

# SECONDARY STEELMAKING

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*Principles and Applications*

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# 1 Introduction

## 1.1 HISTORY OF SECONDARY STEELMAKING

Prior to 1950 or so, after steel was made in furnaces such as open hearths, converters, and electric furnaces, its treatment in a ladle was limited in scope and consisted of deoxidation, carburization by addition of coke or ferrocoke as required, and some minor alloying. However, more stringent demands on steel quality and consistency in its properties require controls that are beyond the capability of the steelmaking furnaces. This is especially true for superior-quality steel products in sophisticated applications. This requirement has led to the development of various kinds of treatments of liquid steel in ladles, besides deoxidation. These have witnessed massive growth and, as a result, have come to be variously known as *secondary steelmaking*, *ladle metallurgy*, *secondary processing of liquid steel*, or *secondary refining of liquid steel*. However, the name *secondary steelmaking* has more or less received widest acceptance and hence has been adopted here.

Secondary steelmaking has become an integral feature of modern steel plants. The advent of the continuous casting process, which requires more stringent quality control, is an added reason for the growth of secondary steelmaking. Steelmaking in furnaces, also redesignated now as *primary steelmaking*, is therefore increasingly employed only for speedy scrap melting and gross refining, leaving further refining and control to secondary steelmaking. There are processes, such as *vacuum arc refining (VAR)* and *electroslag remelting (ESR)*, that also perform some secondary refining. However, they start with solidified steel and remelt it. Hence, by convention, these are not included in secondary steelmaking.

Harmful impurities in steel are sulfur, phosphorus, oxygen, hydrogen, and nitrogen. They occupy interstitial sites in an iron lattice and hence are known as *interstitials*. The principal effects of these impurities in steel are loss of ductility, impact strength, and corrosion resistance. When it comes to detailed consideration, each element has its own characteristic influence on steel properties. These will be briefly mentioned in subsequent chapters associated with them. Oxygen and sulfur are also constituents of nonmetallic particles in steel, known as *inclusions*. These particles are also harmful to properties of steel and should be removed as much as possible. Carbon is also present as interstitial in iron lattice. However, unlike the other interstitials, it is generally not considered to be harmful impurity and should be present in steel as per specification. But, today, there are grades of steel in which carbon also should be as low as possible.

Historically, the Perrin process, invented in 1933, is the forerunner of modern secondary steelmaking. Treatment of molten steel with synthetic slag was the approach. *Vacuum degassing (VD)* processes came in the decade of 1950–1960. The initial objective was to lower the hydrogen content of liquid steel to prevent cracks in large forging-quality ingots. Later on, its objective also included lowering of nitrogen and oxygen contents. Purging with inert gas (Ar) in a ladle using porous bricks or tuyeres (*IGP*) came later. Its primary objective was stirring, with consequent homogenization of temperature and composition of melt. It offered the additional advantage of faster floating out of nonmetallic particles. It was also found possible to lower carbon to a very low value in stainless steel by treatment of the melt with oxygen under vacuum or along with an

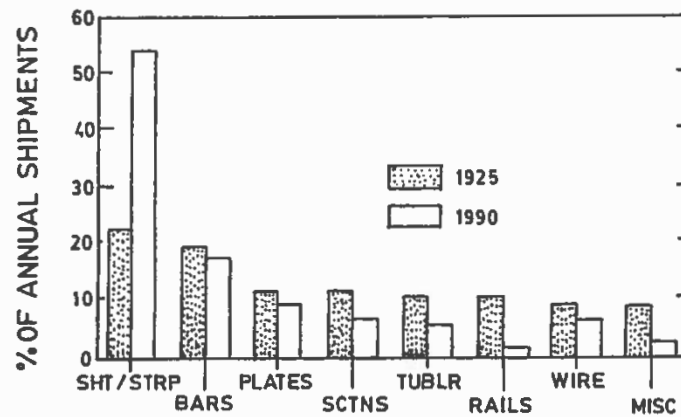


FIGURE 1.1 Product mix in the United States of America: 1925 vs. 1980<sup>1</sup> (reprinted by permission of Iron & Steel Society, Warrendale, PA, U.S.A.).

TABLE 1.1  
Various Secondary Steelmaking Processes and Their Capabilities

| Item                                               | Processes |       |       |       |     |     |          |
|----------------------------------------------------|-----------|-------|-------|-------|-----|-----|----------|
|                                                    | VD        | VOD   | IGP   | IM    | VAD | LF  | ASEA-SKF |
| Desulfurization                                    | minor     | minor | minor | yes   | yes | yes | yes      |
| Deoxidation                                        | yes       | yes   | yes   | yes   | yes | yes | yes      |
| Decarburization                                    | minor     | yes   | no    | no    | no  | no  | yes      |
| Heating                                            | no/yes    | yes*  | no    | no    | yes | yes | yes      |
| Alloying                                           | minor     | yes   | minor | minor | yes | yes | yes      |
| Degassing                                          | yes       | yes   | no    | no    | yes | no  | yes      |
| Homogenization                                     | yes       | yes   | yes   | yes   | yes | yes | yes      |
| Achieving more cleanliness (i.e., less inclusions) | yes       | yes   | yes   | yes   | yes | yes | yes      |
| Inclusion modification                             | no        | no    | minor | yes   | yes | yes | yes      |

\*chemical heating only

Source: data primarily from Ref. 1.

With the passage of time, customers are demanding better and better quality steels, which means

1. fewer impurities
2. more cleanliness (i.e., lower inclusion content)
3. more stringent quality control, i.e., less variation from cast to cast
4. microalloying to impart better properties (for plain carbon and low alloy steels)
5. better surface quality and homogeneity

The above demands, combined with other requirements such as (a) the need for cost reduction in view of competition from polymers etc., (b) environmental pollution control, and (c) a relatively stagnant world steel market, pose enormous challenge to the steelmaking community. Before any

**TABLE 1.2**  
**World Steel Consumption**

|                                | Millions of Metric Tonnes of Steel Products |                  |
|--------------------------------|---------------------------------------------|------------------|
|                                | 1990 (actual)                               | 2000 (predicted) |
| North America                  | 96.5                                        | 99               |
| European Community             | 115.5                                       | 117              |
| Japan                          | 92.6                                        | 85               |
| Latin America                  | 22.3                                        | 35               |
| P. R. China                    | 54.9                                        | 80               |
| Other Asian countries          | 78.6                                        | 120              |
| Africa                         | 8.6                                         | 9                |
| Former USSR and Eastern Europe | 148.5                                       | 100              |
| Others                         | 36.4                                        | 41               |
| Total                          | 653.9                                       | 686              |

Source: data from Ref. 4.

secondary steelmaking treatment, the lowest levels of impurities attainable with present-day practices, including a metal pretreatment facility, would be approximately as follows:

|             |          |
|-------------|----------|
| sulfur:     | 100 ppm  |
| phosphorus: | 20 ppm   |
| nitrogen:   | 40 ppm   |
| hydrogen:   | 5 ppm    |
| carbon:     | 400 ppm  |
| oxygen:     | variable |

Upon traditional deoxidation in a ladle, oxygen can be brought down to lower than 30 ppm. Thus, the minimum total of S + O + P + N would be about 200 ppm, and including carbon about 600 ppm.

Changing demands on quality may be illustrated with the example of line pipe steel for North Sea gas.<sup>6</sup>

| Year      | Maximum ppm in Steel, by Element |    |     |   |     |    |
|-----------|----------------------------------|----|-----|---|-----|----|
|           | C                                | S  | P   | H | N   | O  |
| 1983      | 400-600                          | 20 | 150 | — | 100 | —  |
| 1990      |                                  | 10 | 15  | — | 35  | 20 |
| Long-term | S + O + P + N = 45 ppm           |    |     |   |     |    |

Ramaswamy<sup>6</sup> has reviewed the subject and has outlined some of the quality requirements of line pipe steel for sour gas applications, steels for offshore platforms, bearing steels, steel for the rod and wire industry, and for power plant rotors. Figure 1.2 shows the trends in residuals attained by Japanese Steel Works.<sup>7</sup> A special mention may be made of a recent spurt in demand for *ultra-low carbon steel* (C < 30 ppm or so) for the manufacture of thin sheets by cold rolling with continuous annealing for automobiles. These steels not only have ultra-low C but have other residuals also at ultra-low levels, e.g., N < 15 ppm, S < 10 ppm, P < 15 ppm, H < 2 ppm. In addition, inclusion contents are also drastically lower as compared to regular steels. An expansion