Technical paper

The Generation Mechanism of Blisters Formed on Oil Seals for Construction Machinery (The Second Report)

Yoshimi Konno

Tetsu Nagata

Akiko Konishi

Hiroshi Yamamoto

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 the previous report (Vol. 62, No.169), we estimated the generation mechanism of blisters which occurred in oil seals by investigation in detail.

In this report, we have reported results of verifying the estimated mechanism by experiment and observation, including other factors which we could not find out in the previous report.

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. Construction machinery is equipped with many components having rotating shafts such as an engine, a hydraulic pump and motor, and a transmission, and various types of oils encapsulated in them are sealed with oil seals.

Nevertheless, the sealing action of such oil seals sometimes degrades while in use, which causes oil leaks from the components. If that occurs, the oil may leak to the outside, or in the worst case, the components themselves may stop operating properly. Therefore, oil seals are 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, reversal of the lip, and deterioration of the lip rubber material. In particular, the oil leak faults due to bumps called blisters which are generated on the atmosphere side at the seal lip tips, as shown in **Fig. 1**, have been observed since before. 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.

In the previous report, [1] we dealt with the oil seals which were actually mounted and used on a construction machine and on which blister generation was observed, systematically investigated them in terms of the blister sizes and observed the process from the generation of blisters to their growth in order to study this blister generation mechanism.

The study result has showed that the generation and propagation of cracks in the rubber are closely related to the generation and growth of the blisters on the oil seals for construction machinery, unlike the conventionally considered mechanisms. [2] [3] [4]

This report presents the results of our attempt to validate the driving forces for the generation and propagation of internal cracks in the rubber as shown below.

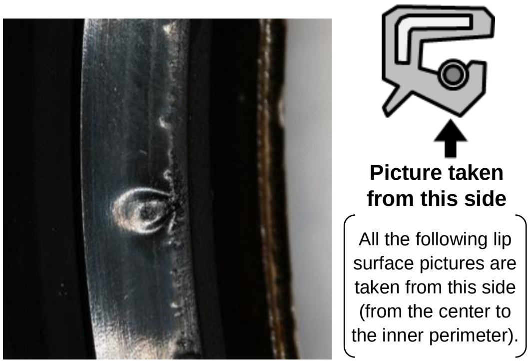


Fig. 1 Example of a blister generated on an oil seal [1]

2. Blister Generation Mechanism

It was inferred in the previous report that the process from the generation to the growth of the blisters on the oil seals for construction machinery could be roughly divided into three stages, considering from the observation results of blisters generated in oil seals used on a construction machine (refer to **Fig. 2**).

(a) Generation of starting point of cracking

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

(b) Crack propagation

The crack starting point cavities around the filler interconnect with each other, thereby causing the blister to grow.

(c) 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.

However, the driving forces for the generation and propagation of cracks in the rubber which are required for the generation and growth of blisters were not made clear, such as why “the cavities around the filler ((a) Generation of starting point of cracking)” are generated which serve as a starting point of blisters and why “the swelling of blisters ((b) Crack propagation and (c) Crack expansion)” occurs to such an extent that it causes oil leaks from the oil seals.

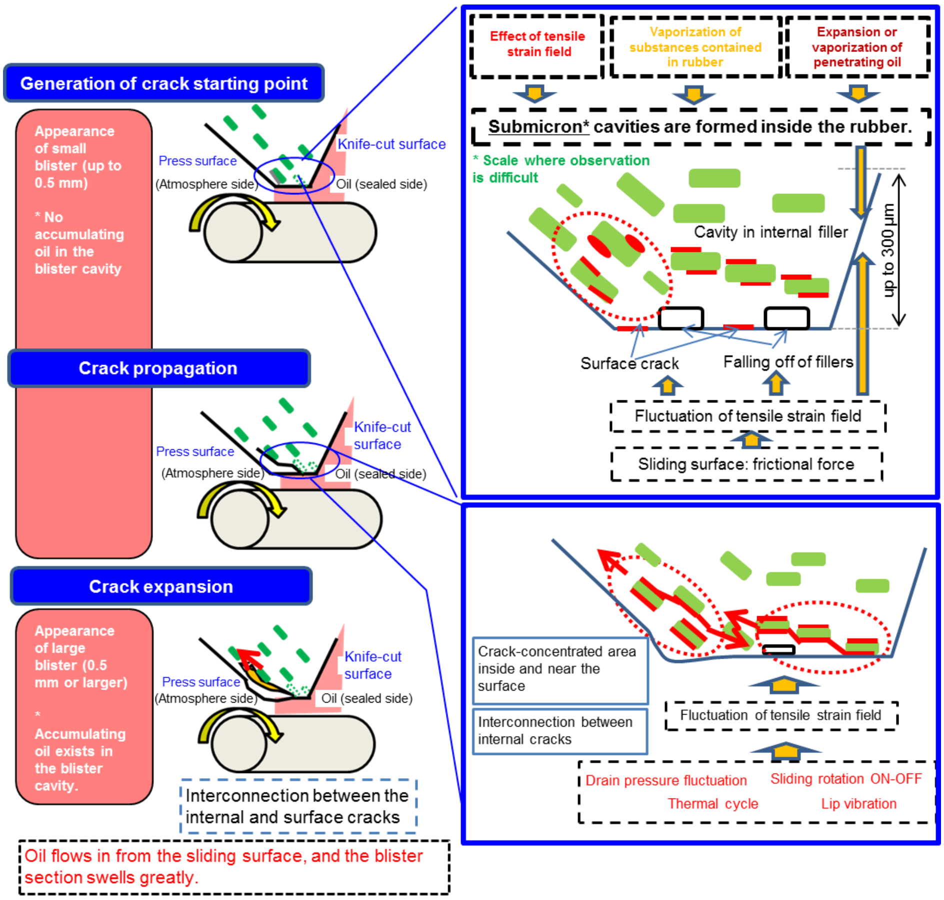


Fig. 2 Generation mechanism of blisters formed on oil seals for construction machinery [1]

3. Verification of Mechanism

3.1 Generation Factors of Cavities Around Filler

Though it was inferred in the previous report that “the cavities generated around the filler serve as a starting point of the cracks inside the rubber”, the reason for generation of such cavities could not be identified. According to the conventionally proposed mechanism, it was believed that “the repeated penetration and coagulation of vaporized oil into the rubber led to blister generation”. However, no oil has been found to be accumulating inside any small blisters no larger than 0.5 mm in the product investigation until today.

We performed verification by later described thermal cycle test using the oil seal units, considering that the repeated penetration (diffusion) and coagulation of even the air into the rubber will cause generation of a blister starting point similarly. **Table 1** shows the test conditions.

Verification was performed by providing the test seals with a thermal cycle in a dry environment.

Table 1 Conditions for thermal cycle test

Thermal Cycle Conditions	Heating	Held at 140 °C for 2 hours (Air atmosphere furnace)
		ΔT≒120 °C
	Cooling	Water cooling (Room temperature: Approx. 20 °C)
Number of cycles (in cycles)		12

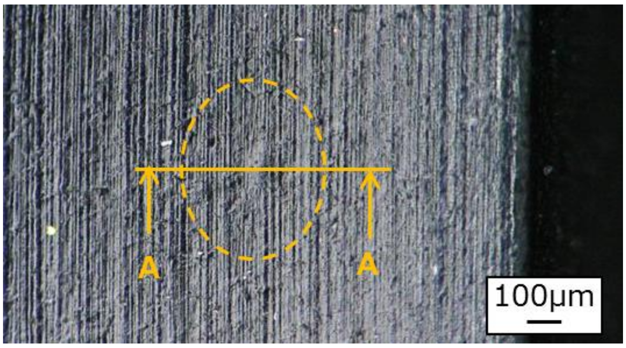


Fig. 3 Oil seal lip surface after testing

A minute swelling was found on the atmosphere-side surface of the oil seal’s main lip after testing (refer to **Fig. 3**). In order to check the inside of this swelling, a minute section was fabricated from the surface, using a Focused Ion Beam (“FIB”) and observed. **Fig. 4** shows the observation result. Cavities were recognized (arrowed) around the fillers (parts looking black and uniform) near the surface. It is inferred that the air diffused inside the rubber while held at a high temperature must have been coagulated in the cavities without being able to go outside during cooling.

Thus, we have confirmed that a thermal cycle is one of the factors for the cavity formation around the fillers which serve as a starting point of blisters.

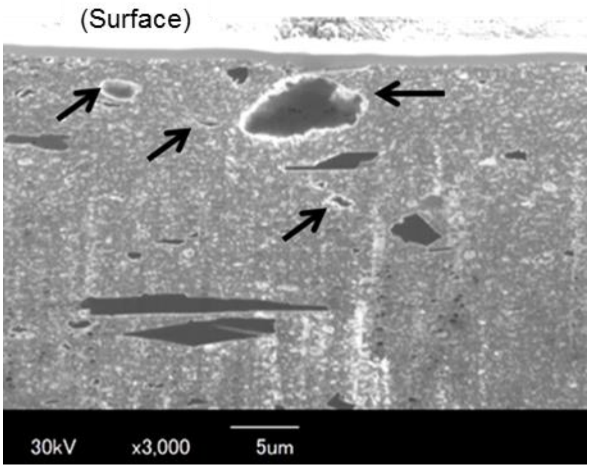
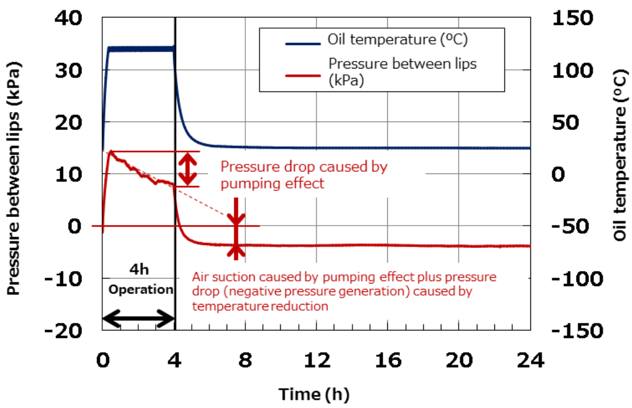


Fig. 4 Cross section of swollen surface of lip (Section A-A in Fig. 3)

3.2 Driving Forces for Forming Blister Swelling

We set up the later described hypothesis and performed verification on the driving forces for forming blister swelling to such an extent that would affect the oil leaks from oil seals.

An oil seal keeps oil inside because fluid flows from the atmosphere side to the sealed fluid side due to the pumping action during rotation. However, if there is any dust lip, the air between lips is also sucked into the sealed fluid side, which lowers the pressure. And then, as it stops and cools down, the pressure is further lowered, and a negative pressure was found to be generated between lips (refer to **Fig. 5**).



Rotational speed: 2,050 rpm
Internal pressure: 0.05 MPa
Sample oil: Genuine Power Line Oil TO10 (SAE10W)

Fig. 5 Results of lip-to-lip pressure measurement test

Therefore, we set up a hypothesis as shown by the schematic diagram in **Fig. 6**. When the temperature falls after continuous operation at a high temperature, a negative pressure will be generated between lips. We considered that this negative pressure might act on the atmosphere side of the main lip, pull the lip’s surface layer and expand the cracks inside the seal, which would cause the blister swelling to grow and the oil to flow into the inside.

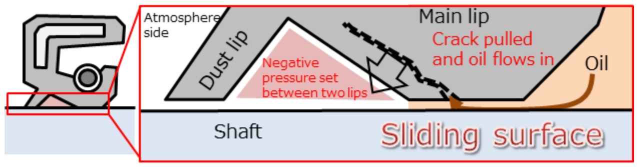
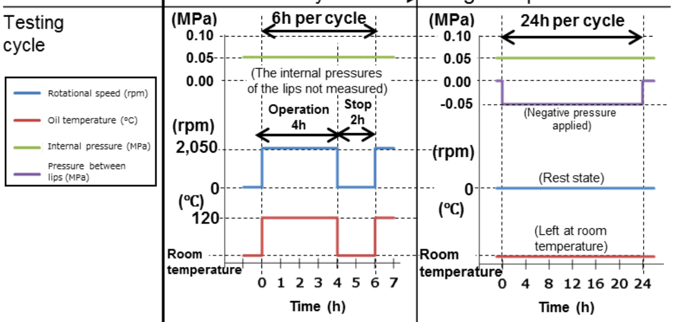


Fig. 6 Schematic diagram showing attached area of oil seal with dust lip

Hence, a test forcibly applying a negative pressure between the lips was performed on the assumption of the pumping action during operation of a construction machine plus a pressure drop caused by cooling the whole component during non-operation.

The testing procedure was as follows: A cycle operation at a high temperature was performed in a "preliminary test" first so that the sliding surface of the oil seal might be formed, simultaneously causing a crack starting point to grow inside the rubber. Subsequently, the sliding surface formed as stated above was forcibly cut in the blister crack propagation direction with a cutter. The oil seal with such a sliding surface was mounted on the shaft, and the pressure between lips was set to and held at a negative pressure (**Table 2**).

Table 2 Blister swelling verification test conditions

	Preliminary test	Negative pressure test
Testing cycle		
Number of cycles (in cycles)	8	1
Sample oil	Genuine Power Line Oil T010 (SAE10W)	

When the test seal was checked after testing, swelling like a blister was generated in the cut section on the lip surface (refer to **Fig. 7**), and when pressed with tweezers, oil came out of the inside. **Fig. 8** (a) shows the cross section after cutting this swelling area of the lip with a cutter. It can be confirmed that the cut cavity is wider, affected by a negative pressure, compared with the cross section of another sample prior to the negative pressure test which is shown in **Fig. 8** (b). Though we were not able to check the crack propagation in this study, it is presumed that if the time is increased, the crack will be propagated.

Thus, it was made clear that a negative pressure generated on the atmosphere side of the main lip was one of the factors for promoting the blister growth.

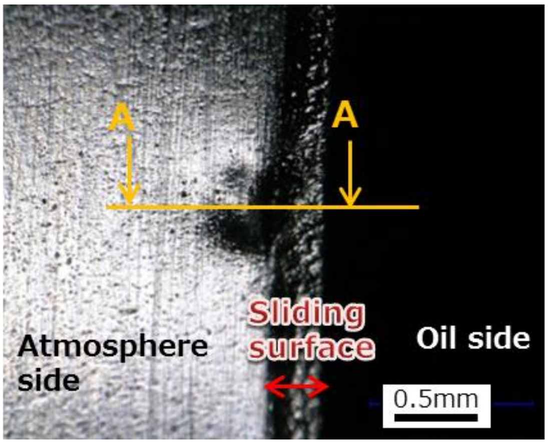
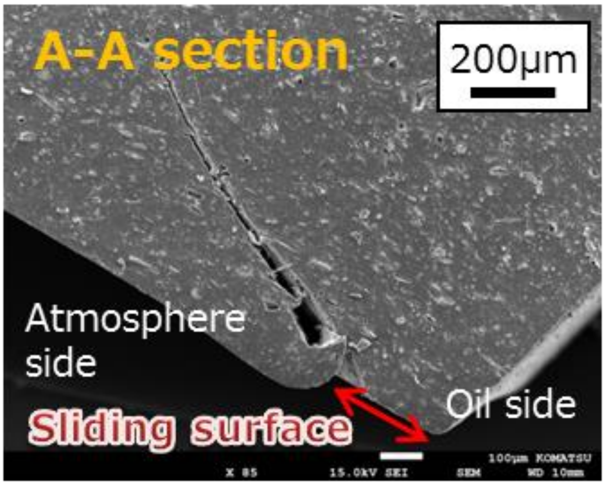
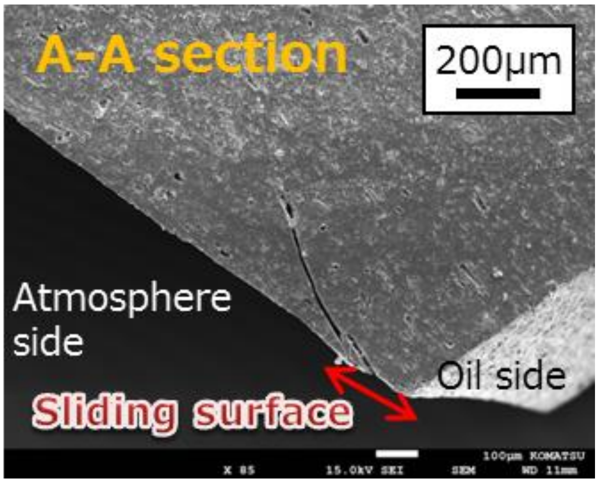


Fig. 7 Lip surface after verification test (Swelling generated in the cut section)



(a) Section A-A after negative pressure test



(b) Section A-A of another sample prior to negative pressure test

Fig. 8 Cross sections of swelling area on lip surface after verification test

3.3 Summary of Blister Generation Mechanism

It was found in the previous report that the generation and propagation of cracks in the rubber were closely related to the generation and growth of the blisters. In this report it was found that addition of the following operating environment factors would promote the generation and growth of the blisters.

1) Generation of starting point of cracking
<Cavities around the filler>
Diffusion and coagulation of the air into the rubber which are caused by thermal cycle
<Cracking on sliding surface>
Tensile force caused by sliding torque

2) 3) Crack propagation and inflow of oil
Tensile force caused by negative pressure generated on the atmosphere side of the lip

4. Verification of Estimated Mechanism by Product Investigation

4.1 Mechanism Estimation by Product Investigation of Seals with Blisters

The product investigation was conducted on the oil seals on which blisters were generated in a component bench test. **Fig. 9** shows the summary of the generated blisters. When the inside oil accumulating was checked for by making a cut in each blister, no accumulating oil was identified inside the blisters except for the largest one (size 0.9 mm) (refer to **Fig. 9**).

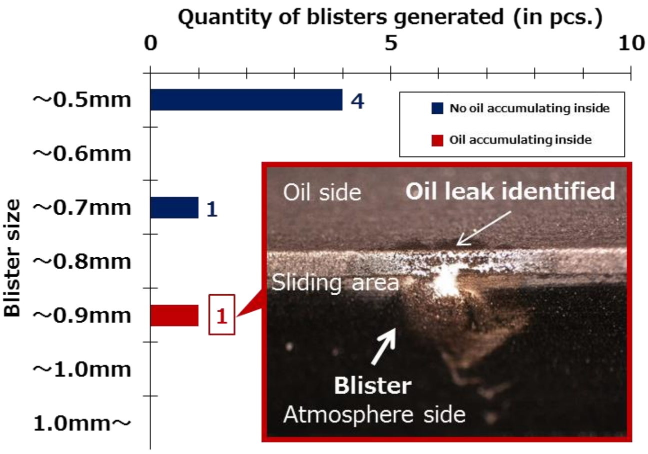


Fig. 9 Summary of blister generation on oil seals in component bench test

When the actual products were investigated in detail, such faults as the roughness of the sliding surfaces near blisters and the falling off of fillers were identified (**Fig. 10**). That can be considered to have been caused by the possibility that the sliding surface may not have been provided with sufficient amount of lubricating oil. It was inferred that the sliding torque (friction coefficient) was increased under this poor lubrication conditions, which caused the cracks on the surface and in the inside (**Fig. 11**) to be propagated, finally leading to their interconnection with surface cracks and subsequent inflow of oil.

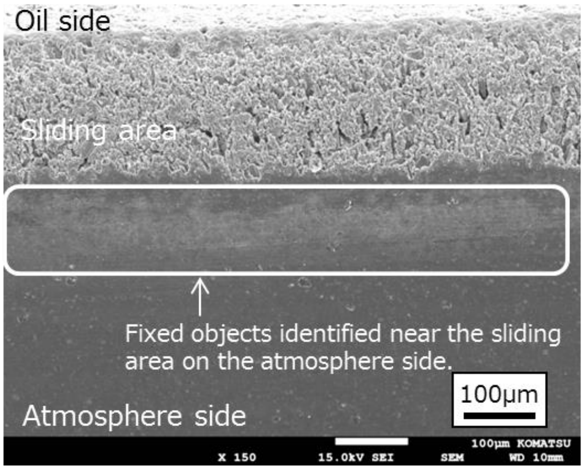


Fig. 10 Lip surface near blister

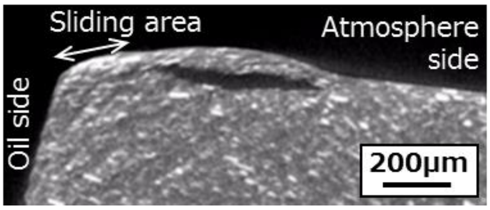


Fig. 11 X-ray CT image of blister section (Blister size: 0.7 mm)

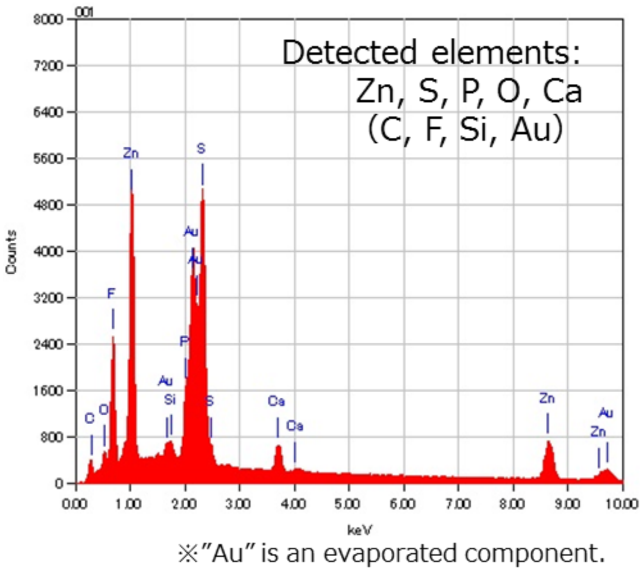


Fig. 12 Results of elemental analysis (energy dispersive X-ray spectrometry (EDS)) of fixed objects identified on lip surface near blister

Besides, an elemental analysis was conducted on the fixed objects identified near the sliding area on the atmosphere side (refer to **Fig. 10**) with an energy dispersive X-ray spectrometer (EDS). The result indicated that the major components of the fixed objects were oil additive components such as Zn, S and P (**Fig. 12**). Thus, from the fact that the fixed objects derived from oil additive components were generated, it can be inferred that the seals were locally exposed to a high temperature.

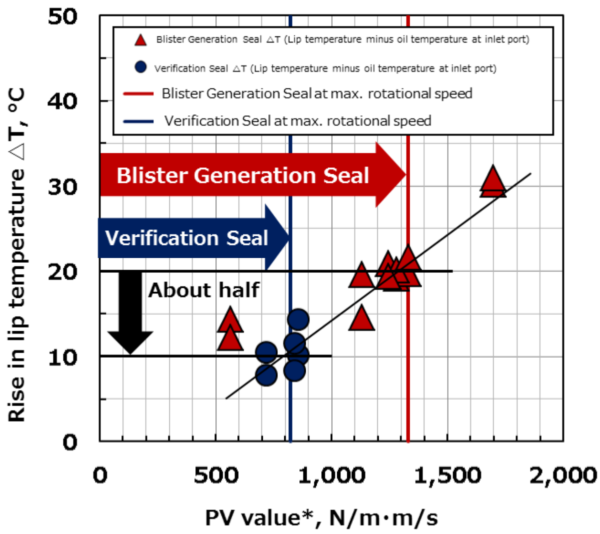
4.2 Verification of Blister Generation Mechanism

Assuming that the main factors for blister generation in this case were the heat generation caused by sliding torque and the negative pressure acting on the atmosphere side of the main lip, comparison and verification tests were performed on single-lip seals (hereinafter “Verification Seals”) that generate no negative pressure while reducing the tension by 40% to reduce the sliding torque.

First, the “Blister Generation Seal” and “Verification Seal” were integrated into the same component sequentially, and the lip temperature was measured when the rotational speed (rpm) was changed for each. **Fig. 13** shows the results summarized with “PV values (the product of seal’s tension and circumferential speed)” and “rises in lip temperature”.

Since the heat generated by sliding (∝, rise in lip temperature) is proportional to the product of friction coefficient and contact load (bearing), and circumferential speed, the inclination of the graph corresponds to the friction coefficient. It is considered that there is no significant difference between the lubricated conditions of the oil seals because they lie on almost the same approximate lines. Hence, we have found that the rise in lip temperature can be reduced by half if the tension is reduced (**Fig. 13**).

A component bench test was similarly performed on the Verification Seal. As a result, it was confirmed that only one minute blister was generated, which indicated that the generation and growth of blisters were suppressed.



*Product of tension per unit circumferential length, P (N/m), and circumferential speed V (m/s)

Fig. 13 Measurement results of lip temperature rises in component

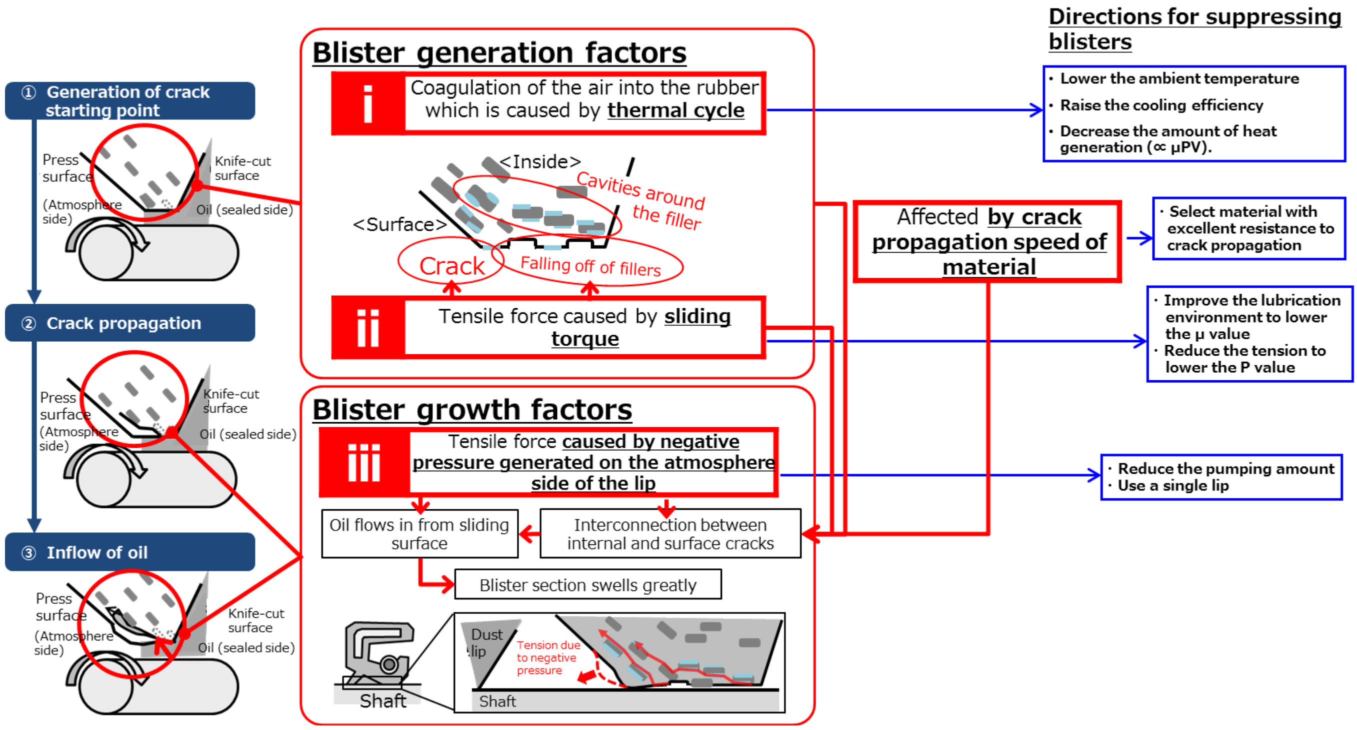


Fig. 14 Blister generation and growth mechanism and directions for suppressing blisters

5. Conclusion

In this study, we were able to clarify the driving forces for the generation and propagation of cracks in the rubber which were required for the generation and growth of blisters, which led to the directions for suppressing the blisters as shown in **Fig. 14**.

Moreover, the countermeasures against the blisters were incorporated into the oil seals, and it was confirmed by the bench test on the actual machinery that blister generation was suppressed.

Thus, it was made clear that the severe use specific to construction machinery resulted in the driving forces for the generation and propagation of blisters, which led to blister generation. Consequently we have confirmed that it is important to well understand how the components are used and the operating environment and choose oil seals accordingly.

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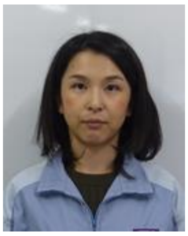
Introduction of the authors



Yoshimi Konno
Joined Komatsu Ltd. in 2008.
Material Technical Center,
Development Division

Tetsu Nagata
Joined Komatsu Ltd. in 2002.
Material Technical Center,
Development Division

Akiko Konishi
Joined Komatsu Ltd. in 1991.
Material Technical Center,
Development Division

Hiroshi Yamamoto
Joined Komatsu Ltd. in 1987.
Material Technical Center,
Development Division

[A comment from the authors]

We were able to clarify the outstanding issue in the previous report, which was the driving forces for the generation and growth of blisters. Therefore, we will propose the oil seal optimal for each component and thereby work to drastically prevent a blister growth that will cause oil leaks.