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CSR Department, JSR Corporation

LCA-based Analysis of GHG Emission Reduction Effect of Fuel-efficient Synthetic Rubber Tires

1. Introduction

To help curb global warming, there is an increasing need to reduce the greenhouse gas (GHG) emissions from automobiles by improving fuel efficiency. When designing a rubber material for tires, it is known that reducing the rolling resistance of tires improves fuel efficiency; more specifically, reducing the hysteresis losses in the rubber constituents of tire treads, that is, lowering the loss coefficient (tan δ), reduces the rolling resistance (Reference 1).

To meet this need, JSR develops, manufactures and sells synthetic rubber for fuel-efficient tires. This rubber is a modified solution polymerization SBR (hereafter, "modified SSBR") designed to achieve rubber constituents with improved loss coefficients.

Material manufacturers have a duty to quantitatively grasp how much they contribute to society by reducing GHG emissions, instead of merely supplying products that satisfy customers' requirements. With companies across value chains now cooperating to reduce GHG emissions, it is useful to quantitatively determine the degree of contribution achieved in each stage. Life cycle assessment (LCA), which makes assessments by converting the amounts of GHG emitted during the entire life cycle into a CO_2 equivalent, is an approach that "visualizes" the amounts of emissions in order to assess, analyze and evaluate environmental burdens quantitatively. Various estimates have already been published such as the Tyre $LCCO_2$ Calculation Guidelines Ver. 2.0[2)] by the Japan Automobile Tyre Manufacturers Association (hereafter, "the Calculation Guidelines"). We referred to these to assess and examine the GHG emission reduction effect in each stage of the value chain. This report also considers the effects on society of the materials supplied by JSR.

2. Objective

JSR has been designing materials that reduce tire rolling resistance and thus reduce GHG emissions from automobiles. This report quantitatively demonstrates the efficacy of our material design for reducing GHG emissions and determines the degree of contribution by modified SSBR. We examined:

(1) The GHG emission reduction effect in each stage of the value chain

(2) The GHG emission reduction effect attributable to modified SSBR

3. LCA Evaluation

Evaluation methods:

・ Basically, the study referred to the Calculation Guidelines. While the numerical figures used in the Calculation Guidelines are typical values, JSR products do not significantly deviate from these figures when used, judging from the results for the products that JSR has continued to provide.

・ For simplification, we evaluated the passenger car tire (PCR) defined in the Calculation Guidelines.

(1) CO_2 reduction effect in each stage of the value chain

Estimation:

・ The GHG emissions in each stage are shown in Fig. 4 quoted from the Calculation Guidelines. The GHG emissions per tire during the life cycle are transferred to [1] in Table 1 below, and the reduction effect per tire in each stage can be determined as shown in [2], where the emissions for a fuel-efficient tire are subtracted from those for a general tire.

Table 1: GHG emissions and reductions per tire in each stage

	General tire	Fuel-efficient tire	Unit	Reference
[1] GHG emissions per tire				
Raw material procurement stage	25	23.9	kg CO_2/tire	Fig. 4, Reference 1
Production stage	7.8	7		
Distribution stage	1.6	1.5		
Usage stage	263.4	210.8		
Disposal/Recycling stage	2.9	0.7		
Total	300.7	243.9		
[2] GHG emission reduction per tire				
Raw material procurement stage	−1.1		kg CO_2/tire	GHG emission difference in [1]
Production stage	−0.8			
Distribution stage	−0.1			

Usage stage	−52.6		
Disposal/Recycling stage	−2.2		
Total	−56.8		

Table 2: GHG emissions in synthetic rubber procurement stage

	Fuel-efficient tire	Unit	Reference
[3] Coefficient of GHG emissions in synthetic rubber production stage	4.8	kg CO_2/tire	Table 5, Reference 1
[4] Coefficient of GHG emissions in synthetic rubber distribution stage	0.19	kg CO_2/tire	Table 8, Reference 1
[5] Amount of GHG emissions in synthetic rubber procurement stage	5.0	kg CO_2/tire	[3] + [4]

Consideration 1

・ From [1], which lists the GHG emissions in each stage, the usage stage is by far the highest. In [2], the GHG emission reduction effect of using fuel-efficient tires is very high in the usage stage. Hence, JSR's product development and design focusing on reducing GHG emissions in the usage stage is the most efficient means of reducing emissions.

・ As a materials manufacturer, we focus on comparing the GHG emissions in the raw material procurement stage shown in [1]. The GHG emission reduction of −52.6 kg CO_2 per tire in the usage stage, which is the purpose of a tire, is more than double the GHG emissions of 23.9 kg CO_2 per tire relating to all raw materials. It is also approximately 10 times the GHG emissions of 5 kg CO_2 per tire in the synthetic rubber procurement stage estimated in Table 2. Note that an accurate comparison is not possible because there are various types of synthetic rubber other than the modified SSBR developed by JSR.

・ For example, the number of tires sold worldwide in 2018 (new and replacement tires for passenger cars and light trucks) was 1,580 million (Reference 3). If fuel-efficient tires were used in all of these, there would be a massive reduction in GHG emissions in the usage stage of 83 million tons CO_2 (−52.6 kg CO_2 per tire × 1,580 million tires).

(2) CO_2 reduction effect with modified SSBR

Measurement method:

・ Estimate the LCA CO_2 assuming modified SSBR for fuel-efficient tires in comparison with conventional unmodified SSBR, and employ the difference as the GHG emission reduction effect.

・ The GHG emission reduction in the usage stage was determined as follows: tire tread compounds were prepared with a formula using unmodified SSBR, and another formula using modified SSBR for fuel-efficient tires instead of unmodified SSBR; the rolling resistance of each tire was measured; the results were used to calculate the automobile fuel economy; and the differences in calculated automobile fuel economy were used to determine the GHG emission reduction in the usage stage. Note that the weight ratio of the tire tread compound in the tire was taken from Fig. 2 in Reference 4.

・Considering that automobile fuel economy is correlated with the rolling resistance of the tires, an estimation was made based on the correlation with the rolling resistance index (ratio) for fuel-efficient tires, which was calculated with respect to the rolling resistance index of 100 for general tires as shown in Table 19 on page 16 of the Calculation Guidelines.

・The Calculation Guidelines were referred to for other data of tires.

Estimation preconditions:

[1] The weight per tire is 8.2 kg (the numerical figures of PCR fuel-efficient tires in the Calculation Guidelines were used).

[2] The number of tires per automobile is four.

[3] The weight of tire tread is 33% of the weight of the tire (Reference 4).

[4] The compositions of the tire tread compounds prototyped by JSR, and the actual measured values of the rolling resistance of the tires using these compositions, are shown in Table 3.

[5] From the Calculation Guidelines (Table 19), the ratio of the tires' contribution to fuel economy is 0.125.

[6] The production volume of JSR's modified SSBR for fuel-efficient tires is 200,000 tons/year.

[7] From the Calculation Guidelines, the operating life of a tire is 30,000 km, and the automobile fuel economy with general tires is 0.1 L/km.

[8] From the Calculation Guidelines (Table 20), the coefficient of GHG emissions of volatile oil is 2.81 kg CO_2/L.

Table 3: Tire tread compound composition and rolling resistance

	Formula 1	Formula 2
Unmodified SSBR	85	35
Modified SSBR		50
BR	15	15
Silica	80	80
Carbon black	6.4	6.4
Silane coupling agent	6.4	6.4

Oil	33	33
Zinc oxide	3	3
Stearic acid	2	2
Antioxidant	1	1
Processing aid	3	
Vulcanization accelerator A	1.5	1.5
Vulcanization accelerator B	1.8	1.8
Sulfur	1.5	1.5
Total	239.6	236.6
Rolling resistance (RR)	**8.1**	**7.7**

Estimation:

・ Among all of the fuel-efficient effects of an automobile, the contribution of an automobile's four tires of formula 2, in comparison with those of formula 1, is as follows, from [5] in Table 3 of the Calculation Guidelines (page 16, [2]):

(Tire rolling resistance with formula 1 − Tire rolling resistance with formula 2)
/ Tire rolling resistance with formula 1 × Tires' contribution to fuel economy
= (8.1 − 7.7) / 8.1 × 0.125
= 0.0062 ...... [D]

・ In comparison with the automobile with four tires of formula 1, the fuel economy gained by an automobile with four tires of formula 2 during the tires' useful life is as follows from [7] and [D], noting that the fuel economy of an automobile with tires of formula 1 was taken from the Calculation Guidelines for general tires:

30,000 km × 0.1 L/km × 0.0062 = 18.5 L ...... [E]

・ From the above calculation result [E] and the coefficient of GHS emissions in [8], the CO_2 emission reduction effect per tire of an automobile with four tires of formula 2 during the tires' useful life in comparison with that of formula 1 is estimated as follows:

18.5 L × 2.81 kg CO_2/L / 4 tires = 13.0 kg CO_2/tire …… [F]

・ From Table 3, the ratio of modified SSBR in the tire tread compound is:

50 / 236.6 = 0.211 ...... [G]

・ From [3] and [G], the weight ratio of modified SSBR contained per tire is:

0.2111 × 0.33 = 0.070 …… [H]

・ Thus, from [1] and [H], the weight of modified SSBR contained per tire is:

8.2 kg/tire × 0.070 = 0.57 kg/tire ...... [I]

・ From [6] and [I], the number of tires that can be manufactured, based on the annual supply volume of JSR's modified SSBR for fuel-efficient tires, is as follows:

200,000 tons/year at 0.57 kg/tire = 350 million tires/year ...... [J]

・ From [F] and [J], the annual CO_2 emission reduction effect of fuel-efficient tires in which unmodified SSBR is substituted by modified SSBR is as follows:

13.0 kg CO_2/tire × 350 million tires/year = 4.6 million tons CO_2 ...... [K]

Consideration 2

・ Modified SSBR was used in fuel-efficient tires instead of unmodified SSBR in part (50 units), and the resulting GHG emission reduction effect was −13.0 kg CO_2/tire. Comparing this result with the −52.6 kg CO_2/tire in the usage stage of tires in Table 1-[2], it has been revealed that SSBR, which accounts for a mere 7% (from [H]) by weight of the tire, contributes approximately one quarter. The contribution also has an enormous reduction effect (positive impact), which is approximately 2.6 times the above-mentioned GHG emissions of 5 kg CO_2/tire (negative impact) in the procurement stage of synthetic rubber.

・ In addition, the annual CO_2 emission reduction effect, based on JSR's SSBR production volume with unmodified SSBR substituted by modified SSBR, was calculated as 4.6 million tons CO_2. This is a huge reduction compared to the GHG emissions in the entire JSR Group (Reference 5).

・ Although these estimations are based on in-house data, have not been validated, and should be interpreted as reference values, our tires certainly make a large positive contribution to society. We hope to improve precision further through future research and experiments based on appropriate variables.

4. Conclusion

JSR, which provides SSBR, has estimated that the modified product greatly reduces GHG emissions (positive impact) compared with the material (negative impact). As a material manufacturer, we are proud to contribute to society and the environment. As mentioned earlier, the effect assessed in this report on the GHG emission volume of synthetic rubber is not the effect of synthetic rubber alone but the combined effects of all materials including synthetic rubber. Therefore, the effect considered in this report is the result for the entire value chain. In particular, the usage stage when the product is used by consumers has the biggest GHG emission reduction effect, and so cooperation with consumers is also important.

To reduce GHG emissions, it is effective to substitute raw materials derived from fossil fuels by those of plant origin. For example, if all the synthetic rubber used in tires could be substituted by raw materials of plant origin such as natural rubber, the CO_2 emissions in the manufacturing stage of raw material rubber and the disposal stage of tires could be reduced to almost zero. When viewed from the entire LCA, however, as assessed earlier, it is more effective to improve the reduction effect in the usage stage of tires by using modified SSBR in the tread formula.

Solution polymerization SBR, whose composition and molecular structure can be easily controlled due to its manufacturing engineering characteristics (living anionic polymerization), has a great degree of freedom in polymer design. In addition to polymer design that reduces tire rolling resistance, it is also possible to achieve diverse tire performance in the future. CO_2 emissions are largest in the usage stage of tires, so JSR will continue to design products in cooperation with all suppliers.

1) H. Mouri and K. Akutagawa (Tire Material Development, Bridgestone Corporation, Tokyo, Japan), “Reducing Energy Loss to Improve Tire Rolling Resistance”, Presented at the 151st Meeting of the Rubber Division, American Chemical Society, Anaheim, California.
2) Tyre $LCCO_2$ Calculation Guidelines Ver. 2.0, April 2012, The Japan Automobile Tyre Manufacturers Association
3) Michelin 2018 Registration Document, pp. 37–38
4) The Current Technology of Pneumatic Tires, Doi Akimasa, Journal of The Society of Rubber Science and Technology, Japan, 71 (1998), No. 9, pp. 588–594
5) JSR CSR Report 2019, ESG Data