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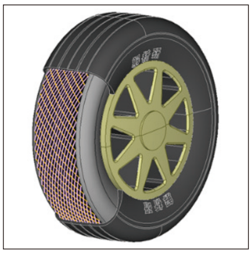

Performance Prediction Technologies for Steel Cord and Tire Using CAE

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Steel cords, used as reinforcement in rubber products, are essential components for automotive tires that require high standards of fuel efficiency, durability, handling stability, and noise reduction. Conventionally, the development process involved repeated experiments, evaluations, and modifications to ensure the steel cords meet the required tire performance levels. However, this approach posed challenges such as extended development periods due to the time and effort required for evaluations, difficulties in achieving sustainable society due to tire waste, and the influence of tire design factors on tire performance. To address these issues, we developed a performance prediction technology that incorporates steel cord features. This technology enables efficient and accurate examination, specification refinement, and narrowing-down and evaluation of technical interpretation in tire design involving steel cords. The technology not only enhances tire performance but also contributes to achieving the Sustainable Development Goals, earning high praise from our customers.

Keywords: steel cord, tire, analytical technology, simulation, SDGs

1. Introduction

Automotive tires are made by combining rubber in which many kinds of additives are complexly blended, resin materials, reinforcing fiber, and metal wire. Polyester, nylon, aramid, or cotton is mainly used as the reinforcing fiber, while a steel cord is mainly used as the metal wire. Because steel cords have features of low cost, high strength and flexibility, and high compression stiffness, they are indispensable as tire components.

In recent years, the evolution of automobiles has been remarkable. Electrified*1 and connected*2 automobiles are now widely recognized as environmentally friendly, and they are at the stage of widespread use. Self-driving technology has also been demonstrated and is on the eve of practical implementation. Even amidst such significant advances in automotive technology, tires continuing to be used for moving forward, turning, and stopping automobiles, and the performance required of these tires is becoming increasingly stringent. The race among tire manufacturers to develop higher fuel-efficient, higher durability, higher performance, and lower cost tires is also becoming especially intense on a global scale.

To achieve the high performance required of tires, it is necessary to examine a large number of parameters when designing tires and to repeat numerous evaluations to confirm the outcomes. However, since these evaluations require a considerable amount of labor, time, and other costs, it is not practical to try all possible combinations. In addition, from the viewpoint of the increasingly important SDGs, it has also become essential to reduce the energy and resources used for prototype evaluation, as well as waste and scrap. In addition, as some design parameters conflict with each other, situations may arise that necessitate certain compromises. Therefore, a different approach was required to address the challenges of tire performances and their development process.

As a solution to these challenges, we have developed a simulation technology that can reflect the features of steel cords. This technology has made it possible to design steel cords and tires that fullfil the performance requirements with high precision and efficiency, thereby remarkably improving tire performance. Customers highly appreciate the tires designed using the new technology. The following sections describe this technology.

2. Automotive Tire and Steel Cord

2-1 Structure of automotive tire

The structure of a typical tire is shown in Fig. 1. In this figure, the steel cord is used as a “belt (breaker)” that reinforces the outer circumference the tire and as a “carcass (ply)” that radially supports the area between the side surfaces and the tread.

The belt and carcass cords are made of twisted wires composed of fibers, steel, and other materials. The main reason for using twisted wires is to ensure strength, flexibility, and fatigue endurance simultaneously. In recent

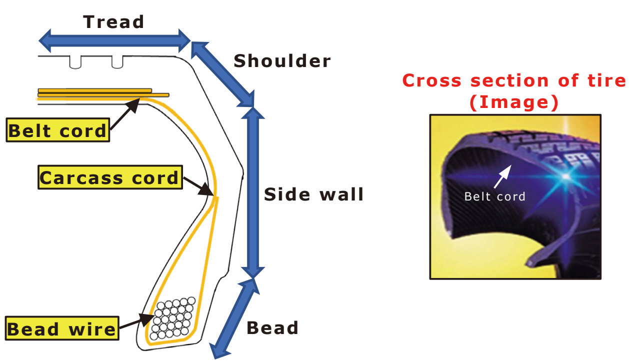

Fig. 1. Schematic illustration of cross-sectional structure of an automotive tire

years, fibers such as aramid fiber and carbon fiber have been developed and have found applications in various products. However, steel is used almost exclusively in automotive tires because it can achieve required features, such as high-speed performance, steering stability, and ride comfort, at a high level, while also being cost-effective.

2-2 Steel cord and its usage

A steel cord (Photo 1) is a twisted wire made by twisting together several to dozens of high carbon steel strands with a diameter of approximately 0.15 to 0.40 mm.

The surface of the strands is plated with brass, an alloy of copper (Cu) and zinc (Zn) to ensure workability in the wire drawing process and adhesion*3 to rubber.

Steel cords are usually wound on reels and shipped (Photo 2). In the process of manufacturing tires, several tens to several hundreds of, or in some cases, more than 1,000, reels of steel cords are used as one lot.

Steel cords are roughly classified into general-purpose cords and customized cords. General-purpose cords are manufactured and sold by steel cord manufacturers around the world with basically the identical specifications. In contrast, customized cords are manufactured and sold after their configuration is designed based on the required features (e,g,, cord diameter, strength, elongation, stiffness) in accordance with the requests of a specific customer.

Several of these steel cords are embedded in rubber and processed into a sheet (Photo 3) and are used as a tire reinforcement member.

Photo 1. Enlarged photo of steel cord

Photo 2. Steel cords wound on reels as products

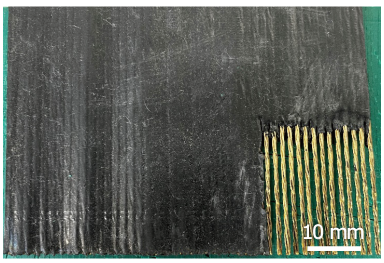

Photo 3. Rubber sheet into which steel cords are embedded

3. Environment Surrounding Automotive Tires and Requirements for Them

Tires are manufactured and used all over the world. As automobiles evolve and diversify, along with the expansion and progress of automobile society, the demand for tires is expected to continue to grow.

The types of vehicles (e.g., compact cars, hatchbacks, SUVs, minivans), power sources (e.g., gasoline engines, diesel engines, hybrids, battery-powered electric motors), and sizes (e.g., mini-vehicles, ordinary cars, trucks, buses) are diverse. In addition, the manner of use and surrounding environment, such as atmospheric temperature, humidity, and road surface conditions create a wide variety of conditions. Accordingly, the features required of tires are also varied.

In the above environment, it is virtually impossible to meet all the diverse requirements with tires of identical specifications.

In response to this challenge, each tire manufacturer studies and designs various tire components and structures to create different types of tires. However, as discussed above, many parameters must be considered in tire design. The workload, including prototype evaluations, is substantial. Therefore, there has been a strong demand for the establishment of an efficient design evaluation method.

4. Steel Cord Development Process

As described above, development of a steel cord undergoes a number of processes. The work flow for developing a conventional customized cord is shown in Fig. 2.

In the development of a steel cord, it is examined and experimentally manufactured based on the performance required of the tire. The evaluation results of the tire

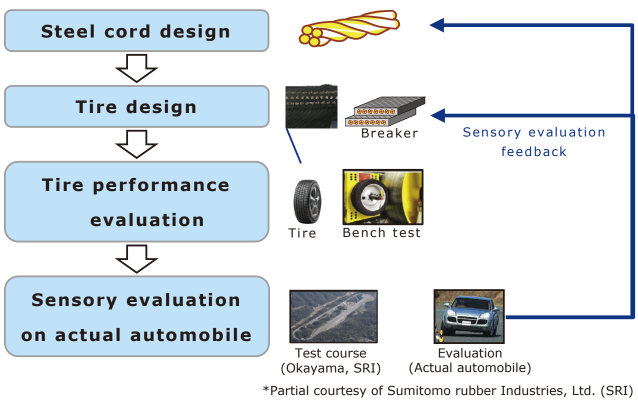

Fig. 2. Steel cord development process

composed of the steel cord are fed back to repeat the design and experimental manufacture as needed.

Major design parameters for steel cords and tires are shown in Table 1.

As this table shows, there are many design parameters for both steel cords and tires. These parameters must be appropriately controlled to efficiently develop tires that will achieve the required features.

Table 1. Major design parameters for steel cords and tires

	Performance/features	Design parameter
Steel cord	Cord diameter Strength Elongation Stiffness Rubber penetration	Strength(material) Strand diameter Number of strands Cord construction Lay length Preforming Flattening, etc.
Tire *Reference	Rolling resistance Weight Stiffness Cornering stability Durability	Ends Angle Gauge thickness Reinforcement Rubber compound *Only cord-related parameters

Based on the idea that a simulation technology capable of incorporating the features of steel codes is effective for solving these problems, we worked on developing "performance prediction technologies for steel cord and tire using CAE.*4"

5. Development of CAE Technology That Can Predict the Performance of Steel Cord

5-1 Development of CAE technology

When developing CAE technology that can predict the performance of steel cords, it was necessary to examine the output features. We set roughly two features: (1) performance of tire and (2) durability of tire. Then we considered that Item (1) corresponds to rolling resistance, weight, and steering stability, shown in Table 1, and that Item (2) corresponds to durability, shown in Table 1. In addition, simulations are generally performed using the simplest possible model in order to save computational resources.*5 In the case of this study, for example, the steel cord is treated as an iron plate. However, in this case, the features of the steel cord may not be reflected in the simulation results. In this study, we combined the steel cords in strand geometry units in order to reflect the features of the steel cords, which was another objective of this study.

The interaction between the steel cord and rubber through adhesion, rather than the action of the steel cord alone, must be considered to predict its behavior in the tire. Accordingly, it is required to consider various factors, such as the thickness and angle*6 of the rubber sheet, in addition to the composition and number of embedded steel cords. Therefore, we devised a part cut out of the tire as a model (a steel cord with rubber) as shown in the figure below (Fig. 3). The tensile stiffness, bending stiffness, and shearing stiffness of this cut-out model were considered to be corelated with the performance and durability of the tire. Regarding the shape of the steel cord, if it is complicatedly twisted, creating it on CAD*7 will be difficult. To address this problem, we used a database that was created by measuring an actual steel cord with X-ray CT*8 and processed with our original analysis technique. For the boundary conditions given to the steel cord model with rubber, we used the results of a tire simulation (Fig. 4) conducted by a tire manufacturer.

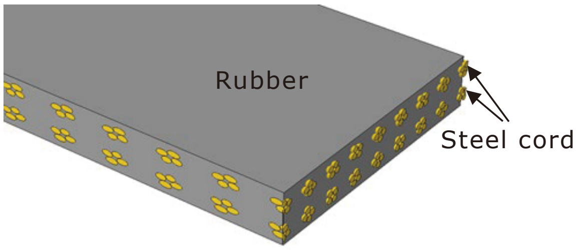

Fig. 3. Cut-out model

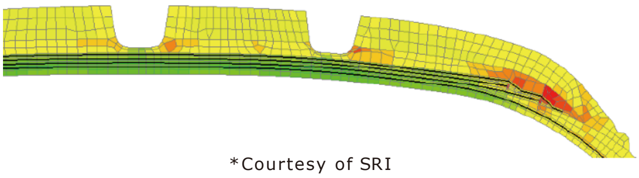

Fig. 4. Tire simulation result

5-2 Steel cord model

To improve adhesion to rubber, steel cords are often made with a wide gap between the strands by, for example, deforming them. Therefore, steel cords do not follow an ideal spiral path. In such cases, we obtained the actual shape of steel cords by performing X-ray CT measurement of an actual steel cord. Due to resolution limitations in X-ray CT measurement, the filaments*9 may seem to be in contact or interfere with each other. We avoided this problem by using our proprietary image analysis and correction technology for the trajectory of a filament. The use of the analyzed and corrected data has made it possible to create a model that simulates actual steel cords more reliably, even if they are complexly twisted (Fig. 5).

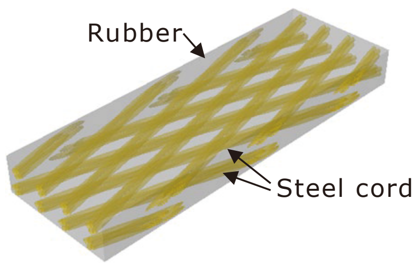

Fig. 5. An example of steel cord model (Two-layer belt model)

5-3 Tire performance prediction model

Tires are required to have a capability of gripping uneven road surfaces, together with cornering power*10 necessary for turning around corners. When a tire is replaced with a steel cord model adhered with rubber based on the tire simulation results, the tire is required to be low in bending stiffness and high in shearing stiffness (Fig. 6).

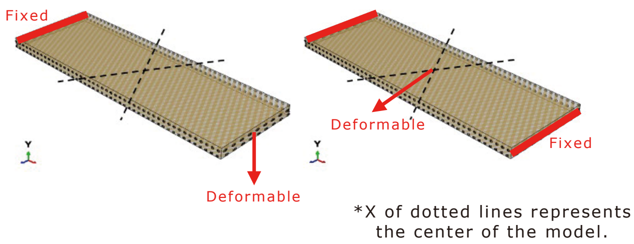

Fig. 6. Tire performance prediction models
(Left: Bending stiffness, Right: Shearing stiffness)

5-4 Tire durability prediction model

To enhance the durability of tires, it is indispensable to improve the adhesion between the steel cords and rubber. We have developed a model that makes it possible to estimate the stress on the interface between the steel cord and rubber (Fig. 7).

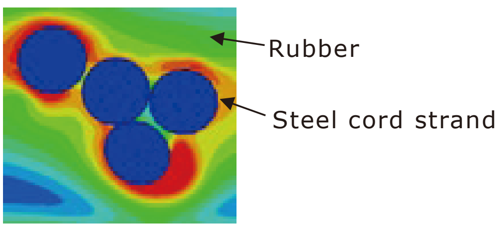

Fig. 7. Stress model on the interface between steel cord and rubber

5-5 Confirmation of consistency between CAE and actual evaluation results

The applicability of the CAE model was verified through actual prototyping and evaluation of the prototype, and consistency with the evaluation results was confirmed for both performance (Fig. 8) and durability (Fig. 9).

To establish the CAE model, it was necessary to combine the CAE results with the evaluation results for tires prototyped by changing several design parameters. We repeated prototyping and modifications of the CAE model and were finally able to establish a prediction technology that makes it possible to simulate the performance and durability of tires.

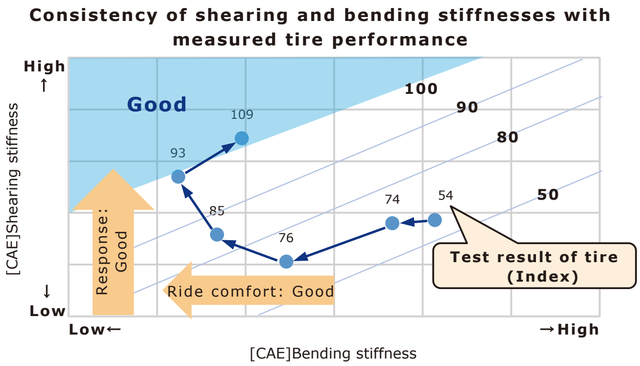

Fig. 8. Consistency between CAE and measured tire performance

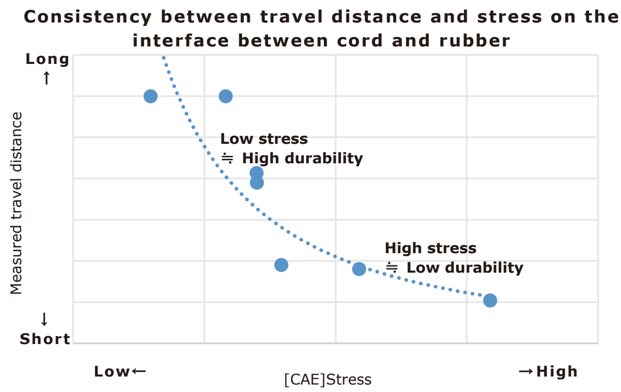

Fig. 9. Consistency between CAE and measured tire durability

6. Application of CAE Technology to Tire Design

The newly established CAE technology was applied to new steel cord and tire designs. As described above, we designed a steel cord that would meet the needs and performance targeted for a tire. The use of the CAE technology has made it possible to examine a large number of conditions in a short period of time while omitting many prototype evaluations that were indispensable in the past. Furthermore, the CAE technology was also used to clarify the trade-offs and limits in design parameters and to determine the allowable manufacturing variation, thereby demonstrating the effectiveness of this technology in narrowing down the conditions for evaluation of prototypes.

The newly built CAE technology has already been used successfully for the mass production of tires. Further, this technology is also playing an important role in the design of next-generation tires, and it is highly evaluated and expected by our customers.

7. Conclusion

Aiming to meet various requirements and needs in an increasingly competitive development race and rapidly changing environment, we have developed a simulation technology that can predict the performance of tires while incorporating the features of steel cords. This technology significantly reduces the number of conventional tire development processes, which require a lot of time, labor, and resources, while enhancing tire performance and achieving the SDGs.

The environment surrounding automobiles is expected to change at an even faster pace, and further stringent requirements will be imposed on automobiles. It is clear that further improvement of automotive tires will become indispensable to meet these requirements. We are convinced that this technology will become indispensable for the development of high-performance tires that meet the needs of the coming era.

8. Acknowledgement

This report has described the technology that was created and improved through collaboration with Sumitomo Rubber Industries, Ltd. We would like to express our deep appreciation for their cooperation in the simulation of tire performance and the evaluation of proto-typed tires, as well as in the interpretation and discussion of the simulation/evaluation results.

Technical Terms

∗1 Electrified automobile: An automobile that is powered by electric motors in place of a traditional internal combustion engine, diesel engine, or other internal combustion engine.

∗2 Connected automobile: An automobile equipped with a communication system that can connect to a network.

∗3 Adhesion: A chemical adhesion reaction between a plated material and rubber, in which copper (Cu) in the material and sulfur (S) in the rubber combine to form copper sulfide (CuxS). This reaction is essential for strong adhesion of a steel cord to rubber. Strong adhesion is also very important for ensuring safety since insufficient adhesion may cause the tire to break (blow).

∗4 CAE: The abbreviation for Computer Aided Engineering, a technology for simulating designs, manufacture, and processes using computers.

∗5 Computational resources: In this report, this term is defined as hardware resources, such as the processing speed and memory capacity of a computer, and the time required for calculations.

∗6 Angle: The angle at which a steel cord is embedded in a tire. Usually, the breaker cord in the tire is angled from parallel to a certain degree to the contact surface.

∗7 CAD: The abbreviation for computer aided design, the process of designing things using a computer.

∗8 X-ray CT: A computed tomography (CT) technique that scans an object using X-rays and processes the results with a computer, thereby visualizing the internal structure of the object as an image.

∗9 Filament: Individual strands comprising a steel cord (twisted wire) are called filaments.

∗10 Cornering power: An indicator for the responsiveness of tires. The response of the tire to steering stability is improved as cornering power increases.

Contributors

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