

## Lecture 36 - Polymer Testing-01

Hello, friends, and welcome to the polymer testing section of the polymer processing course. In this introductory session, we will delve into the significance of polymer testing, highlighting its essential role in understanding the diverse properties of polymers and ensuring they meet desired standards for various applications.

Polymeric materials find extensive applications across different industries, each with specific end-uses. To gain comprehensive knowledge about these materials, including their properties and whether they align with the required standards, rigorous testing becomes crucial. Our discussion will provide a concise overview of the importance of polymer testing and how it plays a pivotal role in ensuring quality.

The session will cover various aspects, starting with a brief introduction to polymer testing. We'll explore the testing perspective in the context of quality control, emphasizing the need to assess whether polymers meet the desired properties. Predicting service performance will also be discussed, highlighting the role of testing in ensuring the functionality and reliability of polymeric materials.

The concept of design data will be elucidated, showcasing how testing contributes to generating valuable data for designing new products. Investigating failures is an integral part of polymer testing, allowing us to understand and rectify any shortcomings in material performance.

Our discussion will extend to test conditions, shedding light on the parameters that influence testing outcomes. We'll explore the limitations of testing and delve into sampling and quality assurance practices. Fundamental statistical principles will be covered, emphasizing their application in polymer testing.

Moving on to the physical testing of polymeric materials, we'll discuss how measuring physical properties is essential for predicting service performance and generating design data. The importance of investigating failures will be reiterated, underlining the critical role testing plays in quality assurance and product development.

In essence, testing is the foundation for ensuring the quality of polymeric materials, providing empirical evidence for successful product design. Standardized testing procedures have been developed to suit the unique properties of different classes of polymeric materials. Join us in this exploration of polymer testing, a crucial aspect of the polymer processing journey.

### ❖ Testing perspectives

- The polymer is a complex materials, and their behavior are sometime unexpected.
- So, the tests of polymers needs to be well chosen and wide ranging in order to avoid embarrassing failures.
- It is important to establish early on that the grade of materials chosen fully matches the design criteria for product.

**e.g,** a plastic component although initially of adequate strength, may on constant exposure to detergents suffer from environmental stress cracking.



In the realm of polymer testing, each class of material comes with specific requirements, necessitating the recognition and emphasis of standardized procedures tailored for diverse industries. The complexity of polymer behavior adds a layer of unpredictability, influenced by factors such as temperature and environmental conditions. To ensure the desired properties of a product, a thorough understanding and study of polymer behavior are imperative.

Testing polymer samples becomes crucial, and a well-chosen, wide-ranging selection is necessary to prevent any potential embarrassing failures. The early establishment of the material grade's compatibility with the product's design criteria is paramount. For example, in the case of a plastic component, initial strength may suffice, but constant exposure to detergent may lead to environmental stress cracking, highlighting the importance of comprehensive testing.

Testing serves four primary areas: quality control, predicting service performance, generating design data, and investigating failures. The quality control aspect ensures that materials meet predefined specifications, while predicting service performance involves anticipating how polymers will behave under real-world conditions. Design data generation contributes to developing valuable insights for product design, and investigating failures is crucial for identifying and rectifying any overlooked properties.

Understanding the specific purposes of testing is essential before initiating any test, as different requirements accompany each purpose. Failure to align with these purposes may result in time-consuming tests that fail to yield the necessary results. Therefore, a strategic

and purpose-driven approach to polymer testing is crucial for ensuring the reliability and functionality of polymeric materials in various applications.

Failure to understand the reasons behind specific tests can lead to misunderstandings and conflicts between research and quality control departments in a plant. The ability to automate tests and a preference for non-destructive methods add to the various characteristics of testing methods, including precision, reproducibility, speed, and complexity. The balance of these features and associated costs depends on the test's goals, with precision and repeatability being crucial in every case.

In quality control tests, especially for output evaluation, non-destructive approaches are often advantageous and sometimes necessary. The tests should be quick, affordable, and automation can enhance efficiency. When evaluating product performance, tests should align with the service conditions and aspects relevant to the product's function. Testing in a humid environment, for instance, requires conditions reflecting real-world service conditions. Although speed and cost may be less critical, overly complicated tests should be avoided. Non-destructive tests may not always be appropriate for predicting product performance, especially when determining the point of failure is crucial.

### Cont...

- **Predicting service performance**

- ✓ The test should be relate to the service conditions and aspects of product performance.
- ✓ Even though speed and cost are less important, the testing shouldn't be too complicated.
- ✓ Non-destructive test are not always appropriate when predicting product performance, as it may be necessary to establish the point at which failure occurs.



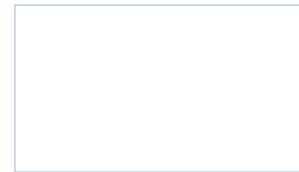
For generating design data, test pieces are usually of simple shapes and sizes, even though the actual product may have a different geometry and size. Balancing simplicity with relevance to the final product is essential in design data testing. Overall, a nuanced approach considering the specific goals and requirements of each test is crucial to ensure effective and meaningful polymer testing.

In the realm of polymer testing, the need for a prototype for test pieces, even if different from the actual product, highlights the importance of conveying information that allows designers to account for modifications in geometry and time scale. Designers must be aware of this aspect, demanding a profound understanding of material behavior and often requiring multiple data points. Producing such data is costly and time-consuming, and results may not be swiftly achieved. Automation, however, can be beneficial, particularly in prolonged tests like creep tests.

When testing to investigate failures, it is crucial to comprehend the failure mechanism beforehand and ensure that the chosen tests are relevant. Identifying the root cause of a failure is paramount, making such investigations essential. While absolute accuracy may not be critical, the test should be capable of distinguishing between good and bad products. The classification of groups of tests becomes important in this context, facilitating a systematic approach to failure analysis. Therefore, a comprehensive understanding of the material's behavior, coupled with effective communication between designers and testing personnel, is fundamental for successful and meaningful polymer testing.

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- ✓ **The classification of the testing**
  - Tests related to fundamental properties
  - Tests related to apparent properties
  - Tests related to functional properties



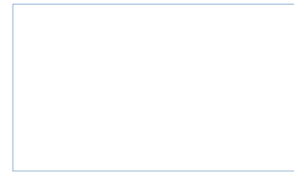
When discussing the classification of testing, it can be categorized based on fundamental properties, apparent properties, or functional properties. Test conditions encompass various parameters such as material preparation methods, storage history, temperature, and velocity. Storage history is particularly crucial, as it can significantly impact the product based on environmental conditions. Test procedures demand attention, and even minor deviations can yield significant changes in results. Accurate initial setting and continuous monitoring of test conditions are imperative.

When adhering to published standards, deviations may be unavoidable due to limitations in available material or other factors. In such cases, deviations should be recorded, and a thorough investigation into the root cause must be conducted. The test report should explicitly state the procedure, providing transparency and documentation.

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#### Limitations of test results

- ✓ However, in a careful environment the tests are carried out but there will be some limit to the attainable accuracy.
- ✓ The precision of a particular method may be lower than anticipated after considering the interlaboratory variables.
- ✓ It is essential to be conscious of the order of magnitude of the range within the true result lies.
- ✓ It is not sufficient to present the results to a statistician once the test have been done.
- ✓ No measurement is exact, there always some uncertainty.



However, it's important to acknowledge the limitations of test results. While tests are conducted in a controlled environment, there are inherent limits to achievable accuracy. Precision may be lower than anticipated due to inter-laboratory variables. Awareness of the magnitude range within which the true result lies is crucial for a comprehensive understanding of test limitations.

When presenting test results, it is not sufficient to merely provide statistical outcomes, as no measurement is exact, and there is always an inherent level of uncertainty. Calibration laboratories must estimate uncertainty for every measurement, and accredited testing laboratories may also be compelled to adopt this practice. This process involves evaluating the uncertainty contributed by each measurement component, a task that is not always straightforward.

Sampling plays a crucial role, and efficient sampling involves selecting small quantities that accurately represent a much larger whole. The significance of the test result is closely linked to the efficiency of sampling. Financial considerations often dictate the sampling frequency and the number of test items per sampled item. In continuous quality control systems, testing frequency holds greater importance than the quantity of test pieces at each point. The number 5 is often considered optimal when ample test pieces are available, as an odd number is advantageous when calculating the median.

Efficient sampling requires that the small quantity selected and tested be truly representative of a much larger whole. The test pieces should accurately reflect the sample taken, and the sample itself should be representative of the batch, which in turn must be representative of the broader population of the material. This hierarchical representativeness ensures the reliability and relevance of the test results.

Quality control is an indispensable aspect of ensuring product quality, encompassing the need for controlled production processes, inspection of raw materials, and testing of finished goods. These three parameters constitute the foundation of effective quality control. The implementation of physical testing methods plays a pivotal role in this domain, with the majority of tests being conducted to guarantee quality.

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#### Quality control

- ✓ In order to ensure product quality, production processes must be controlled, raw materials must be inspected, and finished goods must be tested.
- ✓ The physical testing methods are important in this regime.
- ✓ In order to ensure quality, the majority of tests are performed first.
- ✓ The quality control is often thought of as applying only to products, since this affects the lives of the entire population.



Quality control extends beyond the product level; it is a comprehensive approach that impacts the well-being of entire populations. Reliable results in quality control require adherence to a quality assurance system that subjects equipment, methods, and workers to scrutiny. Laboratories embodying such systems produce dependable results. Widely utilized standards, such as the ISO 9000, are applied across various organizations, encompassing their laboratories within the system's comprehensive framework.

These standards go beyond controlling test pieces and ensuring equipment calibration; they also address the crucial aspect of staff training—a facet often overlooked in discussions of quality control. The stipulated requirements set a high standard, and it is essential to acknowledge that maintaining these standards is both time-consuming and challenging.

To maintain the reliability of testing equipment, thorough calibration is imperative, covering all parameters associated with the machine. Each level of measurement introduces

a certain degree of uncertainty, which needs to be carefully addressed and averaged out. Calibration should adhere to specific standards and be part of a robust quality system.

The accuracy of reported results is contingent upon both the validity of data handling and the precision of the original measurement. Maintaining an accredited status involves rigorous discipline, impacting various aspects such as calibration of test equipment, training, documentation of test protocols, sample control, and formal audits. These measures collectively contribute to error reduction and the preservation of reproducibility.

In the realm of physical testing and measurement, the quality assurance process is crucial. The intrinsic value and reliability of decisions hinge on the quality of measurements used in the decision-making process. Quality, in the context of a test system, is characterized by the uncertainty in the measured result. Good quality corresponds to a small or low uncertainty.

Quality in a test system is shaped by two primary components. Firstly, it depends on how well the measured variable aligns with the characteristics used for decision-making. Secondly, it is influenced by the level of uncertainty associated with the measured parameter value or values. Higher uncertainty levels are indicative of poorer quality. Confidence in achieving a certain level of quality must be an integral part of any ongoing project, and once established, this quality level should be maintained through the implementation of specific control procedures.

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### Elementary statistical principles

#### ✓ Test data variation

- Variation may be described in terms of deviations of the output value from a true value which would be obtained for any measurement.
- All measurements are influenced to some degree by perturbations that influence the measurement process and generate these deviations.



The elementary statistical principles governing test data variation are essential to understand. Variation is characterized by the deviation of output values from a true value that would be obtained under ideal conditions. All measurements are subject to



perturbations, influencing the measurement process and causing these deviations. There are two main types of deviations:

1. **Random Deviation:** These are positive or negative variations from a central value, which could either be true or a reference value. In a long series of repetitive measurements, each test execution yields a unique difference, and the mean value of these differences is zero.
2. **Bias or Systematic Deviation:** These are constant offsets of variation from the true value. These offsets, which can be positive or negative, are often specific to each set of given test conditions.

**Data Distribution:** Each specific data value is part of, or derives from, a population of values with specific characteristics known as distribution. A population can be a single object, a limiting mass of material, a finite but large number of objects or a large mass of material, or a hypothetical infinite number of objects or mass materials. The frequency of occurrence of individual data values around a central value, such as the mean or median, is described by the distribution. Understanding data distribution is crucial for interpreting and analyzing test results.

**Characterizing Distribution:** A probability distribution function expressing the distribution in terms of a central tendency-related distribution parameter is used to describe the distribution. The fundamental concepts characterizing a distribution include mean, variance, standard deviation, and range. Assuming a normal distribution, two statistical parameters represent it: one with a median or mean as the central value characterizing the dispersion of values around it, and the other detailing variations and standard deviation.

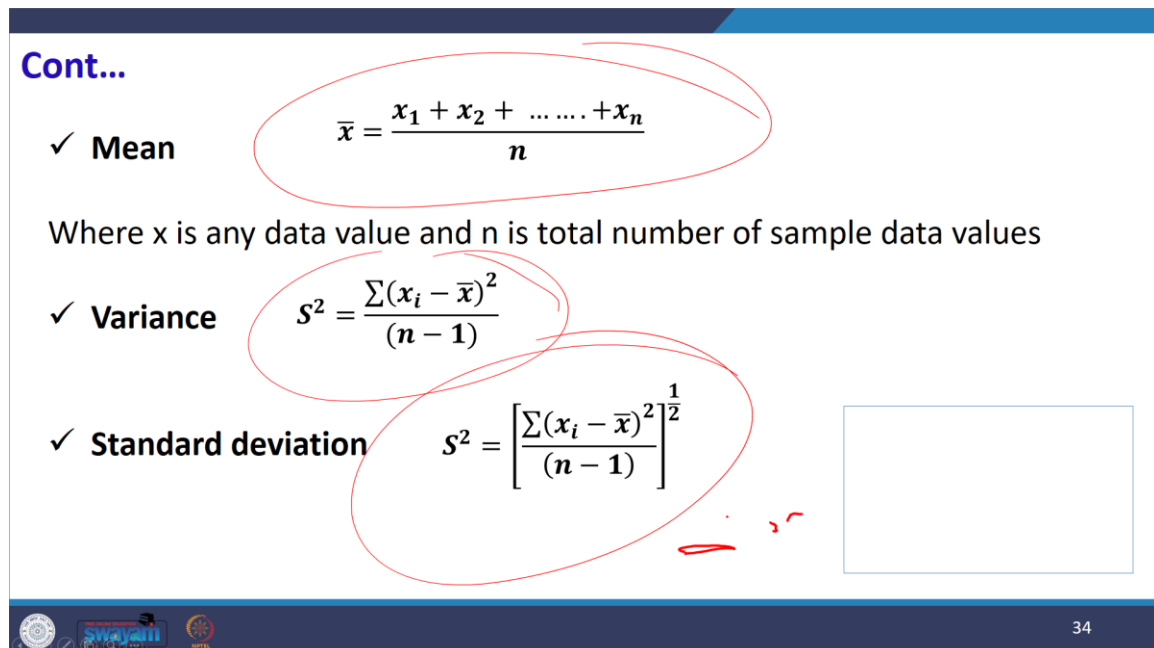
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✓ **Mean**  $\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n}$

Where x is any data value and n is total number of sample data values

✓ **Variance**  $s^2 = \frac{\sum(x_i - \bar{x})^2}{(n - 1)}$

✓ **Standard deviation**  $s = \left[ \frac{\sum(x_i - \bar{x})^2}{(n - 1)} \right]^{\frac{1}{2}}$





The mean ( $\mu$ ), variance ( $\sigma^2$ ), and standard deviation ( $\sigma$ ) can be realized based on extensive measurements, denoted by symbols  $\mu$ , small theta, and square theta, respectively. The estimates of the true values are based on examples from the population, represented by symbols  $\bar{X}$ ,  $S^2$ , and  $S$ . The mean is calculated as

$\bar{X} = (X_1 + X_2 + \dots + X_n) / n$ , where  $X$  is any data value, and  $n$  is the total number of sample data values. The variance ( $S^2$ ) is given by

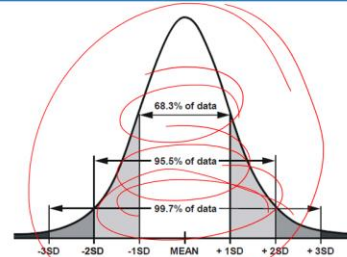
$S^2 = \frac{\sum(X_i - \bar{X})^2}{(n-1)}$ , and the standard deviation ( $S$ ) is represented as

$$S = \left[ \frac{\sum(X_i - \bar{X})^2}{(n-1)} \right]^{\frac{1}{2}}$$

For a normal distribution, the interval of  $\pm\sigma$  about the mean  $\mu$  will contain 68.3 percent of all values in the population, and the interval of  $\pm 2\sigma$  contains 95 percent and  $\pm 3\sigma$  interval contains 99.7%. Understanding these parameters is essential for interpreting the distribution of test data.

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- ✓ The standard deviation provides a measuring units-based approximation of the dispersion around the center value or mean.
- ✓ For a normal distribution the interval of  $\pm\sigma$  about the mean  $\mu$  will contain 68.3% of all values in population,  $\pm 2\sigma$  interval contains 95.5% and  $\pm 3\sigma$  interval contains 99.7%.



**Figure;** Showing standard normal distribution curve

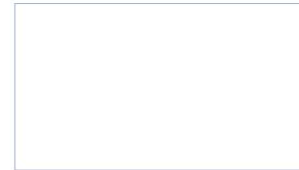


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- ✓ A relative or unit free indicator of the dispersion is the coefficient of the variation.

$$CV = \frac{S}{\bar{x}}$$

- ✓ CV can be expressed as a ratio or a percentage value.



Another critical indicator is the coefficient of variation (CV), offering a unit-free measure of dispersion. CV is calculated as the ratio of the standard deviation (S) to the mean ( $\bar{X}$ ) and is often expressed as a percentage. Understanding these concepts is crucial for assessing and interpreting the dispersion of data in statistical analysis.

A relative or unit free indicator of the dispersion is the coefficient of the variation.

$$CV = \frac{S}{\bar{x}}$$

CV can be expressed as a ratio or a percentage value.

**Z Distribution and Coefficient of Variation:** In the realm of distribution characteristics, the Z distribution plays a pivotal role. The normal distribution curve is characterized by the normal probability density function, providing the probability of finding a given distribution value as a function of that value. To ensure the total area under the distribution curve equals 1, the equation is modified, leading to the standard normal distribution.

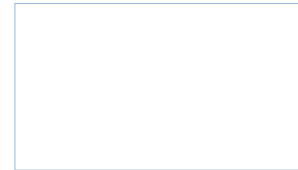
The Z distribution comes into play with a straightforward change of origin and scale. The variable X, with a known mean ( $\mu$ ) and variance ( $\sigma^2$ ), is transformed into the Z variable using the formula  $Z = (X - \mu) / \sigma$ , where  $\sigma$  is the standard deviation. For a standard normal distribution, the expected value of Z is 0, and the standard deviation is 1. This distribution is particularly useful when both the population mean and variance are known.

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- ✓ The x variable, which has a mean and standard deviation, is transformed into the variable Z.

$$Z = \frac{x - \mu}{\sigma}$$

- ✓ For standard normal distribution, the expected value of Z is zero and the standard deviation is 1.
- ✓ Z-distribution are applicable when both the population mean and the variance are known.



## t-Distribution and Measurement Principles:

In statistical analysis, when determining variance from a sample, the Z distribution's relevance diminishes, and the t distribution comes into play. The t distribution involves a random variable, denoted as t, which can be expressed as  $t = \frac{(\bar{x}_n - \mu)}{S/\sqrt{n}}$ . Unlike the Z distribution, the t distribution's variance is influenced by the degrees of freedom associated with S, where degrees of freedom equal (n-1). As the sample size (n) increases, the t distribution converges toward the normal (Z) distribution, and its variance approaches 1.

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### ➤ t-distribution

- ✓ The z-distribution and the proportion of sampling values that fall within the - and + limits as stated above are no longer relevant when the variance must be determined from a sample.
- ✓ T-distribution is employed in this situation; t is a random variable and can be represented as;

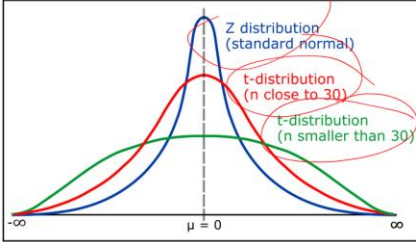
$$t = \frac{\bar{x}_n - \mu}{S/\sqrt{n}}$$



The principle of measurement, calibration, and traceability is fundamental in the field of metrology. Measurement involves a specific technological process that generates data related to the class of items or materials under consideration. It essentially entails comparing an unknown parameter to a known or standard value. Measurement theory elucidates how the measured parameter correlates with a specific property. Two general types of measurement exist: direct, where the property of interest and the measured parameter align, and indirect, where they differ.

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- ✓ While the t-distribution resembles the typical z-distribution in terms of shape and expects a mean of zero, its variance is determined by the degree of freedom connected to S, which is equal to  $(n-1)$ .
- ✓ The t-distribution moves closer to the normal or z-distribution and its variance moves closer to 1 as n approaches infinity.



**Figure;** Showing z-distribution and t-distribution curve

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Understanding these principles is crucial for ensuring accurate and reliable measurements in various scientific and industrial applications.

### Measurement Principles and Terminology:

Measurement processes are classified into two types: direct and indirect. In direct measurement, the parameter being measured aligns with the property of interest. Conversely, indirect measurement involves a theoretical connection between the measured parameter and the relevant properties, typically in a direct or linear manner.

Several key terminologies are essential in understanding measurement:

**Standard:** A recognized quantity, object, or creation used for comparison in measurements.

**Standardization:** Protocols established by organizations for specific technical operations or objectives.

**Measurement System:** The entire set of tools or equipment required for a particular measurement, often including data recording devices.

**Technique:** A technical protocol or procedure utilizing a measurement system, often based on a scientific theory.

**Test Method:** The adoption of a technique for a specific action or procedure, typically accompanied by a written guide for measurement.

**Protocol:** A strategy and comprehensive set of unambiguous instructions for achieving specific testing or measuring goals.

**Absolute Method:** A technique where test outcomes are determined by accepted physical, external, or standard values derived directly from theory.

**Relative or Comparative Method:** A procedure where test outcomes are evaluated by comparing them to the measurement of a reference substance or object.

Understanding these terms is crucial for establishing accurate measurement practices and protocols, ensuring reliability in various scientific and industrial applications.

### **Measurement Methods and Key Characteristics:**

Several key measurement methods and characteristics play a crucial role in ensuring accurate and reliable results. These include:

**Standard Method:** A process adopted by a standardization organization such as ASTM. Widely accepted in technology, it possesses a declared level of precision.

**Reference Method:** A proven technique known for consistently high accuracy and precision.

**Figures of Merit:** Measuring systems are often chosen based on figures of merit, including precision, bias, uncertainty in test results, useful range, cost-effectiveness, testing speed, automation feasibility, ruggedness, and ease of operation.

### **Precision, Bias, and Uncertainty:**

- **Precision:** Precision is characterized by a low standard deviation, indicating close agreement of measured quantities. It refers to the repeatability and consistency of measurement results.
- **Bias:** Bias represents the systematic error or the difference between the average measured value and the true value. High accuracy is achieved with little or no bias.

- **Uncertainty:** Often used interchangeably with accuracy, uncertainty refers to the range within which the true value is expected to lie. Low or acceptable uncertainties indicate high accuracy.

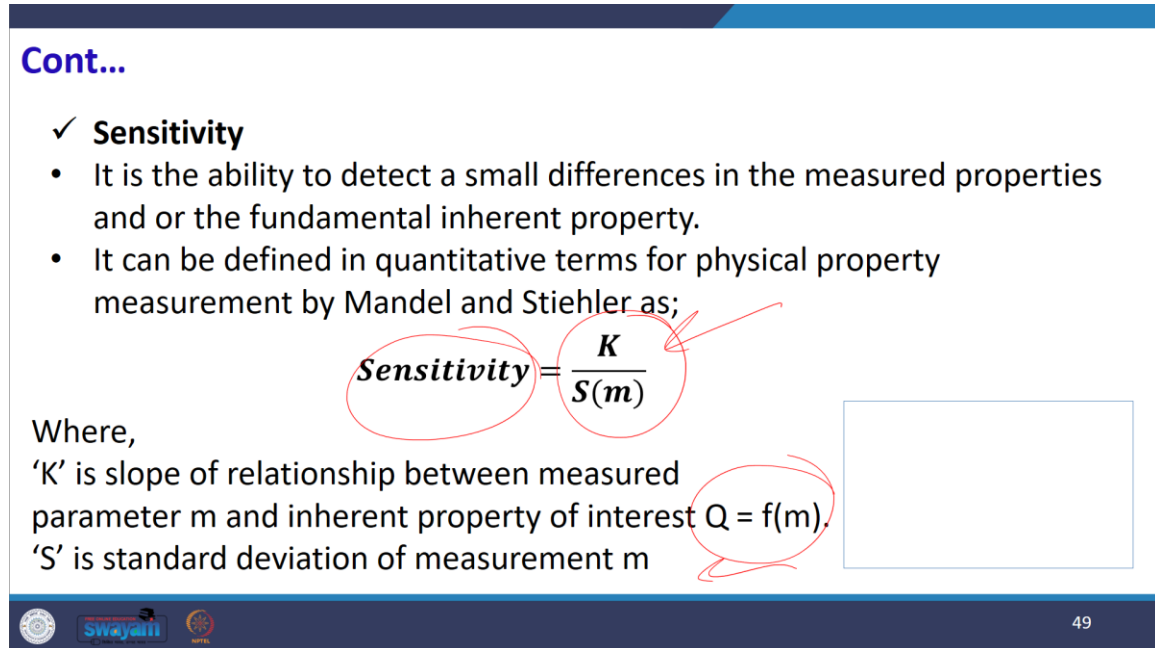
**Sensitivity:** It measures the ability of a method to detect small differences in measured properties. Sensitivity is a fundamental inherent property crucial for precise measurements.

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- ✓ **Sensitivity**
  - It is the ability to detect a small differences in the measured properties and or the fundamental inherent property.
  - It can be defined in quantitative terms for physical property measurement by Mandel and Stiehler as;

$$\text{Sensitivity} = \frac{K}{S(m)}$$

Where,  
 'K' is slope of relationship between measured parameter m and inherent property of interest  $Q = f(m)$ ,  
 'S' is standard deviation of measurement m



Understanding these characteristics is essential for selecting appropriate measurement methods and ensuring the reliability of results in various scientific and industrial applications.

**Quantitative Definition and Calibration in Measurement:**

**Sensitivity in Quantitative Terms:**

**Definition:** Sensitivity in quantitative terms for physical property measurement is given by the formula:  $Sensitivity = \frac{K}{S(m)}$ , where K is the slope of the relationship with the measured parameter,  $Q = f(m)$ , and S is the standard deviation of measurement m.

**Useful Range:**

**Definition:** The useful range is the range to which the instrument responds appropriately to measure the property. It is expressed based on the presence of a linear relationship between instrument output and the level of measured uncertainty, ensuring precision, bias, uncertainty, and sensitivity are at acceptable levels.

**Calibration:**

**Definition:** Calibration is fundamental to all measurement systems. It involves marking a scale on a test device graduated in the output parameter, and the process of comparing a measured test result with a value considered true, referenced, or standard. Calibration aims to adjust for bias, ensuring a perfect match with the true value.

### **Requirements for Calibration:**

**1. Accuracy, Precision, and Bias Estimate:** Calibration requires an estimate of accuracy, precision, and biasing in the output measurement or response function.

**2. Documented Calibration Standards:** Calibration necessitates the availability of documented calibration standards to ensure a systematic and reliable process.

Understanding and adhering to calibration principles are essential for maintaining accuracy and reliability in measurement systems. Calibration addresses the adjustment of measurements to align with known standards, contributing to the overall quality of data and results.

### **Statistical Control, Calibration Protocol, and Traceability in Measurement Systems:**

#### **1. Statistical Control:**

- *Definition:* Statistical control refers to the presence of a state where the test system is in a controlled and predictable condition. It ensures that the system operates within established statistical limits.

#### **2. Calibration Protocol:**

- *Documentation:* Calibration requires a fully documented protocol, providing clear instructions and procedures for the calibration process. The documentation ensures transparency and repeatability.
- *Experienced Personnel:* Calibration should be carried out by experienced individuals who understand the intricacies of the calibration process and can ensure accuracy.

#### **3. Traceability:**

- *Definition:* Traceability is the capacity to identify or establish a continuous and recognizable path from a fundamental standard or standard values to the targeted measurement system.



- *Magnitude of Uncertainty:* Traceability itself does not imply any level of quantity; it is the capability to trace measurements. However, it is crucial for assigning limits of uncertainty on the output or response measurement.

#### **4. National Standardization Laboratories:**

*Examples:* National standardization laboratories like the National Institute of Standards and Technology (NIST) in the USA or the National Test House in India provide physical standards with certified values and calibration services.

In conclusion, maintaining statistical control, following well-documented calibration protocols, and ensuring traceability to fundamental standards are integral aspects of a robust measurement system. These practices contribute to reliable and accurate measurements in various testing procedures, including those for polymer XF samples.

You're welcome! If you have any more questions or if there's anything else I can help you with, feel free to ask. Happy studying!