use of an inadequate material that fails prematurely at great cost. Not only is there the cost of lost production, the correct material may be on long delivery and many mine sites are at remote locations, which further increases the cost of repairs. Many of the failures have safety and environmental implications. A leak of a hot, acidic process stream is not only dangerous but can also cause irreparable environmental damage.

Just as troublesome is the recognition that a corrosion resistant alloy is required but the selection of the wrong one is made due to a lack of understanding of the complex nature of many mining fluids. Examples of both of these can be found in this book. Despite the lucrative nature of this work for the authors, we decided that we should write a book to act as an introduction to materials selection, to help engineers make more informed materials selection. The original concept was fairly simple, but as writing progressed we realized that we had to add chapters to cover some additional important topics. Hence, the writing of this book took somewhat longer than planned initially. We would like to thank Rolled Alloys, FLSmidth Industries, Lochhead Haggerty, and MMB for the use of some of their photographs and technical information. We would also like to extend our thanks to Ian Francis, who did the original line drawings. We hope that you find this document useful.

STEVE CLARKE and ROGER FRANCIS

Contents

1

Introduction

Mankind first began extracting and processing metals some 6,000 to 10,000 years ago, with the discovery of copper, silver, and gold. This was followed quickly by tin and zinc and the alloying of these with copper to begin the Bronze Age, which occurred around 1500 BC in Northern Europe. This was followed by the discovery of how to extract iron, and since that time many of the metals in the periodic table have been routinely extracted from their ores at mineral processing sites around the world. Initially, the extraction principally involved the use of heat, but in the second half of the 20th century increasing energy costs made alternative extraction methods more attractive. Nowadays, hydrometallurgy is a very common method of extraction for metals such as copper, gold, zinc, nickel, uranium, etc. As the name suggests, this involves dissolution of the metal of interest in aqueous solution. This is most often an acidic solution, particularly sulfuric acid, although caustic environments are used to extract some metals. This means that extraction fluids can be very aggressive and corrosion resistant materials are required.

The problem is exacerbated by the presence of other ions, such as chloride and fluoride, which are either intentionally added or from the slurry make up water, as well as the effect of metal ions or chemical additions that can make the process oxidizing or reducing. All of these can make the solution corrosive and this is further exacerbated by heating the fluid to increase the metal extraction rate. This makes for a complex fluid that means material selection requires great care and understanding of all the variables.

Despite this, materials/corrosion engineers often have little or no input in the selection of materials for expensive mineral processing plants. This has led to some disastrous failures. In a recent bioleach pilot plant, the process was hot, acidic and contained high quantities of chloride. The 316L stainless steel agitator and heater coils were found to last “a day or so.” These were replaced with 2205 duplex stainless steel which lasted “a few days” and this was replaced with 2507 superduplex which “performed well but corroded at the welds.” At this point, a materials engineer was asked to make materials recommendations. An example of the corrosion failure of the agitator is shown in Figure 1.1.

Even when the need for a corrosion resistant alloy is recognized, it can happen that the wrong material is selected due to a lack of understanding of all the factors affecting corrosion. This can lead to a very expensive failure.

An example of this is the positive displacement tailings pumps that were used to pump a corrosive tailing slurry. The slurry composition was:

- 40 °C max
- pH 5 to 6 nominal. Down to pH 4 if not controlled well
- 17 g/L Chloride

- 5-20 g/L sulfate (mostly Mn and Mg with about ~1g/L ferrous).

FIGURE 1.1: A 2205 duplex stainless steel agitator after a few days exposure to a hot, chloride-rich, acidic bioleach slurry.

The tailings slurry also contained a significant amount of quartz. The pump vendor had selected 316Ti (a stabilized version of 316L) for the balls, 301 stainless steel for the springs, and 2205 duplex stainless steel for the valve seats. The very high local slurry velocities combined with the high chlorides caused very rapid material loss. Figures 1.2 and 1.3 show the extent of the damage after 4 days of operation.

The material loss appears to be due to the conjoint action of corrosion and erosion. At the time of writing, trials are underway with Ni-Cr-Mo alloy springs, and valve balls and seats made from a range of materials including alloy C276, Grades 2, 3, and 5 titanium and stabilized zirconia ceramic (see Chapter 2 for details of these materials).

This book was conceived as an introduction to materials selection in the minerals processing industries and all the factors that affect selection. The next chapter discusses metals, ceramics and polymers. It also discusses composition, properties, and the differences between similar materials. The third chapter discusses the common types of corrosion and how different alloys perform under a range of conditions. This is mostly with reference to chlorides, pitting, and environmental cracking, but some other ions and corrosion mechanisms are also discussed.

Chapter 4 discusses the performance of alloys in sulfuric acid, as this is one of the most common chemicals used in mineral processing. In addition to pure acid, the effects of chlorides, oxidizing ions, and temperature are discussed. This includes the use of some previously unpublished data. The limits, where known, are described, but for many alloy systems, these are inadequately understood and the need for material testing in conditions with no data is recommended, and indeed it is often essential.

Sulfuric acid is commonly used as an aid to metal extraction and many sites include a dedicated on-site sulfuric acid production plan acid plant or, alternatively, an acid plant which captures waste SO_2 and converts it into saleable sulfuric acid. Chapter 5 discusses materials for acid plants, the problems that can occur, and their solutions.

FIGURE 1.2: A 316Ti ball from a positive displacement pump after 4 days operation. The original wall thickness was 20mm.

FIGURE 1.3: A 2205 valve seat after 4 days operation.

Chapter 6 looks at materials for tanks, agitators, and spargers in atmospheric leach operations, at temperatures up to ~90 °C. It principally discusses current practice, but does include advice on methods that can be used for improved performance of agitators in abrasive slurries. Chapter 7 discusses materials for high pressure acid leach operations, principally for nickel laterite ores and pressure oxidation of sulfide ores. This includes the heaters, flash tanks and other equipment, as well as the autoclaves. This is based on the experiences at various plants, principally in Australia, and discusses some of the common problems and their solutions.

Chapter 8 looks at downstream processing, and as there are so many possible ways of extracting metals, these are discussed in a general way, rather than trying to deal with specific sites. This includes surge tanks, thickeners, precipitation vessels, re-leach vessels, solvent extraction and electrowinning, raffinates, carbon in leach, and yellowcake. The potash industry does not involve acids, but the high chlorides and temperatures in potash extraction plants can lead to a variety of corrosion problems. In addition, aggressive species, such as sulfides, can be present. The problems and solutions for various parts of a typical processing route are also discussed in Chapter 8. This chapter also includes sections for gold and uranium downstream processing.

It has become more recognized in recent years that some of the problems with materials in the field originate in poor quality. Chapter 9 discusses what information is needed to select materials and what tests, over and above those specified in standards, can detect the required quality for some specific classes of materials. The effects that different finance bases may have on materials selection are also discussed. Some QA/QC checks that need to be imposed either on vendors or on receipt of materials to test for quality are described, as is the desirability of pre-qualifying vendors of corrosion resistant alloys (CRAs) and other special materials. Finally, some issues with regard to getting the best quality during fabrication are covered.

In addition, there are two appendices. The first is a list of common alloys and their nominal compositions. This has been put in an appendix so that it may be easily referenced from any part of any chapter. The second appendix discusses the handling and storage of sulfuric acid, because this chemical is widely used in mineral processing and it is also very aggressive. Reference is made to the appropriate NACE standards.

One thing that has been learned from many years looking at corrosion problems in the mineral extraction industry is that every ore body is different. This means that nominally similar ores from different locations may require somewhat different processing routes and this can mean that very different materials of construction are needed. In addition, the water at every site is different and the water composition can have a significant effect on the most suitable materials. Fresh water is becoming an increasingly precious commodity, and at an increasing number of locations there is no fresh water available for processing, so the slurry has to be made with seawater or a borehole water of very high chloride content. This offers even more potential for corrosion, and materials selection becomes even more critical.

In this book we have used ASTM materials standards[1] and UNS material designations,[2] except where the latter do not exist. This is because of their widespread use by the mining industry. There are similar ISO and EN standards and designations and there are conversion tables for common alloys available on the internet.

If you read this book from cover to cover, you will find a certain amount of repetition. This is because it is expected that most readers will want to dip into sections relevant to their current problem and will not want to keep following references to other chapters. Where the point at issue requires more extensive discussion, references to other chapters have been unavoidable.

References

1 American Society for Testing and Materials International (ASTM) (West Conshohocken, PA, USA).

2 *Metals and Alloys in the Unified Numbering System,* 10th ed. (Warrendale, PA, USA: SAE International, 2004 and West Conshohocken, PA, USA: ASTM International, 2004).

2

Materials

This chapter is concerned with materials that can be used in the aqueous processing of minerals and ores. It discusses the composition and mechanical properties of some commonly used metals, ceramics and polymers.

2.1 STAINLESS STEELS

Additions of chromium to steel increase its corrosion resistance, and when the chromium content exceeds 11%, the steel is said to be stainless. These ferritic stainless steels retain the body center cubic structure of ferrite and are strong, but brittle. They are difficult to manufacture in thick sections and are also difficult to weld.

If some carbon and/or a little nickel are added to the stainless alloy it forms martensite, which is very strong, but brittle. By tempering martensitic stainless steels, their strength is reduced somewhat, but they have some ductility. Although they can be welded, post weld heat treatment is required to retain their mechanical properties. Martensitic stainless steels are not usually highly alloyed with chromium and molybdenum and so their corrosion resistance in oxidizing chloride solutions, as are commonly found in the mining industry, is low.

If more chromium and nickel (≥ 8%) are added to a ferritic stainless alloy, it becomes fully austenitic, with a face center cubic structure. These alloys are not as strong as ferritic or martensitic stainless steels, but they have high ductility and can easily be hot or cold worked. In addition they are readily weldable. The addition of molybdenum and copper increases the resistance to chlorides (and other halides) and sulfuric acid, respectively.

Austenitic alloys can be exposed to aqueous solutions over a wide temperature range and the more corrosion resistant have been used at 400 °C or higher. Because of their high ductility, austenitic alloys are used down to very low temperatures, including cryogenic applications.

If the nickel content of an austenitic alloy is reduced, a duplex stainless steel is formed. These stainless steels contain both austenite and ferrite in roughly equal proportions. Modern duplex stainless steels are roughly 50/50 austenite/ferrite and combine the strength of ferrite with the ductility of austenite. They can be both hot and cold worked and are readily welded. All modern duplex stainless steels contain nitrogen, which confers numerous properties on these alloys. Nitrogen reduces partitioning of chromium between the two phases, it increases the strength and corrosion resistance of the austenite, and it greatly improves weldability.