DEMAND AND DISPOSAL FORECAST FOR CARBON FIBRE BY BOTTOM-UP APPROACH

T. Kirihara[1*], T. Kawashima[1], J. Takahashi[1], T. Matsuo[1] and K. Uzawa[1]
[1] Department of Systems Innovation, The University of Tokyo, Tokyo, Japan
* Corresponding author (t.kirihara86@gmail.com)

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1 Introduction

Demand for carbon fibre (CF) has been increasing in these days and this trend will continue for the next some decades. It is a good situation in one sense for CF industry because it enables the industry to lower the cost of CF. However, it will induce another problem which is often referred as garbage-related problem. Until now, post-use CF had been buried or incinerated [1] because the amount was quite small. But, the waste will have to be treated with great care because the amount will become larger as demand increases. Hence, it is very important to handle the waste as well as to forecast the quantity of CF which will be abandoned in each year. The anticipated amount of demand and disposal of CF is discussed in this paper.

The total demand for CF is determined by necessity amount of CF per product. The problem is that suitable amount of CF per product is not so studied so far. Therefore, to begin with, it is requested to calculate the necessity amount of CF per product. In this paper, the quantity is estimated through a method called life cycle assessment (LCA). From the view point of LCA, the necessity quantity per product is determined so as to make the environmental burden minimum. (Note that environmental burden in this paper refers to CO_2 emission.) The following three fields are considered in this paper: airplanes, automobiles, and wind blades because they are thought to raise the demand for CF.

2 LCA of automobiles and wind turbines

LCA is a method to evaluate impacts on environment. This method is often used to clarify the impact quantitatively. Some people refer LCA as “cradle-to-grave analysis” because this method takes all of the stages which are associated with products’ life into consideration, i.e. from raw material extraction stage to recycling/disposal stage. This chapter aims to calculate the suitable amount of carbon fibre reinforced plastics (CFRP) which can minimize the environmental burden in terms of LCA method.

Only automobiles and wind blades are focused in this chapter because these two fields are assumed to raise the demand for CF increasingly [2], while demand for airplanes are relatively stable compared with these two fields.

2.1 LCA of automobiles

This sector is the most important one because the demand from this sector will become the biggest in the near future. First, the quantity of CF per automobile which optimizes energy efficiency is calculated. And then, total demand from this sector is estimated, which is described in the following chapter.

2.1.1 Materials and Methods

The key materials’ properties assumed in this paper are grouped in Table 1. Other materials’ properties are listed in Suzuki’s work [3]. Also, data set of raw materials and their weights are listed in the paper.

When proceeding LCA, it is necessary to define goal and scope [4]. In this case, the goal is to clarify environmental impact of automobiles quantitatively and show how much CF is optimal to lessen environmental burden. The functional unit is a normal automobile whose weight is 1,380 kg. Also, it is assumed that an automobile runs 100,000 km till it is scrapped. Considering of automobile’s LCA case, the following four stages should be considered; material production stage, parts production stage, running stage, and disposal/ recycling stage.

(1) Material production stage/ Parts production stage

Some data is used to calculate CO_2 emission from these stages. For example, data set of raw materials and their weights [3] as well as CO_2 emission factor from various statistical data are used here. By multiplying weight of each material by CO_2 emission factor, CO_2 emission can be calculated. And, to make calculation result more proper, detailed data which is associated with battery [5] is applied in these stages.

(2) Running stage

With total mileage during the whole life-span and value of fuel consumption, CO_2 emission from this stage can be calculated. The following equation yields a relationship between weight and fuel consumption [6].

$$E=0.0082*m + 0.7575 \quad (1)$$

Where E is fuel consumption [l/100 km] and m is weight of an automobile [kg]. This equation can be applied only to gasoline vehicles and another equation should be applied when electrical vehicles are considered [7].

(3) Disposal/Recycling stage

The way of calculating CO_2 emission from this stage is also similar to Suzuki's work [3]. By adding these four stages' results, the total CO_2 emission can be obtained. This result is shown in Fig.1.

The discussion above is the case of normal automobiles. The next step is to estimate the CO_2 emission from light weight automobiles which are made of CFRP. These automobiles should have the same stiffness compared with normal automobiles, which determines the amount of CFRP. According to Yamauchi's work [8], polypropylene as matrix and CF with volume fraction (V_f) of 0.2 are the best combination to lessen the environmental burden. In such case, the weight of an automobile becomes 884 kg and 233 kg of CFRP is used. Just like above, by multiplying weight of CFRP by CO_2 emission factor, CO_2 emission from material production stage and parts production stage can be attained. In this paper, CO_2 emission factor of CF is set as 20.5 kg-CO_2 / kg [9]. Also, by instituting 884 kg into equation (1), the fuel consumption can be obtained and accordingly, CO_2 emission from running stage is gained. The result is shown in Fig.2.

Subscript *r* is described in the picture. That symbol indicates that recycled CF is applied to an automobile to lessen the environmental burden. The result is obtained in the similar way of fresh CF, while r-CF has a CO_2 emission factor of 1.67 kg-CO_2 / kg [9].

2.1.2 Results

The discussion above says that V_f = 0.2 is the best in terms of environmental burden. Accordingly, an automobile needs CFRP 233 kg. This figure is used in the following chapter to estimate an anticipated demand. Add to this result, Fig.1 shows that PHEV and EV have almost the same environmental burden although PHEV is more likely to become common than EV due to its affordable price.

2.2 LCA of wind turbines

A lot of attention is being paid to this sector in these days because extremely large wind blades are desired in terms of energy efficiency. As is the case with the above sector, some statistic data and forecasts of capacity of wind power are used to estimate the total demand for CF annually. Also, the necessity amount of CF per blade is discussed in this chapter, which makes this paper notable.

2.2.1 Materials and Methods

Key materials are already grouped in Table 1.

The way to estimate CO_2 emission is similar to automobile's case, i.e. CO_2 emission is calculated by multiplying weight of materials by CO_2 emission factor. The functional unit is an onshore wind power turbine whose life-span is 20 years. Regarding wind turbine's LCA, five stages are included. These stages are material production stage, parts production stage, construction stage, transport stage, and maintenance stage.

There are some assumptions here. First, wind velocity increases as height increases. This relationship is often referred as power law [10]. Second, the power of wind turbine is nearly proportional to square of the blade length. By regression analysis from various existing wind turbines, equation (2) is obtained.

$$P=1.1963*L^2 + 9.9448*L - 117.03 \quad (2)$$

Where P is power and L is blade length. Third, the altitude of nacelle is twice of its height of tower.

Basically, five parts compose a wind turbine; foundation, blade, nacelle, tower, and power generator. Regarding foundation, nacelle, tower, and power generator, the way of LCA is almost the same as is the case with automobiles. While, a special

consideration is necessary to implement LCA in the case of blades.
Assume that a blade is under "cantilever beam" circumstance, midair, and taper beam. Its shape is supposed as follows; blade length / blade width = 10 and blade width / blade height = 4. Also, the blade is assumed to follow so-called similarity rule. The necessity amount of CFRP per blade is estimated as follows: Safety factor is calculated from the data of existing GF-made wind blades. And then, CF-made blades' V_f is determined so as to fulfil this factor. With this V_f and some assumptions, the shape of blade is fixed. Accordingly, LCA results of material production stage and parts production stage can be obtained. The rest three stages' calculations are done by the way which is similar to previous work [11].

2.2.2 Results

CF can make blades longer than GF. This is shown in Fig.3. Although some special assumptions are made in this paper, it is safely said that CF has more merits than GF. Therefore, CF makes it possible to produce extremely large wind blades.
Fig.4 says that CF-made wind blades have less environmental burden than GF-made wind blades.

3 Demand and Disposal Forecast

In this paper, bottom-up approach is applied to obtain demand and disposal forecast. In other words, by summing up each sector's demands, which have already been obtained above, total demand is obtained. The amount of disposal is estimated based on demand forecast. The durable time of each product is almost fixed. Taking this durable time into consideration, the amount of disposal is evaluated. The following verse only discusses the demand and disposal in Japan, but the same method can be applied to estimating the amount all over the world.

3.1 Airplanes

Recently, more and more CF has been applied to airplanes than before. For example, 35 tonnes CFRP, which is almost half of B787's weight, is applied to it. It is said that about 570 new planes are produced from 2009 to 2028 in Japan [11]. Given that these new planes are to be scrapped until 2050, anticipated amount of disposal from this sector becomes 20,000 tonnes at most.

3.2 Automobiles

In this paper, about 230 kg of CFRP is used per automobile. Assume that light weight automobiles are released from 2010 and spread at the same rate of TOYOTA PRIUS, the anticipated disposal amount of CFRP until 2050 becomes almost 850,000 tonnes in Japan.

3.3 Wind Blades

New energy and industrial technology development organization (NEDO) has already set a target regarding wind turbine capacity. It says that Japan should increase its wind turbine capacity to 20,000 MW by 2030. Also, it is calculated that a 5MW wind turbine needs around 50 tonnes CFRP in this paper. Considering these facts, estimated amount of disposal until 2050 is about 200,000 tonnes CFRP.

4 Conclusions

LCA result shows that there are optimal amount of CF per product in terms of environmental impact. Sometimes, overmuch amount of CF may cause worse result than that. Due to the fact that the best amount varies according to products, we need LCA method to evaluate it.
Where material production stage consumes a lot of energy, recycling can reduce environmental burden effectively. This trend is shown in the case of wind turbines. Hence, recycling has two major merits; decreasing environmental burden of CF and resolving garbage-related problem.
By bottom-up approach, the estimated amount of demand and disposal become clear. With this result, some suitable methods such as cascading can be implemented effectively.

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Table 1. Materials properties [3].

	Density	Tensile Strength
Carbon Fibre	1.8 g/cm^3	4900 MPa
Glass Fibre	2.6 g/cm^3	3430 MPa
Steel	7.8 g/cm^3	420 MPa
Polypropylene	0.9 g/cm^3	35 MPa

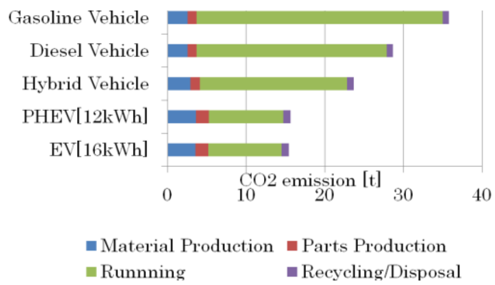

Fig.1 Life cycle CO_2 emission of automobile with various kinds of power source.

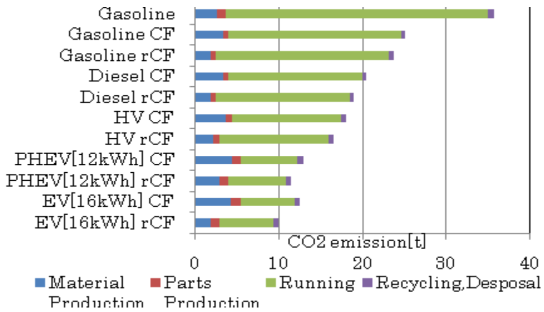

Fig.2 Effect of weight reduction and recycling on life cycle CO_2 emission with various kinds of power source.

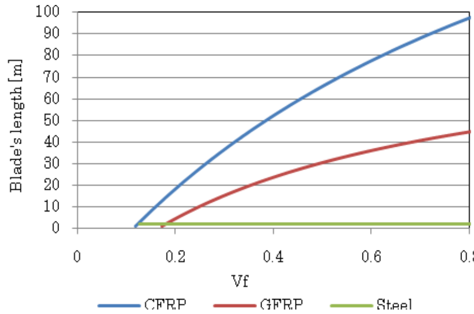

Fig.3. Relationship between fiber volume fraction (V_f) and the length of wind turbine blade.

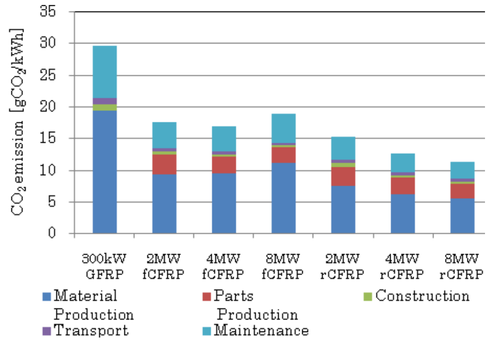

Fig.4. Effect of the CFRP recycling on the specific CO_2 emission of wind power generation. (The result of 300 kW’s case is obtained from [11].)