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DYNAMIC MODELING OF WORLD STEEL CYCLE TOWARD 2050

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ABSTRACT

In this work, a dynamic material flow analysis (MFA) was conducted to estimate the global flow and in-use stock of steel for 42countries until 2010. The growth of the future in-use stock and demand of steel for three products (civil engineering, building, and vehicles) towards 2050 was also estimated under the concept of "stocks drive flows", considering the economic and population growth in every country. In addition, we analyzed the steel scrap generation in each product and in every country up to 2050, and investigated the steel use potentials by using waste input-output material flow analysis (WIO-MFA).

INTRODUCTION

For the conservation of natural resources and protection of environment, effective use of material stock in the society as the secondary resources should be enhanced. Therefore, material flow analysis (MFA), which can estimate the flow of materials, has been developed (Graedel et al. 2004a; Graedel et al. 2004b; Wang et al. 2007). MFA can be distinguished into two types, a dynamic MFA and a static MFA. A dynamic MFA can estimate the in-use stock over extended time intervals (Spatari et al. 2005), whereas A static MFA can only estimate the flow of materials in a specific area over short periods,

As steel is the most widely used material in the world, numerous studies have been conducted to investigate the flow of steel on the developed countries. For instance the United States (Müller et al. 2006), the United Kingdom, and Japan (Hatayama et al. 2010). Hatayama et al. (2010) conducted a dynamic MFA for steels to estimate the flow and in-use stock of steel globally until 2005. They classified the steel end-uses into eight groups (civil engineering, building, vehicles, electric appliance, machinery, shipbuilding, containers and packaging, and other) in each country. Moreover, the growth of future in-use stock and demand of steel for three products (civil engineering, building, and vehicles) towards 2050 was estimated. However, they have not evaluated the steel scrap use potentials.

Hsu et al. (2012) investigated the country differences on steel use intensity for building which was one of the largest products of steel. They indicated that the steel use intensities for buildings in Asian countries were about two times larger than those in European countries. These country differences should be considered in estimating the future demand of steel for building.

Therefore, in this paper, we conducted a detailed dynamic MFA for 42 countries during 1950-2050 in which the country differences in steel use intensities for buildings were taken into account, and investigated the recycling potential of the steel scraps.

METHODS

A dynamic material flow analysis of steel
In this paper, based on the method by Hatayama et al. (2010), we conducted a dynamic MFA to estimate the global flow and in-use stock of steel until 2010 and the growth of future in-use stock and demand of steel for three products (civil engineering, building, and vehicles) towards 2050. We focused on 42 countries and regions, which accounted for 87 % of steel consumption of the world in 2010.

Estimation of future in-use steel stock for building considering country differences
We estimated the in-use stock of steel for building of each country with the assumption that in-use stock of steel would grow along the S-shaped logistic curve represented by Eq. 1.

$$S_t = \frac{S_{sat}}{1 + \exp\left(\alpha - \beta \times GDP_t\right)} \qquad \text{Eq. 1}$$

S_t is the in-use stock of steel per person in year t, S_{sat} is a saturation value of the in-use stock, GDP_t is GDP per capita in year t, α *and* β are parameters that determine the shape of the logistic curve. We calculated for the curve fitting by the method of least squares.

In the countries whose GDP per capita was 20,000 USD or more in 2010, and average growth rate of in-use steel stock for building per person from 2006 to 2010 was more than 2%, S_{sat} was obtained by the curve fitting method mentioned above. In contrast, in the countries whose average growth rate was below 2%, we considered that the in-use steel stock for building per person would not increase much in the future and it is assumed to be stable with the level of 2010.

For the countries whose GDP per capita in 2010 was 20,000 USD or less, S_{sat} was adopted from the maximum, average and minimum values obtained from the countries mentioned above, and the future in-use stock of steel for building was estimated by Eq. 1.

Waste Input-Output Material Flow Analysis (WIO-MFA)
The WIO-MFA model is a top-down MFA method for estimating the material or substance composition of a product, which can assess the mass balance between inputs and outputs of each industry. We calculated pig iron and obsolete steel scrap component in the finished products from this method and obtained the obsolete scrap use intensity for each product from Eq. 2.

$$\text{the obsolete scrap use intensity} = \frac{\text{the obsolete scrap component}}{\text{the pig iron component} + \text{all scrap component}} \qquad \text{Eq. 2}$$

Although the obsolete scrap use intensity for each end-use was calculated in the basis of material components in Japan, it was applied globally, because WIO-MFAs in other countries were not available. By multiplying this intensity by steel demand for each product, we calculated the future obstacle steel scrap demand and evaluated the steel use potentials.

RESULTS&DISCUSSION

A dynamic material flow analysis of steel

Figure 1 shows the in-use steel stock in the world up to 2010 by region. The in-use steel stock had doubled during 1980-2010, and reached to 16 billion ton in 2010. It is attributable to the rapid growth in Asia.

Estimation of future in-use steel stock for building considering country differences

It was found that the saturation value of steel for building in Asia was twice as large as that in other areas. It is likely that people in Asia preferred structural material because there were always many damages caused by natural disasters such as an earthquake in this area.

It was also estimated that steel demand for building would be stable from 2020 and would reach about 13 billion ton. This value is about 2.5 times as much as that in 2010, which is attributable to the growth of developing countries.

We estimated the change of steel demand, in-use stock, and obsolete scrap generation for three products (civil engineering, building, and vehicles). Figure 2 shows the estimated in-use steel stock towards 2050. The in-use steel stock for civil engineering and vehicles is 4 times as much as those in 2010, and in-use steel stock for buildings is 5 times as much as that in 2010.

Waste Input-Output Material Flow Analysis (WIO-MFA)

The obsolete scrap use intensity for each product obtained by WIO-MFA was shown in Table 1. With these results, the demand of obsolete steel scrap was estimated. If we will use the obsolete steel scrap in the same use intensities in 2010, the obsolete steel scrap generation will exceed the demand around 2035, and be as twice as its demand.

CONCLUSIONS

In this study, we conducted a dynamic material flow analysis of steel in the world until 2010. In addition, taking into account the countries differences in steel use intensity for buildings, we conducted a dynamic flow analysis of steel for tree products (civil engineering, building, and vehicles) in the world towards 2050.

We calculated the obsolete scrap use intensity by WIO-MFA. By comparing the obsolete steel scrap demand to the generation, we estimated the steel use potentials. The steel use intensities for each product should be enhanced because the obsolete steel scrap generation may expect to exceed the demand in a couple of decades.

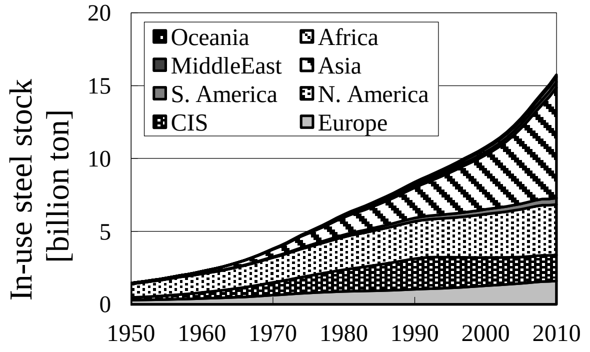

Figure 1. In-use steel stock by region, 1950-2010

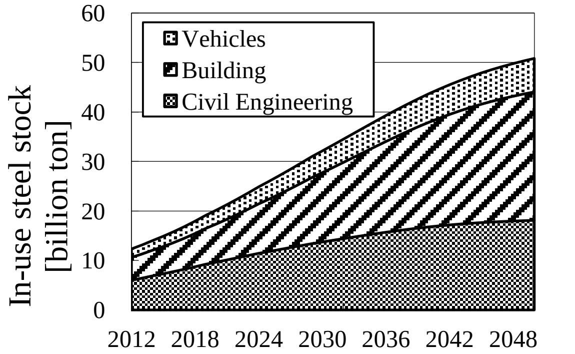

Figure 2. Change of steel in-use stock

Table 1. Obsolete scrap use intensity for each product

Product	**Intensity (%)**
Vehicles	15.7
Building	36.2
Civil engineering	36.9

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