

Development of Puncture-Resistant Tubeless Tire for Motorcycles

Tomoyuki HARADA* Toshio YAMAGIWA*
Hirohisa TAKAHASHI* Akiko TANAKA*

ABSTRACT

A puncture-resistant tubeless tire has been developed using the same principles as the puncture-resistant double-chamber inner tube. The inside of the newly developed tubeless tire is a double-chamber structure. The new double-chamber tires were tested at high and low temperatures for puncture resistance and to determine a damage-size limit. They were also endurance-tested with a hole deliberately created in the tire, and positive results were attained. The high-temperature test has proven that the tire prevents air leakage after piercing with a pin as large as 9 mm in diameter. In addition, the endurance running tests have proven that the tire with pierce damage is able to run up to the tire wear limit, 20 000 km.

1. Introduction

Robert Thomson invented the pneumatic tire in 1845, but the first practical tire was not developed until 1888, by the Scottish veterinarian John Boyd Dunlop. Even after 120 years, pneumatic tires are still manufactured in large quantities. The merit of pneumatic tires is that they fulfill the four major functions of a tire, as follows:

- (1) Supporting the vehicle load.
- (2) Transmitting driving force and braking force to the road surface.
- (3) Reducing impact from the road surface.
- (4) Providing optimum elasticity for changing and maintaining direction.

The history of the pneumatic tire is also a history of anti-puncture measures, but these measures had not resulted in an effective solution.

Today's motorcycles present fewer mechanical malfunctions during operation, due to increases in their quality and durability.

However, generally, motorcycles do not carry spare tires, and therefore cannot be operated until repaired if a puncture occurs. The development of a high puncture-resistant tire was desired.

In 1996, Honda developed a puncture-resistant, sealant-filled double-chamber tube for motorcycle tires, and it has been marketed in Japan, India, Brazil and other countries.

2. Double-chamber Tire Tube

2.1. Structure of the Double-chamber Tire Tube

Figure 1 shows the structure of the double-chamber tube⁽¹⁾. The 180 degrees of the tube that faces the tread is double-chambered. That chamber is filled with an anti-puncture sealant. This sealant chamber and the air chamber are separate, and air pressure constantly presses against the sealant chamber. Because of this pressure, if the tube is punctured at any point by a nail or other object, sealant will be forced out of the puncture hole. Due to the contractile force of the rubber, fibrous materials in the sealant are

* Asaka R&D Center

trapped and plug the hole, preventing air leakage. Even if the motorcycle is left parked for a long time with the hole in the tire facing upwards, the sealant will maintain its grip around the hole and prevent air from leaking.

2.2. Sealing Mechanism

The sealing mechanism of the double-chamber tube is shown in Fig. 2. When a nail or other sharp object pierces the tread, it normally punctures through the sealant chamber to the air chamber. As air leaks from the hole in the tire, fibrous components in the anti-puncture sealant are carried to the hole by the liquid component. These fibrous materials are squeezed by the contractile force of the rubber. Microscopic particles and liquid fill the spaces between the fibrous materials, and the hole is plugged. Different types of fibrous materials are used to ensure excellent performance in plugging large and small holes. The liquid will not leak into the tire as long as it is pressed on by the air pressure in the tire. Figure 3 shows an image of the sealant sealing an actual puncture, clearly showing the fibrous material squeezed between the rubber.

2.3. Effectiveness of Double-chamber Tire Tube

To verify the effectiveness of the double-chamber tube in actual use, comparisons were conducted of 98 motorcycles used in newspaper delivery. Motorcycles for newspaper delivery are usually used under heavy conditions such as frequently starting, accelerating, and braking during relatively short travel distances. Figure 4 shows a comparison of results obtained when conventional tubes and double-chamber tubes were used for a period of four to six months each. The use of the double-chamber tubes resulted in a 90% reduction in punctures compared to the conventional tubes.

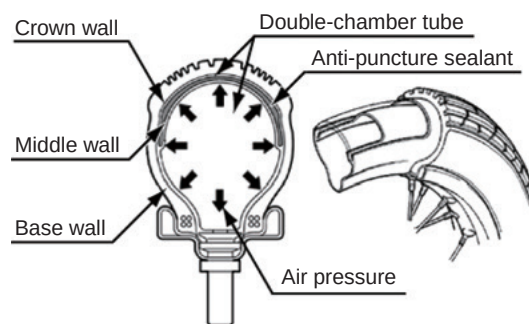


Fig. 1 Structure of double-chamber tube

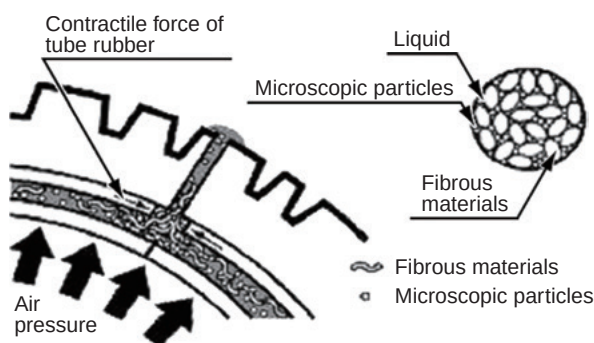


Fig. 2 Filling mechanism

3. Overview of Double-chamber Tubeless Tire

The double-chamber anti-puncture technology was applied to a tubeless tire to develop a puncture-resistant double-chamber tire.

Figure 5 shows the structure of the double-chamber tubeless tire (hereinafter referred to as "double-chamber tire").

A sealant chamber filled with anti-puncture sealant is formed on the tire inside against the tread. When the tire is fitted on the wheel, the sealant chamber and the air chamber are separate, and air pressure constantly acts on the sealant chamber. For this reason, no matter where a puncture penetrates the sealant chamber, air pressure will force the sealant out of the hole and prevent air from leaking. Even if the motorcycle is parked with the hole facing upwards, the anti-puncture sealant will maintain a seal. The tire can also be deflated for inspection or repair, and no sealant will come out from an air-valve.

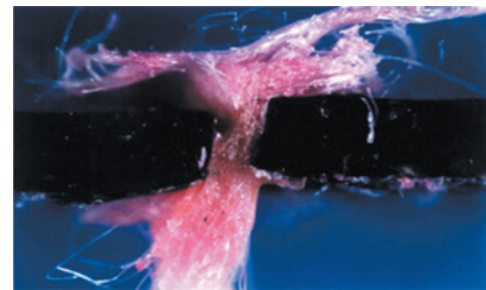


Fig. 3 Photo of filling situation

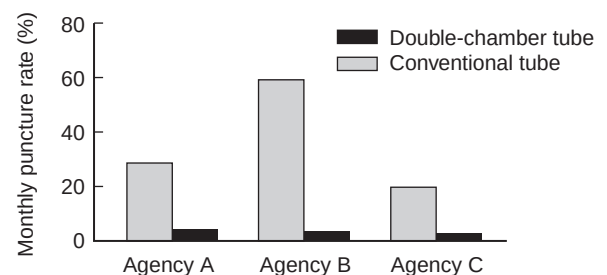
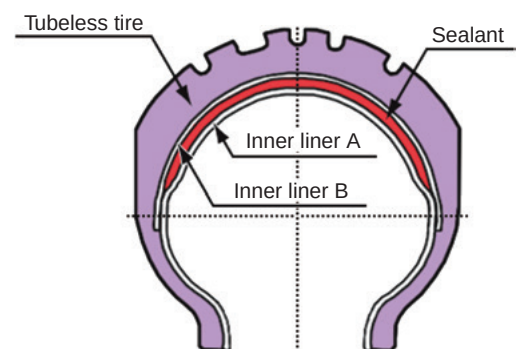


Fig. 4 Effectiveness of double-chamber tube



Inner liner added to conventional tubeless tire

Fig. 5 Double-chamber tire

Figure 6 shows a schematic diagram of technologies for dealing with punctures^{(2), (3)}, including the double-chamber tire. In preventing the leakage of air even when the tire is punctured, this technology differs significantly from conventional technologies that respond to punctures after the air has escaped.

4. Development of Double-chamber Tubeless Tire

4.1. Development Goals

To achieve an equivalent level of performance to that of double-chamber tubes, the following were set as development goals.

- (1) Ability to be manufactured without major changes in the conventional tire manufacturing process.
- (2) Ability to continue use for the standard life of the tire even when punctured by a nail.
- (3) Equivalent handling and stability to that of a normal tire.
- (4) Interchangeability with conventional wheels.

4.2. Development of Production Technology

4.2.1. Production process

To determine a method of forming the sealant chamber in the conventional tire manufacturing process^{(4), (5)} was an issue. Figure 7 shows the production process.

The forming stage for bias tires normally involves wrapping the various sheets from which the tire will be composed of around a drum and forming them into circular shapes. First, an air-impermeable butyl rubber sheet known as the inner liner is wound around the drum. This is followed by the tire carcass, formed from crossed plies of woven materials sandwiched between layers of rubber. Finally, the tread rubber, which will form the area that will contact the ground, is wound around the drum.

These untreated rubber tubes are subjected to heat and pressure in the vulcanizing process to form them into a tire. The tread pattern on the surface of the tire is formed by the application of pressure during the vulcanization process.

The sealant chamber of the double-chamber tire was manufactured using a rubber sheet; the rubber material forming the sealant chamber can be peeled away after forming the sealant chamber.

This concept of peeling away a layer after formation is the same for the double-chamber tube. The expansion rate of the tube in the vulcanization process is less than 10%. Talcum powder is used to eliminate an adhesion between the rubber sheets and allows the peeling of the rubber sheet.

However, as shown in Fig. 8, the expansion rate of the tire in the vulcanization process is around 150%. When using talcum powder, the rubber in the area without the powder adheres because the powder cannot cover the entire surface of the rubber sheet on a stretched tire.

Therefore, requirements of peeling are as follows:

- (1) To expand to the same extent as the rubber, in order to enable peeling after formation.
- (2) To have no effect on puncture-resistance performance.

Various materials were tested as the peeling sheet, as shown in Table 1. As a result, Film D satisfied both requirements, cost and durability. Forming the double-chamber tire was enabled by the selection of this material.

4.2.2. Homogeneous distribution of puncture sealant

Because the sealant in the sealant chamber is required to prevent air from escaping no matter where the tire is punctured, it should be homogeneously distributed. Diagonally opposed punctures on the tread of double-chamber tire were pierced using pins of 0.8, 3, and 5 mm in diameter. The pins were used to make two, four, and two, punctures respectively, eight in total. After running using this tire, the distribution of the sealant was inspected by a CT scan. Figure 9 shows the result of the distribution.

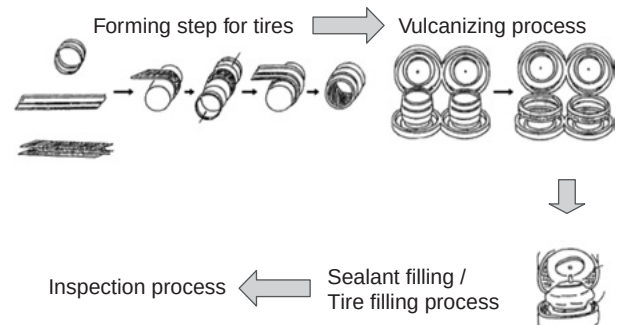


Fig. 7 Manufacturing process for tires

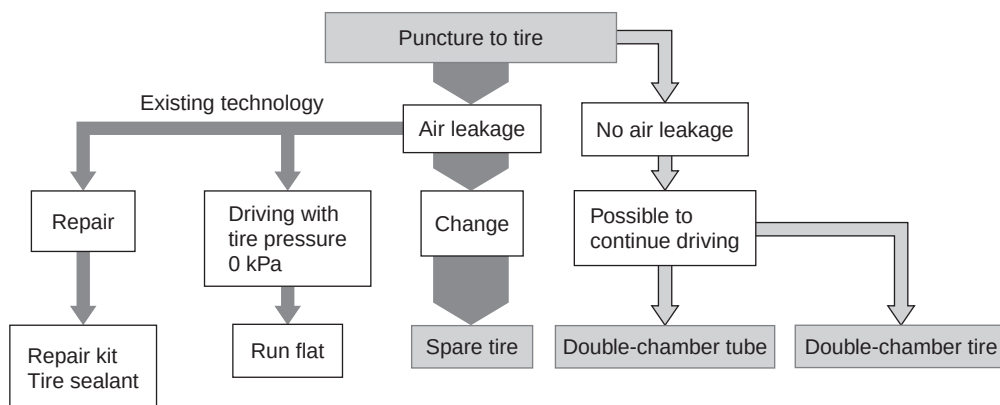


Fig. 6 Schematic diagram of technology dealing with puncture

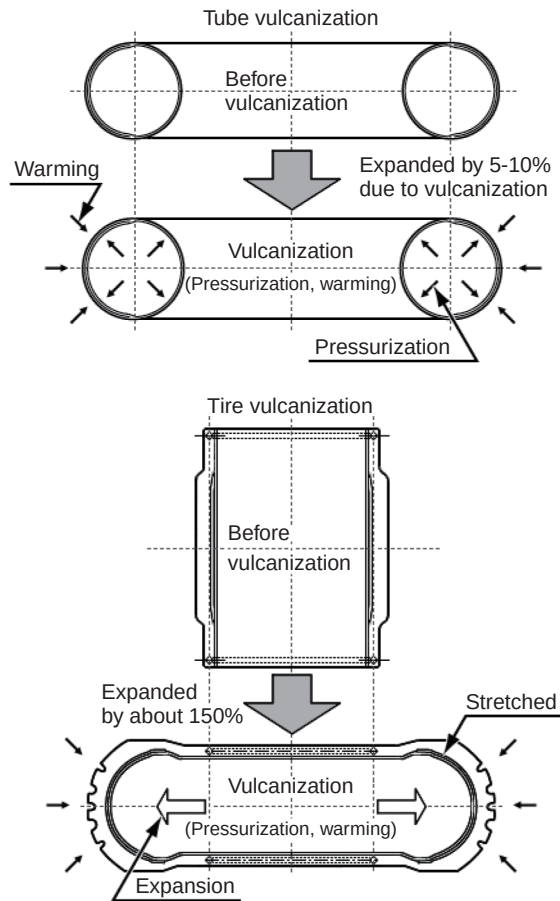


Fig. 8 Vulcanizing process

Table 1 Consideration of release agent

Test sample	Formability of fluid chamber	Initial anti-puncture performance	Anti-puncture performance after durability test
Talcum	Insufficient	Insufficient	—
Sheet A	Insufficient	Insufficient	—
Tape A	Sufficient	Insufficient	Insufficient
Film A	Sufficient	Insufficient	Insufficient
Film B	Sufficient	Insufficient	Insufficient
Film C	Sufficient	Sufficient	Insufficient
Film D	Sufficient	Sufficient	Sufficient

Measurement of the thickness of the tread showed that the sealant remained homogeneously distributed under these conditions.

4.3. Results of Puncture-resistance Test

An important function of the double-chamber tire is to be capable of driving after punctured. A drum endurance test was conducted using the pierced tire. As a result, the tire accomplished continuous drive for 10 000 km at 65 km/h drum operation speed as shown in Fig. 10.

Figure 11 shows the change in the tire pressure when the tube tire and the tubeless tire were rotated on the drum after a 2.8 mm diameter nail puncture.

The change in the tire pressure is minimal until the nail comes out. However, the nail comes out when the centrifugal force grows in a high-speed rotation, and the air leakage occurs. At that time, the air leakage of the tube tire was earlier than that of the tubeless tire. Moreover, when running at the same speed the angular velocity of the small radius tire was large and the centrifugal force acted strongly on the nail in the outer surface of the tire. Therefore, the stuck nail on the small diameter tire came out easily in a low-speed rotation.

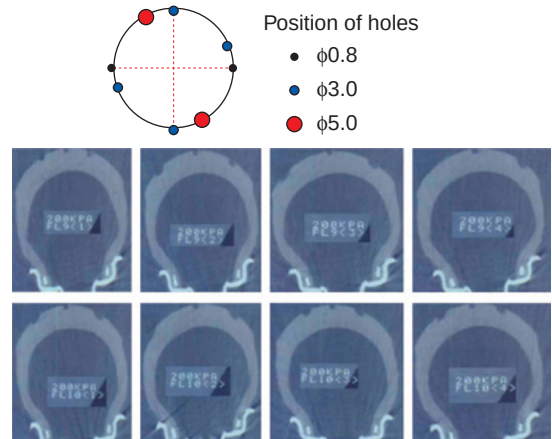


Fig. 9 Pictures of tire by CT scan

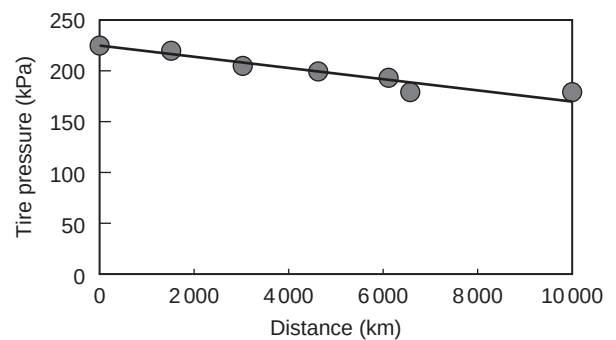


Fig. 10 Result of durability test on drum bench

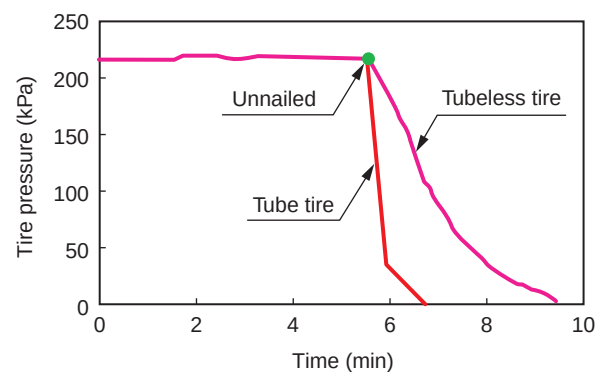


Fig. 11 Result of air leakage by drum bench test with sticking nail

4.3.1. Actual running durability test

Actual running durability tests were conducted on a pierced tire up to the tire wear limit of 20 000 km, and its air leakage was inspected. The sealant demonstrated stable plugging and actual running performances at limit tests under high and low temperatures.

Figure 12 shows the results of the actual running durability test conducted with a pierced tire. In actual running durability, the test motorcycle with the pierced tire ran 20 000 km on the road. To make the puncture conditions even more severe in this 20 000 km test, the hole was made with a blade of 2 mm in width instead of a round pin. After 12 000 km, the air pressure of the tire had declined by approximately 30%, but after being refilled to the correct pressure, the tire was able to be used until the tread wear limit of 20 000 km.

4.3.2. High-temperature test

Figure 13 shows the results of tests conducted at high temperatures with holes in the tire. In this test, nine holes were made in the same tire in ascending order of diameter with pins of 1 to 9 mm in diameter.

Every time a puncture was made, the motorcycle ran the range of 6 km, and the tire pressure was measured. When the 7 mm pin puncture was made there was a 15% drop in tire pressure, but since this was a large hole, a certain degree of time was required for the sealant to fill in the hole and stop air from escaping. The drop in tire pressure represented the amount of air that escaped during that period. The test was carried out in Death Valley in the United States under atmospheric temperature of 48 °C.

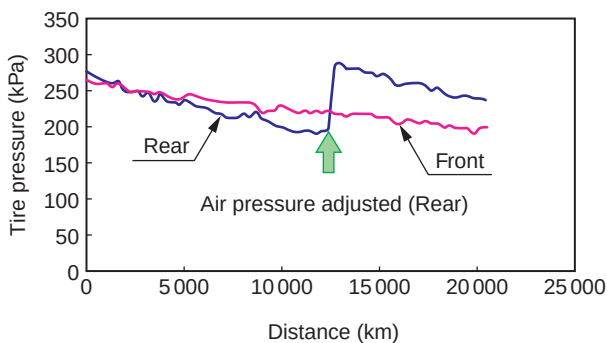


Fig. 12 Result of durability road test with tire with hole

Figure 14 shows the results of a 300 km durability test with a puncture made by a 3 mm diameter pin in the rear tire. The results were compared with the air pressure of the front tire without punctures. In Fig. 14, the drop in pressure was a result of the overnight drop in atmospheric temperature. Comparison with pressure changes in the front tire indicates that no air was leaking from the tire.

4.3.3. Low-temperature test

Figure 15 shows the results of test runs over 200 km at low temperatures. A puncture was made in the rear tire only. Because the rear tire is the drive wheel, at low temperatures, the temperature of the rear tire increases greater than the front tire, and hence its pressure increases greater, as the results indicated.

4.3.4. Handling and stability

The double-chamber tire developed for small sized scooters was tested for handling and stability. Because the double-chamber structure changed the stiffness of the tire case, the internal structure of the tire, including cord angle, was modified and the tire achieved handling and stability equal to those of a normal tire.

4.3.5. Verification of wheel interchangeability

The developed double-chamber tire has a double-chamber inside the tire facing the tread. The other part of the structure is almost the same compared with conventional tires. Tests of fitting the double-chamber tire on a conventional rim demonstrated that the new tire satisfied the development target of being interchangeable with conventional tires.

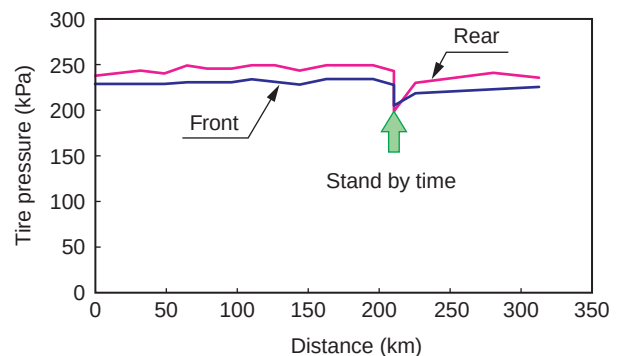


Fig. 14 Test run at high temperature with tire with hole

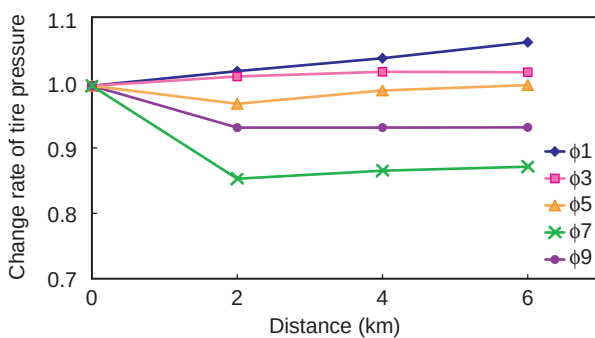


Fig. 13 Result of performance test at high temperature with tire with hole

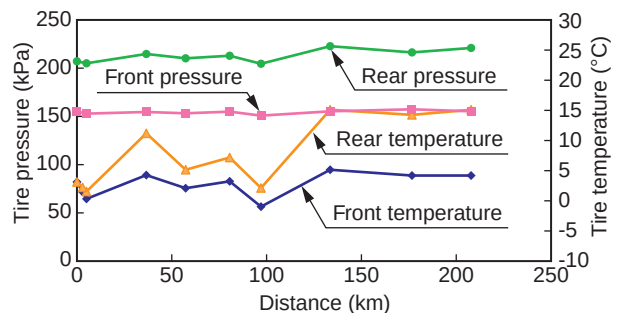


Fig. 15 Test run at low temperature with tire with hole

5. Comparison of Other Puncture-Resistant Technologies

Figure 16 shows some potential running distance of puncture-resistant tires punctured by a pin of 3 mm in diameter. A reinforced sidewall type and a Core type have been developed as “Run-flat tires” technologies for automobiles. The reinforced sidewall type is reinforced by the thick sidewall of tire. This tire can drive by supporting the vehicle mass by the thick sidewall even when air has completely leaked out. There are various types of Core type tires. This tire can drive by supporting the vehicle mass by the core equipped on the wheel rim. PAX tires are core-type tires.

Because double-chamber tires prevent air leakage, they are able to drive for longer distance than “Run-flat tires.”

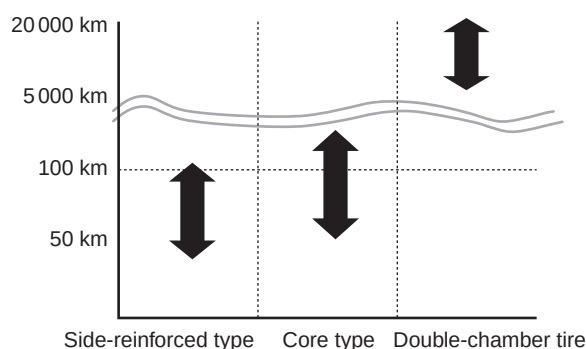


Fig. 16 Comparison of potential travel distance after puncture

6. Conclusion

A double-chamber tire containing a chamber filled with a puncture sealant has been developed to enhance the puncture resistance of small-diameter tubeless tires. Results in this development are as follows:

- (1) Specifications of double-chamber tire such as material and structure were established, and its puncture-resistance has been verified.
- (2) A manufacturing technique has been developed that does not necessitate major changes in the conventional manufacturing line.
- (3) A method of ensuring the handling and stability of the double-chamber tire has been determined.
- (4) Tests verified that the double-chamber tire could be fitted onto a conventional rim.

References

- (1) Yamagiwa, T., Nakayama, K., Kiyota, S., Tanaka, A., Makisaka, N.: Development of puncture resistance tire tube, 1997 JSAE Annual Congress Proceedings, No. 976, p. 279-282
- (2) Maniwa, T.: Understanding Automobile Tires & Their Characteristics, Sankaido, p. 211-217 (1980) (in Japanese)
- (3) Sakai, H.: Tire Engineering, Grand Prix, p. 403 (1987)
- (4) Sadamasa, T.: Automotive Engineering, Vol. 1, Gendaikougakusha, p. 182 (1979) (in Japanese)
- (5) Sadamasa, T.: Automotive Engineering, Vol. 2, Gendaikougakusha, p. 235 (1979) (in Japanese)

■ Authors ■



Tomoyuki HARADA



Toshio YAMAGIWA



Hirohisa TAKAHASHI



Akiko TANAKA