Interaction between the ultrasound velocity and material properties using *ANOVA*

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Abstract: By using ultrasound velocity measurements, it is possible to estimate the material anisotropy. Because of material anisotropy, distinct sound velocities are obtained for different measured directions. To qualify the ultrasonic inspection procedure, four conditions of the material, three different directions (with relation of the rolling direction) and two operators were used. After the measurement, the values were analyzed using the *ANOVA* method. Finally, it was possible to verify that there is no interference of the operator, which guarantees a good reproducibility of the inspection procedure, and that there is interference of the direction of inspection, demonstrating the condition of anisotropy of the material.

Keywords: Ultrasound velocity, material anisotropy, *ANOVA*

1. INTRODUCTION

Non-destructive testing are techniques used in the industry for inspection of components and equipment, which aims to control the integrity of the material. This type of test does not cause any damage to the component and, beyond that, can be performed in the field, without interfering in the production.

The ultrasound technique is one of the most used nondestructive tests adopted in the industry [1]. This technique is applied, for example, to characterize corrosion process, micro-cracks, intermetallic precipitates that arise on material due to the action of the temperature and the time of exposure in use, porosities, arising from the welding process, between other possibilities.

The basic principle of this technique is the measurement of the ultrasonic velocity of the material, which can be modified depending on the material microstructure, in different conditions [2]. The intensity of the ultrasonic wave decreases with the distance of the source of emission, suffering losses. These losses can be attributed to diffraction, reflection and absorption mechanisms [3].

A measurement has good reproducibility when it follows procedures in such a way that, regardless of the operator, the results can be reproduced.

Thus, this work considers the influence of the rolling direction of the material, the ultrasonic velocity variation and the influence of two operators on the obtained results, using the ANOVA method, a methodology that evaluates the significance of the various factors and interactions [4].

2 –MATERIAL AND METHOD

2.1. Material

The material selected for inspection in this work is a stainless steel duplex UNS S 31803, in four different specimen conditions: as received from the supplier, and heat treated at 760°C for three different times (10, 30, 60 and 120 minutes), in order to induce the precipitation of intermetallic phases which in practice is undesirable in the material, because it is cause loss in mechanical properties and corrosion resistance.

From the point of the inspection, these phases act as barriers to the passage of the sound, thus causing loss in the sound intensity of the material (attenuation), which modifies the value of the ultrasound velocity. The higher the amount of precipitated intermetallic, the greater the attenuation expected.

The test specimens were identified as A (solubilized – without intermetallic), B, C and D, according to the quantity of precipitated intermetallic, in increasing order.

2.2. Pulse-Echo Ultrasonic Inspection Technique

The non-destructive ultrasound technique is widely used in industry because it is sensitive to heterogeneities presented by the material, such as cracks and micro-cracks, inclusions, precipitates, porosities, among others, and can characterize them due to the interaction of the sonic beam with the microstructure.

The attenuation is caused by the loss of sound energy when the beam is passing through the material. The intensity of the beam received by the transducer is significantly less than the initial transmitted intensity. According to researchers, losses occur due to interference effects and reflections [6].

For the application of pulse-echo method, basic devices are required: a piezoelectric crystal transducer, which transmits and receives the ultrasonic waves that propagate through the material, and ultrasound equipment capable to transmit the pulse, receiving the echo and amplifying it [7].

This analysis is possible because through the ultrasound velocity (m/s), one can estimate the elastic modulus of the material. By definition, the variation of the elastic modulus indicates the material anisotropy, demonstrating that the rigidity may vary according to the direction of measurement [8]. The higher the ultrasound velocity, the higher the elastic modulus of the material, and thus greater rigidity of the material. In other words, the more significant the increase, the greater the material anisotropy.

2.3. ANOVA

The ANOVA method is the statistical tool used to analyze the results obtained in this study. A complete factorial design was performed, with two replicates for each condition of the material, at a 95% confidence level [9,10].

3 –RESULTS AND DISCUSSION

The results obtained by ultrasonic inspection showed that when there is a significant variation of the material condition and when there is a modification of the transducer position at the inspection, there is a variation of the ultrasound velocity. So, the greater the amount of precipitate in the material, the greater the attenuation of the sound, and physical changes in the material occur, as in the elastic modulus (Table 1).

In this way, it can be said that the material experiences change in elastic modulus, allowing to predict that the material undergoes anisotropy. Through the ANOVA method, it was possible to analyze the factors: condition, measurement direction and operator. Table 2 presents the results. Minitab® software was used to perform the analysis.

Table 2 presents the ANOVA results, were:

DF: degree of freedom;
SQ: Sum of squares;
MQ: Mean square;
F: Ratio between the variance of the analyzed factor and residual variance;
P-value: Significance level;
F-critical: Tabulated value, obtained from the desired confidence level (95%), the degrees of freedom of the analyzed factor and the residual degrees of freedom;
Significant: A factor or interaction is significant when F > F-critical or when P-value <0.05;

The interaction between sample condition vs direction was significant for the ultrasound velocity values. This result was expected, since the specimens were submitted to different treatments, which implies a change in the attenuation. In addition, the direction factor was also significant, which was expected, and even extrapolating this result, it is possible to verify a change of its elastic modulus, being the material seen as anisotropic.

The operator factor and the conditions, condition vs operator and direction vs operator were not considered significant.

4. CONCLUSION

Through this work, it was possible to analyze a procedure of inspection by the non destructive ultrasound method, performed by two operators, in four material conditions.

The operator factor and the conditions condition x operator and direction x operator were not considered significant, which is a satisfactory result. It is concluded that the operator does not affect the sonic speed measurement process.

On the other hand, the condition and direction factors significantly affect the result obtained, due to metallurgical changes for each condition. This allows us to affirm that the material is anisotropic, due to the sonic velocity variation in the different conditions. One can also predict that there is variation of its elastic modulus, and thus, confirming the condition of anisotropy presented by the material.

Finally, it is stated that the method is adequate, since it has good reproducibility (the variation between operators was not significant).

Table 1 - Ultrasound velocity values (m/s).

Condition	Direction	Operator A	Operator B
A	0	5889.5	5885.7
	45	2945	2976
	90	5827.3	5822.3
A	0	5891	5893
	45	3081.7	3083.4
	90	5848.9	5849.9
B	0	5850.4	5847.5
	45	5837.6	5846.2
	90	3208	3230
B	0	5863.4	5861.4
	45	3082.1	3080.7
	90	5835.7	5838.2
C	0	5896.6	5892.4
	45	2912.4	2980.2
	90	5811	5813
C	0	5864.9	5870.3
	45	3046.3	3050.2
	90	5898.7	5900.1
D	0	5857	5853
	45	3280.9	3293.2
	90	5858.7	5853.1
D	0	5845.3	5856.7
	45	2995.9	3001
	90	5857.4	5855.6

Table 2 – Results obtained from *ANOVA.*

Source	DF	SQ	MQ	F	P-value	F-critical	Significant (?)
Condition	3	15547	5182	0.01	1.00	3.01	No
Direction	2	56860200	28430100	46.76	0.00	3.40	Yes
Operator	1	453	453	0.00	0.98	4.26	No
Condition vs Direction	6	11224338	1870723	3.08	0.02	2.51	Yes
Direction vs Operator	2	605	302	0.00	1.00	3.40	No
Condition vs Operator	3	178	59	0.00	1.00	3.01	No
Condition vs Direction vs Operator	6	598	100	0.00	1.00	2.51	
Error	24	14593259	608052				
Total	47	82695177					

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