

Life-Cycle Environmental Impact of Michelin Tweel® Tire for Passenger Vehicles

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ABSTRACT

Recently Michelin has been developing a new airless, integrated tire and wheel combination called the Tweel® 1 tire. The Tweel tire aims at performance levels beyond those possible with conventional pneumatic technology because of its shear band design, added suspension, and potentially decreased rolling resistance. In this paper, we will focus on the environmental impact of the Tweel tire during its life-cycle from manufacturing, through use and disposal. Since the Tweel tire is currently still in the research phase and is not manufactured and used on a large scale, there are uncertainties with respect to end-of-life scenarios and rolling resistance estimates that will affect the LCA. Nevertheless, some preliminary conclusions of the Tweel tire's environmental performance in comparison to a conventional radial tire can be drawn.



Figure 1. Michelin's Tweel® [1]

INTRODUCTION

The Tweel tire (the name is a contraction of “tire” and “wheel”) is an airless one-piece wheel-and-tire combination with a rubber tread bonded to a wheel hub with polyurethane spokes as shown in Figure 1. The Tweel tire aims at performance levels beyond those possible with conventional pneumatic technology because of its shear band design, added suspension, and decreased rolling resistance. It delivers pneumatic-like load-carrying capacity, ride comfort, and as it has no pressurized air cavity, it cannot fail by loss of air pressure. Eventually it may be able to outperform conventional tires since it can be designed to have high lateral stiffness for better handling without a loss in comfort.

However, it is unclear what environmental impact this radical new design will have. Currently there are environmental issues all throughout a tire's lifespan from rubber manufacturing emissions to tire disposal, and the rapidly growing method to evaluate all of these points is Life Cycle Analysis (LCA). LCA is the essential tool required by businesses in order to understand the total environmental impact of their products - cradle-to-grave. By considering the entire life cycle of a Tweel tire assembly from manufacturing, through use and disposal, and comparing it to knowledge of current tires, an assessment of its environmental impact will be made in this paper.

1. “Tweel” is a registered trademark of Michelin North America, Inc.

LIFE-CYCLE ANALYSIS

According to the life cycle analysis (LCA) standard ISO 14040, LCA is defined as “a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.”[2] LCA is a technique for assessing all of the environmental aspects associated with a product from “cradle-to-grave”, or from a product's manufacturing stage through its life, and into its disposal route. This environmental assessment tool is critical to the foundation of this report and will be used extensively to compare the Tweel tire to a standard pneumatic, or air-filled, tire by adhering to the standards ISO 14040, 14041, 14042, 14043, 14044, and more recent ISO14046. These standards outline a basic four step process to complete a life cycle analysis consisting of a goal and scope, inventory analysis, impact assessment, and interpretation. There is a logical progression through these steps, but changes to any step throughout the analysis will have effects through other stages, so this becomes somewhat of an iterative process until a valid scope is defined that leads to an impact assessment that can be verified with confidence. The analysis in this report will be performed using this rough outline with a consistent goal to compare Michelin's Tweel tire to a current pneumatic radial tire.

To facilitate the study, we used the SimaPro version 7.1 LCA software developed by PRé Consultants. SimaPro features a user interface that allows the environmental inventory of any product or process to be modeled by specifying inputs (resources, fuels, electricity) and outputs (emissions to air, water, and soil, etc.). Each component of every phase of a product's life can be modeled separately and then combined to form a complete model of the entire life cycle. These components, such as raw materials production or disposal routes, can either be developed as new data sets by the user or existing pre-packaged databases that contain detailed environmental inventory data for thousands of products and processes across the world can be used. These databases (BUWAL, IDEMAT, Franklin USA, etc.) are developed by environmental professionals and are peer reviewed to assure confident data sets describing any potential environmental impact of a process, but each data set is usually geographically specific and may differ if the process is being modeled in a different country.

ASSUMPTIONS

GEOGRAPHIC BOUNDARY

Vehicle use differs across the world, but for the purposes of this report only U.S. data and emissions will be used when appropriate. In the case of some of the raw materials needed to produce a tire, the inventory data of required inputs and outputs will come from the country where the material is produced, and then the environmental costs of transporting

that material to the U.S. will be added on. For example, natural rubber is almost entirely produced in Southeast Asia, so it would be inaccurate to assume it is produced in the U.S. to ignore the transportation emissions. For the majority of the analysis however, American standards and values will be used. The life cycle model will consider a tire made in the U.S., driven by an average American, and disposed of by ratios corresponding to American recycling plants.

Two very important differences arise between an American tire and a European tire. The average driving distance and tire use varies drastically between countries, but more importantly, the energy mix supplied by power plants in the U.S. is very different from that of a European country. The U.S. gets a larger percentage of its electricity from coal plants instead of wind and water power like some European countries, which directly affects the environmental impact of tire production that takes a large amount of electricity.[3]

The U.S. DoE's Energy Information Administration (EIA) updates the United States' energy mix numbers every year [4], so the American energy data used throughout this report will be representative of the EIA's numbers shown in [Table 1](#).

Table 1. DoE EIA energy mix, 2008 [4]

	Coal	Natural Gas	Crude Oil	Nuclear	Hydro
2008 Energy Production Billion Btu (TWh)	23,855,916 (6,991)	21,150,164 (6,199)	10,519,487 (3,083)	8,455,236 (2,478)	2,452,073 (719)
Percentage of Total	36%	32%	15%	13%	3%

So, for these reasons it is important to distinguish that this is a U.S. analysis. Thus, all estimates will only be valid for American tires, so conclusions about the environmental effects of European tires should be made with caution.

LCA IMPACT CATEGORIES: EI99 AND EDIP

The ISO 14040 and 14046 documents provide a solid framework to assess the impact of the life cycle inventory, but their generalizations provide room for a variety of different impact assessment techniques. A number of different impact assessment methodologies are available to the LCA practitioner, and several of them are implemented in software commercially available on the market. For the purposes of this report, the EcoIndicator99 method will be the primary impact assessment tool used, but the EDIP2003 method will be used for validation to ensure that the results are not skewed simply because of the wrong choice of impact assessment methods. A fundamental difference between these two methods is that the Environmental Design of Industrial Products (EDIP) method has a problem-oriented approach to impact assessment as opposed to the EcoIndicator method.

which has a damage-oriented approach.[5] This means that whereas the EDIP method models the impacts between emissions and damages, EcoIndicator aims its assessment directly at the damages caused by the emissions. This difference in approach will give two very different views on the collected life cycle inventory, which will greatly contribute to the validity of the results if the two assessments agree on the relative environmental impacts of the non-pneumatic compared to a conventional tire.

MATERIAL COMPOSITION

The production of a new tire is a fairly complicated process that involves many steps at a manufacturing plant, but before they can be considered, it must be understood how the necessary raw materials made it to the plant in the first place. Tables 2 and 3 describe the material composition of both functional units (P205/45R17 and an equivalent Tweel tire) that will be analyzed throughout their life cycles. The details of the production processes of each of these raw materials are described in this section and all the Life Cycle Inventory (LCI) data quantifying the material inputs and emissions are provided in [6].

Table 2. P205/45R17 tire material composition [7]

	Carcass	Tread	Total tire	Hub
Raw material	wt %	wt %	wt %	wt%
Synthetic rubber	15.78	41.72	24.17	0
Natural rubber	24.56	3.53	18.21	0
Carbon Black	23.40	9.54	19.00	0
Silica	0.80	28.07	9.65	0
Sulfur	1.60	0.80	1.28	0
ZnO	1.83	0.91	1.58	0
Oil	4.02	10.64	6.12	0
Stearic Acid	0.87	1.47	0.96	0
Recycled rubber	0.60	0	0.50	0
Coated wires	17.2	0	11.4	0
Textile	7.0	0	4.7	0
Steel	0	0	0	100
Totals %	100.0	100	100	100
Weight (kg)	7.25	2.75	10.0	4.0

Table 3. Michelin Tweel tire material composition [7]

	Carcass	Tread	Spokes	Hub	Total
Raw material	wt %	wt %	wt %	wt%	kg
Synthetic rubber	0	41	0	0	1.15
Natural rubber	0	4	0	0	0.10
Carbon Black	0	10	0	0	0.26
Silica	0	28	0	0	0.77
Sulfur	0	1	0	0	0.02
ZnO	0	1	0	0	0.03
Oil	0	11	0	0	0.29
Stearic Acid	0	1	0	0	0.04
Recycled rubber	0	0	0	0	0
Coated wires	10	0	0	0	0.62
Textile	0	0	0	0	0
Polyurethane	90	0	100	0	8.44
Steel	0	0	0	100	4.00
Totals %	100.0	100	100	100	
Weight (kg)	6.35	2.75	2.65	4	15.75

MANUFACTURING OF P205/45R17 TIRE

The tire production process is a complicated one that involves several complex parts that are mated together. The general process of constructing a tire involves assembling the numerous components shown in Figure 2 and then vulcanizing these parts together to achieve the desired properties. The details of the production process of each tire manufacturer are difficult to find because of the confidentiality of their specific process, so for the purposes of this thesis, an average tire production process will be modeled. Combining this generic process with the specific material breakdown of a P205/45R17 tire described in section 4.1 will represent an average tire built anywhere across the country with the given specifications of a section width of 205 mm, aspect ratio of 45%, and a wheel rim diameter of 17 in. This generic and somewhat simplified tire production process is outlined in Figure 3. Each of these production stages has its own environmental inventory. They are described in [6], but omitted here for brevity.

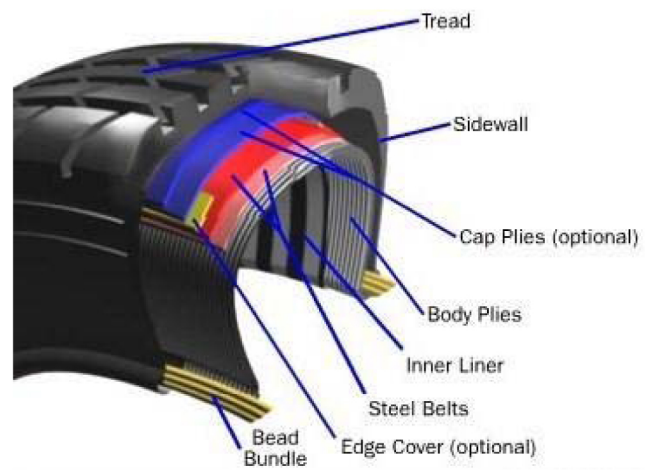


Figure 2. Tire component breakdown [8]

The process begins with the mixing of basic rubbers with process oils, carbon black, accelerators and other additives. The environmental inventory of these basic ingredients has been described above, so simply considering the correct proportions described in Table 2 is all that is necessary to analyze the environmental impact of the raw materials entering the mixing process in the manufacturing plant. It is out of the scope of this paper to consider the transport of most of the raw materials to the tire manufacturing facility due to the difficulty of modeling the distribution of raw materials from multiple production sites to multiple tire production sites across the country. As a result, it will be assumed that the raw materials are produced near the manufacturing plant so this transportation can be ignored. Most LCAs of raw material productions already include a standard transportation distance and in general the transportation of domestically

produced bulk materials over a few hundred miles to a manufacturing plant has insignificant life-cycle effects. We can see this also in the results section where the distribution/transport of tires has negligible effects on the overall life-cycle impacts. Thus, the only thing to consider in this mixing stage is the intense heat and pressure required in this process, the water required to cool the mixing so that vulcanization does not occur prematurely, and any emissions that result from these extreme conditions. Details for the required heat and pressure are not well-documented, so the only source available for the environmental inventory of this mixing process is the EcoInvent database. PRé Consultants documented the entire tire production process in their life cycle analysis of an average European tire, but due to some possible differences between European and American tire production, these values are only used as a comparison.[10]

15 minutes.[11] Details for the energy requirements of this curing process are modeled in Han's report titled *Dynamic Simulation of the Tire Curing Process*. [12] After the curing process is complete, the finished tires are inspected (which requires no extra environmental resources), and are sent out for distribution. Again, details of these intermediate steps are not listed here in order to simplify the inventory, but the inventory data from these small processes are combined and presented in [6].

MANUFACTURING OF TWEEL TIRE

Two problems limit the ability to present a complete environmental inventory of the Tweel tire. One of them is the confidential nature of Michelin's invention and the second is the immaturity of the Tweel production process. The Tweel tire is not being mass produced yet, so there is only a hypothetical knowledge of the process requirements and capabilities available. The manufacturing inventory will be as thorough as possible, though.

Tweel tires are produced in three steps: tread, hub, and polyurethane. In the first step, the tread is constructed by a similar method as the tire tread manufacturing process. The tread on a Tweel tire is exactly the same as a pneumatic tire and is extruded in the same way, and it is mated to layers of belts in the same manner as conventional tires. The process of rolling plies onto a drum to achieve the correct diameter currently is performed manually, but the same basic process that is performed on tires will be mimicked when the Tweel production is fully automated. In this fairly simple process, rectangular sheets of rubber and steel cord are rolled onto a steel drum, and the excess material from each sheet is removed. Once the desired base thickness is achieved in this manner, the extruded tread is rolled onto the top, and the entire assembly is vulcanized. The second step is a very simple 4 kg steel hub casting that is well documented in several databases including BUWAL250.

In the third step, the hub and the tread are secured concentrically and polyurethane is poured into a spoke and shear band mold while the entire assembly spins so that the polyurethane will sufficiently fill the mold in the radial direction. The energy needed to spin the Tweel assembly and polyurethane mold for just 5 minutes while the polyurethane is poured is considered irrelevant compared to the large amount of energy required to heat and pressurize the ovens needed to cure the shear band and then cure the entire assembly after the polyurethane is poured, so it can be ignored in this inventory. Before the pouring process occurs though, all the surfaces that contact the polyurethane are cleaned and covered with either an adhesive or a mold release for the shear band and spoke mold, respectively. The quantities of these additives were supplied by Michelin, and are listed in Table 4.

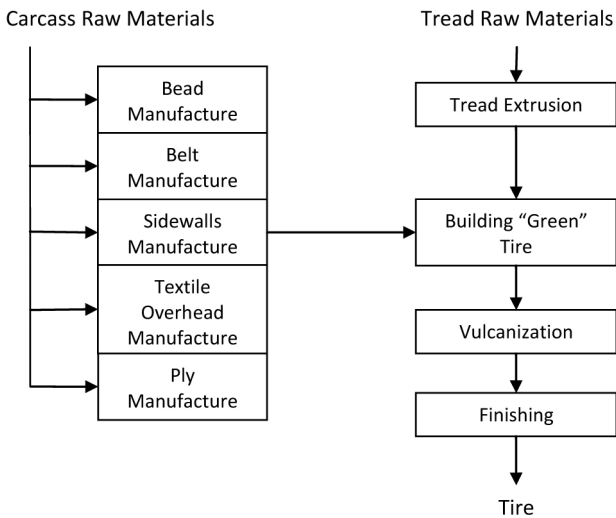


Figure 3. Generic tire production process [9]

This mixed rubber then takes all the different forms shown in Figure 2 - sidewalls, tread, liner, etc. Most of these sub-components are made by calendaring or extruding the uncured rubber into the desired dimensions. Rough assumptions about the energy requirements and necessary lubricants in these two rubber processing techniques are taken from J.L. White's book titled *Rubber Processing*. [11] Transporting these rubber components around the factory takes place on rollers, so minimal energy or ancillary materials are required; as a result this transportation can be ignored. So, modeling the assembly process of all the components can be simplified to the rubber mixing process combined with the necessary lubricants and adhesives that secure the coated wires and textiles in place.

Once all the components are assembled, the "green" tire is cured or vulcanized to glue everything together and to achieve the final dimensions and rubber properties. This curing process takes place under conditions of roughly 350 degrees Fahrenheit with pressures around 350 psi for around