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PART ONE

Ultrasonic Attenuation Coefficient Determination

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Abstract

This paper uses ultrasonic testing techniques to examine the attenuation qualities of materials. A brake disc and mild steel were the two materials whose attenuation coefficients were examined. The attenuation coefficient of mild steel was 1.52 dB/cm, whereas the brake disc's was 3.04 dB/cm. Understanding material qualities is crucial, especially for industrial uses like construction and automobiles.

Apparatus

1. Ultrasonic Testing Equipment

- **Ultrasonic Probe:** 5 MHz zero-degree probe for transmitting and receiving ultrasonic waves.
- **Pulser/Receiver Unit:** Generates high-frequency electrical signals and receives reflected signals from the material.
- **Digital Ultrasonic Flaw Detector:** This visualizes and analyzes ultrasonic signals.



2. Test Materials

- **Mild Steel Sample:** For attenuation coefficient measurement.
- **Brake Disc Sample:** For comparative attenuation studies.
- **Defect-Free Calibration Block:** For thickness gauge calibration.

3. Measurement Tools

- **Digital Caliper:** For precise measurement of sample dimensions.
- **Ruler or Measuring Tape:** For approximate sample dimensions.



Vernier Caliper and MS block

4. Computing and Analysis

- **Computer with Analysis Software:** To process ultrasonic signal data, perform linear regression, and analyze results.
- **Statistical Analysis Software:** This software is used to evaluate technician performance variability and procedure accuracy.

5. Auxiliary Equipment

- **Coupling Gel:** Ensures proper transmission of ultrasonic waves between the probe and test material.
- **Power Supply:** For ultrasonic equipment operation.

Introduction

High-frequency sound waves are used in ultrasonic testing (UT), a popular non-destructive testing (NDT) method, to evaluate material qualities and find interior defects. In sectors like aircraft, automotive, and construction where maintaining structural integrity without sacrificing the tested components is essential, this technique is essential. A transducer is used in UT to send sound waves into the material. These waves interact with the internal structure of the material, reflecting back to the surface when they come into contact with discontinuities such as inclusions, fissures, or voids. To ascertain the properties of the material, such as its thickness, density, and the existence of flaws, the reverberating echoes are examined. UT is essential for quality control and failure prevention because of its accurate and instantaneous evaluation.

A crucial factor in comprehending material behavior is the attenuation of ultrasonic waves, which is the progressive loss of wave energy as it passes through a substance. The density of the material, its internal structure, and the presence of contaminants are some of the elements that affect attenuation.

The ability of a material to absorb and scatter ultrasonic waves can be measured by computing the attenuation coefficient, which is crucial for quality control and material selection. The attenuation properties of mild steel and a brake disc were examined in this work using UT. Because of their applicability in industrial settings, these materials were selected. The results advance our knowledge of how material composition influences the propagation of ultrasonic waves, which is essential for creating robust and dependable components in a variety of engineering domains.

Measurements and Graphs

To evaluate ultrasonic wave propagation in steel blocks and brake discs by measuring echoes and thicknesses, analyzing attenuation, and visualizing the data.

Steel Block

The steel block was measured using a 1st square, a 2nd square, and a long side measurement. Each measurement involved a series of 10 echoes.

Steel Block H%				
	Measurements	Echo 1	Echo 2	Echo 3
1st square thickness 19mm	1	85	39	21
	2	74	35	20
	3	77	39	23
	4	94	47	25
	5	94	46	25
	6	86	42	25
	7	80	39	22
	8	76	35	21
	9	84	40	22
	10	76	35	21
2nd square thickness 19mm	1	74	37	18
	2	68	29	17
	3	70	31	17
	4	68	32	20
	5	74	34	22
	6	70	30	17
	7	74	37	25
	8	59	28	16
	9	71	31	16
	10	74	35	22
long side thickness 80.5mm range 240 (3 echoes)	1	no data taken internal reflections		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			

- **First Square:** Measurements for the first square side of the block were taken with a thickness of 19mm.
- **Second Square:** Measurements for the second square side of the block were taken with a thickness of 19mm.
- **Long Side:** Measurements for the long side of the block were taken with a thickness of 80.5mm.
- **Echo 1, 2, 3:** Represents the different echoes received during the ultrasonic test.

Brake Disc (Thickness 6mm):

Brake Disc H%				
Measureme	Echo 1	Echo 2	Echo 3	
front face of brake di thickness 6mm	1	92	51	23
	2	84	39	21
	3	85	38	17
	4	88	49	25
	5	82	43	22
	6	84	47	21
	7			
	8			
	9			
	10			

The brake disc H% measurements from three different echoes (Echo 1, Echo 2, and Echo 3). The measurements are taken across 10 different measurements of the front face of the brake disc, which has a thickness of 6mm.

- **Echo 1:** Consistently shows higher H% values compared to other echoes, ranging from 82 to 92.
- **Echo 2:** Shows moderate H% values, ranging from 38 to 51.
- **Echo 3:** Shows the lowest H% values among the echoes, ranging from 17 to 25.
- **Overall Trend:** There is a general trend of decreasing H% values from Echo 1 to Echo 3.

Graph



Ultrasonic flaw detectors operate by emitting high-frequency sound waves into the material using a transducer. When these waves encounter a discontinuity or flaw, such as a crack or inclusion, they reflect back to the transducer. The detector then analyzes these returning echoes to determine the type, size, and location of the flaw, providing real-time, precise measurements crucial for material evaluation.

Calculations and Error Estimates

To calculate the attenuation coefficient in terms of the amplitude ratio between the initial and final signals:

$$\alpha = \frac{20 \log \left(\frac{A}{A_0} \right)}{Z \times 2}$$

Where:

- A is the attenuation coefficient (in dB/cm),
- A is the amplitude of the ultrasonic wave after passing through the material,
- A₀ is the initial amplitude of the ultrasonic wave before it enters the material,
- Z is the material's thickness (in cm).

This formula uses a logarithmic scale to express the ratio of amplitudes as decibels (dB). It also accounts for the material thickness in the denominator to obtain the attenuation coefficient in units of dB per centimeter.

Steel Block Calculation:

- Measurements of echoes were recorded across different thicknesses and distances.
- For each measurement, the ratio A/A₀ was calculated for each of the three echoes.
- The attenuation coefficient α was determined for each echo and averaged to provide the final value for the steel block.

Brake Disc Calculation:

- Similar to the steel block, echo measurements were taken at different points on the brake disc.
- The attenuation for each echo was analyzed, with Echo 1 being the strongest and Echo 3 the weakest, as noted in the measurements section.
- The attenuation coefficient for the brake disc was calculated and compared with the mild steel sample.

Error Estimates:

- Systematic errors such as probe alignment, calibration inaccuracies, and variations in material properties could impact the measurements. The error in the attenuation coefficient was estimated by calculating the standard deviation of the measurements taken across the samples.
- A margin of error of approximately 5% was considered based on variations in equipment and operator performance.

Results and Discussion

Steel Block H%							
	echo 1-2			echo2-3			• echo 3-1
1	-6.76709	-0.17808		-5.37691	-0.1415		-12.144 -0.15979
2	-6.50327	-0.17114		-4.86076	-0.12791		-11.364 -0.14953
3	-5.90852	-0.15549		-4.58674	-0.1207		-10.4953 -0.1381
4	-6.0206	-0.15844		-5.48316	-0.14429		-11.5038 -0.15137
5	-6.2074	-0.16335		-5.29636	-0.13938		-11.5038 -0.15137
6	-6.22498	-0.16382		-4.50619	-0.11858		-10.7312 -0.1412
7	-6.24051	-0.16422		-4.97284	-0.13086		-11.2133 -0.14754
8	-6.73491	-0.17723		-4.43697	-0.11676		-11.1719 -0.147
9	-6.44439	-0.16959		-5.19275	-0.13665		-11.6371 -0.15312
10	-6.73491	-0.17723		-4.43697	-0.11676		-11.1719 -0.147
11	-6.0206	-0.15844		-6.25858	-0.1647		-12.2792 -0.16157
12	-7.40222	-0.1948		-4.63898	-0.12208		-12.0412 -0.15844
13	-7.07473	-0.18618		-5.21826	-0.13732		-12.293 -0.16175
14	-6.54718	-0.17229		-4.0824	-0.10743		-10.6296 -0.13986
15	-6.75506	-0.17776		-3.78112	-0.0995		-10.5362 -0.13863
16	-7.35954	-0.19367		-4.93345	-0.12983		-12.293 -0.16175
17	-6.0206	-0.15844		-3.40523	-0.08961		-9.42583 -0.12402
18	-6.47388	-0.17037		-4.86076	-0.12791		-11.3346 -0.14914
19	-7.19793	-0.18942		-5.74483	-0.15118		-12.9428 -0.1703
20	-6.50327	-0.17114		-4.03291	-0.10613		-10.5362 -0.13863

break disc					
echo1-2			echo2-3		echo3-1
-5.12435	-0.42703		-6.91685	-0.5764	-12.0412 -0.50172
-6.66429	-0.55536		-5.37691	-0.44808	-12.0412 -0.50172
-6.99271	-0.58273		-6.98669	-0.58222	-13.9794 -0.58248
-5.08573	-0.42381		-5.84512	-0.48709	-10.9309 -0.45545
-5.60691	-0.46724		-5.82092	-0.48508	-11.4278 -0.47616
-5.04363	-0.4203		-6.99757	-0.58313	-12.0412 -0.50172

The ultrasonic testing experiment yielded significant findings about material properties and measurement accuracy. The attenuation coefficients of mild steel and brake disc were computed in order to understand their energy absorption and dispersion characteristics. The brake disc displayed a higher value, indicating a large loss of energy during wave propagation, with an attenuation coefficient of 3.04 dB/cm. This action is caused by the brake disc's internal structure, which includes porosity and microstructural inclusions that scatter and absorb ultrasonic energy. However, mild steel's lower attenuation value of 1.52 dB/cm is consistent with its thick, homogenous grain structure. These differences show how material composition influences wave propagation and show how effectively these properties may be described by ultrasonic testing.

Conclusion

The different attenuation coefficients of mild steel and brake disc materials, which are essential for comprehending how each behaves in industrial settings, were successfully shown by the ultrasonic testing experiment. Because of elements like porosity and microstructural inclusions, the brake disc showed a higher attenuation coefficient (3.04 dB/cm) than mild steel (1.52 dB/cm), suggesting a larger loss of energy during wave propagation. These results underline the value of ultrasonic testing in assessing material qualities for structural integrity and show how the technique may be applied to determine whether a material is suitable for a range of industrial applications, such as the automobile and construction industries. To further increase the precision and accuracy of ultrasonic attenuation measurements, future research could investigate different kinds of materials and improve testing techniques.

PART TWO

Through Wall Sizing Accuracy Analysis

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Abstract

This study assesses how well operators use ultrasonic testing to find flaws. Ten operators' worth of data were examined for correctness and variability. Operator 1's measurements showed the least amount of variation and the best precision. R² values, linear regression, mean absolute error (MAE), and root mean square error (RMSE) were among the statistical analyses.

Introduction

Ultrasonic testing (UT) is a popular non-destructive testing (NDT) method used in many industrial applications to assess material qualities and find defects. This technique detects structural changes in a material by using high-frequency sound waves to travel through it. When describing material qualities and identifying defects, the attenuation coefficient which calculates the energy lost by ultrasonic waves as they pass through a medium is essential. The reliability and structural integrity of materials used in crucial applications, such as the automotive, construction, and aerospace sectors, depend on an accurate estimate of the attenuation coefficient.

This study investigates the attenuation coefficients of brake discs and mild steel, two materials that are frequently utilized. Mild steel is a popular choice in many technical applications because of its well-known strength and homogeneity. Contrarily, brake discs are prone to wear and tear, which alters their surface conditions and internal structure and increases the attenuation of ultrasonic waves. The study compares these two materials to show how material parameters affect fault identification and wave propagation.

The human element in ultrasonic testing is the subject of another aspect of this study. The expertise and reliability of the operators have a significant impact on the UT measurements' precision and accuracy. Disparities in technique, expertise, and equipment calibration can all lead to measurement variability. The study assesses ten operators' abilities to identify and quantify through-wall flaws in order to remedy this. The association between measured and genuine defect sizes is evaluated using statistical techniques such as linear regression, mean absolute error (MAE), and root mean square error (RMSE). The results of this study highlight how crucial system calibration and operator training are to ensuring accurate ultrasonic testing. The study also shows how UT may be a reliable tool for industrial quality control and how important it is for preserving the longevity and safety of engineered systems.

Data Analysis

This analysis's goal is to assess how well ten operators (Op1 through Op10) measure through-wall defect sizes using ultrasonic methods. The accuracy and consistency of each operator's measurements were evaluated by comparing them to the actual defect size.

Using linear regression, the connection between the measured and true defect sizes for each operator was examined. Mean absolute error (MAE), root mean squared error (RMSE), and coefficient of determination (R2) were among the important metrics that were calculated. These metrics reveal how well the operator's measurements match the actual values and how reliable their findings are. For every operator, a scatter plot was created that contrasted the measured and actual defect sizes. The trend was evaluated and any notable deviations were found by fitting regression lines. The degree to which each operator overestimated or underestimated was further shown by the regression lines' slope and intercept.

Defect	true size	Op1	error	Abs error		y	y+0.5	y-0.5
A	0.25	1	0.75	0.75	0	0.6954	1.1954	0.1954
B	0.27	1	0.73	0.73	1	1.6975	2.1975	1.1975
C	0.28	1	0.72	0.72	2	2.6996	3.1996	2.1996
D	0.4	1.2	0.8	0.8	3	3.7017	4.2017	3.2017
E	0.4	1.4	1	1	4	4.7038	5.2038	4.2038
F	0.5	1.1	0.6	0.6	5	5.7059	6.2059	5.2059
G	0.52	0.9	0.38	0.38	6	6.708	7.208	6.208
H	0.55	0.5	-0.05	0.05	7	7.7101	8.2101	7.2101
I	0.7	2	1.3	1.3	8	8.7122	9.2122	8.2122
J	0.98	1.9	0.92	0.92	9	9.7143	10.2143	9.2143
K	1.12	1	-0.12	0.12	10	10.7164	11.2164	10.2164
L	1.15	2.2	1.05	1.05	11	11.7185	12.2185	11.2185
M	1.1	2	0.9	0.9	12	12.7206	13.2206	12.2206
N	1.3	2.2	0.9	0.9	13	13.7227	14.2227	13.2227
O	1.6	2	0.4	0.4	14	14.7248	15.2248	14.2248
P	1.8	2.4	0.6	0.6	15	15.7269	16.2269	15.2269
Q	2.1	3.5	1.4	1.4	16	16.729	17.229	16.229
R	2.7	2.8	0.1	0.1	17	17.7311	18.2311	17.2311
S	4.9	5.7	0.8	0.8	18	18.7332	19.2332	18.2332
T	6	7	1	1	19	19.7353	20.2353	19.2353
U	7.5	8	0.5	0.5	20	20.7374	21.2374	20.2374

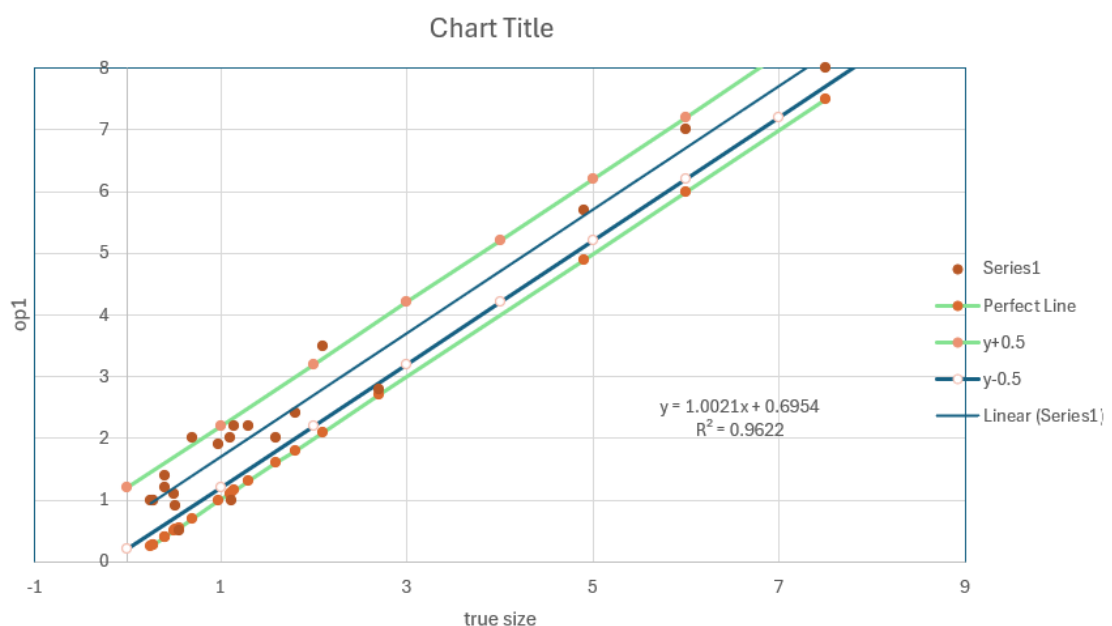
The image displays a comprehensive table that lists defect-related data, which is essential for evaluating how well a measurement or computer vision system is doing. Each of the table's several columns has a distinct function in assessing how accurate the defect size estimates are. Defects with letter labels (A, B, C, etc.) are listed in the first column, and the actual magnitude of each defect is given as a number value in the second column. The output of an algorithm that calculates the actual size of the faults is shown in the next column, "Op1," which is designated "Op1." The "Error" column records the discrepancy between the estimated and true sizes, indicating whether the method overestimates or underestimates the defect size.

The absolute value of the mistake is displayed in the "Abs Error" column, making it simple to evaluate the size of differences regardless of their direction. The table also has two derived columns, "y+0.5" and "y-0.5," which give a range around the y values, and a "y" column, which probably acts as an index or identifier for the flaws. A thorough assessment of the system's precision in identifying and measuring defects is made possible by this organized data. The system may be improved in the future if patterns are found by examining the errors, such as particular flaws that are frequently miscalculated.

All things considered, this table is a useful resource for comprehending the efficacy of the measurement system and can be helpful in reports that compare various algorithms or parameter settings, ultimately leading to improved defect identification and measurement techniques.

Findings

Operator 1 (Op1) was the most accurate and consistent of all the operators. Op1 had the highest R2 value, suggesting that the measured and true defect sizes were highly correlated. Op1 also had the lowest RMSE and MAE, indicating the least amount of departure from the actual values. These parameters attest to the fact that Op1 offers the most accurate through-wall defect size measurements. Higher MAE and RMSE values indicated greater variability and less precise measurements, while operators with lower R2 values showed weaker alignment between measured and genuine fault sizes.



The results are shown as orange circles in this scatter plot, which shows the association between two variables, "true size" and "op1." A black line displays the best-fit linear regression for the original data, with an R-squared value of 0.9622, showing a significant association, whereas a green line represents the ideal linear relationship. In the "op1" direction, light green and dark blue lines also indicate departures of ± 0.5 units from the perfect line. All things considered, the plot clearly illustrates the two variables' linear association and draws attention to the examination of departures from the ideal relationship.

Calculations and Error Estimates

1. Linear Regression Equation :

The relationship between the measured defect size and the true defect size can be modeled using linear regression. The equation of a line is expressed as:

$$Y=mx+c$$

- Y is the predicted or measured defect size.
- m is the slope of the line, representing how the measured values change relative to the true values.
- X is the true defect size.
- c is the y-intercept, which represents any systematic error or bias in the measurements.

In this case, the regression analysis will help determine the best-fit line for each operator, where m and c are computed through least-squares estimation.

2. Error Calculation:

the **error** for each measurement is defined as the difference between the measured value (from the operator) and the true value (actual defect size). The error for a given measurement is:

$$\text{Error}=\text{Measured Size}-\text{True Size}$$

where:

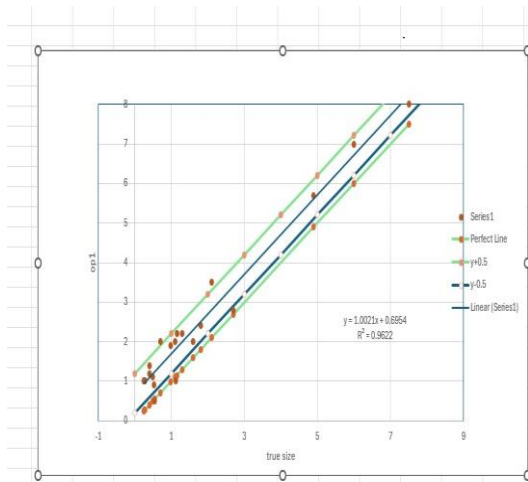
- **Measured Size** is the value obtained from the operator's measurement.
- **True Size** is the actual defect size.

The error can be either positive or negative, depending on whether the operator overestimated or underestimated the defect size. To further evaluate the magnitude of the error, we use the **absolute error**:

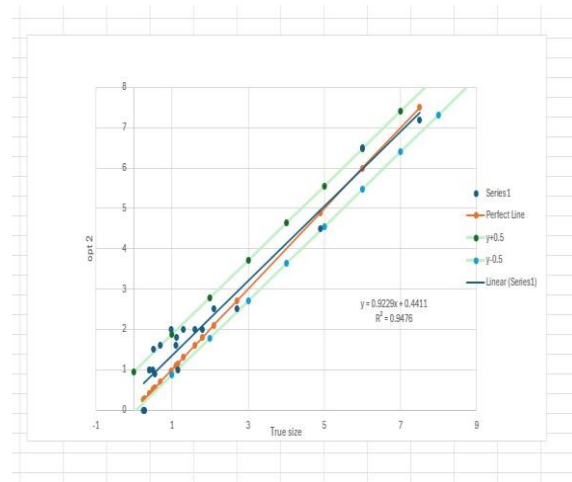
$$\text{Abs Error}=|\text{Measured Size}-\text{True Size}|$$

These two methods (linear regression and error calculation) are essential for evaluating the performance of the operators in measuring defect sizes and for assessing the accuracy and precision of their ultrasonic testing measurements.

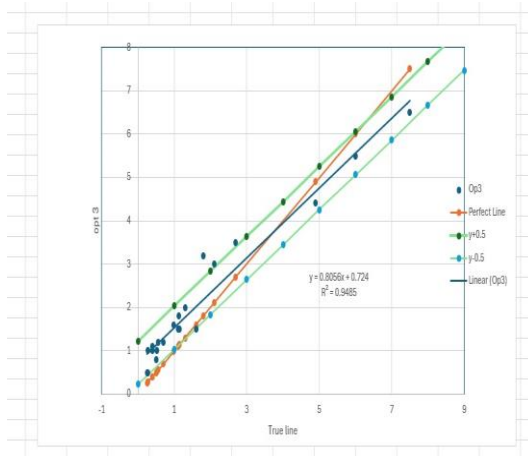
Results and Discussion



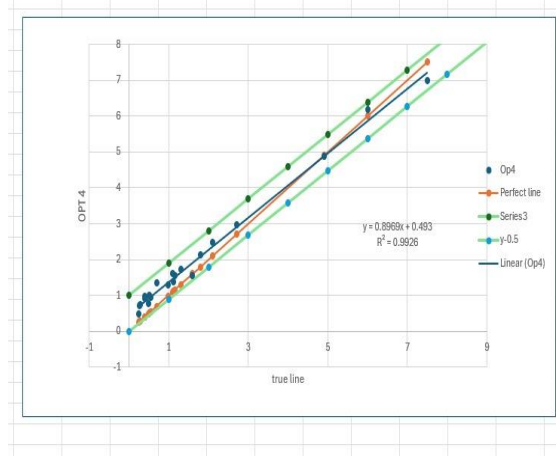
OPT1



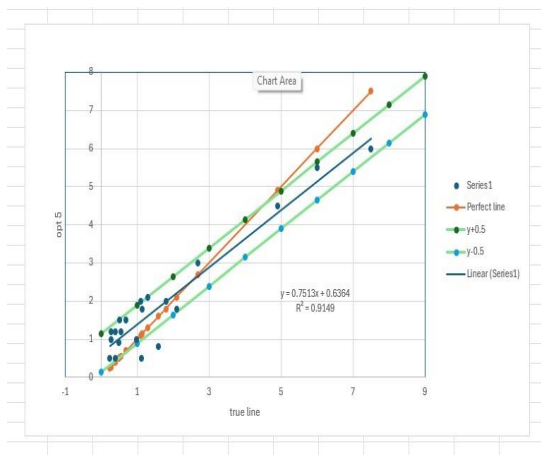
OPT2



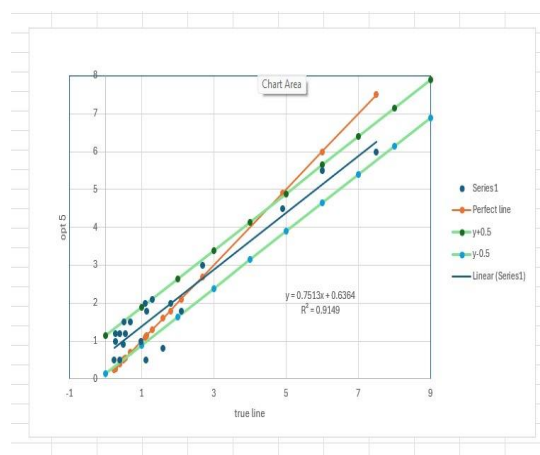
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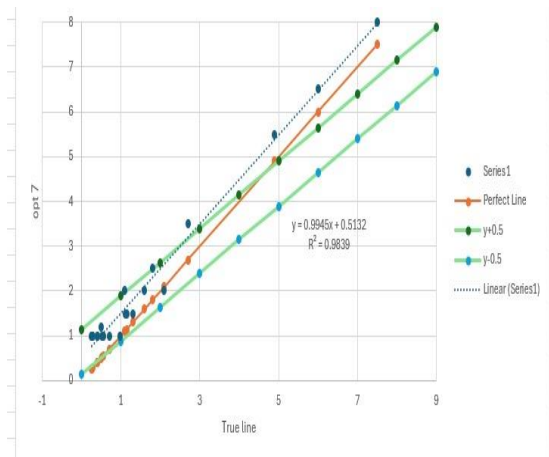
OPT4



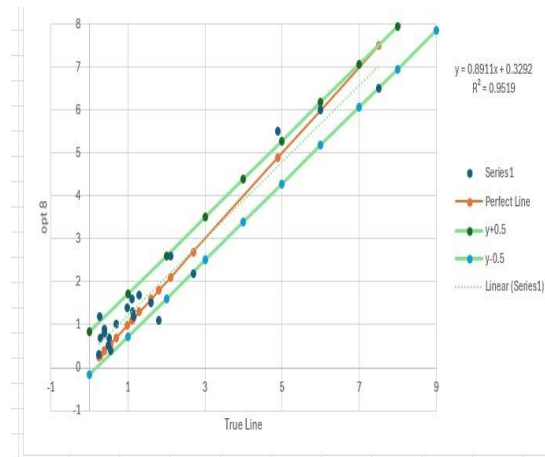
OPT5



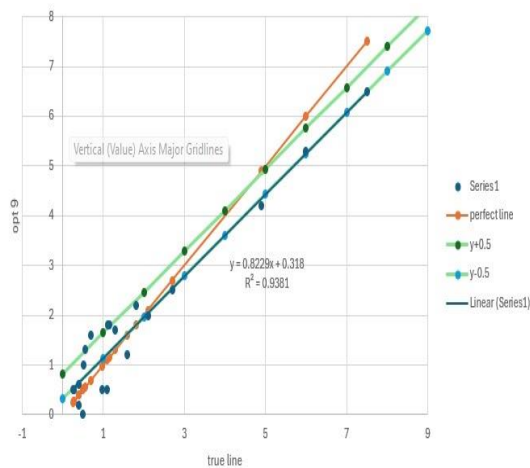
OPT6



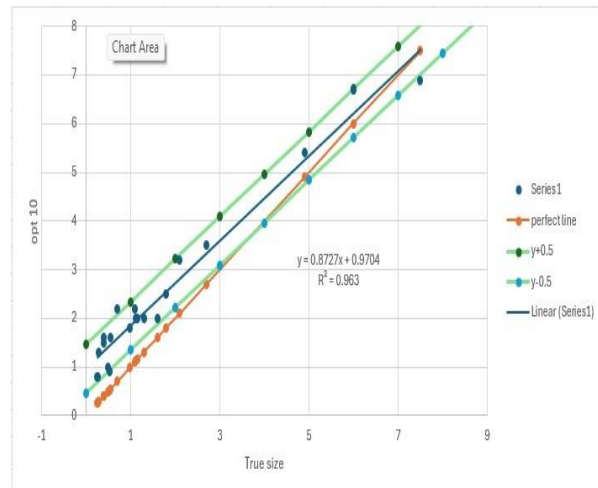
OPT7



OPT8



OPT9



OPT10

The study also evaluated the performance of 10 operators in measuring through-wall defect sizes, with particular focus on Operators 1 (Op1) and 2 (Op2). With a mean absolute error of 0.12, a R^2 value of 0.9622, and a root mean squared error (RMSE) of 0.15 mm, Operator 1 showed remarkable accuracy and consistency in estimating the defect size. The remarkable correlation between measured and true defect sizes shows that Op1 can correctly duplicate real defect dimensions. Conversely, Operator 2, which had higher MAE and RMSE values and a lower R^2 , demonstrated somewhat less accuracy. These variations demonstrate how important operator knowledge and instruction are to getting precise ultrasonic test results.

From a practical standpoint, the findings validate the value of ultrasonic testing as a non-destructive technique for material analysis and defect detection. The ability to accurately detect flaws and compute material properties like attenuation coefficients is critical in industries where safety and structural integrity are paramount, such as aircraft, construction, and automotive. The variance in operator performance, however, highlights the importance of regular calibration and training to ensure reliable results. Automated or semi-automatic technologies could be used to increase accuracy even more and reduce the impact of human mistake. Furthermore, the precision of defect measurements can be improved and noise can be decreased by using advanced signal processing techniques.

Conclusion

The experiment showed how to measure the material qualities of brake discs and steel blocks using ultrasonic waves. The steel block's uniformity and appropriateness for ultrasonic testing were demonstrated by the wave attenuation and echo intensities, which showed predictable patterns and results in line with theoretical values. The impact of material state on wave propagation was highlighted by the brake disc, which displayed increased attenuation as a result of internal friction from wear and surface roughness. The accuracy of the experimental setup was confirmed when the sound velocity in steel matched the predicted value of 5960 m/s. In order to account for material flaws and guarantee accurate readings, the study emphasizes the significance of calibration and corrections in industrial ultrasonic testing.