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Time-series analysis of global zinc demand associated with steel

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ABSTRACT

This study aimed to analyze the global-scale substance flow of zinc associated with steel in order to discuss the sustainable use of zinc resources in the future. The relationship between the demand for steel and zinc was characterized in terms of zinc intensity for galvanized steel and the percentage of galvanized steel that accounts for the total steel demand. Zinc consumption for steel was divided into end uses according to the statistics on steel. Zinc demand in the future was forecasted with three scenarios for zinc intensity. Future steel demand was estimated using the stocks-drive-flows model, in which the demand is determined by the change in stock. The growth of in-use stock of galvanized steel in the future was estimated by considering economic growth on the basis of the transition of in-use stock of galvanized steel in the past. The cumulative zinc demand for galvanized steel up to the year 2050 was compared with the zinc reserves. It was found that the global average recovery rate of zinc was estimated at approximately 20% by the dynamic substance flow analysis for zinc. It is hoped that the recovery rate will increase. Even if zinc intensity is continuously reduced according to an experience curve based on technological development, a large portion of the current reserves will be consumed for galvanized steel. It was concluded that technological development in reducing zinc intensity will play a significant role in zinc resource conservation.

1. Introduction

The global annual zinc consumption in 2012 was about 13 million tons, making it the fourth highest consumed metal, after iron, aluminum, and copper (U.S. Geological Survey, 2013). Zinc is widely used in metal products, rubber, pigments, and medicines. The principal zinc products are given in Table 1. Most of the zinc consumption is associated with other materials, e.g., a plated metal for steel (50%) and an alloying element for brass (17%). Zinc reserves are not abundant. A total of 250 million tons of reserves are extractable, which is 19 times larger than the current annual consumption (U.S. Geological Survey, 2013). Zinc resources are one of the mineral resources that are potentially supply-limited, at least at contemporary prices, although zinc is a useful and essential metal (Tilton, 2001; Gordon et al., 2003). The sustainability of zinc resources is a key issue.

Several papers have focused on the substance flow of zinc up to this point. Jolly (1993) analyzed time-series zinc flow in the United States from 1850 to 1990. Gordon et al. (2003) specified and described each process in anthropogenic zinc cycles and discussed data availability to analyze the substance flow of zinc. In other papers, substance flows of zinc in Europe (Spatari et al., 2003) and Japan (Nakajima et al., 2008) have been characterized. Graedel et al. (2005) statically analyzed the global substance flow of zinc. Tabayashi et al. (2009) dynamically analyzed the substance flow of zinc in Japan, particularly as it pertained to recycling. To discuss the sustainability of zinc resources, it is necessary to evaluate the recyclability of zinc and to estimate future demand on a global scale.

The substance flow of zinc is determined by the material flow of steel, which accounts for approximately 50% of the total zinc consumption. In addition, the main stream of zinc recovery from end-of-life products comes from galvanized steel scraps via electric arc furnace (EAF) dust. The substance flow of zinc associated with steel is the key issue with regard to both the magnitude of consumption and the recycling of zinc. Matsuno et al. (2012) investigated the correlation between the demand for steel and zinc in Japan. However, the linkages of these materials have rarely received attention, especially on a global scale. It is promising to analyze the substance flow of zinc by multiplying the zinc content in galvanized steel, which is analyzed by the material flow of steel. The material flow of steel on a global scale has been characterized by Wang et al.

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Table 1
First use breakdown for zinc (principal products of zinc) on a global scale (International Lead and Zinc Study Group, 2012).

Principal product	Share of consumption (%)
Galvanizing	50
Brass and bronze	17
Die casting (zinc alloying)	17
Chemicals	6
Other products	10

Table 2
List of countries and regions analyzed in this study.

	Names of countries and regions	Number of countries and regions
Asia	China, India, Indonesia, Japan, Korea, Malaysia, Philippines, Taiwan, Thailand	9
Oceania	Australia, New Zealand	2
Europe	Belgium, Luxembourg[a], Germany, Russia, Norway, Spain, the United Kingdom	7
America	Brazil, Canada, Mexico, the United States	4
Africa	South Africa	1

[a] In subsequent analysis, Luxembourg is included in Belgium due to data availability.

(2007) and Hatayama et al. (2010). Furthermore, a new approach to estimate the future demand for steel, which is based on time-series steel stock, has been developed (Hatayama et al., 2010).

The goal of this study is to analyze the global-scale substance flow of zinc associated with steel in order to discuss the sustainable use of zinc resources in the future.

2. Methodology

2.1. Dynamic material flow analysis of steel and dynamic substance flow analysis of zinc

2.1.1. Relationship between the demand for steel and zinc

In this paper, a dynamic material flow analysis (dMFA) of steel and a dynamic substance flow analysis (dSFA) of zinc were conducted on a global scale. In dMFA/dSFA, the historical consumption and lifespans of end-use products are used to estimate material stock and discards in end-of-life materials. Therefore, end uses of material consumption should be distinguished and classified based upon lifespans. The statistics of zinc consumption indicate the first use of zinc, including galvanized steel, brass, diecasting, rolled zinc, and chemicals. On the other hand, the principal end uses of zinc have rarely been recognized (Jolly, 1993).[3] The end use of galvanized steel can be obtained from steel statistics. Consequently, this study distinguished zinc consumption for galvanized steel based upon end use.

The number of countries and regions to analyze is restricted due to the availability of data classified into end uses. The zinc consumption classified into eight end uses in 23 countries (shown in Table 2) was estimated by using statistics on steel, which accounted for approximately 80% of the total zinc consumption for galvanized steel in the world. The eight end uses were classified as buildings, civil engineering, automobiles, industrial machines, electric machines, ships, containers, and other products.

The data on the time-series zinc consumption based upon end use were obtained from 1900 to 2009. They were estimated by multiplying the steel consumption and two parameters, i.e., the galvanized steel ratio to total steel consumption in each end use and zinc use intensity in galvanized steel. The galvanized steel ratios were obtained from Japanese steel statistics (JISF, 1964–2009) and applied to other countries due to data restriction. The ratios for eight end uses were obtained in the form of time-series data, which are plotted in Fig. 1. The ratio in electric machinery is the largest, followed by automobiles, other products, and buildings. The ratios in the other four end-use categories are lower than 0.05. The time-series zinc use intensities in several countries were estimated as shown in Fig. 2 (World Steel Association, 1976–2006; ILZSG, 1991–2008). In almost all countries, trends of a decrease in zinc use intensities were observed. A detailed description on data preparation is in the Supporting Information.

Zinc consumption for galvanized steel could be estimated by multiplying the galvanized steel ratio and the zinc use intensity. On the other hand, zinc consumption for steel was shown in the statistics on zinc. Here, the yield ratio of the plating processes, 0.92 (Tabayashi et al., 2009), was multiplied by the statistical consumption. The statistical and estimated values are compared in Fig. 3. The estimated zinc consumption was fairly close to the zinc consumption obtained from the statistics on zinc. The estimation method mentioned above successfully disaggregated the zinc consumption associated with galvanized steel into eight end uses.

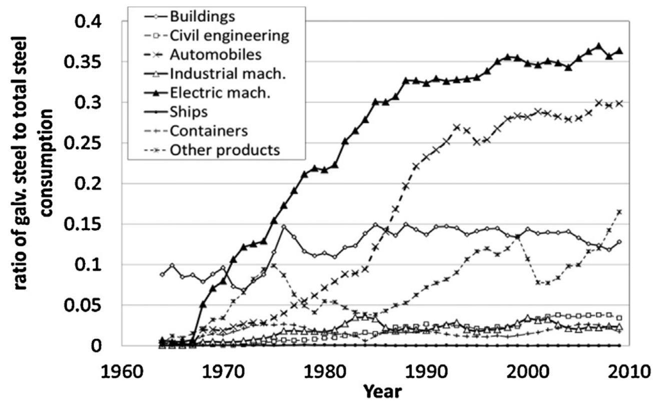

Fig. 1. Ratios of galvanized steel to total steel consumption by end-use category in Japan.

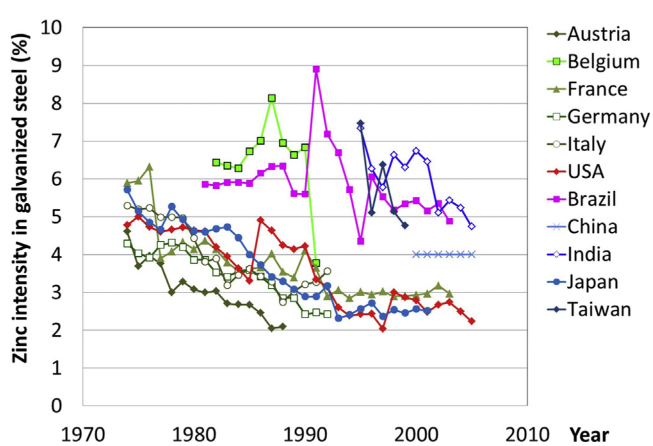

Fig. 2. Time-series zinc use intensities in galvanized sheet and strip by country. Asian countries, European countries, and American countries are colored blue, green, and red, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

[3] Here, the term "end use" is employed for a category of finished products, in contrast to "first use," which indicates a category of material containing zinc.