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Materials Flow Analysis of Metallic Cobalt and Its Powder in Korea

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Abstract The basis of the cobalt demand analysis by use was established via the investigation and analysis of the cobalt materials flow, and the overall cobalt metal material and parts industry structure in Korea was examined to determine the cobalt material flow. The markets of the cobalt material for machinery were studied, including their interrelations, via market and study trends, and relevant plans were examined. The results of the study indicated that the advanced core technology for advanced industry and technology-intensive industry development is required to structurally innovate the parts materials and basic materials industries and to upgrade the catch-up industry structure to the new frontier structure.

Keywords: Material flow analysis, Cobalt, Powder, Product supply chain, Rare Metal

1. Introduction

With the fast increase in the use of cobalt for lithium secondary batteries and carbide tools, interest in cobalt resources and in their production and transportation volumes is also increasing. The Republic of Congo has large cobalt deposits and export volumes, and Korea has very small deposits [1]. To address problems with cobalt supply and demand in Korea, studies are underway on cobalt material flow. To clarify the cobalt metal material flow, this study aimed to establish statistics on objective and concrete cobalt material flow through an information survey and analysis. The basis of the cobalt demand status analysis was established, the cobalt metal material and parts industry structure in Korea was examined, and the cobalt metal material flow was studied. Based on the results, the markets of cobalt for machinery were studied, including their interrelations, via the market and study trends, and relevant plans were examined.

2. Survey of cobalt flows in Korea

The survey was conducted based on existing national statistical data that included mining and manufacturing statistics and Korean trade statistics, and on the established MFA data [2-5] to analyze the flows of primary and secondary resources. For insufficient data such as on product contents and demand sources, a representative cobalt consumption company was selected and a visiting research was conducted therein. Main cobalt-containing products include lithium secondary cells, carbide tools, diamond tools, and tire adhesives. To objectively calculate the material flow and volume, a list was completed based on direct data with advice from experts, including the company's purchasing personnel. For the eight stages of cobalt flow, i.e., the raw materials, primary processed goods, interim products, final products, use/accumulation, collection, recycling, and disposal stages, the cobalt transportation volumes in the cobalt-relevant industries were calculated. By combining the material flow analy-

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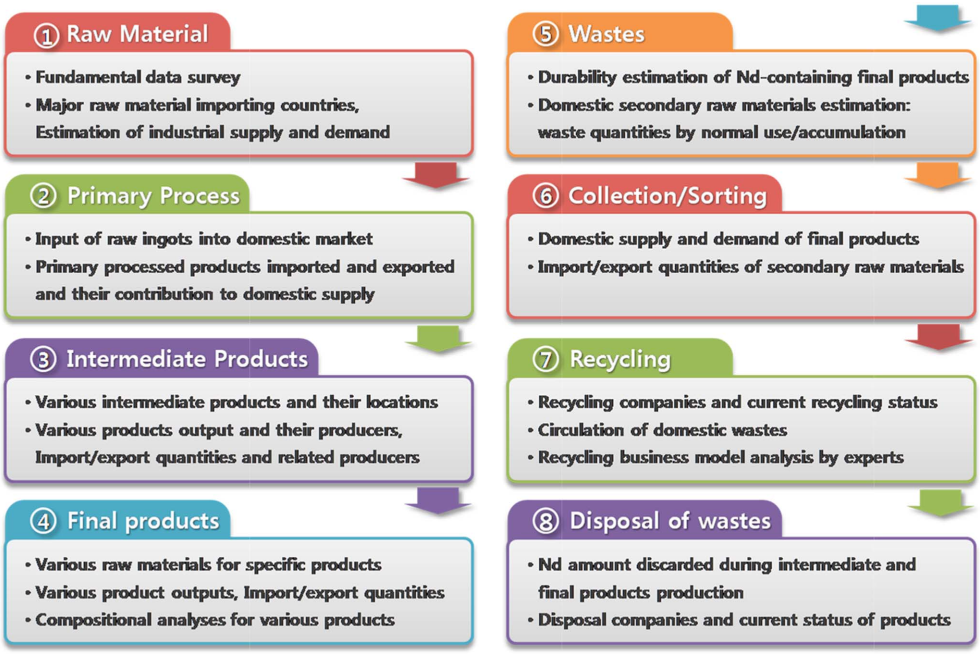

Fig. 1. Materials flow data collection summary.

sis method that is based on existing statistics (a top-down method that uses the inter-industry IO table) with that which is based on the complete enumeration for relevant companies (a bottom-up method that uses visiting surveys of raw materials importers and materials/parts/product manufacturers and recyclers), the problems with the material flow analysis (MFA) methodologies were supplemented and priority was given to the resulting reliability. The definitions and descriptions of the stages follow (Fig. 1).

2.1. Raw Materials

Raw materials stage: The mined and extracted cobalt ore and cobalt salt that are ready to be processed into primary processed goods were defined as comprising the raw materials production stage, and the data from Korea International Trade Association, the Korea Mineral Resources Information Service [6], and Korean trade statistics [7] were referred to in this study.

2.2. Production of Primarily Processed Co

Primary processed goods stage: This stage refers to the primarily processed cobalt that includes the powder of cobalt metal such as cobalt oxide, cobalt metal lumps, and other cobalt materials, which are prepared to manufacture products or goods. Objective data such as the HS

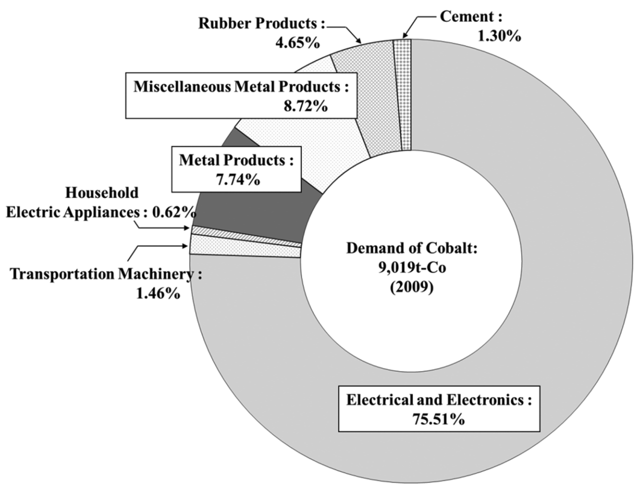

Fig. 2. Demand of Cobalt in Korea.

code from Korea International Trade Association database, and experts were referred to via a questionnaire survey among raw materials stage companies.

2.3. Intermediate Products

Interim product stage: Interim products are produced from the primary processed goods to use or produce the final products [including the volume of the recycled secondary resources (scrap) that are put into the interim products). The bottom-up formula for calculating the interim cobalt product demand and supply in Korea, which was

Table 1. Estimation of cobalt market (unit : 100 million Won)

		2011	2013	2015	2017	2019	CAGR
Domestic	Hard metal tool	12,167	13,287	14,509	15,845	17,303	4.5%
	Diamond tool	3,449	3,702	3,974	4,265	4,578	3.6%
Overseas	Hard metal tool	337,674	364,526	393,514	424,806	458,587	3.9%
	Diamond tool	71,484	76,723	82,347	88,383	94,861	3.6%
Sum		424,774	458,238	494,344	533,299	575,329	

specified in the MFA guidelines for the establishment of the national resource management system, was used to verify the determined supply and demand in Korea for the interim product stage and the consistency of the interim product production statistics. The professional statistics such as the trade statistics, secondary cell market trend, export/import data, and cobalt content of interim products (resource bibliography and KS standards) were referred to in this study.

2.4. Final Products

Final industry (product) stage: This is the stage wherein interim cobalt products are finally used and that have representative products of relevant industries such as the construction, general machinery, and metal products industries. The final classified products of the 403 basic categories from the inter-industry table were selected. The supply and demand of the final cobalt products were calculated using the input coefficients in the inter-industry table, and the results were compared with the results of the primary processed products and the interim products from the subject company to prove and supplement the flow of the final products.

2.5. Consumption and Accumulation of Rare Earth Products

Use/accumulation stage: The consumption, use, and persistence period of the final products that were produced in the appropriate year in the final industry (product) stage were considered to examine the accumulation of the final products that were produced in the previous year and their collection as secondary resources for cobalt recycling.

2.6. Collection of End-of-life Products

Collection stage: This is the stage wherein the primary cobalt resource is discharged from each stage and collected after its use to be recycled as the secondary resource. The waste volume by product and the cobalt content of the waste were considered to examine the secondary resource (scrap) collection volume and material flow.

2.7. Recovery and Recycling of End-of-life Products

Recycling stage: For the recycling process stage (which includes the impurity removal process for maintaining the scrap quality) after the collection stage, this study was conducted based on the statistical data from the analysis of the import/export volume for the secondary resource recycling and input, which include Korean trade statistics, the cobalt content of the scrap, and the recycling input (in the raw material and primary processed product stages).

2.8. Disposal of Wastes

Disposal stage: The scrap collection disposal volume discharged from the collection stage and the scrap disposal volume discharged from the recycling stage were considered.

3. Results and Discussion

3.1. Cobalt Material Flow Trend in Korea and Related Problems

In Korea, cobalt ore is intermittently produced in small amounts as by-products of gold mines, as there are no cobalt mines. According to the statistics of the Korea International Trade Association, the import amount of cobalt ore and concentrate (HS code: 2605000000) is very small (25 tons in 2008), and their export has been reported to be approximately 1,474 tons. There is no primary processed product manufacturer that uses cobalt ore and concentrate in Korea, though. According to the Korea Mineral Resources Information Service and Korea Resources Corporation, the cobalt powder, lump, and scrap export figures were taken from the statistics on the exports of cobalt ore and concentrate. Therefore, there are no cobalt supply and demand figures in Korea based on the import and export of cobalt ore, and training and relevant policies are required to come up with accurate import/export statistics from businesses and relevant institutions.

As for the primary processing stage, the most essential is the basis of the stable supply of raw cobalt and its import replacement through the construction of the raw material supply base (cobalt sulfate), because all products are imported, including cobalt oxide. The need for cobalt replacement increased due to its unstable supply, so a quota tariff was imposed (for secondary cells) in 2008 and the export ban of Congo in March 2007 (resource inequality rate: 45%) significantly increased the price of cobalt (by 83% yearly), which has made it more expensive than other materials. In addition, the volume of cobalt oxide imports increased yearly by 65% on the average from $40 million in 2003 to $440 million in 2008.

In the interim product stage, more than 5,000 tons of cobalt is used for secondary cells (78%) and carbide tools (6%) yearly, and the scrap produced from the production of $LiCoO_2$ and secondary cells is recovered and reproduced. Part of the cobalt scrap is exported to Japan, however, due to the lack of advanced extraction technology in Korea, so Korea needs advanced cobalt extraction and refining technology. As for the final product stage, there were few data on the cobalt contents of final products, and it was difficult to find accurate information on the supply and demand of cobalt. Therefore, provision of data on the cobalt contents of final products must be made obligatory, and accurate statistics on cobalt import and export volumes must be established.

In the after-use stage, approximately 3,000 tons of after-use products will be discharged yearly if the secondary cell is designated as EPR in 2011, and a long-term cobalt collection system and recycling (direct extraction) technology are required. In the disposal and recycling stage, waste tires (34% of the total production), waste carbide scrap (20% of the total production), and spent catalysts are discharged, but a large amount of them are disposed of due to the lack of cobalt recovery technology. Therefore, an appropriate cobalt refining technology is required.

Addressing these problems requires a stable supply basis via raw material supply base construction (cobalt sulfate), advanced eco-friendly technology (by Umicore, Belgium) for import replacement, and spent secondary cell cobalt recovery technology. All the cobalt in the scrap that is exported overseas must be recovered using advanced extraction and refining technology.

If a cobalt refining facility that can process more than 1,000 tons of cobalt is established, the 28 billion won processing cost will be reduced (LME prices: cobalt = $44,000/ton and cobalt oxide = $69,000/ton; 1 dollar = 1,120 won), more than 3,000 tons of cobalt can be recovered using the secondary cell cobalt recovery technology (231 billion won worth of cobalt oxide), and the cost of recycling 240 tons of waste cobalt will be reduced by 18 billion won. Cobalt is also used to record media (hard disk), pigments, livestock feeds, bills, medals, thermisters (semiconductor parts), variable resistors, glass, copper foil, medical devices, etc., but its quantity is very small and replacements are being introduced.

3.2. Demand of Cobalt Materials

In Korea, the demand of cobalt in 2009 was about 9,000 ton. Cobalt was mostly used in electrical and electronic industries and more than 75% cobalt was used in this industry. The second largest area was metal product and 7.7% cobalt was used in this industry. So, more than 600 ton of cobalt was demanded in tool-making industries as metallic powder form. In Korea, Daehan Tungsten and Korea Metallurgy started studying and developing carbide alloy in the 1960s, and produced commercial products from the 1970s. Companies such as Daehan Tungsten conducted a study on grain refining in the 1980s, and are now producing carbide alloy products with a carbide particle size of 0.5 μm, which are not as exquisite as those of other countries. Therefore, a significant amount of Korea's particle carbide powder products are still imported.

Since 1992, the Korea Institute of Machinery and Materials has been leading the academic-industrial study of ultrafine carbide tools [8] and has developed a new powder production process (the thermochemical process) that enabled the successful production of ultrafine carbide powder with a carbide particle size of 100 nm. The vapor phase method, which involves carbide powder and new high-density product production, is now being studied as a national designated project, but it is not in the commercial stage yet. Besides, Andong University conducted a study on the characteristic change in carbide alloy according to the particle size of the WC and Co material [9].

Nanocarbide products are produced by Nanotech Co., Ltd., which was established in 1999. The particles of the final sintered product, in which 100nm carbide powder is used, are 200 nm big, and ultrafine carbide products reportedly have a 30% greater hardness and deflective strength than the existing carbide alloy. Nanotech's technology produces nanocarbide powder from liquid salt (chloride or nitrate). Studies on cobalt sulfate, which is the material used for cobalt refining, and on the cobalt and WC combination for carbide production are not underway yet.

Existing patents include those on the "production method for nanophase WC/TiC/Co composite powder," "process of manufacturing WC-based powder by vapor reaction under vacuum pressure" (Korea Institute of Machinery and Materials), "method of manufacturing ultrafine composite powder from tungsten carbide and cobalt" (Nanotech), and "cobalt nanoparticles and their preparation method" (Korea Atomic Energy Research Institute). These patents use precursors such as chloride, nitrate, and carbonyl as the raw cobalt material, however, and there has been no direct tool application of cobalt from cobalt sulfate, which is the mineral resource of cobalt.

The relevant product group in the trade statistics data include the gamma-coated products made from tungsten carbide in the HS code for carbide tools (HS8209001010), the cement products (HS8209001040), other products (plate, pole, tip, and equivalent products for tools) (HS8209001090), tungsten carbide products (HS8209002010), other products (HS8209002090), products with a tungsten carbide functioning part (HS8202391000), and diamond tools (HS8207901000) .

4. Summary

In this study, the basis of the cobalt demand status analysis was established, the cobalt metal material and parts industry structure in Korea was examined, and the cobalt metal material flow was studied. The R&D, sales, planning, and promotion teams of relevant companies were inspected via visits, e-mails, and calls.

Main cobalt-containing products include lithium secondary cells, carbide tools, diamond tools, and tire adhesives. To objectively calculate the material flow and volume, a list was completed based on direct data with advice from experts, including the purchasing personnel. For the eight stages, i.e., the raw materials, primary processed goods, interim products, final products, use/accumulation, collection, recycling, and disposal stages, the cobalt transportation volumes in the cobalt-relevant industries were calculated.

By identifying the economic feasibility of cobalt resource recycling based on the calculation results, the unstable cobalt resource supply and demand and price can be proactively addressed, and accurate cobalt material flow by use will facilitate the selection of waste cobalt products that need to be studied for recycling with ease and accuracy. The analysis technology for cobalt recycling products will improve international trust in Korea and accelerate its sale and use of its recycled resources, and awareness raising through public relations activities will encourage local businesses to voluntarily reduce their resources and to recycle without the need for regulations.

The results of this study will be used as basic data for the government's cobalt metal R&D support policies. In this study, data on cobalt material flow were collected and analyzed to provide data for the national strategic metal supply and demand policies, and the recycling status was examined to provide basic data for cobalt recovery from secondary resources.

The improvement of the hardness and the wear resistance of carbide products via the nanotechnology for the cobalt material for machinery is expected to lead to their application to ultrafine carbide tools that have better characteristics than the existing ones, and to generate new application areas. The establishment of an original technology for addressing the unstable supply and demand of cobalt for machinery is expected to improve Korea's cobalt self-sufficiency and enable innovative technical development in its material parts sector. The technology for developing cobalt for machinery can be considered an advanced core technology for advanced national industries and technology-intensive industries that should contribute to the structural innovation of the parts materials and basic materials industries and help the catch-up industry structure to move to a new-frontier structure.

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