Practical Use of Computer-Aided Engineering in the Development of Automotive Rubber Grommets

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Sumitomo Wiring Systems, Ltd. designs and develops rubber grommets used for the protection and sealing of automotive wiring harnesses. These grommets are required to have good sealing properties, reduce the insertion force, and increase the pull-out force. To evaluate the insertion and pull-out forces, we use computer-aided engineering (CAE), in which the calculation results conform to the experimental results by reflecting the frictional force and material properties. We can also evaluate the change of the forces according to the surface roughness of grommets by CAE. For the sealing properties, we investigate water intrusion paths and the relations between water quantity, pressure, and leaks. This Paper reports on the results.

Keywords: wiring harness, grommet, frictional force, sealing, CAE

1. Introduction

In response to the rapid advances in automobile functionality, the number of vital circuits for airbags and other electronic apparatuses used in automobiles has been increasing. Under these circumstances, the automotive wiring harnesses*1, core products of Sumitomo Wiring Systems, are required to be more functionally reliable. A wiring harness is a bundle of electric wires enclosed by a protective covering (to protect the wires from physical interference with the vehicle body frame). It connects onboard electric and electronic apparatuses to transmit information between them and to supply electrical power to them. An example of wiring harnesses installed in an automobile body is shown in **Photo 1**.

Sumitomo Wiring Systems designs and manufactures wiring harnesses with particular focus on the improvement of their performance and installability in automobile bodies. The Experiment and Evaluation Dept. (former name: Research and Evaluation Center) of the company is mainly responsible for the performance evaluation of existing products and for enhancing the functional reliability of new products under development. To further expedite these tasks, this department is promoting active use of CAE*2 technology at the initial stage of product design. Although the practical use of CAE technology is currently limited to bending fatigue (prediction of burn-out life due to repeated flexion) for wiring harnesses, and vibration analysis of their components, the department is planning to further expand the use of this technology. The use of CAE analysis for rubber grommets, which work as wiring harness protectors, is now under investigation as an effective method for evaluating their insertability, pull-out resistance, and water-sealing properties.

This paper reports on the current status of CAE analysis system development concerning automotive grommets.

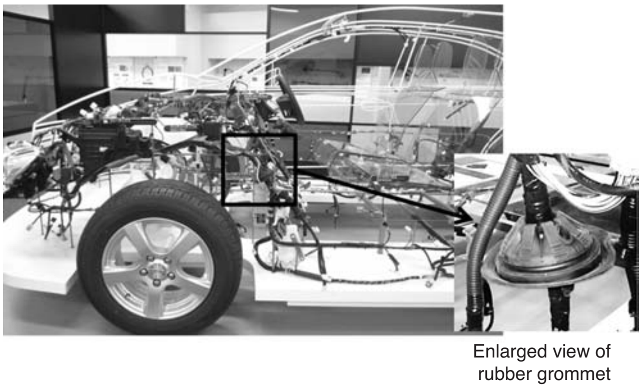

Photo 1. Automotive wiring harnesses (engine compartment, instrument panel, floor)

2. General Description of Automotive Through-Hole Grommets

An automotive grommet is a circular rubber item that is inserted through a hole bored in an automobile body or other equipment to protect an electric wire, tube, or hose from physical abrasion, and to prevent the intrusion of water through the hole. Various types of grommets are made by Sumitomo Wiring Systems, as shown in **Photo 2**. These grommets are required to provide a low insertion force and a high pull-out force, in addition to protecting electric wires, tubes, hoses, etc. from physical damage and preventing the intrusion of water. For grommet insertion force and pull-out force, customers specify target values. For many years, we have repeated prototyping and testing to select and determine the materials and configurations most suitable for grommets. However, utilization of CAE analysis techniques, rather than repetitive prototyping and testing, is becoming essential to meet the required grommet specifications, and for shortening grommet development time and cutting costs.

The following sections describe CAE analysis results

Photo 2. Automotive grommets

for insertion and pull-out forces and water-sealing properties of grommets, in this order.

3. Study of Grommet Insertion Force and Pull-Out Force Analysis Method

3-1 Outline of insertion force and pull-out force measurement test

The insertion force and pull-out force measurement test is schematically illustrated in **Fig. 1**. A test sample was prepared by passing a bundle of a predetermined number of electric wires through a grommet.

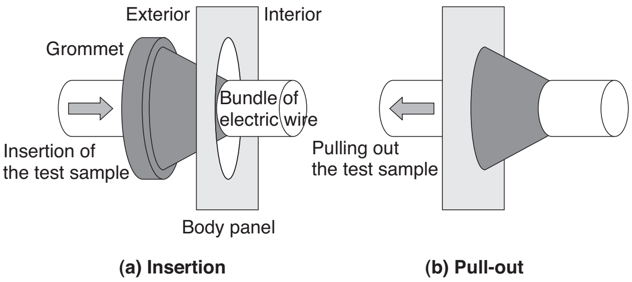

Fig. 1. Schematic illustration of test

For the insertion force, the load and stroke necessary for inserting the grommet through a hole bored in a metallic panel (body panel) at a specified velocity were measured. A metallic panel was prepared so as to be comparable with an automobile body. For the pull-out force, the load and stroke necessary to remove the grommet from the body panel at a specified velocity were measured. The measured loads and strokes were compared with the CAE analysis results in order to verify the effectiveness of the analysis system. In this test, the loads and strokes were defined as shown in **Fig. 2**. The insertion force was defined as the load exerted on the bundle of electric wires during the time period from the initiation of contact of the grommet with the body panel until completion of grommet insertion; the insertion stroke was defined as the distance the bundle of electric wires moved during the above action (see **Fig. 2(a)**). The pull-out force was defined as the load exerted on the bundle of electric wires during the time period from the initial state of the grommet until completion of its removal from the body panel; the pull-out stroke was defined as the distance the bundle of electric wires moved during the above action (see **Fig. 2(b)**).

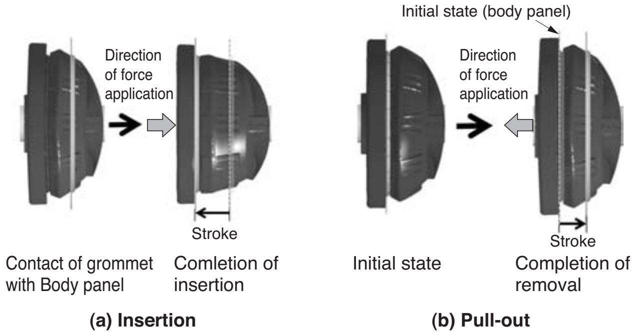

Fig. 2. Definition of insertion and pull-out forces and strokes

3-2 Observations on grommet insertion and pull-out behavior

Before studying the use of CAE for analyzing grommets, we observed how the grommet was deformed when inserted into and removed from the body panel (see **Fig. 3**). When inserted, the grommet was deformed due to friction with the body panel (**Fig. 3(b)**). When removed, two sections of the grommet contacted with each other (**Fig. 3(c)**). Using these observation results, we drew up a cause and effect diagram (**Fig. 4**) and established three steps for CAE analysis system development. Step 1 enables estimation of the insertion/pull-out forces and strokes for a single grommet body; Step 2 determines the effect of a bundle of electric wires on the insertion/pull-out forces and strokes; and Step 3 takes into account the effect of the grommet insertion work environment in automobiles (differences between workers in the rate of grommet insertion and the

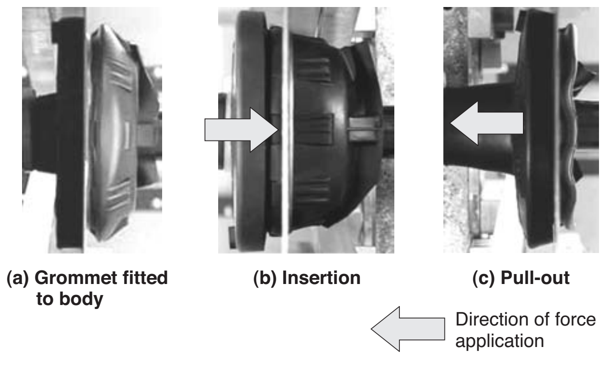

Fig. 3. Deformation of grommet
(b and c show deformations under peak loads.)

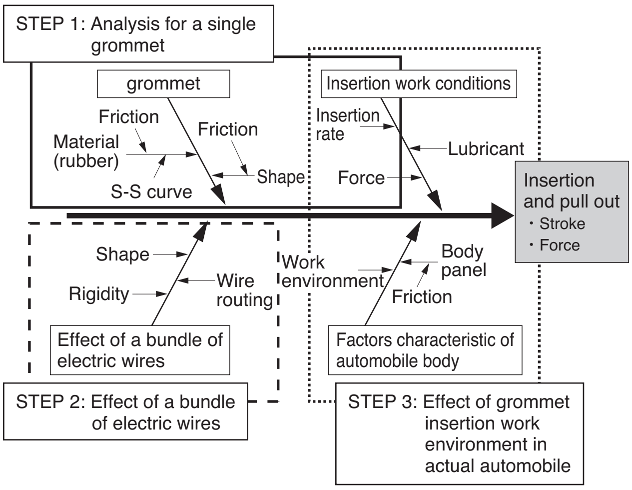

Fig. 4. Cause-Effect Diagram (insertion and pull-out)

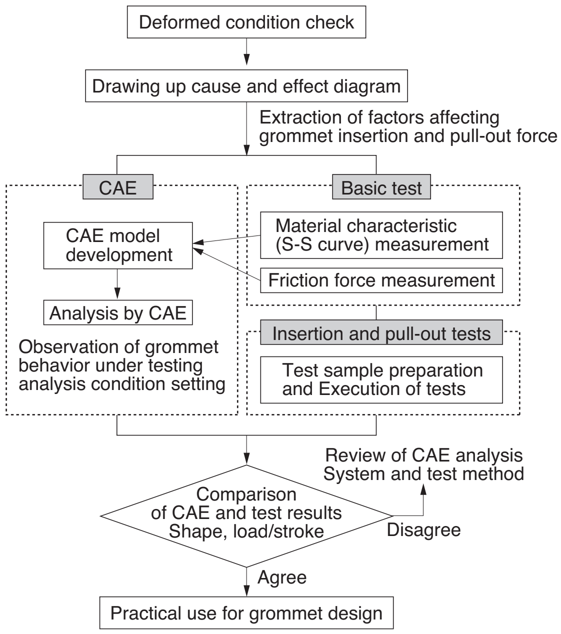

Fig. 5. Practical work flow

use of insertion force). The work was performed in the order of step number. The practical work flow for each step is shown in **Fig. 5**. From the grommet deformation observation results and cause and effect diagram, it was estimated that the stress-strain curve (S-S curve*3), and the friction of the rubber material would be key factors in the analysis. In Step 1, basic tests were carried out to determine these characteristics. The test results were reflected in the CAE analysis model, and the grommet deformation, insertion/pull-out force, and stroke analysis results were compared with the test results. The comparison results are discussed in the following sections.

3-3 Basic Test

Considering that a grommet was deformed in both the tensile and compressive directions, the S-S curve was measured for both tension and compression. The measurement results were reflected in the CAE analysis model. In the S-S curve measurement test, the test sample tension/compression rates were set at the grommet insertion and pull-out rates since the S-S curve was estimated to differ depending on the tension/compression rates. The S-S curve determined from the test is shown in **Fig. 6**.

Following the S-S curve measurement, the frictional force was measured in accordance with JIS K 7218. The frictional forces generated between rubber materials and between the rubber material and the body panel were measured. To reflect the measured frictional forces in the CAE analysis model, both static and dynamic friction coefficients were calculated from the test results. The frictional forces obtained from the measurement tests are shown in **Fig. 7**. It was verified from the test results that the frictional force between rubber materials is greater than that between the rubber material and body panel.

The surface characteristic of molded rubber products differs depending on the surface roughness of the mold used. Assuming that the magnitude of frictional force between rubber products would vary depending on their surface condition, we tested the dependence of the frictional force on the surface roughness of the rubber product (**Fig. 8**). Four types of test samples were used: Sample A having a glossy surface; Samples B and C having the same S-S curve and shape but different surface roughness; and Sample D

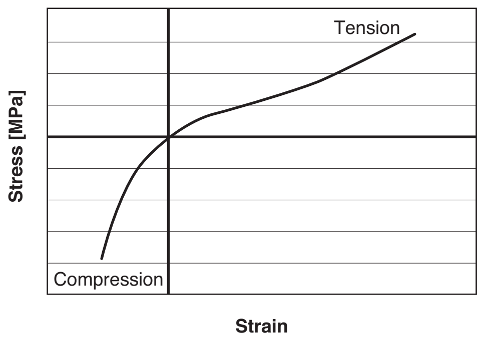

Fig. 6. S-S curve of rubber material

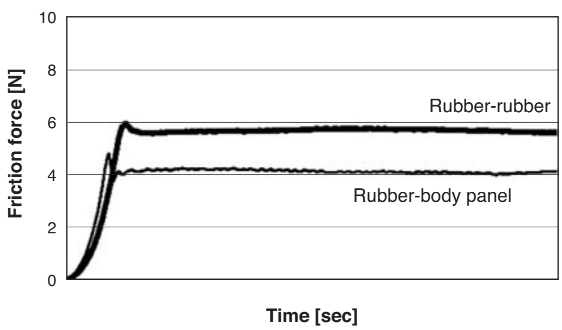

Fig. 7. Comparison of frictional forces

having a rough surface and an S-S curve different from Samples A to C. The frictional forces between each sample and a body panel were compared. For Samples B and C, their insertion forces were also compared (**Fig. 9**).

Figure 8 shows that frictional force increased as mean surface roughness, Ra, decreased. **Figure 9** shows that insertion force was largely dependent on mean surface roughness. (In **Fig. 8**, the force necessary for inserting Sample B, whose mean surface roughness was 0.7 times that of Sample C, was 1.5 times that for inserting Sample C.) When designing grommets, we must therefore pay attention to both their S-S curve and surface conditions (mold surface roughness) to provide products with a low insertion force and large pull-out force.

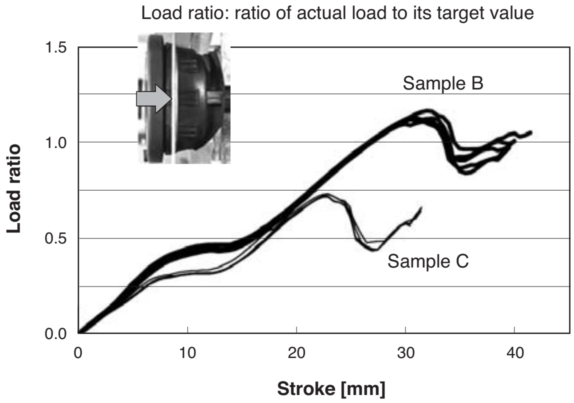

Fig. 9. Insertion force comparison

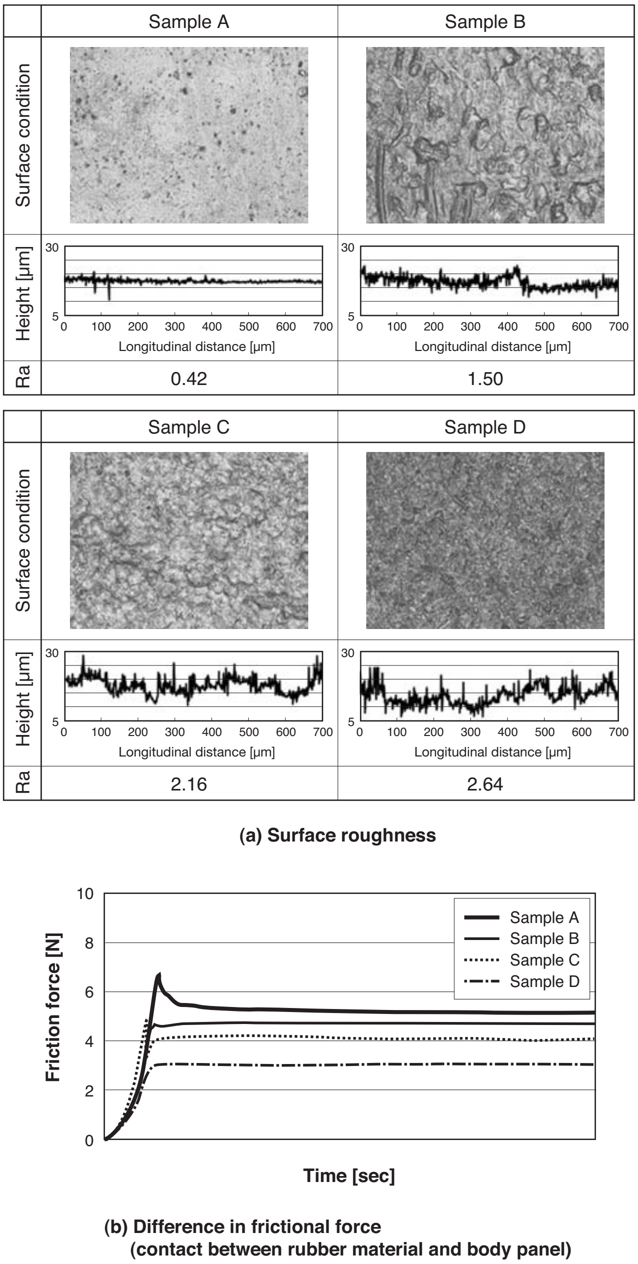

Fig. 8. Dependence of frictional force on surface roughness

3-4 Test for a single grommet body and comparison between test and CAE analysis results (Step 1)

Using the S-S curve and friction coefficients determined in Section 3-3, we carried out the CAE analysis of grommets and compared the analysis results with the test results. Since the objective of Step 1 was to establish an evaluation method for a single grommet body, we prepared test samples with particular care so that their insertion and pull-out forces would not be affected by the rigidity of the bundle of electric wires and that the measured values would be distributed within an acceptable range.

Figure 10 compares the grommet deformation estimated by CAE analysis with the test results, while **Fig. 11** compares the load ratio/stroke curve. In **Fig. 11**, the load ratio is defined as the ratio of actual insertion or pull-out force to its target value. For a structure made of such flexible material as rubber to deform largely in response to physical contact with other objects, it is generally difficult to check the consistency between the test results and the CAE analysis results. The reason is that it is difficult to set

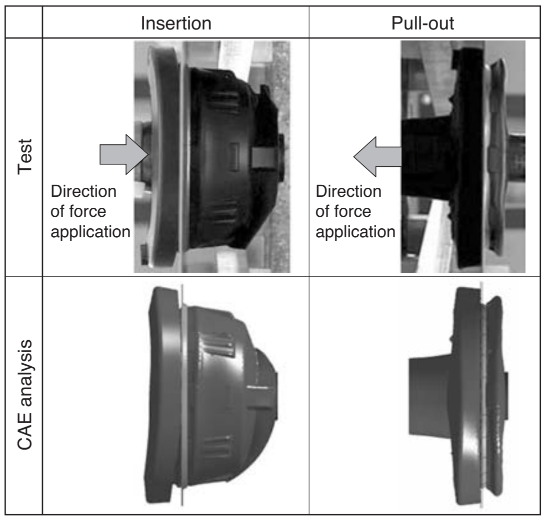

Fig. 10. Deformation comparison (under peak loads)

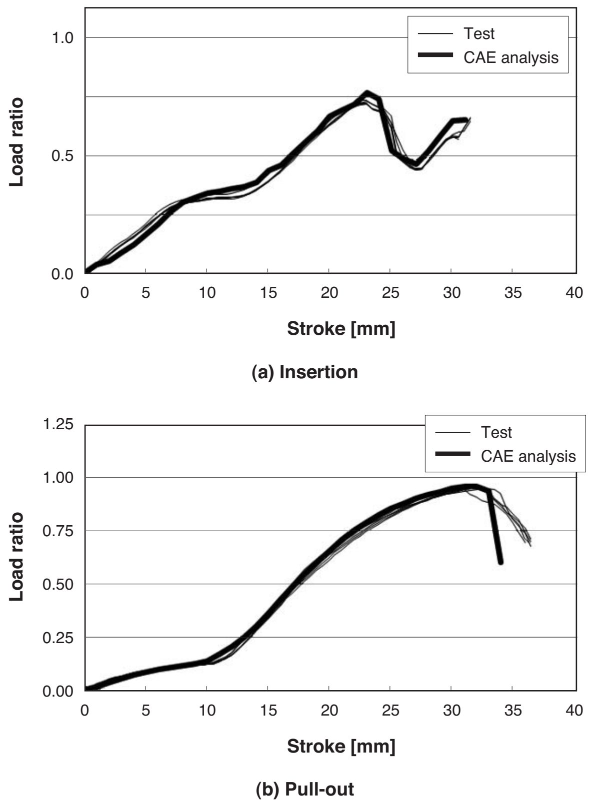

Fig. 11. Comparison between CAE analysis and test results in terms of load ratio/stroke curve

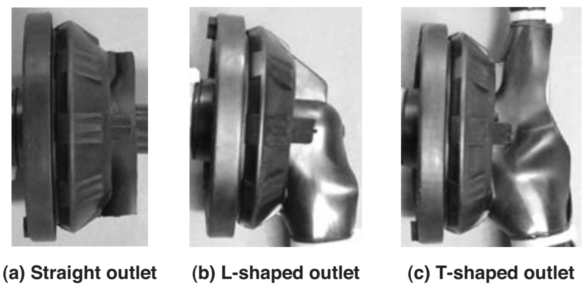

Fig. 12. Grommets with different shapes of wire outlets

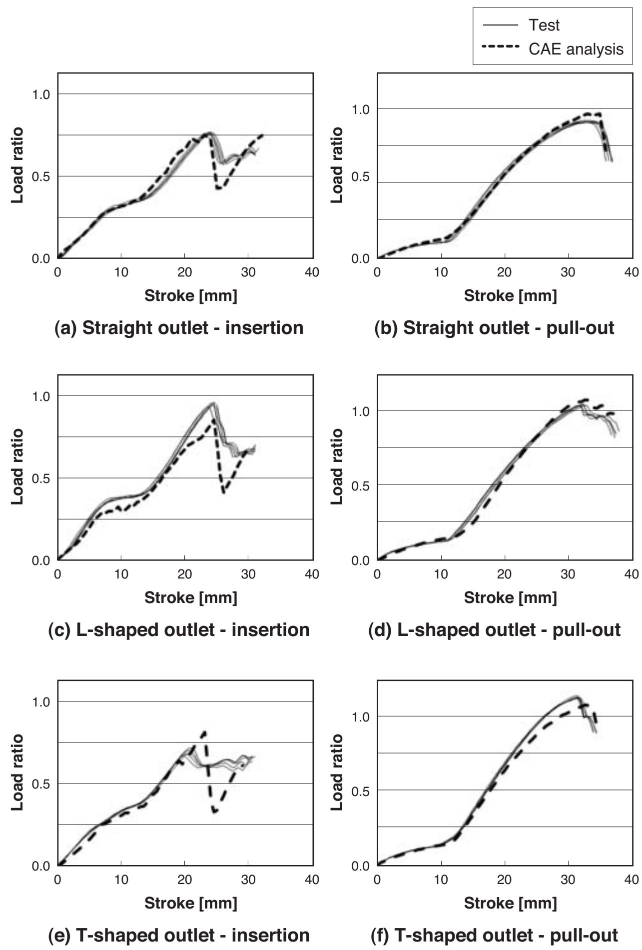

Fig. 13. Load ratio/stroke curve comparison

a proper strain velocity and select a material model that can accurately represent the deformation of rubber material. Despite this, we could reflect the actual measured S-S curve and friction coefficients, as well as the behavior of the test sample in the test, within the analysis model. As a result, we could obtain CAE analysis results that agreed well with the test results. The effectiveness of the CAE analysis was also verified for grommets of different shapes, since the analysis system also agreed well with the test results for these other grommets.

This CAE analysis system has already been transferred to the Components Group of the company. This analysis system can thus be used for examining the insertion and pull-out forces of grommets at their configuration evaluation stage, thereby contributing to expeditious finalization of the design specifications. To date, the system has been used to design the grommets for several automobile models.

3-5 Effect of a bundle of electric wires (Step 2)

Grommets with various electric wire outlets are designed in accordance with the arrangement of the electronic apparatuses within a given automobile. Grommets with typical electric wire outlets are shown in **Fig. 12**. On the assumption that the rigidity of a bundle of electric wires will differ depending on the type and number of electric wires, and that such difference in rigidity will affect the grommet insertion force and stroke, the test and CAE analysis results for the load ratio/stroke curve of grommets with different wire outlets were compared. The results are shown in **Fig. 13**.

Figure 13 shows that both the maximum force and stroke determined by the CAE analysis agreed well with the test results, although slight differences were observed after the insertion force reached the peak value. As a result, it was confirmed that the CAE analysis system can yield data almost equal to the test data even when a grommet carries a bundle of electric wires.

Our future task is to reflect the grommet-fitting work environment inside the automobile within the CAE analysis system (Step 3). Regarding insertion, grommets are required to be easy to insert into a hole bored into the body frame. It is desirable from the ergonomic standpoint that the worker responsible needs to exert only the minimum force to install each grommet. The objective of Step 3 is to find a load/stroke curve that will enable the worker to feel comfortable in inserting grommets.

4. Study of Water-Sealing Properties Analysis Method

This section discusses the water-sealing properties of grommets. When an automobile travels in the rain or is washed, water may enter the body and wet the grommets, causing the electrical system to malfunction.

To prevent the electrical system from malfunctioning, the grommets are required to prevent the intrusion of water. **Figure 14** illustrates a water-sealing properties test for a grommet and a performance analysis model.

In this study, the water intrusion path in an automobile fitted with grommets was first checked. For this purpose, the water-sealing section of a grommet was cut out. After coating the surface of the sealing section with a paste that would change color when exposed to water, we pressed the surface against a transparent panel. Then, we sprayed water over the water-sealing section at different

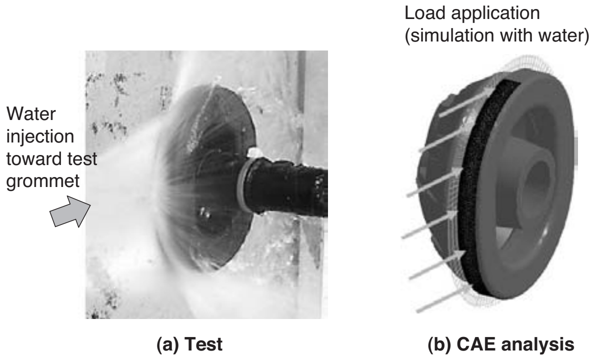

Fig. 14. Testing and analysis of grommet simulating car washing

Fig. 15. Water intrusion path (water injection)

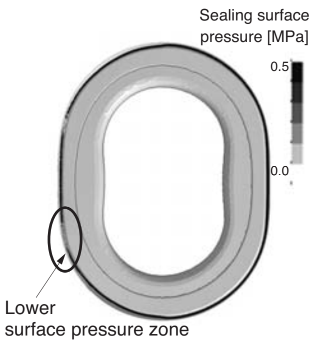

Fig. 16. Pressure distribution on the sealing surface (CAE analysis)

pressures. When the water pressure reached a certain level, a gap appeared between the sealing surface and the transparent panel and water leaked through the gap (**Fig. 15**). CAE analysis was also carried out to determine the relation between sealing surface pressure and the load applied to the surface by the water pressure. The analysis revealed that the sealing surface pressure would drop at the point where water began to leak through (**Fig. 16**).

In the future, we will verify the relation between sealing surface pressure and water flow rate/pressure through testing and CAE analysis.

5. Conclusion

A CAE analysis system concerning the insertion and pull-out forces of automotive grommets has been developed. This system can be used for developing new grommets and designing commercial grommets. The Sheathing Design Dept. of the company is now using this system effectively. Products designed by using this system have already been installed in automobiles and are well received by customers.

Use of this analysis system at the initial stage of grommet development enables selection of the grommet material and determination of the configuration that can meet the required grommet performance, thereby improving functional reliability, shortening the development period, and reducing both development and mold fabrication costs.

For grommet insertion and pull-out forces, we will continue using CAE analysis methods to establish a grommet insertability indicator while also focusing on the ease of actual fitting within automobiles by an employee.

Regarding the method for analyzing the water-sealing properties of grommets, we carried out a test to observe the water intrusion paths. As a result, it became possible to check the correlation between the water leakage pressure and the sealing surface pressure determined by CAE analysis and thereby compare the water-sealing properties of water-sealing sections of different shapes. One future task is to reflect the water intrusion path observed in the test within the CAE analysis system in order to derive the relation between water-sealing surface pressure and water flow rate/pressure and increase the number of system verification examples.

Technical Terms

*1 Wiring harness: A cable comprising a bundle of electric wires enclosed by a protective covering. A wiring harness is used for connecting the electronic and electrical components used in automobiles, copying machines, printers, and various other types of equipment, to transmit information between these components and to supply electric power to them. Each electric wire within a wiring harness has its own role, such as supplying electrical power, transmitting sensor signals, or communicating operational information.

*2 CAE: Standing for computer-aided engineering, CAE is a technology that uses computers to assist in solving engineering problems. In this report, CAE is particularly defined as a computer simulation for checking whether or not a product has been designed so that it meets performance requirements (stress, strain, strength, etc.).

*3 S-S curve: A stress versus strain diagram that is determined experimentally from tensile and compression tests on a specific material.

References

(1) Sumitomo Wiring Systems' website http://www.sws.co.jp/en/index.html

(2) JIS K6251, K6254, and K7218

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