FDR（Flat-die　Rheometer）vs　MDR (Moving-die Rheometer) 2025.9.2 M..Hasumi

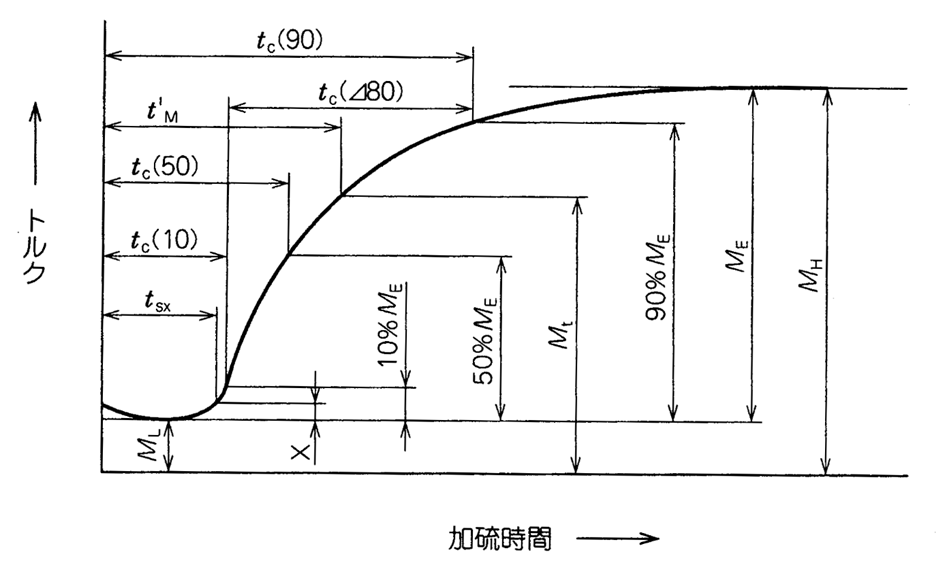
1. Purpose and Overview of the Testing Machine

In the rubber manufacturing process, compounding, mixing, building (forming), and curing are essential processes. A rheometer (curemeter) is a device that measures curing behavior, but since curing behavior is influenced by compounding and mixing, it is also a device for managing those processes.

There are FDR (Flat-die Rheometer) and MDR (Moving-die Rheometer). FDR was developed by the Japanese company JSR(now ENEOS), and it is manufactured by three companies: ENEOS (JSR), Ueshima, and Toyo-seiki. It is the mainstream in Japan, but it is not widely exported overseas, where MDR types are predominant. MDR is a product name of Monsanto (now Alfa-Technologies), and many manufacturers other than Alfa-Technologies produce similar products, making it the mainstream in cure-testing machines; however, there are various issues. This will be discussed later.

In either device, uncured rubber samples are placed in sealed circular chambers (dies) , and pressure is applied. One die is subjected to torsional vibration, while the torque transmitted to the other die is measured. As the dies are heated to 100-230°C, the rubber cures, and as it hardens, the transmitted torque increases. By graphing the curing time and torque changes, known as the curing curve, the optimal curing temperature and curing time can be determined.

The frequency of the torsional vibration for both is 100 cpm. The torsion angle is FDR (±1 degree) and MDR (±0.5 degrees or ±1 degree).

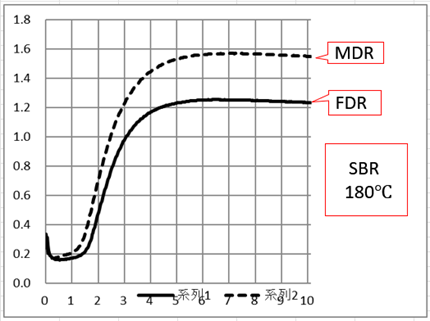
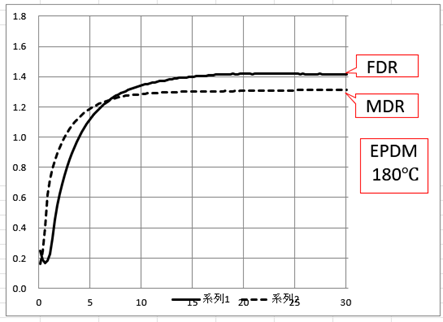


Generally, ML, MH, tc(10), tc(90), and tc(Δ80) are used as management parameters.

By analyzing curing-curve with PC, we can obtain viscoelastic properties (DMA) such as dynamic elasticity, dynamic viscosity, complex elasticity, and tanδ. This can be measured similarly for both FDR and MDR, but the numerical results will not match. The reason for this discrepancy is due to the differences in the shape and dimensions of the dies, which will be discussed next.

1. Vulcanization Curves of FDR and MDR

Two compounds (SBR & EPDM) were tested using FDR and MDR.

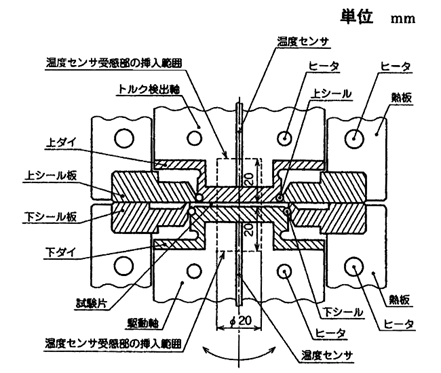
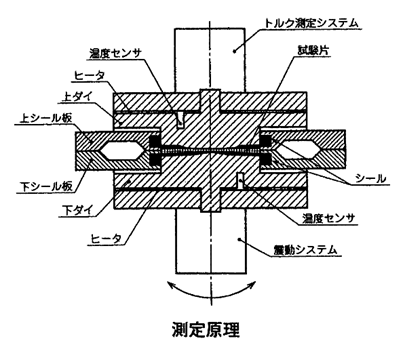
SBR EPDM

As shown in the figure, the curing curves are very similar. This is to be expected, as rubber will reach the same vulcanization state if vulcanized at the same temperature and for the same duration. If the inspection purpose is simply to be able to plot the vulcanization curve and confirm that it is always the same without abnormalities, either rheometer can be used.

1. Disadvantages of MDR : Unclear shape and dimensions of dies

The difference between FDR and MDR lies in the profile and dimensions of the dies. FDR uses parallel dies that are split into upper and lower parts, with a die spacing of 2.0mm and lattice grooves carved to a depth of 0.5mm. The shape and dimensions of FDR dies are precisely specified as JIS K6300-2 Method-A. The three manufacturers of FDR (ENEOS, Ueshima, Toyo-seiki) adhere to this standard, which ensures that measurement values are reproducible and yield the same curing curve.

On the other hand, MDR consists of conical (corn-shape) bicornical dies for both the upper and lower parts. The center is thin while the edges are thick. It is categorized as JIS K6300-2 Method-B, and while a cross-sectional diagram is provided, only the cross-sectional shape and the taper angle formed by the upper and lower dies are described, with no dimensions specified. Similarly, ISO 6502 and ASTM 6601-02 also only provide the cross-sectional shape without specifying dimensions. As a result, it is unclear whether the Rheometers from various manufacturers that mimic the α-Technologies MDR are identical to the original α-Technologies MDR. It is obvious that if the diameters or gaps of the upper and lower dies differ, the transmitted torque values will not be the same, thus measurements from imitation MDRs cannot be guaranteed.

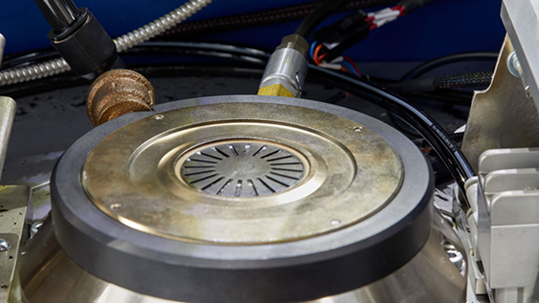
FDR MDR



It seems that the recent MDR has become a radial groove with 20 channels. (Almost no users are aware of this.)

Since the shape and profile of the dies are not standardized, it is questionable whether reproducibility is guaranteed even among α-Technologies' products. Moreover, it is unlikely that other companies' rheometers that mimic the MDR will yield the same results as the MDR. This is a significant drawback of the MDR.



Recently, the grooves of α-Technologies RPA are 20 in number and of the same length.

1. Disadvantage of MDR : Uneven temperature

MDR is a bicornical die, so the gap is thin in the center and thick at the periphery. The rubber in the center cures quickly, while the rubber in the surrounding area cures slowly, leading to insufficient curing of the rubber in the outer region. As you move away from the center, the thickness increases and the volume grows, thus the insufficient curing in the peripheral area has a significant impact. The dies of MDR are heated with a film heater, but there are no heaters on the sides. Because of this, heat radiates from the sides, causing the die temperature in the outer region to drop, which further exacerbates the lack of curing.

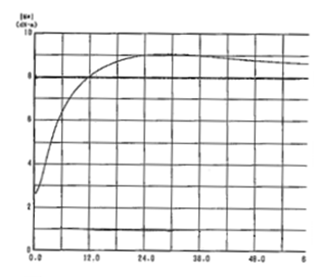
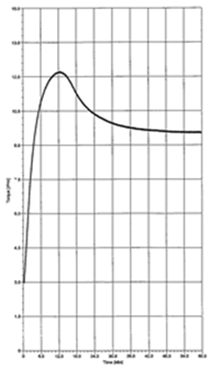
It is completely strange that, although it is a tester for observing the progress of curing, the state of curing in the sample is not uniform. I cannot understand why it is shaped this way. The dies of FDR are parallel circular discs of 2mm, and also have heaters on the sides (4-heater drive) to prevent heat radiation, maintaining both uniform temperature and uniform curing state.

1. Disadvantage of MDR : Slip of rubber

As curing of the rubber progresses, a slip occurs between the die and the rubber. MDR is designed with radial grooves (usually 24) to prevent slip, but it may not completely prevent it. FDR has fine lattice grooves, so slip does not occur.

FDR (Flat die) MDR ( Bicornica die)

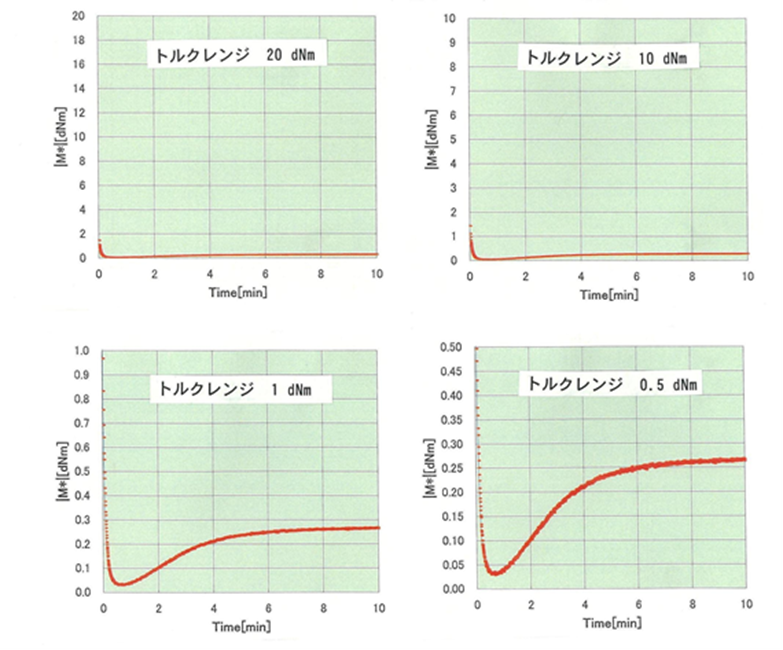
FDR MDR

The above image shows an example of slip of a tire curing bladder (Butyl rubber).

It is clear that slip does not occur in FDR, but MDR experiences slip, resulting in reduced torque.

1. Advantages of FDR : It can measure low viscosity rubber.

While there are hard rubbers that tend to slip, there are also very soft rubbers.

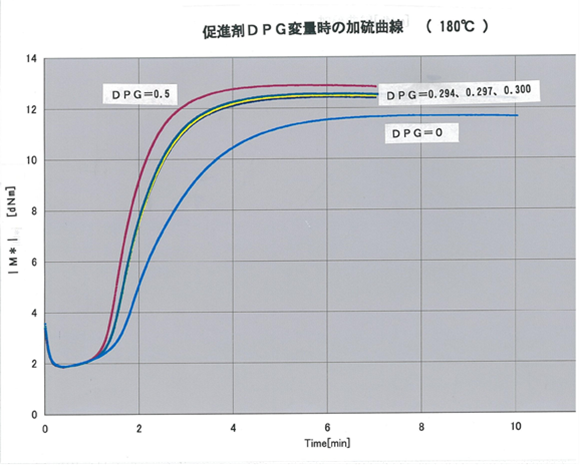


The figure shows the curing test of sealant rubber that is applied to the inner surface of passenger car tires. The sealant is made of a very soft formulation of butyl rubber to prevent air leaks even when a nail penetrates. Under normal conditions, the torque hardly increases during the curing test, making it difficult to analyze the curing behavior. After adjusting the torque scale of the FDR to ranges of 20dN, 10dN, 1dN, and 0.5dN, the curing behavior became clear. Such soft rubbers are not uncommon in non-tire applications like sponge rubber and silicone rubber.

In fact, it is possible to increase the sensitivity and plot the vulcanization curve through PC operation even in MDR. However, the curves drawn in MDR have greater variation compared to those of FDR.

7. Advantages of FDR: Able to detect even minute differences in formulations.

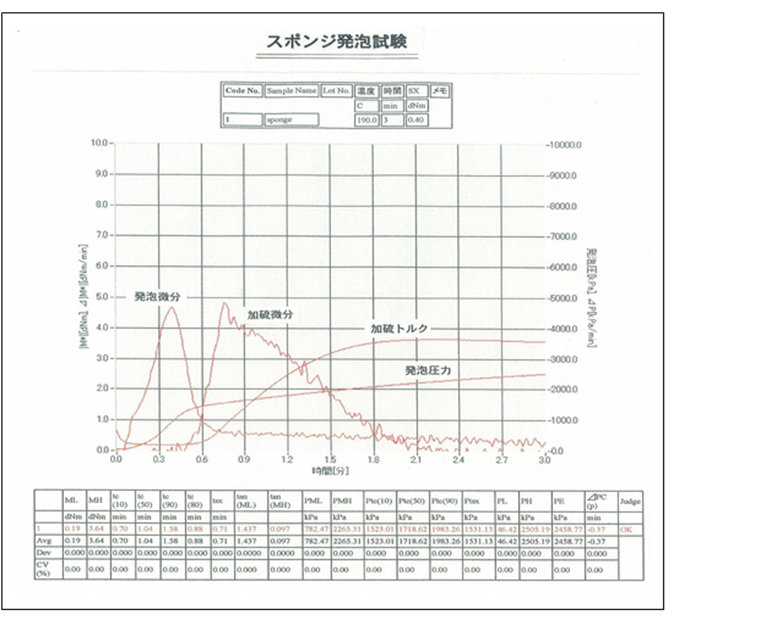
Rubber contains various ingredients. Among them, accelerators speed up vulcanization even in small amounts, so it is essential to measure their weight accurately. Mistakes with accelerators carry the risk of a fatal scorch.



The figure shows the testing of a small amount of Accelerator (DPG) added to SBR 100g at 0.3g, examining cases where DPG is 2% (0.006g) and 1% (0.003g) less than intended. Such minor discrepancies are usually considered negligible. For comparison, tests were also conducted without DPG (DPG=0) and with an excess of DPG (DPG=0.5). As a result, even with reductions of 1% and 2%, the vulcanization curves overlapped, showing no visible differences. However, statistical analysis proved that there were differences. Since the FDR has extremely high measurement accuracy, it can sensitively detect such minor differences, contributing to quality stability.

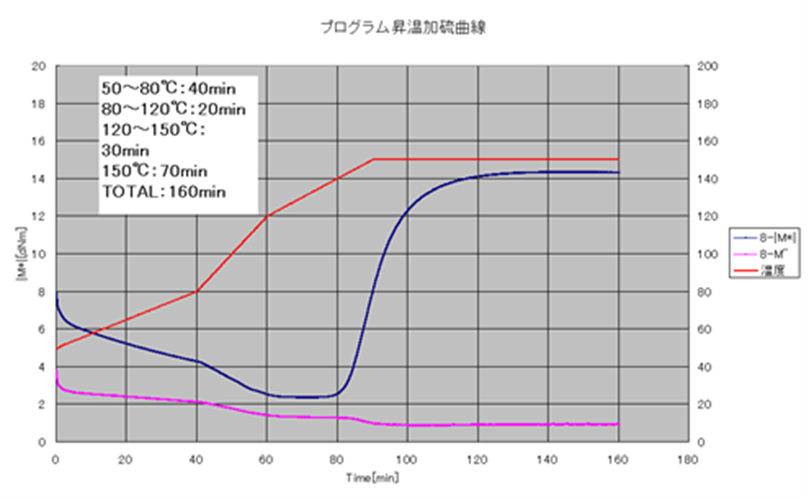
1. Advantages of FDR : Measurement of Foamed Rubber (Option)

Foamed rubber (foamed rubber, sponge rubber) requires careful timing of vulcanization and foaming. If vulcanization occurs too early, it will harden before foaming can take place, resulting in insufficient foaming; conversely, if vulcanization is too late, the foaming gas will escape, leading to shrinkage. Both vulcanization and foaming must progress simultaneously in a balanced manner. FDR can measure foaming as an option. A sensor that measures foaming pressure is attached to the dies, allowing simultaneous viewing of the progress of vulcanization and foaming on the same screen. Although MDR can also measure foamed rubber as an option, Ueshima's PC software visually displays the progression of vulcanization and foaming, assisting in the development of the compounder.



1. Advantages of FDR : Temperature Elevating Test

For products with thick rubber like large tires or large vibration-damping rubber, it takes time for the internal temperature to rise. To verify whether the rubber has been sufficiently vulcanized internally, products were cut open to measure the degree of vulcanization and tensile strength, which is not only very labor-intensive but also requires scrapping valuable products.The FDR Temperature Elevating Test allows for a programmed rise in internal temperature and controls the dies' temperature, thus enabling the reproduction of the vulcanization state within the product.



This vulcanization graph clearly shows that below 140℃, the rubber only softens and does not vulcanize, but once it reaches 140℃, vulcanization begins and completes in about 40 minutes. The functionality of temperature-increasing vulcanization is not present in the MDR.

1. Advantages of FDR : Compactness

The UESHIMA FDR is the smallest and most compact among rheometers worldwide. It is also the lightest in weight. It does not require a large space, so it can be placed anywhere in the lab. A sturdy working bench is not necessary. It can be freely laid out as long as there is electricity and air.

The size and weight of FDR and MDR are documented in another source.

1. Advantages of FDR　: 　It has an exhaust system.

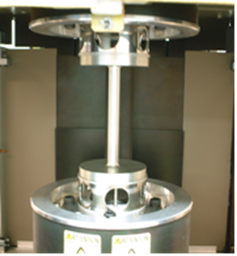
Rubber contains various ingredients that can volatilize and decompose at the curing temperature, producing gases and fumes. Among these, there can be harmful fumes such as chlorine gas. The FDR is equipped with an exhaust fan that discharges fumes to the rear as soon as curing is complete and the dies open, protecting the operator's health.

　　Such matters are often neglected as they are unrelated to the performance of testing equipment or the accuracy of test results, but they are important for protecting the health of workers and ensuring their comfort.

1. Advantages of FDR　: 　Easy Calibration

The rheometer is a precision measuring instrument that requires daily calibration. FDR calibration includes Electrical Calibration and Dynamic Calibration. Electrical Calibration is done as a daily control without using any special tools and can be completed in a few seconds. Dynamic Calibration is performed using a dedicated jig, and a skilled operator can complete it within 15 minutes. MDR is also conducted using a similar jig, but the work is more complex and requires 2 hours.

FDR reduces the burden on operators and increases machine uptime. Although it is often overlooked as it is unrelated to the performance of testing machines or the accuracy of data, it is important when used for the inspection section.

　Dynamic calibration of FDR

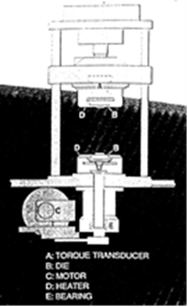
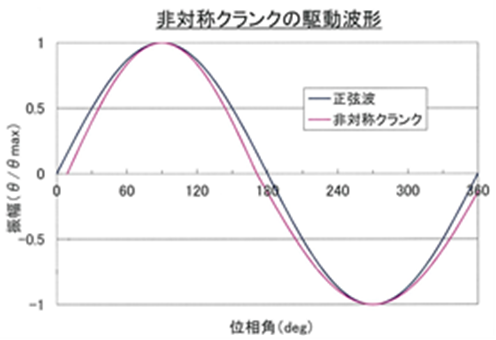
1. Advantages of FDR : Data Storage

Measured data is saved as an EXCEL file on the PC. Results measured at overseas factories can also be sent instantaneously via the Internet and shared. It is possible to compare the vulcanization curves from the prototype with the updated vulcanization curves, or to compare with the pre-set gate values to determine OK/NG.

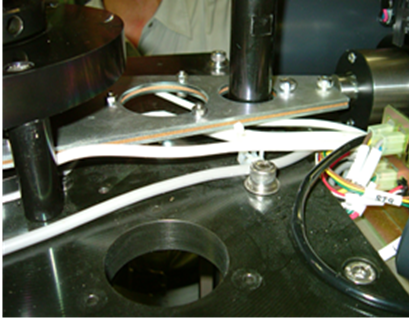
1. Advantages of FDR　: 　FDR as a DMA

The Rheometer (FDR, MDR) is a testing machine used to observe the progress of vulcanization; however, it does not observe the chemical reaction of vulcanization itself.d

It measures changes in visco-elastic behavior due to vulcanization. In other words, it is similar to DMA. DMA measures the visco-elasticity of vulcanized rubber but cannot measure unvulcanized rubber. The Rheometer is the only testing machine that can continuously observe the visco-elasticity from the unvulcanized state to the vulcanized state, and even to the overcured state where rubber deteriorates. This capability is extremely important for R&D applications and is used in the study of cross-linking mechanisms.Visco-elastic testing involves applying a sin curve deformation to the dies and measuring the response. The sin curve must be accurate. In general applications, the crank mechanism converts rotational motion into reciprocating motion to vibrate the dies, but a crank does not yield an accurate sin curve, resulting in a slightly distorted curve.

The above figure shows the driving method and waveform of MDR. The true sin-curve should be the blue line, but in the crank method, it becomes a phase-shifted red waveform. FDR creates a perfect sin-curve through corn-drive.

The corn-drive is a mechanism that eliminates the vertical movement of a rotating disk and extracts only the horizontal movement to transmit to the dies.

Only two companies in the world use corn-drive in their rheometers.(Ueshima & ENEOS)

1. Issues with FDR

The FDR does not have an Auto Sampler. Although one was made in the past, it was discontinued due to reliability issues. Tire Makers have a very high number of tests, and while vulcanization tests can take place between 60 to 120 seconds, many rubber companies have operators in their labs, and if the vulcanization testing cycle is between 5 to 20 minutes, an Auto Sampler is not necessary.