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Measuring the status of stainless steel use in the Japanese socio-economic system

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A R T I C L E I N F O

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A B S T R A C T

To reduce the amount of materials that are extracted from and emitted to the environment, reutilization and long-term use within our socio-economic system are important goals. From this perspective, the average number of times a material comes into use and the total average lifetime of a material are useful indicators for measuring the status of our material use. In general, multiple uses and long lifetime indicate effective and efficient material use. In this article, we estimate these usage and lifetime indicators for stainless steel (SS) for the Japanese socio-economic system and discuss the meanings of these indicators given its main alloying elements. The following conclusions are drawn: (1) Based on Japanese SS use in 2005, SS is estimated to be used 1.9–4.3 times in average over its entire life cycle depending on possible low and high collection rate scenarios of SS obsolete scrap. SS is estimated to be used for 19–100 years in average over its entire life cycle, under the low collection rate and short product lifetime (LCR&SPL) to high collection rate and long product lifetime (HCR&LPL) scenarios. (2) Some SS scrap is used for carbon and other alloyed steels (COAS) production. Although SS scrap that is recycled within COAS cycles no longer functions as SS, iron contained in SS does serve a function in COAS products, considering an elemental interpretation. Iron contained in SS is estimated to be used 3.2–6.8 times and for 56–170 years in average over its entire life cycle, under the LCR&SPL to HCR&LPL scenarios. (3) From the viewpoint of sustainable material use, estimated total average lifetime of SS is not considered to be satisfactory. More effective and efficient material use needs to be achieved through the improvement in collection rates of obsolete scrap and lifetimes of final products.

1. Introduction

In our socio-economic system, material is extracted from the environment, used as products that provide useful functions for human society, and eventually disposed of into the environment as waste. To reduce the amount of materials that are extracted from and emitted to the environment, reutilization and long-term use of the materials within our socio-economic system are important goals. These activities are, in general, better than one way, short-term use of materials from a resource and environmental point of view.

From this perspective, the average number of times a material comes into use and the total average lifetime of a material are useful indicators for measuring the status of our material use. In general, multiple uses and long lifetime indicate effective and efficient material use. Past research has reported these indicators: for iron, 2.7 times and 63 years based on the material flows in Japan in 2000 (Daigo et al., 2005; Matsuno et al., 2007); for copper, 1.9 times and 60 years based on the global material flows in 2000 (Eckelman and Daigo, 2008); and for wood pulp, 3.0 times based on the material flows in Japan in 2003 (Yamada et al., 2006b).

In this article, we estimate these usage and lifetime indicators for stainless steel (SS) for the Japanese socio-economic system in 2005 and discuss the meanings of these indicators given its main alloying elements. SS is "steel that contains more than 10% chromium, with or without other alloying elements" (AISI, 2008) and is roughly divided into ferritic SS that contains chromium and austenitic SS that contains chromium and nickel as major alloying elements. Characteristics of SS include corrosion resistance, strength at high temperatures, and easy maintenance. For these reasons, it is widely used in homes (e.g., tableware, kitchen sinks, and cookware), in buildings and infrastructure (e.g., building facades, lifts, and trains), and in industry (e.g., chemical plants, food processing equipment, and potable and waste water treatment plants).

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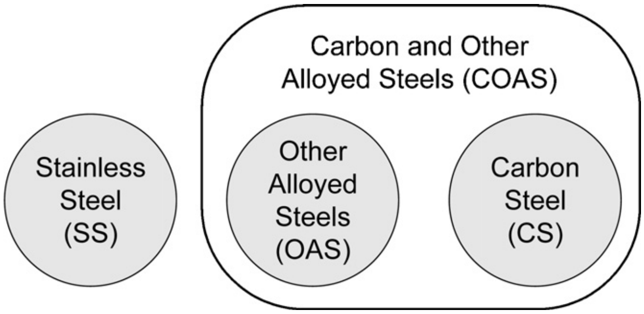

Fig. 1. Steel categories and their abbreviations used in this article.

2. Methods

2.1. Overview

We used a methodology developed by Daigo et al. (2005) and Yamada et al. (2006a) based on Markov chain modeling (see, e.g., Howard, 1971), which consists of the following procedures:

(1) Constructing a material flow model of a material in the socio-economic system (see Section 2.2).
(2) Preparing a state-transition table (see Section 2.2).
(3) Preparing a transition probability matrix (see Section 2.3).
(4) Calculating the average number of times a material comes into use and the total average lifetime of a material (see Section 2.3).

Although this methodology was developed based on Markov chain modeling, the idea is akin to supply-driven models in economic input–output analysis, used for studying direct and indirect production caused by a certain product supply, as well as output environ analysis in ecological network analysis, used for studying distribution of material and energy that are primarily inputs to a certain ecosystem (see, e.g., Suh, 2005; Bailey et al., 2004a, 2004b, 2008). Yamashita et al. (2000) developed circulation indices for analyzing the structure of material cascades. Their "post-circulation index" of primary material is basically the same as the "the average number of times a material comes into use" indicator in this article.

2.2. Constructing SS flow model in Japanese socio-economic system and preparing its state-transition table

SS is an alloyed steel and its flows interconnect with flows of other alloyed steels (OAS) as well as carbon steel (CS). Hereafter, we discuss interconnections between SS and "carbon and other alloyed steels (COAS)." Fig. 1 shows steel categories and their abbreviations used in this article.

Fig. 2 illustrates an overview of the SS and COAS cycles. Because CS scrap is used for SS production and SS scrap is used for COAS production, it was necessary to prepare combined SS and COAS flows.

SS flow data for 2005 in Japan were obtained from Daigo et al. (2009). We used these original data to establish a state-transition table of SS (see notes in Table 1 for more explanation). Steel flow data for 2005 were produced by updating 2000 data reported by Daigo et al. (2005) and Matsuno et al. (2007). Finally, a state-transition table of COAS was generated by extracting SS flows from total steel flows.

The state-transition table is shown in Table 1, which illustrates how SS and COAS move from the states shown in rows to those shown in columns. Note that SS is divided into ferritic and austenitic, and COAS is divided into blast oxygen furnace (BOF) and electric arc furnace (EAF) steel. Final product categories (rows 4–11 and 20–24) follow those of previous researches (Daigo et al., 2005, 2009; Matsuno et al., 2007). For example, this table shows that 810 kt of crude SS is used for ferritic SS semi product (row 1, column 2); 33 kt of ferritic SS semi product is used for construction (row 2, column 4); and 27 kt of construction becomes ferritic SS obsolete scrap (row 4, column 14).

As ferritic SS has magnetic properties, a part of ferritic SS obsolete scrap is collected not only as SS scrap (row 14, column 12) but also as COAS scrap (row 14, column 28). On the other hand, CS scrap is used for production of SS (rows 25–28, column 1). Here, CS scrap is a subset of COAS scrap. As the origin of CS scrap for SS production is not known, we allocated total amount of CS scrap used for SS production based on average proportion of sources of CS scrap (columns 16 and 18). These flows demonstrate the complex linkages between the SS and COAS cycles.

2.3. Preparing transition probability matrix of SS and calculating the average number of times SS comes into use and the total average lifetime of SS

In order to calculate the average number of times a material comes into use, we assumed that the transition from one state to the next is uniquely determined on the basis of a probability obtained from the state-transition table (Daigo et al., 2005; Yamada et al., 2006a). The transition probability matrix **A** was prepared by the

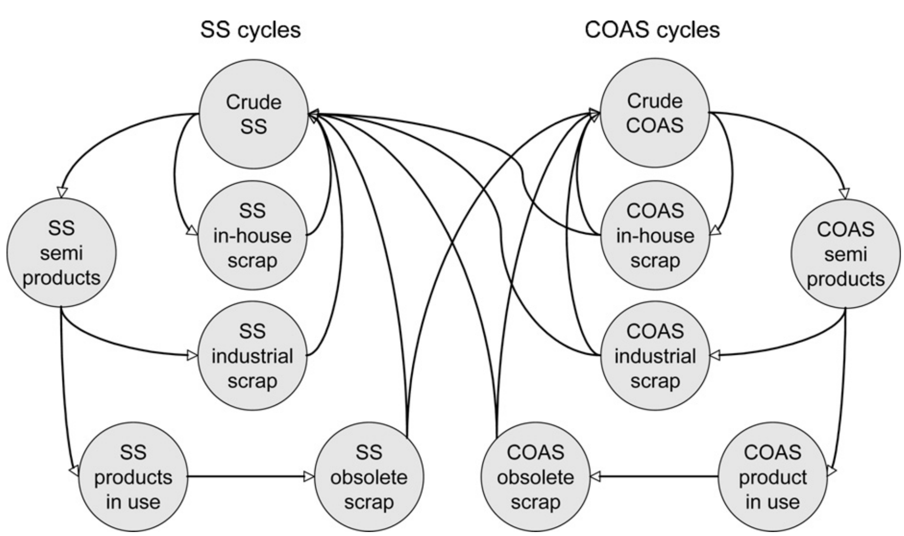

Fig. 2. Stainless steel (SS) and carbon and other alloyed steels (COAS) cycles (without primary metal inputs such as pig iron, ferronickel, and ferrochromium).