学術雑誌 Resources, Conservation & Recycling　2018 年最優秀論文賞*　受賞論文

論文題目：廃セラミック・廃ガラスリサイクルの元素に着目した最適化
著者：醍醐市朗[a]、清原慎[b]、岡田知樹[c,d]、岡本大作[e]、後藤芳一[a]
a 東京大学大学院工学系研究科　b 東京大学生産技術研究所　c 東京大学工学部
d 株式会社神戸製鋼所　e 株式会社キシヤマ

*Resources, Conservation & Recycling 誌では、2018 年から最優秀論文賞の表彰を始め、栄えある第 1 回の受賞論文となった。2018 年に同誌に掲載された全 429 報の中から学術的な貢献の大きさによって厳選された 3 報が表彰された。表彰委員会は、厳密さ、新規性、重要さ、表現の明確さの 4 つの基準で論文を審査した。

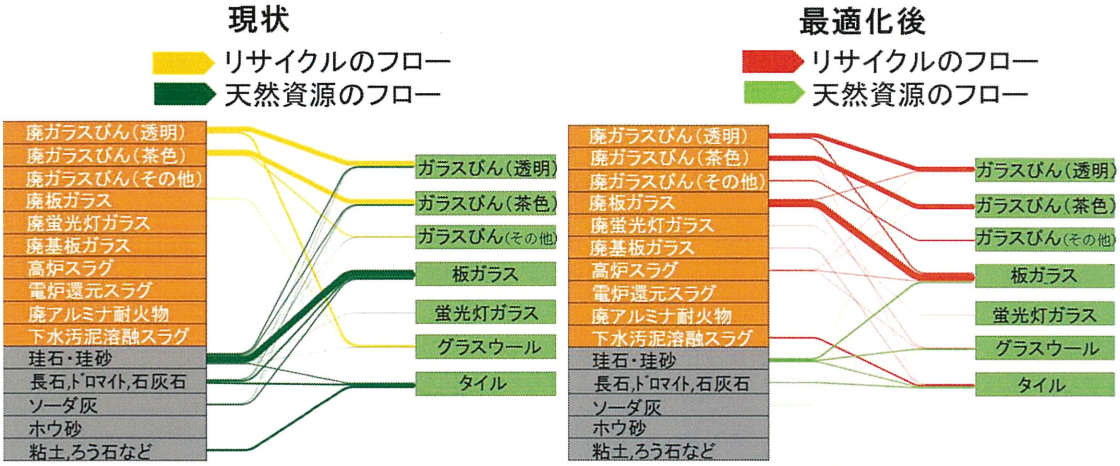
本受賞論文では、

•セラミックとガラス（CerG: ceramic materials and glasses）を、相互にリサイクル可能な材料のグループとして定義した。

•CerG のリサイクルを最適化するための線形モデルを提案した。

•日本におけるケーススタディに基づいて、モデルの適用可能性と限界を議論した。

•経済性と不純物混入を無視した理想的な状態では、今までにないいくつかのリサイクルルートが可能になり、CerG のリサイクルを大きく促進できる可能性が示された。



単位: %		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	MnO	P_2O_5	B_2O_3
板ガラス	上限値	73	1.0	2.1	0.12	9.5	5.5	2.0	16	0.05	N.D.	0.00
	下限値	67	0.0	1.2	0.01	6.5	2.5	0.01	12	0.00	0.00	0.00

Acknowledgements　　論文中 383 ページより謝辞を抜粋

This work was supported by JSPS KAKENHI Grant Numbers 15H02860, 15H01750 and 26281056 and Environmental Economics and Policy Studies (The Third term) of the Ministry of the Environment, Japan. The authors are grateful to So Kato at the Glass Recycling Committee of Japan; Shigeaki Moritani and former staffs at Flat glass

GRCJ
the Glass Recycling Committee of Japan

Resources, Conservation & Recycling 133 (2018) 375–384

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Element-based optimization of waste ceramic materials and glasses recycling

Ichiro Daigo[a,*], Shin Kiyohara[b], Tomoki Okada[c,d], Daisaku Okamoto[e], Yoshikazu Goto[a]

[a] Graduate School of Engineering, The University of Tokyo, Japan, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[b] Institute of Industrial Science, The University of Tokyo, Japan, 4-6-1 Komaba, Meguro, Tokyo 153-8505, Japan
[c] School of Engineering, The University of Tokyo, Japan, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[d] Kobe Steel, Ltd., Japan, 1 Kanazawa-cho, Kakogawa-shi, Hyogo, 675-0137, Japan
[e] Kishiyama Co., Ltd., Japan, 1-54, Gamo-higashi-cho, Koshigaya-shi, Saitama, 343-0841, Japan

ARTICLE INFO

Keywords:
Glass recycling
Recycling of ceramics
Refractories
Ironmaking slag
Sewage sludge
CerG

ABSTRACT

Many waste ceramic materials and glasses (CerG) such as glass, concrete, pottery, porcelain, brick, and tiles are landfilled because they have been recognized to be less conducive to recycling. In this study, to enhance the recyclability of ceramic materials and glasses, a linear model to minimize natural resource consumption of CerG materials production is proposed. The model focuses on elementally based contents of substances in the CerG materials. The model demonstrates a case for major industrial ceramic materials consisting of eleven oxides: Al_2O_3, B_2O_3, CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, and TiO_2 in Japan. In addition to the ceramic materials and glasses within the eleven oxide systems, application of the same natural resources to by-products or waste materials such as ironmaking slag and sewage sludge molten ash, are included in this analysis. In the proposed model, for minimizing natural resource consumption to produce the target CerG, linear programming was employed to assess waste generation and new production of CerG, subject to supply and demand balance and elemental tolerance ranges of chemical compositions in CerG materials. Two discrepancies were found between the proposed model and the characteristics of materials or usages of materials. Therefore, in the case study, several kinds of CerG materials were not applicable in the analysis. Even though costs for recovered materials restrict economic feasibility for recycling waste CerG, economic aspects were not taken into consideration in the analysis. In addition, impurity contamination during recovery processes restricts recycling of CerG. If those two factors (which may restrict the current recycling systems) were ignored, around two-thirds of the current natural resource consumption for CerG could be reduced by promoting recycling in the case of Japan. Further, new recyclable paths could be found by those analyses such as ironmaking slag for flat glass, glass bottles, and glass wool; and sewage sludge molten slag for tiles.

1. Introduction

Ceramic materials and glasses (CerG) have been used in natural forms from ancient times (Ashby 2005) as stone, flint, and pottery. Recently, industrial CerG such as porcelain, fused silica, cement, refractories, and soda-lime glass, have been widely used. The CerG and raw materials for these are produced in large amounts (USGS 2017): 4.20 billion tonnes of cement, 700 million tonnes of wollastonite, 350 million tonnes of lime, 56 million tonnes of clays, 53 million tonnes of soda ash, and 23 million tonnes of feldspar were produced in the world in 2016. On the other hand, their end-of-life materials are hardly recovered and recycled, except for concrete recycling for construction aggregates and cullet glass recycling (Jani and Hogland 2014; Santos et al., 2017). Meanwhile, their raw materials are abundant and practically inexhaustible; large amounts of waste are generated and dumped into landfill sites every year (Du and Tan 2013; Jani and Hogland 2014). In addition, greenhouse gas emissions associated with the mining and transportation of the large amounts of raw materials and the production of the materials should not be ignored (Jani and Hogland 2014). Madivate et al. (1996) revealed mechanisms of the energy requirement in reactions and proposed measures for energy saving such as using cullets, replacing carbonates in the glass batch with corresponding hydroxides, and reducing the melting temperature. Therefore, recycling of CerG can effectively contribute to reducing the amounts of dumping and GHG emissions associated with CerG production.

* Corresponding author.
E-mail address: daigo@material.t.u-tokyo.ac.jp (I. Daigo).

https://doi.org/10.1016/j.resconrec.2017.11.012
Received 11 May 2017; Received in revised form 17 November 2017; Accepted 17 November 2017
Available online 28 November 2017