Inventory analysis in production and recycling process of advanced composite materials

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This paper described an estimation of inventory data of advanced composite materials. Inventory analysis, especially about energy consumption of production and recycling processes of carbon fiber reinforced plastics (CFRP) was mentioned. In production process, data of energy consumption in various molding processes were calculated and compared with the data of production of carbon fiber and prepreg. Amount of energy required in production of carbon fiber is much larger than other processes and it was proved that it is most important process for improvement. In recycling process, data of material recycling and thermal recycling were estimated. Since energy needed in material recycling is much smaller than that of production process, the validity of material recycling was shown.

Keywords: Advanced Composite Materials, Inventory data, Production and Recycling Process

I. INTRODUCTION

Advanced Composite Materials (ACM) have a great advantages such as high performance (strength, stiffness, etc.) and high function (durability, etc.). However their industrial scale is small. In Japan, the amount of CFRP (carbon fiber reinforced plastics) production is less than 10 kton/year and mainly applied to sporting goods and aerospace field. Even in the case of GFRP (glass fiber reinforced plastics), it is about 400 kton/year and about only 3% of plastics products. Therefore inventory data of FRP is usually ignored in product-LCA.

In the other hand, ACMs have also disadvantages such as high production cost/energy, difficulties in recycling and disposal processes and they are regarded environmental unconscious. However they can greatly contribute for reducing environmental loads during usage process by their advantages such as lightweight and long lifetime. Thus, from a viewpoint of ACM field inside, to evaluate and improve their eco-performance, applying LCA on ACM is necessary. Especially, production process and disposal-recycling process are important because of ACM’s peculiarity.

In this paper, CFRP’s inventory data of production process and recycling process, focusing on energy consumption, were shown.
II. PRODUCTION PROCESS OF ACM

The production process of CFRP is shown in Fig. 1. As can be seen in the figure, pre-impregnation materials (prepreg) are produced intermediately to improve handling and production process is divided in three parts.

II-A. Production of carbon fiber

There are several methods to produce carbon fiber, since most of carbon fiber is made from PAN (polyacrylonitrile), only PAN-base carbon fiber production process is considered. We already reported inventory data of carbon fiber based on data obtained factories (Table 1).

![Diagram](https://via.placeholder.com/150)

Fig.1. Typical process of CFRP production.

![Diagram](https://via.placeholder.com/150)

Fig.2. Process flow of carbon fiber production.

<table>
<thead>
<tr>
<th>energy consumption (MJ/kg)</th>
<th>CO₂ emission (kg/kg)</th>
<th>NOx emission (kg/kg)</th>
<th>SOx emission (kg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>480</td>
<td>30</td>
<td>2.0</td>
<td>0.07</td>
</tr>
</tbody>
</table>

However, for the case of process analysis, based on production process in Fig. 2, accumulating energy consumption of each process data such as machines which are used to produce, atmosphere management and keeping materials and products etc., the obtained data is about 90 MJ/kg. The difference is caused by how to set standard products, process and allocation of electricity etc. In this paper, data in Fig. 1 are adopted. However the accuracy of data should be considered for further analysis.

II-B. Production of prepreg

Prepreg production process is shown in Fig. 3 and energy consumption of each process in Fig. 3 to produce prepreg is shown in Fig. 4. As can be seen in the Fig. 4, indirect production processes, such as atmosphere management, consume much more energy than direct production process.

![Diagram](https://via.placeholder.com/150)

Fig.3. Process flow of prepreg production.
II-C. Production of FRP

There are a lot of forming/molding methods to produce FRP. In the field of aerospace, CFRP are produced by autoclave method. Autoclave curing requires large amount of energy and relatively large amount of materials are disposed as wastes in forming process. Therefore energy consumption and emission of environmental loads are quite large, over 600 MJ/kg for energy consumption. However, as can be seen in Fig. 6, other forming/molding and curing methods consume only 10-20 MJ/kg and FRP’s cumulative energy consumption is estimated about 450 MJ/kg.

III. RECYCLING PROCESS OF FRP

For conventional plastics, recycling methods are well investigated and LCA based evaluation is also carried out. For FRPs’ recycling, essential method is similar with conventional plastics’ case. However, since FRPs are the mixture of materials, there are some difficulties in recycling and disposal processes.

Recycling of CFRP products is technically possible. However, because of the small scale of CFRP industry and complications in decomposition process etc., most of used CFRP are not practically recycled and just disposed at the end of the life cycle. Therefore, data of recycling process of CFRP is based on laboratory-base data and including some assumption.
There are three types of recycling for plastics, material recycling, chemical recycling and thermal recycling. Although use as an agent of blast furnace which is one of the chemical recycling, is an effective method for CFRP products, its inventory data was not obtained and it is not analyzed in this paper. In other general chemical recycling case, pyrolysis and refusing to recover resources take more energy and chemical recycling seems not effective for the present. Therefore, in this paper, material and thermal recycling processes are considered. A typical process flow is shown in Fig. 7.

III-A. Material recycling

For ACM, thermosetting resin, such as epoxy resin, are usually used as matrix. In fiber reinforced thermosetting plastics case, the energy consumption of material recycling was estimated as 50 MJ/kg. One of the usages of recycled materials is filler of SMC or BMC. If waste’s properties are kept in good condition, 50-70% material recycling is possible with low energy consumption. However it is as an ideal case and in many cases material recycling is not easy even in the case of cascade recycling.

For the material recycling of GFRP, a trial plant of producing material of cement from inorganic materials of used GFRP products are tested by Japan Reinforced Plastics Society and produced cement possess enough properties. In this method, organic materials are used for fuel at the same time and both material and thermal recycling are realized.

The other hand, although thermoplastics are not popular in ACM, recently they are researched actively and amount of thermoplastics ACM are increasing. In the case of thermoplastics composites, since resin and fiber/filler are separated easily, it is suitable for material recycling. In addition, energy consumption in the process was about 10 MJ/kg and it is smaller than in the case of thermosetting-ACM.

Closed loop recycling is ideal in material recycling. However, because large amount of energy is required to produce carbon fiber and CFRP, this recycling is very effective even in the case of cascade recycling.

III-B. Thermal recycling

For thermal recycling, energy generation was estimated as 10-20 MJ/kg. It was calculated from calorific value and process energy consumption. The heat recovery ratio of general incinerator is also considered.

The calorific value of FRPs is about 2000-5000 kcal/kg. It is smaller than epoxy resin’s 7000 kcal/kg and 10000 kcal/kg of polyester and FRPs’ effectiveness of thermal recycling is considered smaller than in the case of conventional plastics. At the end of life cycle, including after material recycling, FRPs will be used as fuel. However more effective method, such as blast furnace agent, should be considered rather than simple thermal recycling.

IV. CONCLUSIONS

Inventory analysis, especially on energy consumption, were carried out on production process and recycling process of FRPs. In production process, loads of producing carbon fiber is much larger than other processes.

In recycling process, although the data used in this analysis including assumptions, from the viewpoint of energy consumption, material recycling is very effective, especially in the case of thermoplastics-ACM. Thermal recycling is also effective. But the effect is smaller than that of material recycling.

REFERENCES


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