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Simulation Analysis of Ultrasonic Testing in Steel-based Butt Weld Joint

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Abstract: Within this study, a simulation analysis based on Ultrasonic Testing (UT) is made using Comsol Multiphysics. Comsol Multiphysics is a software that can simplify many aspects of building UT method and also can be used to obtain a fast understanding of the results of altering the fundamental parameters. The software program has useful features which can help in technique development especially for UT inspectors in Non- destructive Testing (NDT) field. The focus of this study is to conduct a simulation analysis of internal weld defects by developing the model of defects in a weld structure sample configured using the software. The model is developed based on actual parameters and characterization of weld structure sample and internal weld defects. The results of analysis show that each type of defects which are incomplete penetration, slag inclusion and lack of fusion have different signal pattern and signal amplitude which are depended on the characterizations of those defects themselves.

Keywords: Simulation Analysis, Ultrasonic Testing (UT), Non- destructive Testing (NDT), Internal Weld Defects

1.0 Introduction

It is known that welding is one of the most important joining process used in manufacturing industry. Welding processes which include GMAW, GTAW and SMAW used several types of weld joints in joining process such as butt joints, lap joints, tee joints, outside corner joints and edge joints [1], [2]. Usually, defects will occur during welding process. The defects can be categorized into two main defects called internal and external defect. NDT methods are used to inspect these defects. Liquid penetrant testing, magnetic particle testing, ultrasonic testing, radiography testing and eddy current inspection are some of the common NDT methods used in industry. Among these methods, ultrasonic testing is typically used due to its ability, versatility and relative cost effectiveness [3], [4]. Simulation analysis based on UT technique is used in this study in detecting internal weld defects in aluminium

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weld structure. The common internal weld defects; incomplete penetration, slag inclusion and lack of fusion are simulated and analyzed using a reliable software which is Comsol Multiphysics.

Basically, simulation analysis consists of two significance parts which are modelling and simulation. The purpose of modelling and simulation involves evaluation of performance, evidence, prediction, training, discovery, entertainment and training. Simulation methods are used in a number of areas including computer systems, production processes, organizational structures, government systems, ecological systems and other complex processes and systems. The use of modelling and simulation methods to understand the performance of complex sociotechnical systems becomes a promising area for research [5]. As mentioned, it shows that this method is needed for this study as it gives a lot of benefits in inspection field such as fast preliminary detection process of defect and can be used to predict the defect location based on its' characterizations. Hence, in this study, the internal weld defects detecting simulation analysis using Ultrasonic Testing (UT) method is utilized for the purpose of technique development in NDT method.

1.1 Problem Statement

Defects are common in any production including welding. Defects in welding can be classified into two categories which are external and internal defects. Compare to external defects, internal defects bring more issues to weld parts as the defects are invisible to the naked eyes. The typical type of internal defects are incomplete penetration, slag inclusion and lack of fusion. Usually, the weld defects are inspected using NDT method. NDT method needs competent and experienced inspectors to utilize it in order to avoid any unnecessary failure during inspection. This has become an issue for newcomer inspectors that does not have adequate experiences in NDT field. However, there is still a way to overcome this issue which is by using simulation analysis in Ultrasonic software for the purpose of technique development in Ultrasonic Testing (UT) method. Indirectly, this method will improve the using of Ultrasonic equipment in real life situation.

1.2 Objectives

The objectives of this study are:

i. To analyze the defect on the structure of welds using Ultrasonic Testing simulation technique.
ii. To illustrate the capability of appropriate software to produce accurate simulations of defect based on their characterizations using Ultrasonic Testing.
iii. To study the characteristics of a real-life system by manipulating variables that cannot be controlled in a real system.

1.3 Scope of Study

The scopes of this study are:

i. The use of Comsol Multiphysics software in detecting internal weld defects using Ultrasonic Testing method.
ii. Types of internal defects used for simulation are incomplete penetration, slag inclusion and lack of fusion.
iii. Aluminium is used for the material of sample.
iv. Elastic wave is used for the type of beam.
v. The transducer of ultrasonic probe is up to 1.5 MHz
vi. The result of simulation analysis is shown in Pressure (Pa) against Time (s) graph.

1.4 Significance of Study

This study used modelling and simulation approach, i.e. the defect is modelled in a sample and then it is simulated using a software. Modelling simulation solves real-world problems safely and

effectively. It offers an important analytical method that is easily verified, communicated and understood. Simulation modelling provides valuable solutions across industries and disciplines by providing clear insights into complex systems. Simulation allows experiments on a valid digital system representation. Simulation software offers a realistic environment for the study of computer models during operation, including the option of displaying them in 2D or 3D. The ability to evaluate the model during operation separates simulation modelling from other approaches. In being able to examine processes and communicate with a simulation model in practice, both understanding and trust are rapidly established. Hence, the use of simulation modelling approach in this study will be a great significant endeavor in technique development of NDT method in NDT field. This study is focusing on Ultrasonic simulation inspection of internal weld defects which focusing in Ultrasonic Testing (UT) simulation technique using elastic wave. The inspection of internal weld defects, which is in simulation, is being utilized in this study for the purpose of technique development for NDT method. This approach will provide a lot of benefits to NDT field [6].

2.0 Methodology

2.1 Overall Flowchart

The flowchart of methodology process of this study has been developed as shown in the Figure 1 below in order to achieve the objectives of this study. There are four main process included in this methodology which are define the problem, development of model, simulation analysis and lastly the process of validation.

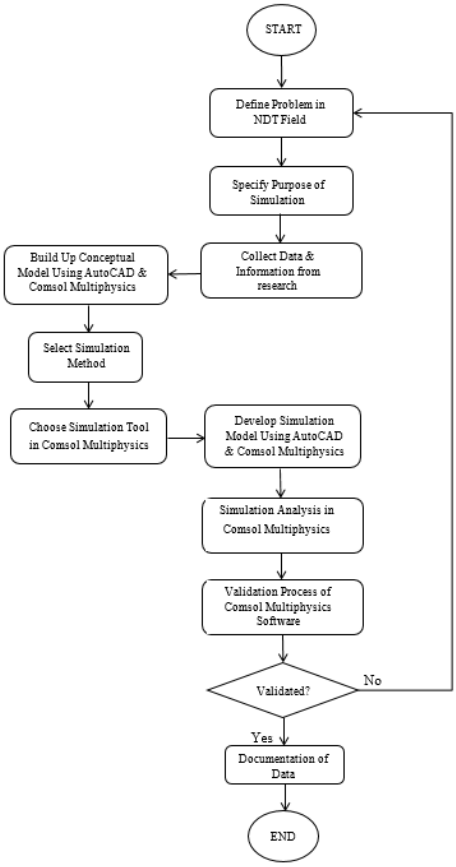


Figure 1: Methodology process flowchart

2.2 Development of Simulation Model

In this study, internal defects are modelled and simulated using a multiphysics software, which is Comsol Multiphysics with the help of CAD software, AutoCAD. The geometry of sample and defects is first sketched in AutoCAD and then was imported into Comsol Multiphysics for another advance steps which is the modelling of defects. Comsol Multiphysics has features, i.e. sketch and geometry, which can be used to model the internal weld defects in the weld region of a specimen. It has several simple geometries that can be utilized in drawing the defect. The defect is modelled based on the characterizations of real internal weld defect. The type of developed internal weld defects are incomplete penetration, slag inclusion and lack of fusion (wall side). All of these defects are developed in 15 mm height and 100 mm width of weld structure sample. The sample and internal weld defects are first developed in AutoCAD as AutoCAD has better features of model developing compare to Comsol Multiphysics. After that, the modelled sample and internal weld defect is imported into Comsol Multiphysics. Then, the internal weld defects are modelled again in the Comsol Multiphysics.

Next is the configuration of UT probe and UT beam that is needed for simulation analysis. This study used UT probe as the placement for internal weld defects simulation and the configuration of the probe is set after the development of model is done. A probe consists of a transducer and an optional wedge. The transducer and wedge used in this study is made manually using the geometry provided in Comsol Multiphysics. The example of finished UT probe and weld sample set up is shown in Figure 2 below. The UT beam configuration is set up after the UT probe configuration is completed. The probe used the Elastic Waves, Time Explicit interface dedicated to transient linear elastic wave propagation problems over large domains with several wavelengths. It is ideal for time-dependent simulations with arbitrary time-dependent sources and fields. The interface is based on the discontinuous Galerkin (dG-FEM) approach and uses a time-explicit solver.

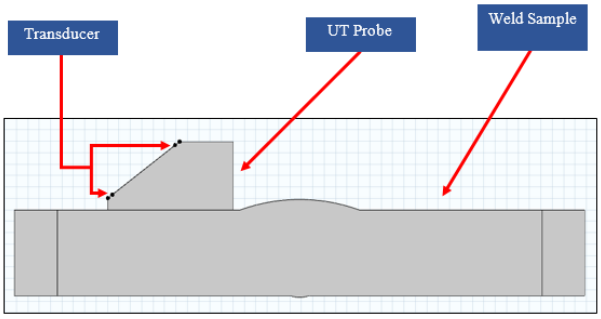


Figure 2: Example of finished UT probe setup on weld sample

2.3 Validation of Software

The validation of Comsol Multiphysics software uses two types of approaches which are thickness measurement analysis and compression wave speed analysis. The thickness measurement analysis is made by analyzing the thickness measurement of aluminium sample. The aluminium sample has 30 mm of thickness and 6320 m/s of compression wave speed. The validation process also used elastic waves as the type of beam for the 0° transducer. For this analysis, the frequency and diameter for the transducer are 2.25 MHz and 10 mm respectively. All of the setup parameters are based on Ultrasonic Testing Thickness Measurement (UTTM) standard [7]–[9]. The thickness measurement the sample is calculated using thickness formula based on the obtained result. Next, the compression wave speed analysis is analyzed by the compression wave speed of aluminium sample. The compression wave speed is determined using velocity formula by also referring to the result obtained from thickness measurement analysis. The formula of thickness, T and velocity, V is as follow [10], [11]:

$$T = \frac{(Velocity)(Time\ taken)}{2} = \frac{Vt}{2} \qquad Eq.1$$

$$V = \frac{Distance\ travelled}{Time\ taken} = \frac{\lambda}{t} \qquad Eq.2$$

Lastly, the obtained results of calculation are compared to the setup value in the parameters using percent difference formula. If the percent difference is acceptable, the Comsol Multiphysics software is validated. The formula of percent difference is as follow:

$$Percent\ difference = \left|\frac{Experimental\ value - Theoretical\ value}{Theoretical\ value}\right| \times 100\ \% \qquad Eq.3$$

3.0 Results and Discussion

3.1 Simulation Analysis Result

Beside the characteristics of internal weld defect analysis which is based on the characteristics of real internal weld defects, this study also made an analysis on the change of the size, angle and location of those defects which is also modelled using Comsol Multiphysics. The result for each of analysis is focused on the signal pattern and signal amplitude.

1. Incomplete Penetration

Table 1: The result for Incomplete Penetration analysis

Criteria	Real Characterization (5 mm)	Change in Size (7.5 mm)	Change in Angle (30°)	Change in Location (left side)	Change in Location (right side)
Signal Pattern					
Amplitude	+0.90E5 - 0.95E5	+1.33E5 - 1.14E5	+2.10E5 -1.55E5	+0.81E5 - 0.84E5	+1.07E5 - 0.97E5

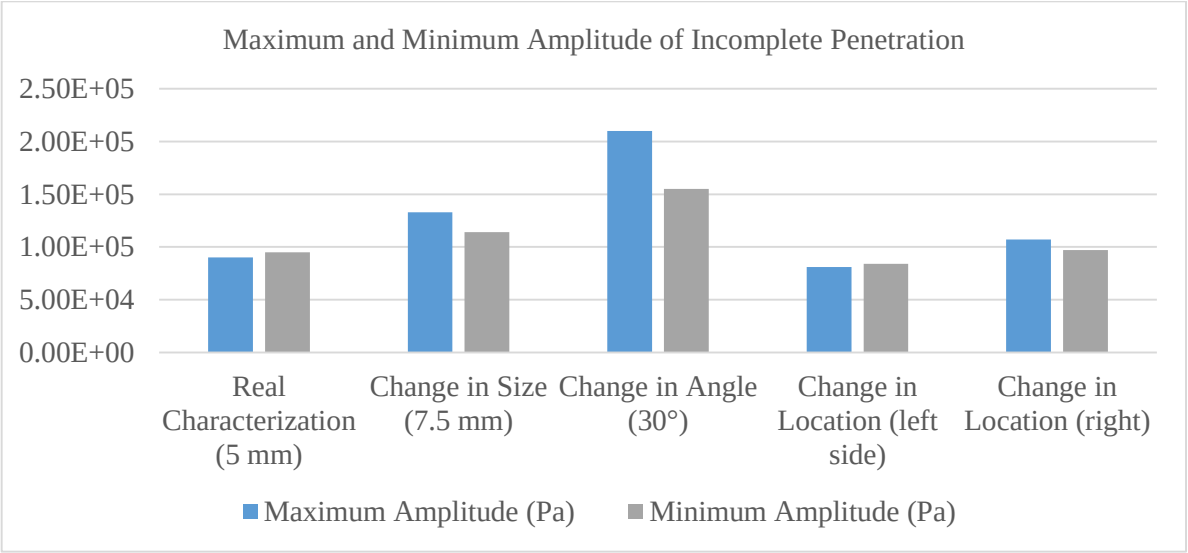
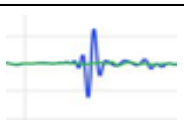


Figure 3: The comparison of amplitude for different characterization of Incomplete Penetration

2. Slag Inclusion

Table 2: The result for Slag Inclusion analysis

Criteria	Real Characterization (8 mm)	Change in Size (4 mm)	Change in Angle (30°)	Change in Location (left side)	Change in Location (right side)
Signal Pattern					
Amplitude	+0.37E5 - 0.61E5	+0.60E5 - 0.70E5	+2.50E5 - 2.47E5	+0.33E5 - 0.63E5	+0.52E5 - 0.86E5

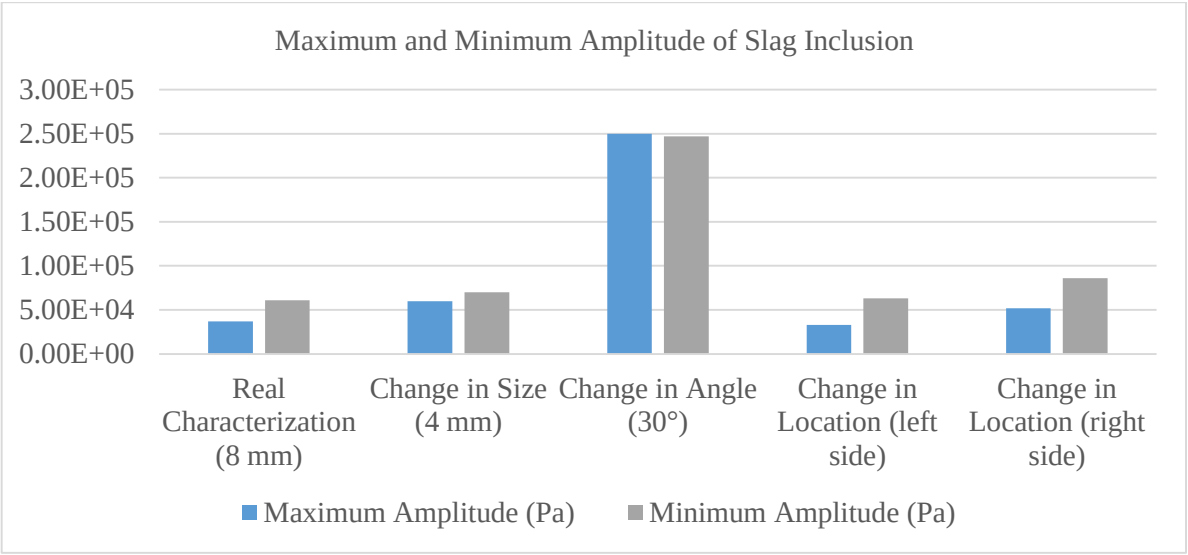


Figure 4: The comparison of amplitude for different characterization of Slag Inclusion

3. Lack of Fusion

Table 3: The result for Lack of Fusion (wall side) analysis

Criteria	Real Characterization (3.27 mm)	Change in Size (4.9 mm)	Change in Angle (30°)	Change in Location (right side)
Signal Pattern				
Amplitude	+0.75E5 - 0.70E5	+0.80E5 - 0.70E5	+1.17E5 - 0.87E5	+0.40E5 - 0.60E5

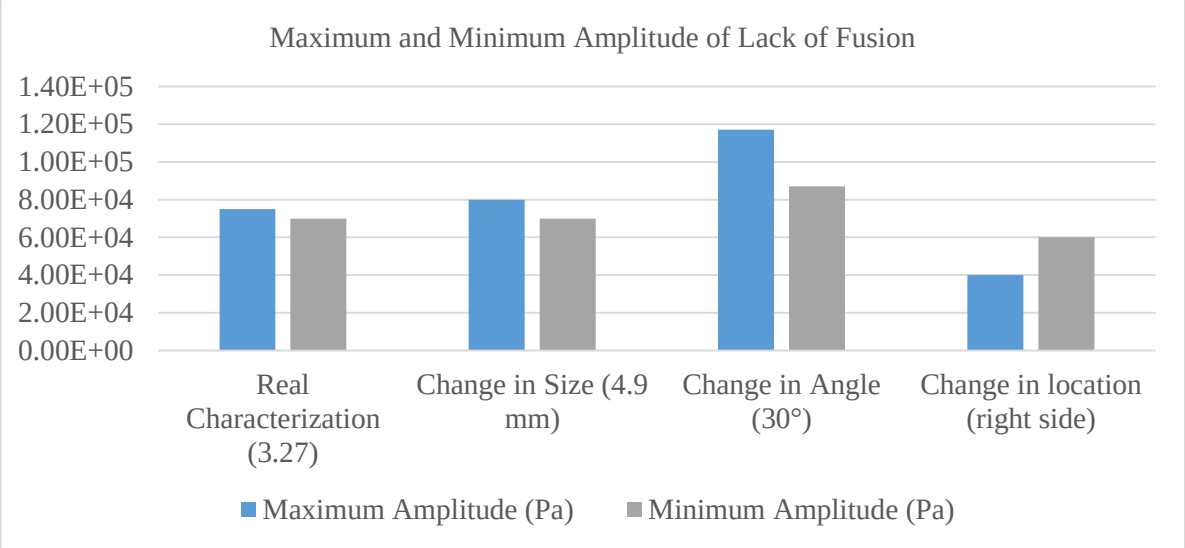


Figure 5: The comparison of amplitude for different characterization of Lack of Fusion

Based on the tables and figures above, it shows that different type of defect has different signal pattern and signal amplitude. It also shows that when there is change in characterization of defect, the signal pattern and signal amplitude also change. It is because each type of defect has different type of characteristics such as geometries, size, angle and location. Overall, based on all of the results comparison, it can be said that the signal pattern and signal amplitude depends on the characterization of the defect itself.

3.2 Validation Result

The first validation result is from thickness measurement analysis for thickness measurement of aluminium sample. The setup thickness for the sample is 30 mm. So, by using thickness of plate formula, the calculated result should be the same or almost the same with the setup sample thickness. The first back wall echo signal from graph plot shows the real time taken for the beam to reflected back from boundary to transducer. The time taken of the beam to reflected back for both samples is 1.03E-5 s. The calculation of sample thickness for aluminium sample is shown below;

$$V = Velocity = 6320\ m/s$$

$$t = Time\ taken = 1.03\text{E} - 5\ \text{s}$$

$$T = Thickness = \frac{Vt}{2} = \frac{(6320)(1.03\text{E} - 5)}{2}$$

$$T = 32.55\ mm$$

Then, the percent difference is calculated. If the percent difference is acceptable, the Comsol Multiphysics software is validated.

$$Percent\ difference = \left|\frac{Experimental\ value - Theoretical\ value}{Theoretical\ value}\right| \times 100\ \%$$

$$Percent\ difference = \left|\frac{32.55 - 30}{30}\right| \times 100\ \% = 8.5\ \%$$

The calculated value shows the results below 10 %. Hence, Comsol Multiphysics is validated.

The second validation result is from compression wave speed analysis for compression wave of aluminium sample determined from velocity formula. The parameters of the formula are obtained from the distance travelled of compression wave in the material and the time taken for the beam to reflected back from boundary to transducer. The compression wave speed for aluminium sample is 6320 m/. The time taken of beam reflection is obtained from the simulation analysis result in thickness measurement analysis. The calculation of compression wave speed for aluminium sample is shown below;

$$\lambda = Distance\ travelled = 0.06\ m$$

$$t = Time\ taken = 1.03\text{E} - 5\ \text{s}$$

$$V = Velocity = \frac{\lambda}{t} = \frac{0.06}{1.03\text{E} - 5} = 5825.24\ m/s$$

Then, the percent difference is calculated. If the percent difference is acceptable, the Comsol Multiphysics software is validated.

$$Percent\ difference = \left|\frac{Experimental\ value - Theoretical\ value}{Theoretical\ value}\right| \times 100\ \%$$

$$Percent\ difference = \left|\frac{5825.24 - 6320}{6320}\right| \times 100\ \% = 7.83\ \%$$

The calculated value shows the results below 10 %. Hence, Comsol Multiphysics is validated.

4.0 Conclusion

The results obtained from this study propose a good solution for newcomer inspectors that does not have adequate experiences in NDT field especially in ultrasonic testing (UT) technique. In other words, it can improves technique development in UT technique which is directly improving the using of ultrasonic equipment in real life situation. In this study, the internal weld defects which are incomplete penetration, slag inclusion and lack of fusion were able to be analyzed. The analysis are simulated using a suitable software which is Comsol Multiphysics by focusing on UT technique. The first objective has been achieved by successfully analyzed the defect on the structure of weld using UT simulation technique. The first analysis was between incomplete penetration, slag inclusion and lack of fusion based on real characterization of each defects. The signal shows different pattern and amplitude for the three different types of internal weld defects. Next analysis was made after the characterizations of real defect were changed based on the size, angle and location for each defects. The signal for this analysis also shows different pattern and amplitude for all of the changed characterizations. With this, the second and third objectives were also successfully achieved.

Acknowledgement

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