Technical paper

The generation mechanism of blisters formed on oil seals for construction machinery

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Oil seals are used in components that have a rotating shaft, to keep oil inside and prevent entry of foreign matter.

Blisters are one of the problems found in oil seals. These are round bumps that may form around the sliding surfaces of seal lips. As they grow they will cause oil leakage. Countermeasures have been taken based on the generation mechanism of blisters explained, however, problems of blisters are still found occasionally.

In order to take drastic measures against blisters this time, we systematically investigated blisters which occurred in oil seals actually mounted and used on machines. As a result, unlike the mechanism considered conventionally, it turned out that the generation and growth of blisters are concerned deeply with the generation and growth of cracks inside the rubber.

***Key Words**: Oil seal, Blister, Oil leak*

1. Introduction

Oil seals are used for sealing liquid such as oil and for preventing intrusion of foreign material from the outside.

Oil seals are often used for rotating shafts of automobiles and industrial machines, and construction machines also use many oil seals. For example, a wheel loader, one of construction machines, has an engine, hydraulic pump/motor, transfer, and axles each mounted as a component having a rotating shaft as shown in **Fig. 1**, and various types of oil encapsulated in these are sealed with oil seals.

Fig. 2 shows an example of oil seal structure. The seal lip, made of flexible rubber, keeps the contact between the peak of the lip and shaft surface stable against the effect of machine vibration and sealed liquid pressure fluctuation. The spring works to increase the press force of the seal lip against the shaft and keep that press force for a long period. The oil seal is designed to maintain a stable sealing function with these. [2]

Nevertheless, the sealing action of the oil seal may decrease to an extent that oil leaks from the component. If this occurs, the oil may leak to the outside, or in the worst case, the component itself may not operate properly; thus, the oil seal is required to be highly reliable.

The sealing action of the oil seal may be lowered due to various causes such as abnormal wear of the lip, turnover of the lip, and deterioration of the lip rubber material. In particular, from before, there have been those oil leak faults noticeably found here and there that may be generated at the atmosphere side of the seal lip peak for the cause of a projection; these are called blisters. Until now, when a fault due to blisters has occurred, we took action, for example, by changing the seal shape or rubber material. Blister generation has, however, not been completely prevented yet, and to prevent it, it is necessary to figure out the blister generation mechanism.

This paper reports on the results of studying the blister generation mechanism based on the systematic analysis of blisters that was conducted with the oil seals actually used on a machine body.

Fig. 1 Schematic of a wheel loader [1]

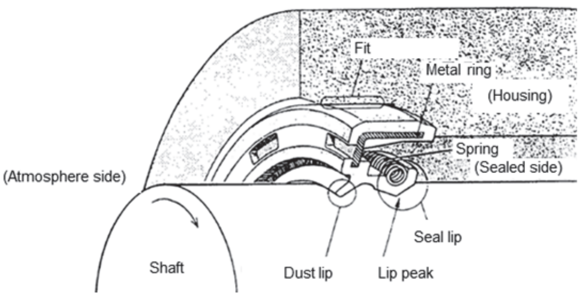


Fig. 2 Oil seal structure example [2]

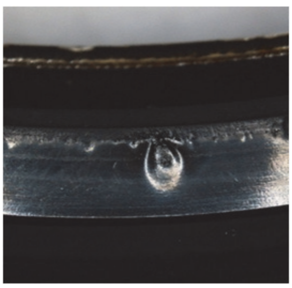


Fig. 3 Example of a blister occurred on an oil seal

2. Conventional hypothesis of the blister generation mechanism

There are some previous studies concerning blisters. The blister generation mechanism was proposed as follows because sealing oil was present inside the blisters generated in the oil seal to be studied [3] [4] [5]. Blistering is a mechanism where the oil vaporized on the seal lip sliding surface diffuses into the rubber due to the sliding heat generation of the oil seal in operation, and a blister is generated by condensing the vaporized oil on the low-temperature seal lip atmospheric side. **Fig. 4** shows a typical conventional hypothesis of the blister generation mechanism.

However, investigating the blister generated in oil seals actually used in a machine body has revealed that some blisters have no oil contained therein. Therefore, the conventional hypothesis of the blister generation mechanism cannot fully explain the behavior from the generation of a blister to the growth.

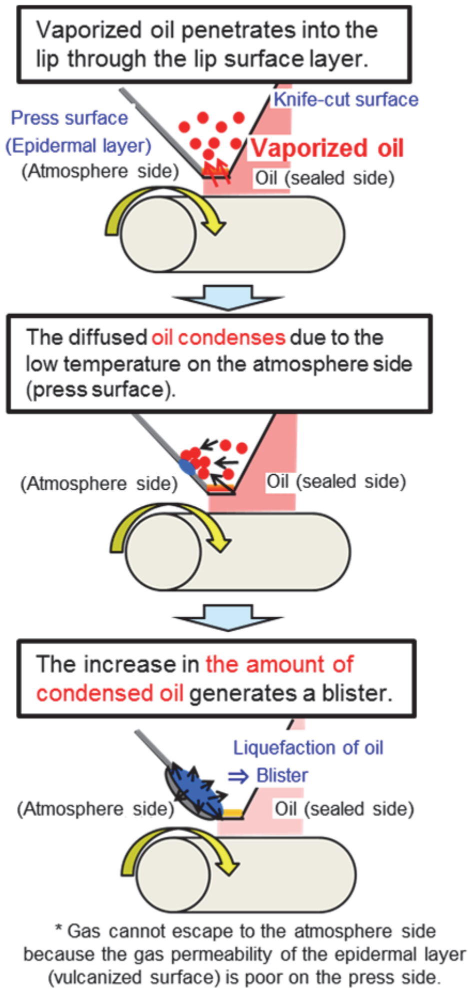


Fig. 4 Conventional hypothesis of the blister generation mechanism [5]

3. Study on the Blister Generation Mechanism

3.1 Status of Blister Generation

To study the blister generation mechanism, we investigated the blister generation status in relation to the operating time with respect to those fluororubber oil seals actually used in a machine body that were recognized to have a blister generated in it.

Fig. 5 shows the blister generation points by blue dots. **Fig. 6** shows the result of counting the number of generation points for each blister size for each operating time. The blister size was defined as the axial width on the seal lip sliding surface viewed from the center of the oil seal. (**Fig. 7**). A blister not larger than 0.5 mm was defined as a “small blister” and a larger one as a “large blister”.

The number of blisters generated increased with the operating time. In addition, in samples (3) and (4), where large blisters were generated, many small blisters were generated all around the circumference (**Fig. 5** and **6**).

These results demonstrated that blisters are growing with the operating time although the blister is very small at the initial stage of generation.

Then, blister samples with different blister sizes were observed in detail to verify the process from the blister generation to the growth.

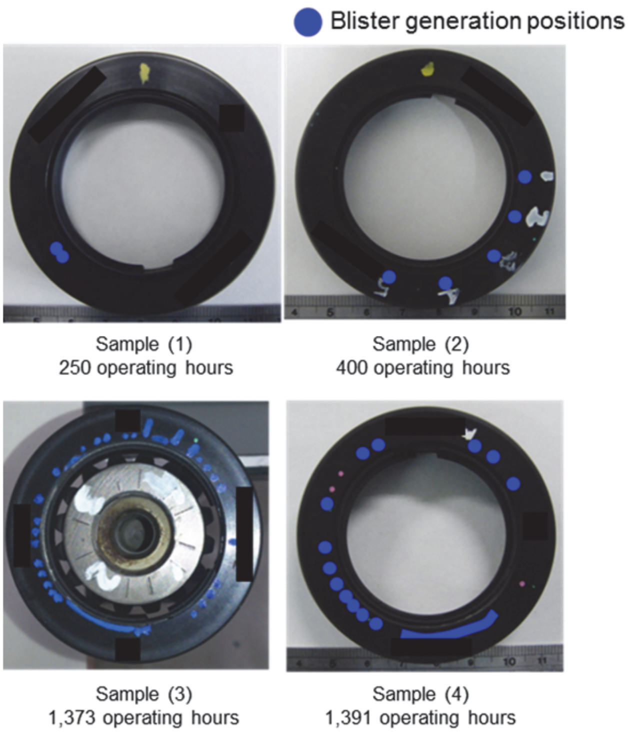


Fig. 5 Blister generation positions

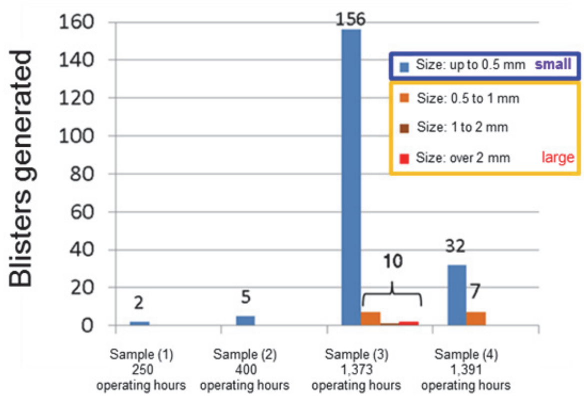


Fig. 6 Blister sizes and number of blisters generated

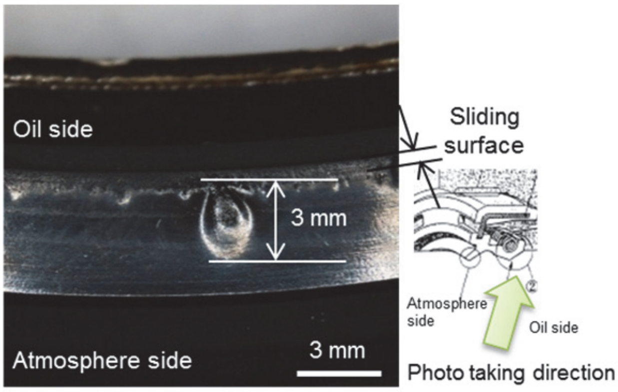


Fig. 7 Definition of blister sizes

3.2 Detailed Observation Results of Small Blister Samples

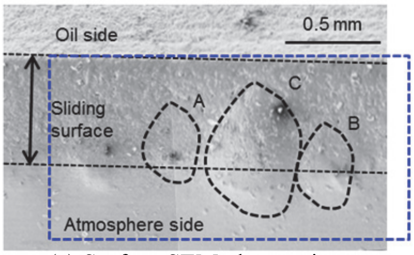
To check the blister status of the initial generation stage, small blister samples (0.3 to 0.5 mm) were observed in detail.

Fig. 8 (a) shows the SEM observation result of the blister surface. **Fig. 8 (b)** shows the result of using X-ray CT equipment to observe the inside of a blister positioned at a depth of approximately 100 μm from the surface. In the result of cross sectional X-ray CT observation, sections that look darker than the surrounding are a cavity, and spots that look white are filler. Filler is an agent added to the rubber material for the purpose of developing the sealing action of the oil seal. The maximum filler size of the samples used in this observation was approximately 100 μm.

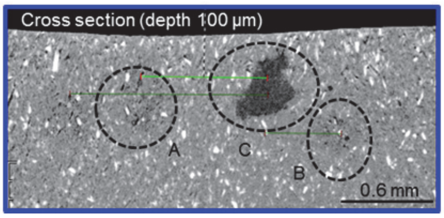
In **Fig. 8**, blisters A and B, which had a blister size of approximately 0.3 mm, did not contain any large cavities observed inside, instead, contain multiple cavities generated.

Blister C had a blister size of approximately 0.5 mm, and it was found that this blister contains a cavity of several hundred micrometers in diameter.

Next, each blister was observed on the cross section perpendicular to the sliding surface in order to observe details of the generation pattern of the internal cavity.



(a) Surface SEM observation



(b) Cross sectional X-ray CT observation

Fig. 8 Result of observing small blisters

(1) Cross sectional observation of blister A

Blister A in **Fig. 8** was observed on a microscopic cross section that was made from the surface with Focused Ion Beam (FIB: method of processing a sample surface by squeeze gallium ions finely). **Fig. 9** shows the result of cross sectional observation with FIB. The area appearing dark and homogeneous is a filler.

Cavities were observed at the external periphery of the filler at depths of 30 µm and 60 µm from the sliding surface, i.e. at the interface between rubber and filler. No evidence of the presence of oil was found in this cavity.

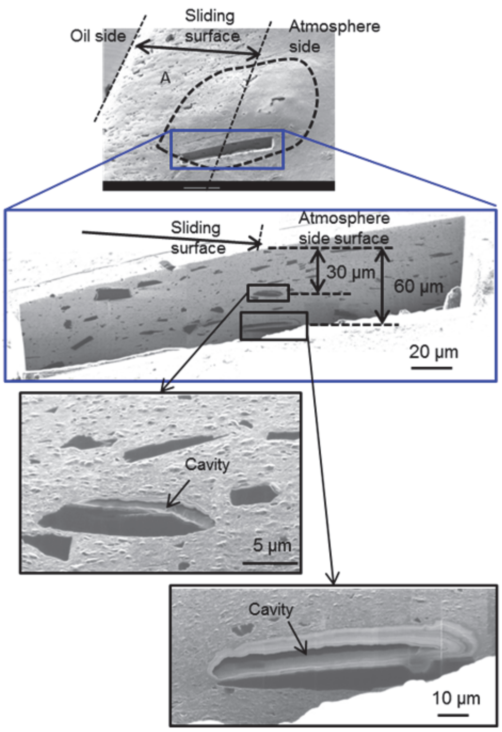
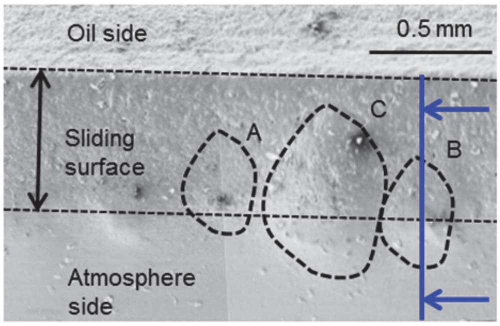


Fig. 9 Result of cross sectional SEM observation of blister A

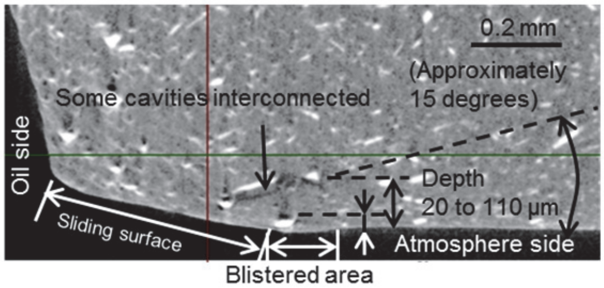
(2) Cross sectional observation of blister B

Next, blister B in **Fig. 8** was observed on the cross section perpendicular to the sliding surface by using X-ray CT equipment. **Fig. 10** shows the result. White spots in the figure are filler.

Like the results observed in **Fig. 9**, cavities were observed at the rubber/filler interface at a depth of several tens of micrometers from the sliding surface. In addition, it was observed that some of these cavities were interconnected. No evidence of the presence of oil was found also in these cavities.



(a) Positions of cross sectional observation



(b) Cross sectional X-ray CT observation

Fig. 10 Result of cross sectional observation of blister B

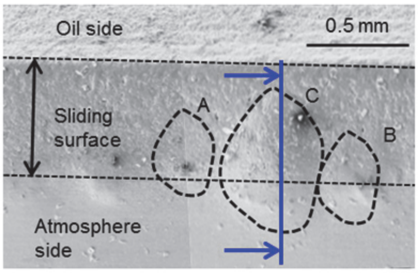
(3) Cross sectional observation of blister C

Blister C, where a cavity having a diameter of several hundred micrometers was found inside in **Fig. 8**, was observed on the cross section perpendicular to the sliding surface by using X-ray CT equipment. **Fig. 11** shows the result. White spots in the figure are filler.

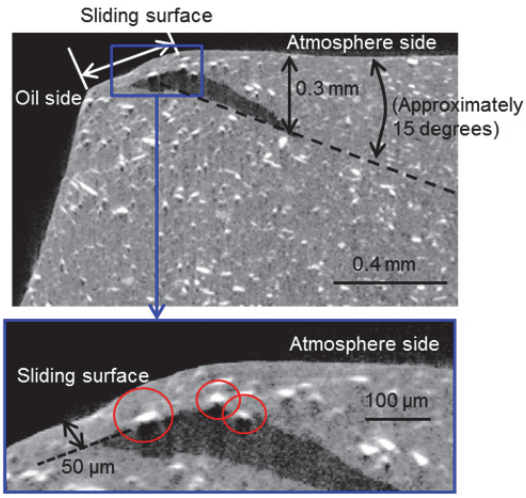
The observation reveals that the cavities were generated from the sliding surface at a depth of approximately 50 µm and are at the same position as the cavity generation position in the smaller blisters shown in **Fig. 8** and **9** (i.e. at a depth of several tens of micrometers from the sliding surface). In addition, since multiple fillers (round areas in **Fig. 11**) existed on the inner surfaces of the cavities, the cavities generated at the rubber/filler interface are presumed to have been interconnected and grown into large cavities.

The cavity spread from it to the atmosphere-side surface in the inward direction on the atmosphere side at an angle of approximately 15 degrees, and the maximum depth of the cavity was approximately 0.3 mm.

Although this cavity was filled with oil, it could not be determined whether the sliding surface interconnected with the inside of the blister.



(a) Positions of cross sectional observation



(b) Cross sectional X-ray CT observation

Fig. 11 Result of cross sectional observation of blister C

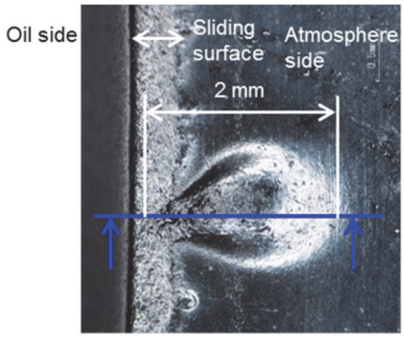
3.3 Detailed Observation Results of Large Blister Samples

A large blister sample of a blister size of 2 mm was observed in detail. In our experiences, the blister of this size was often full of oil inside, and it was confirmed that the oil was filled inside also in this observation. In addition, pushing the bulge of this blister causes oil to bleed on the sliding surface; thus, the sliding surface and the inside of the blister may have been interconnected.

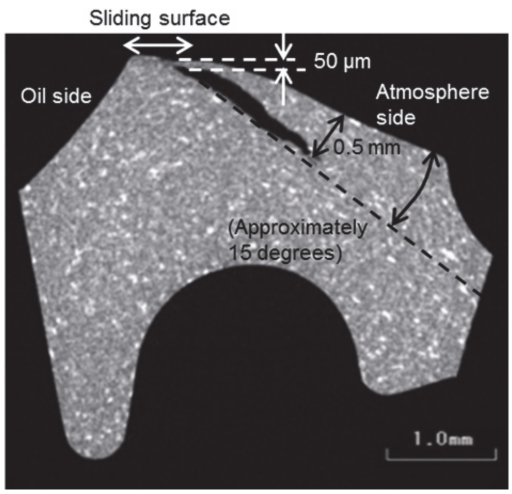
Fig. 12 (a) shows the appearance of the blister. **Fig. 12 (b)** shows the result of observing the blister on the cross section perpendicular to the sliding surface by using X-ray CT equipment. White spots in the figure are filler.

This figure shows that the space inside the blister is pushed out toward the surface at the atmosphere side to form a cavity, so that it is in the form of a projection on the surface.

In addition, in the section immediately under the sliding surface, the depth at which the cavity was generated was approximately 50 µm from the sliding surface like the small blister described above, and the blister had cracks spread inside at an angle of approximately 15 degrees from the atmospheric side surface.



(a) Appearance and cross sectional observation



(b) Cross sectional X-ray CT observation

Fig. 12 Result of observing a large blister sample

3.4 Summary of Blister Generation Mechanism

The process from the blister generation to the growth can be divided into three stages, considering the mechanism of blister generation from the observation results of blisters generated in oil seals used on a machine body.

(1) Generation of starting point of cracking

Generation of cavities around the filler inside the rubber immediately under the sliding surface causes minute blisters to be generated. A small cavity serves as the starting point of the cracks inside the rubber.

The possible causes of generation of a cavity around the filler include a tensile strain field generated when the seal is fitted to the shaft and the lip is pressed and the effect of a tensile strain field resulting from friction by rotation of the shaft.

(2) Crack propagation

The crack starting point cavity around the filler in item (1) interconnect with others, thereby causing the blister to grow.

The possible causes of the propagation of the crack include the effect of the tensile strain field due to the operating condition (e.g. drain pressure fluctuation), in addition to the effect of the tensile strain field mentioned previously.

(3) Crack expansion

When the crack propagates to the surface, the inside of the crack interconnects with the sliding surface and the oil flows into and fills the inside of the blister.

In this case, the inflow of oil may also generate a driving force to push out the crack cavity.

Fig. 13 shows our new hypothesis of the blister generation mechanism as discussed from the present observation results.

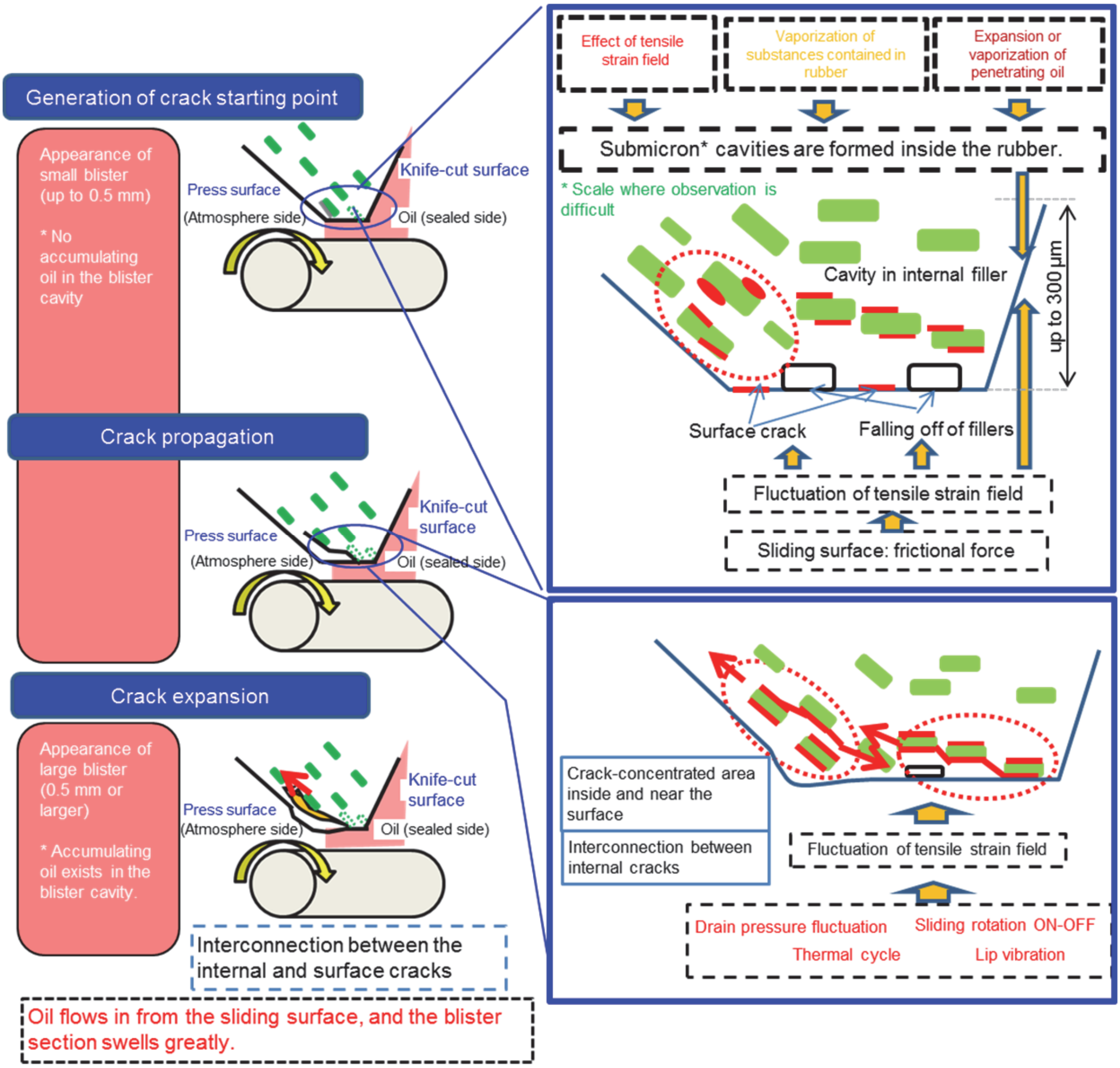


Fig. 13 New hypothesis of the blister generation mechanism

4. Conclusion

We systematically investigated blisters in terms of the blister size and observed the process from the blister generation to the growth for the oil seals which were actually attached to and used on a machine body and on which blister generation was observed.

This study showed that the blister generation and growth are closely related to the blister and propagation of cracks in the rubber, unlike the mechanism considered conventionally.

In order for an oil leak to occur from the oil seal due to blistering generation, the blister needs to grow large. This study, however, did not reach the clarification of the driving force of crack generation and propagation inside the rubber required for the growth of blisters.

From now on, we aim to clarify the driving force of crack propagation in rubber by CAE analysis and bench testing and prevent the oil leak from oil seals caused by blister generation.

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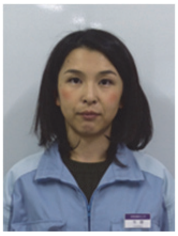

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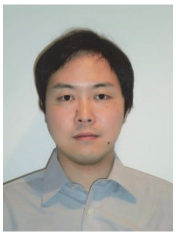

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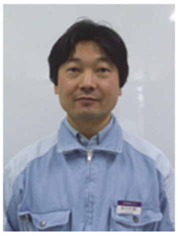

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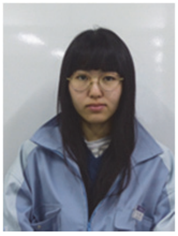

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[A comment from the author]

We were able to reveal the blister generation mechanism through the present study, but could not clarify the driving force of the generation. In the future, we will grapple with this driving force, and in addition to preventing oil leaks by blisters, we will work to make it possible to propose the oil seal optimal for each component.