Fundamental Investigation of LCA of Cross Tie

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As environmental preservation becomes an increasingly important issue on a global scale, railway enterprises are also required to assess and reduce environmental loads of materials used in railway systems. Such loads are mainly related to vehicles and facilities. In this study, we estimated the environmental load of railway facilities, and conducted a case study on four types of cross tie (wood, concrete, synthetic and steel) by applying the LCA method at the production stage. As a result, we found that CO₂ emission from total ties in Japan was about 55,000 tons per year.

Keywords : environment, environmental impact, cross tie, LCA

1. Introduction

As environmental preservation becomes an increasingly important issue on a global scale, railway enterprises are also required to assess and reduce environmental loads of materials used in railway systems. Such loads mainly consist of vehicle-associated factors (e.g. energy for operating) and railway facilities (structures, tracks, stations, etc). However, it is difficult to assess the whole load of railway facilities because they are enormous in kind, number and length. There are very few studies which estimate the environmental loads of railway facilities. This report adopts cross ties for a case study to estimate the loads of railway facilities, and estimates the loads of different materials.

2. Number of ties in Japan

We first investigated “Annual Report on Japanese Railways ¹⁾” to check the number of ties used in Japan. Since the data were shown in length of track, we calculated the number of ties at the rate of 39 ties/25 m that is a popular tie spacing in Japan. Table 1 shows the number of ties calculated. The number of total ties used in Japan is about 65 millions. When broken down by material kind, there are about 36 million concrete ties (55%), which are the most popular, 27 million wood ties (42%), and 2 million of other kinds of ties (4%). Examples of other kinds of ties are organic resin (called synthetic ties) and steel ties.

Table 1 Number of ties used in Japan

Organization	Kind			Total
	Concrete	Wood	Other	
JR Hokkaido	1,811	2,657	361	4,829
JR East	12,775	6,922	107	19,805
JR Central	3,432	1,726	32	5,190
JR West	5,719	5,675	1,344	12,738
JR Shikoku	356	938	107	1,402
JR Kyusyu	1,838	2,194	44	4,076
JR Freight	120	550	26	697
JR Total	26,053	20,662	2,022	48,737
Major Private Railways	5,945	2,046	90	8,082
Small Scale Private Railways	2,171	4,323	193	6,687
Teito Rapid Transit Authority	613	136	1	751
Public Railways	998	180	8	1,186
non-JR Total	9,728	6,686	292	16,705
Total	35,781	27,347	2,314	(×1,000)
		65,442		

3. LCA of ties

To estimate the environmental loads, we used the Life Cycle Assessment (LCA) method. Manufactured products undergo several stages during their lifetime (See Fig. 1), that is producing stage, service stage and the waste treatment stage in this order. If the manufactured products are reused or recycled, the waste treatment stage continues to the production stage. Therefore, the material itself forms several life cycles. LCA is the method to estimate the environmental loads at every stage. This method provides data for comparison of environmental loads between manufactured products. It enables therefore to select products of relatively small loads. But, LCA is a

Fig. 1 Life Cycle Assessment

method under development so the output data is sometimes different even for the same manufactured products because of difference in data source of raw materials or other reasons. Consequently, we need to clarify the data used and calculation conditions. If we use the LCA method, we need to arrange the following steps;

- (1) Decide the purpose and scope
- (2) Collect the inventory analysis data
- (3) Estimate the environmental loads

The relationships of environmental loads between materials are boundless. First we must decide the purpose and scope of estimation. Secondly, we investigate the mass of each raw material making up the manufactured products and energy used because the output data is influenced by these factors. After having obtained these data, we can estimate the environmental loads.

3. 1 Purpose and scope

The purpose of this study is to estimate the environmental loads of four types of ties (wood, concrete, synthetic and steel). Wood, synthetic and steel ties examined were the common types, and concrete ties adopted were the post-tensioned type except for pads, tie plates and other materials. Moreover, only the production stage was discussed because no data was available on the service stage and waste treatment stage. So, this does not make a completely constructed LCA.

3. 2 Inventory analysis

Table 2 shows the materials used and mass of each tie. For wood ties, several kinds of woods are used, which are different in production age or area. At present time, Kempas from Malaysia is the most popular. Creosote is used as antiseptic. This is the important material for elongating the lifetime of wood. Concrete tie is made of concrete, prestressed concrete bar, nut, bearing plate and mortar. The bar, nut and plate are made of steel. The mortar is used for filling up of the hole that is formed in prestressing. Synthetic tie is made of urethane resin, so the raw materials of synthetic tie are polyether polyol, 4,4'-diphenylmethane-diisocyanate (MDI) and glass-fiber. Steel tie is made of steel only.

Figure 2 shows the manufacturing method of each kind of cross tie, and Table 3 shows the energy consumed in production. The data were calculated from the energy used

Fig. 2 Manufacturing method of each kind of cross tie

Table 2 Material and mass of tie

Kind	Material	Mass [kg]
Wood	Wood (Kempas)	56~58
	Creosote	14
Concrete	Concrete	155
	Prestressed Concrete Bar	4.8
	Nut	0.15
	Bearing Plate	1.87
	Mortor	0.9
Synthetic	Polyether Polyol	8.96
	*MDI	12.72
	Glass-Fiber	21.76
Steel	Steel	55

*MDI : 4,4'-Diphenylmethane-diisocyanate

Table 3 Energy consumed in production

Kind	Electric power [kWh]	Light oil [dm ³]	Heavy oil [dm ³]
Wood	0.52	0.057	0.817
Concrete	1.945	0.032	0.702
Synthetic	17.64	—	0.77
Steel	5	—	0

Table 5 Lifetime of ties

Kind	Lifetime [year]
Wood	15
Concrete	50
Synthetic	50
Steel	50

3. 3. 3 Effect of lifetime

The lifetime is different from one kind of tie. Furthermore it is difficult to decide the precise lifetime because various factors (laying condition, quality of tie, etc) are involved. Therefore, we assumed the average lifetime shown in Table 5.

Figure 3 shows the data of CO₂ emission divided by the lifetime. This gives the CO₂ emission per year. Wood ties are by no means insignificant in terms of environmental load. Synthetic ties emit more CO₂ than other kinds of ties. The emission from synthetic ties is mainly due to MDI, so it is effective to reduce the CO₂ emission from MDI.

used per month divided by the number of ties produced.

3. 3 Estimation of CO₂ emission

3. 3. 1 Conditions

Based on this inventory data, we calculated the CO₂ emission by using “Sima Pro 3” software. As we couldn’t obtain the data of creosote, it was excluded from the estimation.

3. 3. 2 CO₂ emission from ties

Table 4 shows the CO₂ emission from one tie. Wood ties emit the least amount of CO₂, and synthetic ties the most. These data involve the CO₂ emission at the collection and the transportation of the raw materials.

Table 4 CO₂ emission from one tie

Kind	CO ₂ emission [kg]
Wood	11.3
Concrete	44.1
Synthetic	99.3
Steel	48.0

4. Total CO₂ emission from ties

Total CO₂ emission from type-k ties can be calculated by this equation.

$$a_{total, k} = (a_k / t_k) \times n_k \quad \dots \dots \dots (1)$$

where $a_{total, k}$, a_k , t_k , n_k mean total CO₂ emission from type-k ties, CO₂ emission from one tie, lifetime of tie and number of ties in Japan, respectively. By this equation, we calculated the total CO₂ emission as follows.

- (1) Wood tie : {11.3 (kg/piece) / 15 (years)} × 27,347,000 (pieces) ≒ 20,000 (tons/year)
- (2) Concrete tie : {44.1 (kg/piece) / 50 (years)} × 35,781,000 (pieces) ≒ 32,000 (tons/year)

Since we could obtain no data on the number of synthetic ties and steel ties, we divided the number of other ties (2,314,000 pieces) into two equal parts, and assumed one part (1,157,000 pieces) as synthetic ties and the other as steel ties.

Fig. 3 CO₂ emission from each tie per year

(3) Synthetic tie : $\{99.3 \text{ (kg/piece)} / 50 \text{ (years)}\} \times 1,157,000$
(pieces) $\doteq 2,000$ (tons/year)

(4) Steel tie : $\{48.0 \text{ (kg/piece)} / 50 \text{ (years)}\} \times 1,157,000$
(pieces) $\doteq 1,000$ (tons/year)

Total CO₂ emission from all kinds of ties can be calculated by summing up each $a_{total, k}$ as shown by this equation.

$$A = \sum a_{total, k} \dots\dots\dots (2)$$

Where A is total CO₂ emission from all kinds of ties. Total CO₂ emission from all kinds of ties is 55,000 (tons/year) as shown in Table 6.

Table 6 Total CO₂ emission from all kinds of cross tie

Kind	CO ₂ Emission (ton/year)
Wood	20,000
Concrete	32,000
Synthetic	2,000
Steel	1,000
Total	55,000

5. Summary

We estimated the environmental loads of railway facilities by performing a case study on ties. Ties made of four kinds of materials (wood, concrete, synthetic and steel) were selected for estimating the CO₂ emission by the LCA method at the production stage. This study proved that CO₂ emissions from concrete and steel ties were relatively low. Synthetic ties emit more CO₂ than other kinds of ties. The emissions from synthetic ties are mainly due to MDI. It is effective, therefore, to reduce the CO₂ emission from MDI. In Japan, total CO₂ emission from all ties at the production stage is about 55,000 tons in weight per year.

Reference

- 1) "Annual Report on Japanese Railways" (in Japanese), Supervised by Railway Department, Ministry of Transport, 1997