Development of Silicone Rubber with Ultrahigh Tear Strength

Clarification of behavior of nanosilica filler aggregates

Achievements

- Clarification of the change in the hierarchical structure of nanosilica filler aggregates along with the elongation of **silicone rubber***
- Marked improvement of hardness, tear strength, and independent control of the elongation of silicone rubber
- Development of silicone rubber with high tear strength while maintaining transparency

R&D facility: Sumitomo Bakelite Co., Ltd.

***Silicone rubber:** Silicone rubber mainly consists of silicon and contains siloxane bonds (SiO) of alternately bonded silicon and oxygen. It has various characteristics such as resistance to high and low temperatures. Silicone rubber has been widely used as a medical material. The development of a material that has high transparency, moderate hardness, and a high tear strength is demanded.

****Small-angle X-ray scattering (SAXS):** SAXS is a technique for analyzing the nanoscale structure of a target specimen using the scattering intensity profile obtained by irradiating the specimen with X-rays.

*****Ultrasmall-angle X-ray scattering (USAXS):** Conventional SAXS can generally identify a structure with a size of 2–30 nm. USAXS is a technique for measuring and evaluating a mesoscopic structure with a size of 200–300 nm using the scattering intensity profile in a range of ultrasmall angles.

Role of SPring-8

Background

With the advancement of medical care, the development of medical equipment with higher performance has been required. Among the various medical materials, silicone rubber has superior resistance to high and low temperatures, chemical stability, electrical insulation, gas permeability, transparency, and a mold release characteristic. However, the tear strength and tensile strength of silicone rubber are inferior to those of other rubber materials and the range of its application has been limited.

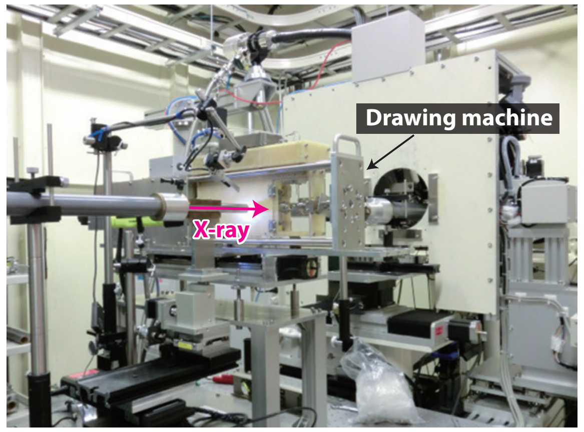
Under such circumstances, the development of transparent silicone rubber with a high mechanical strength has been required. To realize such a rubber, a nanosilica filler was dispersed in silicone rubber as a reinforcing material and the bonding between the nanosilica filler and the surrounding rubber was strengthened to improve the mechanical strength of the silicone rubber. It was also required to clarify the relationship between the structure of the filler aggregate and the tear strength upon the elongation of silicone rubber.

Results

SAXS** and **USAXS***** were used to observe the dispersion state of the filler, including the aggregation structure. The beamline of SPring-8 is appropriate for evaluating structures with a wide size range. *In situ* observation of the hierarchical structure and the behavioral change of nanosilica aggregates was carried out by SAXS at SPring-8 while silicone rubber specimens with a dispersed nanosilica filler and different strengths were elongated using a tensile tester.

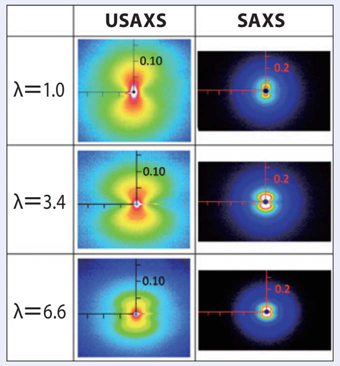
The results indicate that when silicone rubber with strong bonding between the filler and the matrix is elongated, the filler aggregates are also elongated in the same direction, which leads to an increase in the tear strength. In addition, the strength of the interface depends on the state of the aggregation of the filler. This finding has led to the improvement of the property of silicone rubber by controlling the state of the aggregation.

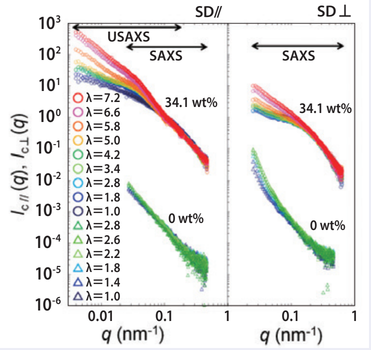
Ultrahigh-speed tensile test and SAXS using BL19B2



Stress relaxation starts to occur simultaneously when silicone rubber is elongated. The state of the aggregation of the filler inside the silicone rubber was observed while the silicone rubber was extended using a drawing machine with a maximum speed of 1 m/s.

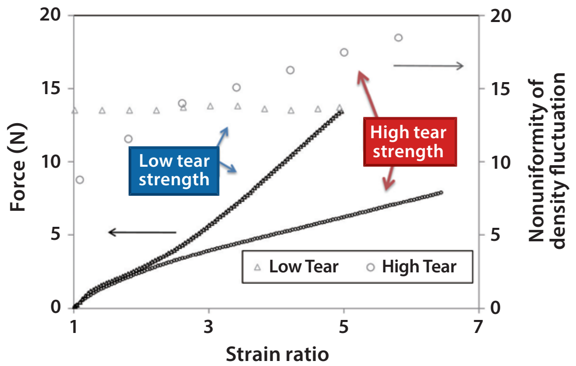
X-ray two-dimensional USAXS and SAXS images of silicone rubber with nanosilica filler





Intensity profile in the direction parallel to elongation of silicone rubber (filler content, 34.1 wt%; λ, elongation factor).
A characteristic pattern indicating the orientation was observed from the beginning of elongation. The state of the aggregation of the filler elongated in the elongation direction of the silicone rubber was clarified.

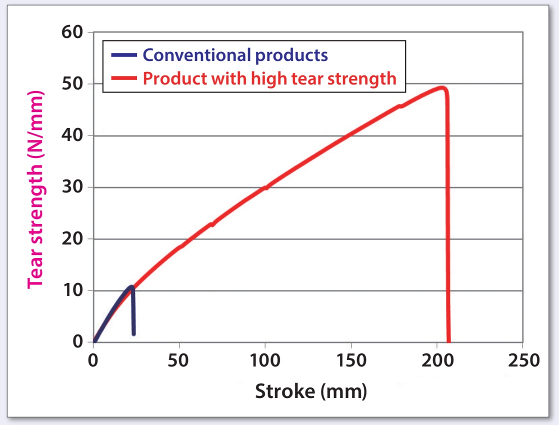
Differences in stress and nonuniformity of density fluctuation depending on tear strength



When the bonding between the filler and the matrix is strong, the tear strength is high.

Example of product using silicone as a medical material: unit for continuous suction of blood, pus, and effusion from wounded area after surgery

Developed silicone rubber with high tear strength



The surface of the filler was treated to improve the interface strength between the filler and the silicone on the basis of the observed change in the state of the aggregation of the nanosilica filler upon elongation. The research group has succeeded in developing silicone rubber with a tear strength that is approximately fivefold (50 N/mm) that of conventional silicone rubber over a wide range of hardness of 30-70 (product name, DuraQ®). It is expected that this ultrahigh-tear-strength silicone rubber will be used as a material not only in medical equipment but also in mechanical parts of automobiles and airplanes, clothing, healthcare products, and wearable products.