Prediction of aluminium content in a metal using SPSS based linear regression analysis.

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Abstract. In an aluminium industry, it is very important to know the type or grade of aluminium metals and its composition present within the aluminium metals using non-destructive testing (NDT). A method is required which is unique and help to know the type of the aluminium material in order to characterize the aluminium samples. Ultrasonic testing is one of the best NDT techniques which are used for characterization of properties of the material. Recently it is observed that ultrasonic testing parameters are significantly depends on microstructural or mechanical properties of materials and the parameters are affected by change in structural properties of materials. To extract the more information from ultrasonic signals, signal processing techniques are the best tools which are using now days. In this paper new technique is introduced to obtain the concentration of aluminium in aluminium material in terms of ultrasonic parameters hardness, velocity, attenuation & modulus of elasticity by using linear regression analysis using Statistical package for Social Sciences i.e., SPSS statistics. The regression equation which is obtained to calculate aluminium percentage is compared with the experimental value of aluminium percentage in the materials. In the present paper the accuracy or reliability of the mathematical model has been estimated. To estimate the aluminium percentage in aluminium this type of model will be very helpful.

1. Introduction
In ultrasonic techniques, ultrasound is allowed to pass through the material and penetrates the interior of the material deeply for inspection. Instead of high energetic beam of x-rays or gamma rays ultrasonic techniques is the most practical alternative method of detecting defects inside metals. Ultrasonic help to determine important details about the structure of big size metals [1,2] and which is also used to determine material properties [3]. Signal processing techniques are the important tools which are used to determine the information present in the received ultrasonic data, [4-7]. Using experimental data, mathematical model is formulated which is a new way to study or characterize the materials [8]. From many years non-destructive testing is used in number of industries and play a very significant role for characterization of materials. Signal processing techniques play very important role and significantly advanced the cutting edge of non-destructive testing and evaluation. This paper briefly reviews the importance of signal processing in NDT. In this paers linear regression analysis by SPSS statistics is used to characterize the aluminium materials and also discussed the relation between aluminium percentages of materials in terms of various ultrasonic parameters. The formulation of this relation on the basis of experimental result is a unique and advance approach towards to analyse the materials. The theory of investigation as suggested by SPSS statistics, IBM Corporation is proper approach of expressing the reaction of any phenomenon in terms of proper interconnection of various inputs of the phenomenon.
2. Material Characteristics Observation

The experimental procedure has been performed at central power research Institute, Nagpur. The instruments used for the experiments are properly calibrated and having greater accuracy. The aluminium alloys of different grades and different dimensions have been prepared for investigation. The surfaces of the materials are smooth to perform ultrasonic testing. Hardness tester is used for the measurement of hardness in the materials as shown in figure 1.

![Hardness Tester](image1)

**Figure 1.** Hardness Tester

The use of OXFORD instrument to determine the chemical composition in the given aluminium alloys. This instrument produces x-rays when energized and hence determine the composition present in the material.

When instrument is switched on, it produces x-ray beam and it passes through the material. This x-ray beam is then reflected back from the material and hence the instrument measure the different composition present in the aluminum samples and it display the readings on the screen of the instrument. By using digital vernier caliper, thickness and dimensions of the material of various samples of aluminum has been measured accurately.

2.1 Ultrasonic Non-Destructive Techniques

The computation has been accomplished by using an ultrasonic instrument ultrasonic thickness gauge. In which 5 MHz transducer has been used. This measurement is used a direct method. The distance between the two parallel external surfaces which are also known as thickness of the material is representing the distance travelled by the acoustic waves in the sample. By knowing this distance, the ultrasonic instrument records the velocity of the sound signal in the aluminium materials which are having different composition as shown in figure 2.

![Ultrasonic thickness gauge](image2)

**Figure 2.** Ultrasonic thickness gauge

By knowing the time of flight and thickness of the sample ultrasonic device calculate the velocity of the acoustic wave in m/sec.

For the NDT ultrasonic test performance, laboratory arrangement which is used is shown in figure 3. Using BNC cable transducers are connected to high voltage pulser and other is connected to digital storage oscilloscope. In between two transducers the aluminium material is placed one by one. On the two ends of a clamp the transducer is attached as shown in the figure (3).
In order to transmit ultrasonic vibration through transducer to different aluminium surfaces glycerine is used as a couplant. DPR 300 Pulser /receiver of JSR Ultrasonic (USA) have been used for the measurement to be performed in the lab. This instrument is used to produce high voltage pulse.

The main function of ultrasonic transducer is to converts one form of energy into another here electrical signal converted to ultrasonic signal. This ultrasonic pulse is transmitted through a material which is connected to the pulser via cable. At the receiver end the function of a transducer is used to identify ultrasonic pulses that have propagated through test material. TDS2024 200 MHz Tektronix Digital Storage Oscilloscope is connected to the receiving transducer. For transmission and reception of ultrasonic signals a pair of MODSONIC transducer of 4 MHz has been used. Coefficient of attenuation $\alpha$, is determine in dB/mm according to the given equation

\[
\text{Coefficient of attenuation } \alpha = (20/t) \log (\text{Input Voltage } V_i/\text{Output Voltage } V_o)
\]

Where ‘t’ is the thickness of the material.

The Modulus of Elasticity (MOE) is calculated by using given mathematical relation

\[
\text{MOE} = (\text{velocity})^2 \times (\text{density})
\]

which is calculated in terms of N/m²

3. An approach to formulate mathematical model using linear regression analysis using SPSS Statistics

SPSS Statistics is used to produce the formulation of mathematical model by using experimental data-based model given by; IBM Corporation in an advanced form is used. This approach is used to forecast the value of given variant based on the value of another variant. The modification is to the expansion of covering only and it is done by identification of variables.

SPSS statistics linear regression analysis is used to formulate the model so that aluminium percentage in the samples can be predicated in terms of other observed NDT parameters.

3.1 Identification of Variables

For formulation of mathematical model first step is to identify the variables in this process. The parameters which are using in the phenomenon are called covariant or variables. These covariant or variables are of two types

(1) Independent variables, and
(2) Dependent variable

Dependent variable is the variable which is to be predicated which is also known as outcome variable. Independent variable is the variable which is used to determine the other variable’s value which is also known as the predictor variable. This correlation which is established is nothing but a mathematical model and this model can be used as an important designed mechanism for such type of situation.
A mathematical equation is used to determine the percentage of aluminium in the samples which is utilized to recognize its utility in various fields. Here in the present case the outcome or dependent variable is to be taken as percentage of aluminium in the aluminium materials while this dependent variable is affected by hardness, velocity, attenuation and modulus of elasticity are the independent variables. Third variable, caseno has created which act as a chronological case number. This third variable is used to make it easy to eliminate cases (e.g., significant outliers) that have identified when checking for assumptions.

4. Results and Discussions

Statistical regression analysis has been carried out by using SPSS tools to obtain percentage of aluminum in given material in terms of dependent variables like hardness, ultrasonic pulse velocity, attenuation and modulus of elasticity. The ANOVA table explains the regression equation which perfectly fits the data for the prediction of dependent variable which is shown below in Table (1).

Table 1. ANOVA Table

| Model       | Sum of Squares | df | Mean Square | F     | Sig.  |
|-------------|----------------|----|-------------|-------|-------|
| Regression  | 8.192          | 4  | 2.048       | 2.477 | .055b |
| Residual    | 42.994         | 52 | 52          | .827  |       |
| Total       | 51.186         | 56 |             |       |       |

a. Dependent Variable: AL
b. Predictors: (Constant), MOE, Velocity, Attenuation, Hardness

From this table it is observed that this regression model remarkably determines the dependent variable. From the Table (1), small value of Sig 0.055 indicates that, overall, the regression model are predicting the outcome variable near to correct value (i.e. it is a good fit for the data).

The coefficients table provides the essential information to evaluate aluminum percentage from independent variables such as hardness, velocity, attenuation & Modulus of elasticity (MOE) as well as to determine whether these independent variables have significant contribution to the model. This can be done by observing the "Sig." column. Furthermore, to develop a regression model we can use the values in the "B" column as shown in Table (2).

Table 2. Coefficients

| Model       | Unstandardized Coefficients | Standardized Coefficients |
|-------------|----------------------------|---------------------------|
|             | Std. B | Error | Std. t | Sig.  |
| (Constant)  | 104.976 | 14.663 | 7.159 | .000  |
| Hardness    | -.010  | .004  | -.327 | -2.335 | .023  |
| Velocity    | -.001  | .002  | -.034 | -.248  | .805  |
| Attenuation | -1.337 | .560  | -.329 | -2.388 | .021  |
| MOE         | -1.094E-10 | .000 | -.082 | -.619  | .538  |

a. Dependent Variable: AL

The regression equation is written as:
Percentage of Al = 104.976 - 0.10(Hardness) - 0.001(Velocity) - 1.337(Attenuation) - 1.094 x 10^{-10}(MOE)

5. Reliability of models

In general, a term which is connected with the chance of failure is the reliability. Hence in order to find out the performance of the model, the value of reliability has to be determined. The reliability of model can be calculated as follows. In the given derived mathematical equation, the value of known independent variables are to be substituted. Estimated or calculated value of dependent variable which is the essential value of dependent variable will be obtained using this equation. After that error in the calculated value & observed value of dependent variable is estimated. By subtracting calculated value from observed value of dependent variable the error is calculated. The calculated error has been used to obtain mean error and the reliability of the model. This can be estimated by using following formula,

\[
\text{Reliability} = 1 - \text{Mean error}
\]

Mean error is estimated by using the formula \(\text{Mean error} = \frac{\Sigma XIFI}{\Sigma FI}\)

Where, \(\Sigma XIFI\) = Summation of the product of % of error and frequency of error occurrence and \(\Sigma FI\) = Summation of frequency of error occurrence.

In current model mean error is calculated as 2.403509

Hence for the present model reliability is calculated by given equation

\[
\text{Reliability} = 1 - \text{Mean error} = 100 - \text{percentage mean error} = 100 - 2.403509 = 97.59649\%
\]

Using this model, the percentage of aluminium present in the aluminium material may be determined which help to identify the applications of aluminium materials.

6. Conclusion

The result of this study showing evidences that the combination of ultrasonic signals in which digital signal processing is used associated with the SPSS based linear regression analysis having the great potential for predicting the aluminium percentage in aluminium samples. For the interpretation of characterization of aluminium metals this linear regression analysis using SPSS Statistics model is very useful to NDT monitoring system. In aluminium samples this statistics model is used to forecast the percentage of aluminium. If this percentage is known, this may help to categorise the aluminium and hence it can be used in required applications. In research and industry, it is needed to know the percentage of aluminium in the samples for its further applications by using various ultrasonic parameters. Indeed, this research will be useful to all researchers and industry persons to obtain the percentage of various components and use various variables as an input to the model and categorise the aluminium.

7. References

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