Transactions of the Materials Research Society of Japan 29[5] 1829-1832 (2004)

Development of Civic Model on Materials Technology for Recycling-Based Society

O. Umezawa, H. Ohya[1], T. Yoshioka[2], S. Kumai[3] and C. Nishimura[4]
Dept. of Mech. Eng. & Mater. Sci., Yokohama National University, Tokiwadai, Hodogaya, Yokohama, 240-8501, Japan
Fax: 81-45-331-6593, e-mail: umezawa@ynu.ac.jp
[1]National Institute of Advanced Industrial Science and Technology, Onogawa, Tsukuba, 305-8569, Japan
Fax: 81-29-861-8086, e-mail: h-ohya@aist.go.jp
[2]Research Institute for Environment Conservation, Tohoku University, Aoba, Sendai, 980-8579, Japan
Fax: 81-22-217-7211, e-mail: yoshioka@env.che.tohoku.ac.jp
[3]Dept. of Mater. Sci. & Eng., Tokyo Institute of Technology
Nagatsuda, Midori, Yokohama, 226-8502, Japan
Fax: 81-45- 924-5622, e-mail: kumai@materia.titech.ac.jp
[4]National Institute for Materials Science, Sengen, Tsukuba, 305-0047, Japan
Fax: 81-29-859-2652, e-mail: NISHIMURA.Chikashi@nims.go.jp

A social technology study has been done for a year under a part of sustainable society project, RISTEX. In this study, we will propose business models with key social technologies to establish circulating products and materials. As the case study, we consider waste automobiles. Firstly an expert survey regarding on social system and technology was carried out. The questionnaires were focused on subjects such as bulk separation, utilization of mixed plastics, buttery recycle and recycling of secondary aluminum alloys. Key issues toward improved recycling in sustainable society are as follows; 1) product design for easy disassemble and material recycle, 2) development of improved bulk-separation method, 3) recovery models for mixed plastics and functional metals, and 4) aluminum scrap recycling system including neighboring countries. As the expert survey, the development of new technological model of which contributes to the construction of sustainable society is generally required, although conventional technology is taken into considerations. Both the economical and technological conditions should be arranged to promote the development.
Key words: Social technology, Sustainable society, Recycle, Materials processing

1. INTRODUCTION

Although the development of industrial technology has realized a rich material life, it has also caused problems with greater consumption of resources and energy, environmental pollution, and increased waste and by-products. Meeting the global environmental issues especially in dealing with reduction of CO_2 emission and industrial waste, and promoting recycling have been considered essential for the coming sustainable society.

A feasibility study on the materials process design and technology for sustainable society in Japan, USA and EU was carried out.[1] Some directions on technology development were proposed to answer the requirements on sustainable materials as follows: (1) consider distribution area of scrap accompanying flow and variability, (2) recovery and reproduction process to answer various needs, (3) novel technologies building high performance and/or service with low costs, low environmental loads and good flexibility. These mean that secondary materials accepted for recycling should be considered with social system and business model. Namely the demands which are to reduce waste and by-products, to save resources and energy, and to recycle materials should be totally managed.

To tackle with the social technology issues of material manufacturing and recycling, the present study has been carried out under a task of the research project, "studies on sustainable society", Research Institute of Science and Technology for Society (RISTEX). The technology developments in the present study have been focused on three subjects such as disposal process system, recovery system of difficult sorting materials, and secondary material utilizing system in products. The developments are taken the social problems behind each subject into account, and key technologies for advanced utilization of scrap are involved. As the case study, we consider waste automobiles, since the automobile is assembled various and high quality materials and generates mass scrap in the whole area.

2. BACKGROUND

The development of recycling technology for residues, especially mixed polymer scrap, is the most important subject. We intend to systematize the mixed polymer scrap with disassembly and recovery processes. Most of mixed plastics are still burned or made landfill. Recently materials industries, especially integrated steelworks, have established the advanced processes of waste plastics recycling such as blast furnace feeding, chemical converting, oil recovery and gas recovery. In the middle of 1990's, the blast furnace feeding which uses waste plastics instead of coke has firstly introduced at Kawasaki and Fukuyama (JFE), Japan.[2] Afterward not only the blast furnace feeding (Kakogawa, Kobelco) but also the advanced processes have been installed as follows;

The coke-oven chemical converting process is a material or chemical recycling of waste plastics from each municipality.[3] In the process, plastics charged into coke ovens are thermally decomposed into coke, hydrocarbon oil and hydrogen-rich gas. Coke is used as a reducing agent in blast furnaces, hydrocarbon oil as a material for chemicals such as plastics, and hydrogen-rich gas as a fuel for power plants. The process has been in operation at Kimitsu, Nagoya, Yahata and Muroran works of Nippon Steel Corp. in Japan.

The THERMOSELECT process recovers a synthesis gas, glass-like minerals, metals rich in iron and sulfur from various wastes in a continuous recycling process by means of high temperature gasification of the organic waste constituents and direct fusion of the inorganic components.[4] The synthesis gas is used to generate electricity with high efficiency. The facility in Japan has been in operation at Chiba (JFE) and Mutsu (Mitsubishi Material).

These processes use waste plastics instead of coke or electric energy and work without direct emissions of dioxin. However, the recovery systems of waste plastics depend on the location of material industry and energy industry. Thus it is necessary to consider the civic network model to utilize both advanced process and conventional process.

Secondary, appropriate ways for functional metallic materials recycle or reuse are brought together, since new vehicles equipped power unit of fuel cell or electric have been delivered. Each power unit has complex structure and consists of various metallic materials as well as polymer.

Thirdly, separated ferrous and nonferrous metals which take a great deal of material recycle have also problems on removing contamination or reducing impurity content, respectively. There is no cost-effective way except bulk sorting to reclaim high quality secondary alloys. However, it is difficult to fully remove trump element in a metal, e.g. contamination of copper in steel, iron in aluminum alloys and so on. In the case of steel, there is a choice and flexibility for the process of wrought products such as modern *integrated* steelmaking and electric arc furnace (EAF) steelmaking.[5] Recently near net shape castings such as strip casting and thin strip casting have been installed to produce flat-rolled steels in *mini-mill* steelworks. Thus the issue on tramp element in scrap has been controlled by dilution.

On the other hand, aluminum scrap has been taken up requirements to recycle themselves as well as steels, since producing primary aluminum from the ore bauxite consumes large amount of energy, and remelting of scrap requires only several percent of the energy needed to produce the same weight of the primary aluminum. However, the cascade of material flow is suitable for the recycling due to without or less dilution by raw material. Furthermore a large amount of reusable products, parts and scrap in the waste has been exported to Asia. As a result, the supply of aluminum scrap in Japan is not enough for the demand, and it has been imported from North America etc. Then the application of secondary alloys has been almost limited to castings. To establish a business model of manufacturing and recycling aluminum in Japan, there is a need to consider the aluminum recycling system including neighboring countries and to expand the utilization of secondary alloys for wrought products as well as high quality casts.

3. OUTLINE OF PROJECT

3.1 Local models of waste treatment and recycling for used cars [6]

Waste automobiles generated in Japan reach more than 5 millions annually and are distributed in the whole area. The recycling and waste treatment plants are also distributed in each area. Recently a large amount of reusable products, parts and scrap in the waste have been exported to East-south Asia, China and Russia. As a result, the social problem and necessary technology would depend on the local condition. It is important to analyze them by statistic data and to decide the necessary development for the location. Then combination system of manual separation and fine shredding in the bulk sorting are studied in the disassembly, recovery and waste treatment stages.

3.2 Waste plastics recycle models incorporating in energy industry and material industry [7]

The most important problem considering of waste plastic recycling is maximizing carbon dioxide reduction. Energy industry and material industry, such as electric power generation, steel industry and cement industry, use much coal at present. Therefore, formation of network system will be realized one of the zero emission by incorporating recycle of the waste plastics in each manufacturing process. In fact, calorie of the waste plastics after the dechlorination treatment is 9774 kcal/kg. This value is higher than the some coals for the industries mentioned in above. Therefore, use of the waste plastics as a substitution coal is very effective for maximizing carbon dioxide reduction.

Dechlorination is the most important technology of recycle for mixed polymer scrap. In the dry process such as manual operation, however, it is difficult to fully remove polyvinyl chloride (PVC) from polymer scrap. To expand recycle of waste plastics in each area, development of dechlorination in concentrated alkali solutions is also needed because of easy chemical and thermal recoveries.

3.3 Recycle and reuse models of functional metallic materials in power unit of fuel cell and electric vehicles [8]

Recently, introduction of hybrid cars and fuel cell cars is progressing in response to the demand for restraining the global warming by reducing CO_2 emission. Materials for power units of these low emission cars contain many functional metals, which are scarce and valuable. Before those cars become widely spread in future society, it is necessary to establish the separation, recycling and reusing processes of those valuable metals, to help constructing a resource circulating society. Power units, including batteries, fuel-cell stacks and gas reformers will be dismantled of the low emission cars at the initial stage of recycling. The processes coming up next to the dismantling, such as recycling and reactivating the metallic materials have not been examined, yet. In this study, the possible problems will be extracted from the recycling and reusing process of the functional metallic materials. Also, guidelines towards selection of reusable materials and reusable devices will be examined.

3.4 A vale-added model of recovery process for secondary aluminum alloys

To provide flexibility in secondary materials, the concept "material systematized in the product" should be applied. Al-Si-X alloys are one of the major cast materials, and blending aluminum scrap can control the alloy compositions. In addition, removal of Fe, Mn and Si from secondary alloys is difficult and higher costly. However, the heavy cold-work cannot be applied to Al-Si, Al-Fe and Al-Mn systems having plural phases with low mutual solid solubility, because it causes severe cracking. To control formability, fine microstructure with plural phases is one of candidates for the alloy design.

Thus a new design concept for the recyclable material is proposed, making secondary materials innocuous from impurities to utilize widely. A novel thermomechanical process, repeated thermomechanical treatment (RTMT) [9], which is a repeat of the multi-steps cold-working followed by heat treatment has been applied to hyper-eutectic Al-Si-Fe-Mn-X cast materials. Through the RTMT the casts could be refined their microstructures with balanced strength and ductility and be plastically deformed for applying automotive forged parts such as engine piston. Since the alloy composition provides high wear resistance, lightweight, low thermal expansion and excellent high temperature strength, developing a value-added model of recyclable aluminum alloy design and production is expected.

3.5 Rapidly solidified aluminum alloy strips for high quality recycling [10]-[11]

Strip casting has potential to meet the demand which is to accommodate more aluminum scrap in cast billets to be used for producing wrought alloys. Solidification is very rapid in twin-roll casting, leading to characteristic features in the microstructure, such as a marked supersaturation of the relatively insoluble elements, fine matrix grain structure and fine and even distribution of secondary particles. These characteristics will be helpful to minimize the bad effect of impurities from scrap. In the present study, rapidly solidified cast strips were cold rolled and heat-treated to form thin sheets. Refined microstructure and improved mechanical properties were obtained and this confirmed that the rapid cooling was critical for high quality recycling.

4. EXPERT SURVEY

4.1 Procedure

The workshop, "Technology development towards sustainable society in East and East-south Asia: eco-design and recycle process", was held under the auspices of *ECOMATERIAL Forum* in the Society of Non-Traditional Technology and us to discuss about efforts towards recycling in East and East-south Asia. The materials flow and product manufacturing accompanied with material recycling have been realized. According to the definition in the feasibility study,[1] three types of materials flow such as local loop, intra-economic-zone loop and inter-economic-zone loop are considered. The intra-economic-zone loop involves neighboring countries.

Then an expert survey was carried out on February 2003 in order to check various ideas for the orientation of this project. The questionnaires were open on the web site of *ECOMATERIAL Forum*, and sent out to the members of the forum and the participants of the previous feasibility study [1]. The number of 101 answers was available totally, which were obtained from various fields such as research and technology, administration, standardization, think tank, society and education, which belong to the industry-university-government. Furthermore, interviews were carried out from the people concerned fuel-cell vehicle, electric automobile, and hybrid vehicle in domestic and overseas.[8]

4.2 Analysis results

Materials flow and intra-economic-zone: In East and East-south Asia, regulatory issues have been setting rapidly to build sustainable society. On the other hand, the materials are imbalance between production and waste or recycle due to the conditions of economy. Then outflow and inflow of scrap are admitted in the East and East-south Asia.

However, the materials flow as products or parts is not clear. The recycling model should be considered the area in which the material is balanced between in production and in waste.

Scientific issue: The environmental engineering is coming a field of science. However it still has difficulties on individual activity and industry-university-government collaboration. From the social aspect, the interests on disposal and strategy of resources are high. From the technological aspect, the issue of recycling process is strongly focused rather than those of material design, manufacturing process, waste treatment and environmental medication.

Bulk separation: The advanced system developments of bulk separation and material distinction are required. Separation of non-ferrous metals and plastics is strongly mentioned. For the automobile design, disassembly is the most important issue. On the material flow in recycling stage, the most persist that not only local loop but also intra-economic-zone loop should be considered.

Regarding on the collection and recovery of plastics in the municipal wastes, opinion is divided whether it should be distinguished between living waste and business one or not. Also the majority are negative for the advanced sorting of mixed plastics.

Recycle of hybrid car and fuel cell car: From the viewpoint of manufacturer, it is as much as the performance improvement and cost reduction on hybrid car and fuel cell car. It is realized that recycling of them has not been considered yet. Danger for lithium ion battery, and difficulty of separation with catalyst, polymer and electrode material are understood as a problem on fuel cell recycle or reuse due to its complex structure. Especially, the consciousness of administration and industrial parties is high. The idea that manufacturer should introduce recyclable design from producing parts stage is dominant, and the importance of *ecomaterial* and ecological design has been widely recognized. Thus most of answer is that the battery recycle of those cars is not serious problem, since the module design will be able to satisfy the battery recover and reuse. It is also noted how we manage the export of used fuel-cell car. Thus it is realized that recycling of fuel-cell car is important and difficult problems. The discussion should be advanced by putting time on worldwide challenge for its recycling system.

Utilization of aluminum scrap and materials design: Better utilization of aluminum scrap is desired. Thus recovery of aluminum scrap should be in the recycle loop of not only local area but also including neighboring countries. It is reflect on the outflow and inflow of aluminum products and scrap. For the recycling technology, there is a need to develop the novel process without or less bulk sorting as well as the advanced sorting mentioned in above. Moreover, product design built in recyclable material is strongly recommended. For aluminum alloy design, various ideas such as removing trump element, alloy system integration, uni-alloy design are considered. In addition, the service equipped material data is a candidate for value-added product design.

5. SUMMARY

As the expert survey, the development of new technological model of which contributes to the construction of sustainable society is generally required, although conventional technology is taken into considerations. Both the economical and technological conditions should be arranged to promote the development.

The importance of social system research and the need of industry-university-government collaboration are widely recognized. But they have not commonly realized yet.

ACKNOWLEDGEMENT

This work has been supported by RISTEX of JST (Japan Science and Technology Agency). We thank the Society of Non-Traditional Technology for the help on expert survey.

REFERENCES

[1] O. Umezawa and K. Nagai, *Trans. MRS-J*, to be submitted.
[2] H. Hotta, *NKK Tech. Report*, **179**, 126-131 (2002).
[3] H. Goto, T. Koseki, T. Ibaraki, H. Matsuguma and H. Kondoh, *Nippon Steel Tech. Report*, **86**, 10-13 (2002).
[4] F. Miyoshi, M. Shimizu and H. Marushima, *Kawasaki Steel Tech. Report*, **32**, 287-291 (2000).
[5] O. Umezawa, *Bulletin Iron Steel Inst. Jpn. (Ferrum)*, 7, 545-554 (2002).
[6] H. Ohya and S. Endoh, *Trans. MRS-J*, to be submitted.
[7] T. Yoshioka and A. Okuwaki, *Trans. MRS-J*, to be submitted.
[8] C. Nishimura, *Trans. MRS-J*, to be submitted.
[9] O. Umezawa and K. Nagai, *Metall. Mater. Trans. A*, **30A**, 2221-2228 (1999).
[10] S. Kumai, K. Suzuki, Y. Saito and T. Haga, *Trans. MRS-J*, to be submitted.
[11] T. Haga, M. Ikama and S. Kumai, *Trans. MRS-J*, to be submitted.

(Received October 10, 2003; Accepted October 31, 2003)