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Enhancing Viscosity Quality Testing Accuracy in the Automotive Industry

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Abstract – The present study aims to examine an issue pertaining to the precision of viscosity measurements crucial to the rubber processing industry within the Western side of Romania, where viscosity is being tested using the PREMIER™ MDR MOVING DIE RHEOMETER by Alpha Technologies. Control charts have raised the alarm regarding the consistency of the analysis results, and therefore a root cause analysis has brought to light a mechanical issue of the rheometer for which a solution has been proposed and implemented. Ultimately, the study shows the enhancement of the viscosity quality testing from the initial state identified until the actual situation, after action was implemented and proven to be efficient.

Keywords: Viscosity, Quality testing, Rubber processing, Rheometer, Control chart, Root cause analysis

I. INTRODUCTION

Rubber materials are increasingly widespread in the automotive engineering applications today, playing an indispensable role in various mechanical components such as tires, seals, and hoses (Nafeesa, Azura, 2018). The selection of suitable rubber types is paramount, as they primarily contribute to the elastic properties of the final rubber products. Therefore, two major categories of rubber are used within the industry: natural and synthetic. Natural rubber originates from the milky sap of the Hevea tree, containing a mixture of organic and inorganic impurities (Maláč, 2009). Synthetic rubbers however, they have enhanced properties and are easier to obtain.

Another publication highlights the same information but focusing on tire production. The composition of the tread compound, which directly impacts tire performance, typically comprises natural and synthetic rubbers. Extensive scientific research has been conducted on liquid rubbers (synthetic) as they offer advantages such as reducing the need for process oils in tire manufacturing and enhancing dispersion (Demir, Altundal, Gerengi, Yüksel, 2023).

In a similar approach, other researchers have emphasized the impact of viscosity on silica dispersion and its correlation with the mechanical and performance characteristics of Natural Rubber compounds. Compound viscosity was measured using a viscometer, while filler flocculation and dispersion were monitored through changes in torque and storage modulus at low strain using a rheometer MDR 2000 and DisperGrader (Kamal, Teku, Ahmad, 2013).

Another similar research available is analyzing the viscoelastic characteristics of rubber compounds containing natural rubber and reinforced with carbon black, commonly employed in rubber bearings, are analyzed using various methods. These include the moving die rheometer, compression set tests, and assessments of mechanical properties through cyclic uniaxial compression and shear tests, as well as tensile tests. Additionally, transient tests such as stress relaxation and creep tests are conducted at ambient temperature. The experimental findings from these laboratory examinations on standardized specimens are assessed, can be correlated with the damping properties, and time-dependent mechanical characteristics of rubber compounds utilized in laminated rubber bearings. (Sánchez, Giraldo-Vásquez, Sánchez, 2020). Viscosity testing stands as one of the prevailing procedures executed within the rubber industry today. It serves as a standard method for assessing the viscosity of raw rubbers and characterizing the quality of both natural and synthetic rubber varieties (Maláč, 2009).

Other researchers have addressed the topic of Mooney viscometer testing, as it is probably the most widely used method for measuring the quality of the natural rubber such as Maláč (2009). Various statistical quality control methods can be effectively employed across different applications within the rubber industry, including the viscosity testing control. Statistical quality control, a component of quality control, utilizes statistical techniques for this purpose (Gunaratne, Wijesooriya, Gunaratne, 2005). Within this paper, the use of control charts will be

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presented to show the accuracy of viscosity testing. However, "the decisions made as a result of the analytics process are only as good as the data on which they are based" says an article (Jones-Farmer, Ezell, Hazen, 2014).

II. PREMIER™ MDR VISCOSITY TESTING PROCESS FOR QUALITY CONTROL

Within this study, the quality output of the viscosity testing has been observed at a rubber processing company from the Western part of Romania, where viscosity is being testing using the PREMIER™ MDR MOVING DIE RHEOMETER by Alpha Technologies, firstly introduced in 1989, which boasts an impressive array of features tailored to the company's needs, its user interface includes a touchscreen for settings management and Online Manager for data analysis. The device design incorporates an LED light in the printed logo to indicate the test status (Dick, 2021). In this test, a serrated rotor is rotated within a rubber specimen enclosed within a sealed, pressurized chamber, as depicted in Fig. 1 (Maláč, 2009).

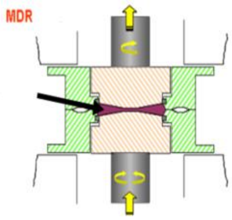
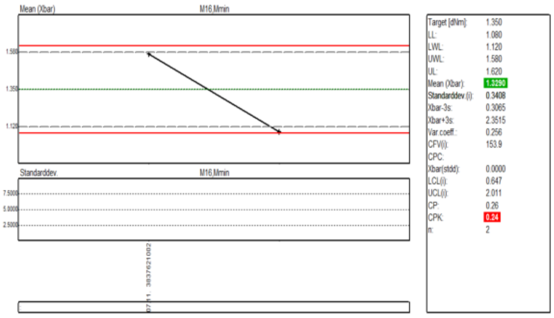
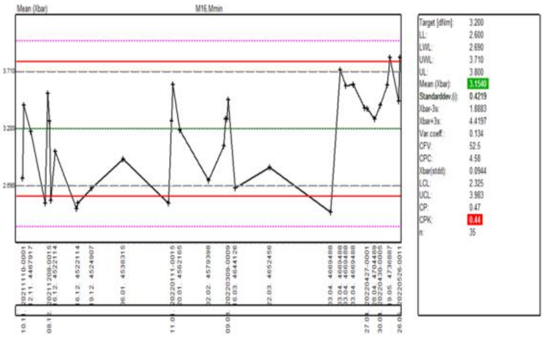


Fig. 1. Viscosity testing principle



Target [dNm]: 1.350
LL: 1.080
LWL: 1.120
UWL: 1.580
UL: 1.620
Mean (Xbar): 1.3290
Standarddev.(i): 0.3408
Xbar-3s: 0.3065
Xbar+3s: 2.3515
Var.coeff.: 0.256
CFV(i): 153.9
CPC:
Xbar(stdd): 0.0000
LCL(i): 0.647
UCL(i): 2.011
CP: 0.26
CPK: 0.24
n: 2

Fig. 2. Example of control chart data for two samples of the same batch analyzed one after the other



Target [dNm]: 3.200
LL: 2.600
LWL: 2.690
UWL: 3.710
UL: 3.800
Mean (Xbar): 3.1540
Standarddev.(i): 0.4219
Xbar-3s: 1.8883
Xbar+3s: 4.4197
Var.coeff.: 0.134
CFV: 52.5
CPC: 4.58
Xbar(stdd): 0.0944
LCL: 2.325
UCL: 3.983
CP: 0.47
CPK: 0.44
n: 35

Fig. 3. Example of control chart data for viscosity testing ("x" material)

To obtain and store the results obtained with the help of the rheometer, an Online Manager program is installed on the server and on the computers of those responsible for this process (the operators who test and the engineers who interpret the data), which makes possible the communication between the production equipment and the server that transmits the data to the equipment Testing. This program displays the type of mixture tested, the number of the test, the pallet of which the tested sample is a part, the name of the test, the result of the test, the date and time of the test, as well as the specification based on which the test is performed.

Furthermore, it converts and sends the results to another interface, Quality Data Analysis, for easier statistical analysis, this software being able to automatically generate a series of analyzes such as: Pareto graphs, Gaussian curve, and point cloud graph statistics. It makes it easier to interpret the results by automatically calculating the standard deviation between successive tests of a production batch.

III. PROBLEM DESCRIPTION

The Quality Data Analysis program has been programmed to directly put the data obtained from testing into a control sheet format. This made it easier to observe a discrepancy between two tested samples of the same lot (sample). Thus, one sample was within tolerance, while the other was well outside the lower or upper limit, as seen in Fig. 2.

The example above depicts what the limits for this measurement are: Lower Limit (LL) - 1.080 and Upper Limit (UL) - 1.620. The first sample tested has a value of 1.5700, which is close to the upper limit, while the second sample tested from the same batch of material has a much lower value of 1.0880, even exceeding the lower limit. Being a cleverly designed program (Quality Data Analysis), it already gave all the data needed for analysis, so it becomes readily apparent that this process lacks stability (CPK = 0.24).

When the values on the control sheet are outside the control limits, it means that there are some special causes of variation that have intervened in the process. This means an investigation must be started to determine the cause or causes. On the other hand, random variation between control limits means that certain common causes are present. Within this paper, the investigation will focus on the cause or causes that determine results outside the accepted tolerances.

Over the weeks numerous cases were identified, which involved extra work for the operators, through the retesting process. In Fig. 3 and 4 it is shown the tests done over a period of 2 months, on two different types of material (different recipes used), made by different operators, on random days. With this data available, next steps is evaluating the possible (special) causes that could lead to such variations in the process, using specific quality management methods.

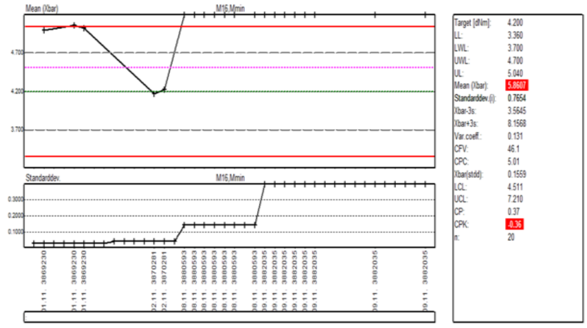


Fig. 4. Example of control chart data for viscosity testing ("y" material)

IV. ROOT CAUSE ANALYSIS

1. SIPOC Diagram

The first step in this analysis is the SIPOC (supplier-input-process-output-client) diagram from Table 1, to have a clear picture of the process preceding and immediately following the process of viscosity testing in the rubber processing company chosen for this analysis.

In the previous chapter we identified a problem: the instability of the viscosity testing process obtained with the MDR tester. At this point, absolutely all hypothesis that can lead to this problem should be considered and analyzed. Thus, with the help of the Ishikawa diagram below we can draw a series of conclusions, as seen in Fig. 5.

Table 1 Ishikawa Diagram

Supplier	Input	Process	Output	Client
Resinex	Natural rubber	Viscosity testing	Rubber Mix	Production
Caron Onex	Synthetic rubber		Quality issues	Laboratory
ET10	Carbon black		Production stoppage	Maintenance technicians
Lubexp	Oil		Machine breakdown	Maintenance engineer
ECHA	Chemicals		Quality issues reporting	Quality engineer
EUROPAGES	Reinforcement and textiles		Scrap	Process engineer

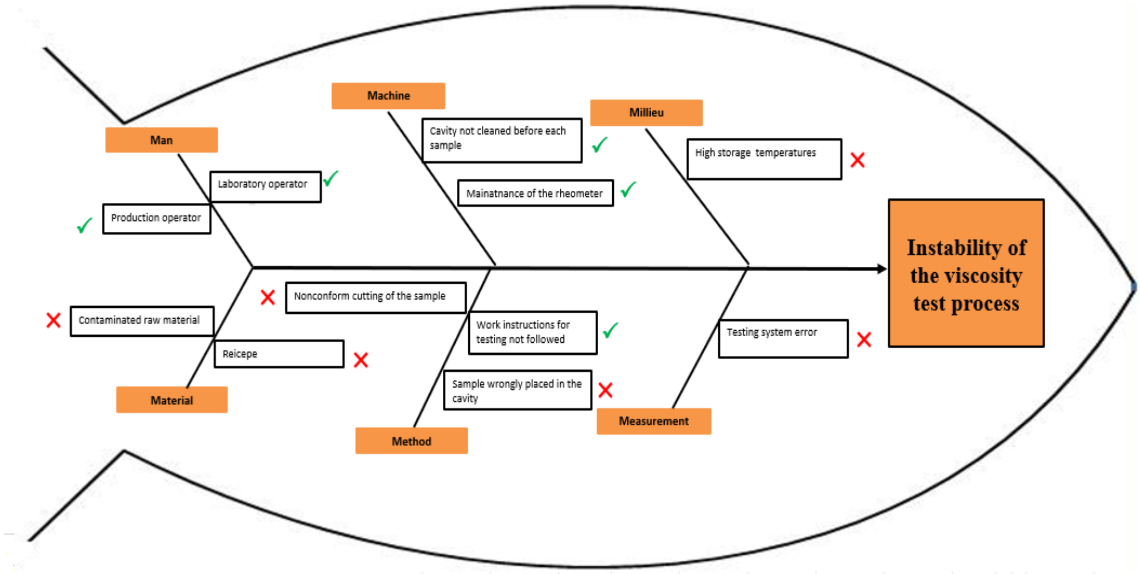


Fig. 5. Ishikawa Diagram for instability of viscosity test process.

2. Hypothesis validation

All the possible hypothesis from the Ishikawa diagram have been verified to prove or not their contribution to the problem identified. The ones who could be verified or proven are listed below.

In terms of Man, the laboratory operator was considered because he is the one testing the viscosity of the sample, which means that human error can make its presence felt. He may contaminate the sample before introducing it into the rheometer cavity, which would explain such large deviations. Since other types of materials (chemicals, oils, carbon black, etc.) are tested in the laboratory, the operator may have a contaminated glove from a previous test. Production operator brings the testing sample to the laboratory and can contaminate during the transport.

Regarding the Material, one reason why the final viscosity has unstable values, may come from the fact that the raw material used is non-compliant. To verify this hypothesis, tests done on the material used in the composition of the mixture were verified, and it has a stable trend, so this hypothesis was canceled by the evidence of the tests. In the first phase, there was also the possibility that the recipes for certain mixtures are not well dosed, and this could be the reason for the instability of the viscosity. However, over time, these deviations and instability were felt for all mixtures, which ruled out this hypothesis.

Within the Machine cluster, rheometer cavity not cleaned after the last test is a possible root cause. It is very important that after testing the sample, once the cavity is opened, the previously tested sample is completely removed and thrown into the sample bin. If there are any remnants from the previous test, they will affect the result of the next test. This hypothesis was validated, as the operators admitted that they do not always have enough time to clean the cavity. Also, preventive maintenance for the MDR rheometer is done once every two weeks or every 300 measurements, by replacing the standard gaskets (S0402 and S0403), but the hypothesis is validated as measurements tend to be more accurate right after maintenance activities.

In terms of method, improper cutting of the sample has been analyzed. Cutting of the sample is done with a special knife, which could not be compliant: either they do not cut well, or they are not cleaned after each sampling, etc. However, by checking their condition, it was found that they are not degraded at all, and at the time of the check they were being cleaned before the next sampling. What was also considered within this cluster is that testing is not in accordance with work instructions. There is a possibility that the test parameters can be influenced by the operator by changing the settings for example, or by mistakes like overlapping two samples (as they are sticky). Also, for the test to be accurate, the sample must be placed firmly on the mold. If the sample is placed incorrectly, there is a possibility that the test will not be relevant, or that pieces of the sample will fall inside the apparatus, which could lead to additional damage.

In terms of Milieu the hypothesis that there are high temperatures in the storage area, but it was not confirmed as there is centralized climatic control for the temperature and the records show no issue here. Lastly, for the Measurement it was considered the hypothesis that the problem comes from an error in reading the data emitted by the test system. IT engineers have checked this track, but there is no loss of communication between the machine and the servers.

3. "5 whys" questionnaire

Following questionnaire "5 Why" presented in Table 2, multiple conclusions regarding the root cause of the problem are brought to light. Firstly, the sample may be contaminated by the production operator due to the gloves he wears and uses for all actions he undertakes. The reason is that he only gets a pair of gloves, which means they are used for everything the same. This cause may have a contribution of up to 10% in producing the deviation. Then, the sample may also be contaminated by the laboratory operator, who uses the same gloves to perform several tests, although special gloves are used for this test. This comes down directly to the level of responsibility of the operator, as it cannot be continuously verified, and this cause can contribute 10%. What is more the cavity not cleaned after each test can have a small influence, of 10%, on the testing process, and the reason why cleaning is not performed is the large volume of samples for testing, which can make the operator skip certain steps.

Non-compliant testing comes very close to the previous reason, because with a large workload and limited time for each action, some checks are done more superficially, which can lead to nonconformities such as two glued samples. This cause has a weight of 10% and like the previous one, it is difficult to intervene on the operation. There are human mistakes, and the only solution that has this risk is automation.

However, the main cause identified is the need for the maintenance rheometer, having a weight of 60%. Following the analysis of the data available, it was obvious that after the maintenance day, which takes place every two weeks, on a Wednesday, the process is stable, and the test data are in the parameters (there are no tests with values much above the lower or upper limit), but the effect is short-lived, because after just a few days, variations begin to appear.

Table 2 Develop the "5 whys" questionnaire

Causes	**Sample contamination by production operator**	**Sample contaminated by laboratory operator**
Why? (1)	Because the operator takes the sample with dirty gloves	Because he uses gloves for protection
Why? (2)	Because he uses gloves for other machine cleaning operations	Because the operator tests other sub-stances
Why? (3)	Because it uses only one set of gloves for all operations	Because gloves can contaminate the sample
Why? (4)	Because it is more convenient not to change gloves every time, he takes samples	Because a special glove was not used
Why? (5)	Because this is a typical human mistake	Because this is a typical human mistake
Contribution	10%	10%
Corrective actions	Operators retraining related to taking samples of the final mixture, so as to use special gloves, not the standard ones offered daily	Retraining of the test operator related to sample handling prior to testing
Causes	**Uncleaned cavity after last test**	**Rheometer maintenance**
Why? (1)	Because the operator does not clean it after the test	Because the maintenance plan needs changes
Why? (2)	Because it has a lot of samples to test	Because the process is stable after maintenance of the device
Why? (3)	Because the production volume is large	Because the appliance needs gasket replacement
Why? (4)	Because staff and production capacity are reduced compared to demand	Because the standard gaskets used are not suitable for such frequent testing
Why? (5)		Because the model was purchased with such gaskets
Contribution	10%	60%
Corrective actions	Opening a new position for laboratory operator so that all tests can be done in a timely manner	Optimizing rheometer maintenance by replacing standard gaskets

V. SOLUTION AND RESULTS

As shown in Fig. 6 immediately after maintenance, under ideal and controlled conditions, the viscosity test results are stable. After 3-4 days, the situation gets out of control, and the results randomly exceed either the upper limit or the lower maximum allowed. From questionnaire 5 Why and from this analysis was generated a possible solution for establishing the viscosity testing process with the MDR rheometer, produced by Alpha Technologies. The solution identified is related to the maintenance policy of the device, because as seen above, a period of two weeks too long for maintenance, considering that more than 300 tests are done during this period. In the past, when the production volume and implicitly the test volume was not so high, the device worked very well with those standard gaskets changed every two weeks, because no more than 300 tests were done in that interval.

Therefore, the solution identified was to replace standard seals with smart seals, the latest innovation of Alpha Technologies. What's the difference between the two and how did they improve this piece?

The classic seal provides for a one-piece sealing plate provided with an upper polymer seal, as seen in Fig. 7 in the right corner.

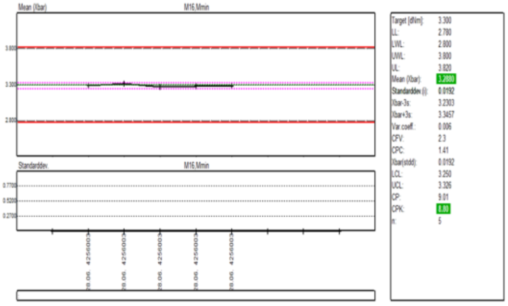


Fig. 6. Viscosity testing immediately after the maintenance day

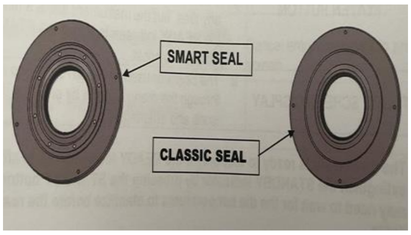


Fig. 7. The two types of seals: classic and smart

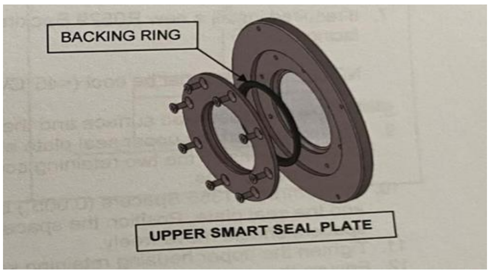


Fig. 8. Smart seal

The smart seal is an upper mold seal to eliminate conventional elastomeric sealing while maintaining a closed, pressurized cavity for improved long-term data stability and reduced the need for torque calibration. Thus, with the change of this seal, its maintenance will be done once a month.

In Fig. 9 and 10, the improvement in the stability of the viscosity testing process can be seen. The results from one sample to another are close in values, but most importantly, those errors no longer occur due to special events, values that exceeded either the upper limit or the lower limit of the maximum allowed. In the two figures below the improvement over a period of two months from the moment the standard seal was replaced to the smart one, for two different materials. What is observed from the start is the disappearance of those erroneous results, which far exceeded the upper or lower permissible limit and clearly came from special causes. The process is now stable, which makes it much easier to detect real problems with the material, ensuring that if the value is far outside the limits, then investigations must be directed towards the material and its possible contamination. Moreover, the improvement is also reflected in operator's workload, who no longer must retest samples as frequently, and preventive maintenance is now done once a month, compared to once every two weeks, and all this is due to the smart gasket, which has a much higher sealing capacity.

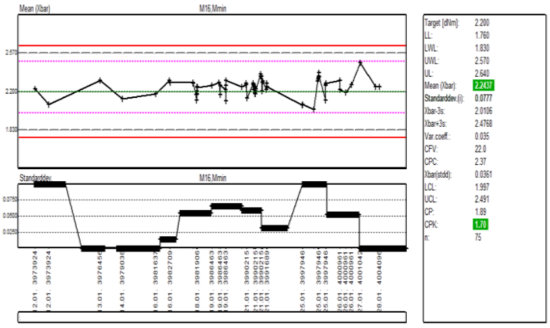


Fig. 9. Viscosity test results after improvement (“x material)

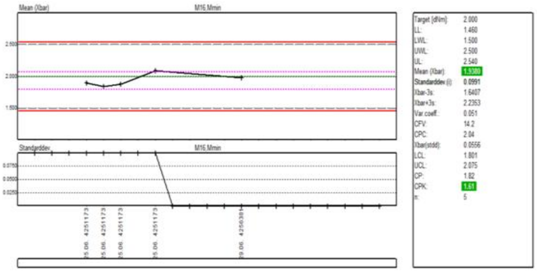


Fig. 10. Viscosity test results after improvement (“y” material)

CONCLUSIONS

Accuracy in viscosity testing is essential for all rubber processing industries. Tools such as Control Chart has proven to be highly efficient in their interpretations and as a trigger for a possible inconsistency. In the case presented, there was a mechanical issue which needed to be improved to obtain process stability in terms of viscosity testing.

Quality tools such as SIPOC, Ishikawa, 5 why have been used for the root cause analysis, successfully revealing the root cause of the problem identified. The reached output of this article is the enhancement of the viscosity quality testing for the rubber processing company from the Western side of Romania, used a case study.

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