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Modeling the Defect in Spot Welding on 5083 Aluminum Sheets and Replacing Them with Steel Sheets in the Automotive Industry

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Abstract

Similar sheets of Aluminum 5083 can be used in the automotive industry and meet the needs of the industry. These sheets have the highest resistance of heat treatment among aluminum alloys and are widely used in the car body; and according to various welding tests, spot welding is used for these sheets, which spot welding is acceptable for these sheets. In this paper, it was used Comsol Multiphysics software. It has been investigated the propagation of ultrasonic waves in two layers of similar sheets aluminum 5083 in different thicknesses of simulation and the effect of amplitude echoes on ultrasonic waves. This test was performed by ultrasonic immersion method and it was investigated the intensity and amplitude of the reaction of the resulting defect waves. It been investigated various factors and conditions such as excitation frequency, the most suitable position for the transducer to stimulate the focused waves in simulation, mesh size sensitivity analysis and appropriate mesh size for simulation. This article discusses the use of aluminum 5083 sheets that can be used instead of steel sheets in the automotive industry. With Studies and experiments conducted in this article, the characteristics of these sheets in the automotive industry have been determined that in addition to saving car weight, more speed is possible in cars that use this sheet. In this paper, for the efficiency of this sheets, it was mentioned the average relative error that can meet the industrial needs. A comparison was made between the simulation and experimental results and a good agreement was observed between them.

Keywords: *Spot Welding, Ultrasonic Waves, Simulation, Similar Sheets of Aluminum 5083, Average Relative Error*

I. INTRODUCTION

The automotive industries is witnessed a lot of progrees daily. The application of aluminum in the automotive industries and the advancement of the industries led to the necessity for new materials with special properties [1-2]. Also, due to closely competition, the automotive and transportation industries are equipped with newer technologies every day and it was use more advanced materials to obtain their economic and technological goals [3-4]. Todays, three main goals are pursued in the transportation industry, which are:

- Reducing the weight of vehicles to save energy and reduce environmental pollution
- Ensure all safety standards using high-strength materials
- Facilitate manufacturing processes and reduce production costs

Since aluminum alloys meet almost all above objectives, much research has been conducted on the replacement of aluminum alloys with steel in the transportation industries. The results of this research have led to such a revolution in these industries that today in most developed countries, it was made a high percentage of wagons, buses and cars from aluminum alloys, in addition to aerospace industries (satellites, aircraft, ships) and marine structures (ships, submarines) [5-8]. The studies indicated that the use of aluminum alloys instead of automobile metal skelecton results in a weight loss of about 50%, with regards to all parts, this weight reduction reached 20-30% of whole weight of automobile. Finding the correct alloy is very important for the body structure and the retaining panels. For automobile exterior shell sheets, it was very important having numerous properties such as good ductility, color strength and surface quality after pressing. To obtain these goals, this group of aluminum alloys is widely used that they show high corrosion resistance compared to steel. One of the methods that has received a lot of attention, today, it is the method of inspecting spot welding by ultrasonic waves in non-destructive tests. Ultrasonic waves have the ability to propagate over long distances; but their use in complex structures is related to problems. In complex structures, it is not easy to interpret the obtained signals from the ultrasonic test. Therefore, to better understand the interaction of ultrasonic waves by complex structures, simulation will be very useful [9]. There can be various defects in spot welding, in which the identification of each can be useful for the industry. By preparation of defect interpretation arrangements, each echo is distinguished from other echoes by

characteristics such as amplitude, width, and number of oscillations (echo teeth) [10].
Liu et al. examined the alloy to address problems such as coarse crystalline grains and poor mechanical properties of welded common aluminum alloys. Continuous ultrasonic vibration between 0 and 200 volts during MIG laser hybrid welding and the effects of ultrasonic power on the microstructures and mechanical properties of the weld were investigated. Experimental results showed that with increasing ultrasonic power, the weld porosity first decreases and then increases and the joint microstructure becomes fully apparent [11]. Hakim and colleagues investigated the welding of 5083 aluminum alloy. A 5083 aluminum alloy tube was used to transport liquefied natural gas (LNG) by the welded tungsten arc welding (GTAW) process. To investigate the defects, metallographic study (optical microscope and scanning electron microscope) and mechanical tests (Vickers micro-hardness test and tensile test) were performed to determine the microstructure evolution and mechanical properties of the welded joints used and good conclusions were obtained regarding the porosity defect [12]. Kohlhauser & Hellmich investigated the mechanical and microstructural properties of cold rolled aluminum alloy (CMT) welded aluminum alloys. Non-destructive tests such as eye tests and radiographs were performed before destructive tests. Tensile, flexural and fatigue tests were also performed on samples extracted from welded joints. The fracture level of fatigue specimens was examined by light microscopy (LOM) and scanning electron microscopy (SEM) which has good efficiency with high welding speed and good tensile performance and fatigue [13].

This paper discusses the replacement of 5083 aluminum sheets in automobiles with steel sheets and the modeling of welding spot defects in these sheets.. In addition to the ultrasonic test by immersion test, it have been performed radiographic and C-scan tests on the welded parts and it was studied their defect effect and dimensions. To better evaluate the defects and industrial performance of the used sheets, it was drawn a diagram for comparison among tests and it was reviewed the average relative error that it can meet the industrial requirement and resolve that error.

II. SIMULATION AND GOVERNING EQUATION

The finite element method of FEM is a numerical solution to approximate solution of differential equationsa and also it was applied to solve integral equations. The basis of this method is the complete elimination of differential equations or their simplification to ordinary differential equations. There are several advantages and disadvantages to this approach, and the finite element method is one of the best. This method is very useful in solving partial differential equations on complex domains, either when the domain is variable, or when high accuracy is not required everywhere in the domain, or it will be very suitable if the results do not have sufficient correlation and uniformity. Next, for each part or element, a suitable approximate solution is assumed in which the methods of equations extraction of the finite element method are performed in several ways. Ultrasound emission simulation requires probe modeling.
The problem consists of modeling acoustic pressure variations in the fluid (water) domain which transfer to the solid (SS 17 4 PH) domain through a planar interface. The coupling methodology is that the fluid pressure is transmitted to the solid boundary as the normal load per unit area, and the acceleration of the solid normal to the interface is transmitted to the fluid. The governing equations for pressure acoustics in transient analysis can be written as eqn. 1 and the governing equation for solid mechanics is given as eqn. 2 [14].

$$\frac{1}{\rho c^2}\frac{\partial^2 p}{\partial t^2} + \nabla \cdot \left(-\frac{1}{\rho}(\nabla p - q)\right) = Q \quad (1)$$

$$\rho\frac{\partial^2 u}{\partial t^2} + d_a\frac{\partial u}{\partial t} - \nabla.\sigma = \mathrm{F} \quad (2)$$

where, $\rho(kg/m^3)$ is the density, $c(m/\varepsilon)$ is the speed of sound, $p(Pa)$ is the acoustic pressure, $t(sec)$ is the time, $q(n/m^3)$ is the dipole sound source, , $Q(1/\varepsilon^3)$ is the monopole sound source, , $u(m)$ is the displacement in the solid, $d_a$is the damping coefficient, σ is the stress tensor and $F(N/m^3)$ is the body force per unit volume. The wave propagation in each media can be calculated based on the sound speed and the distance traveled in that media [14]. In the case of a focused probe, the focal length will change if the wave travels through different media with different acoustic impedance (change in sound speed and density). As the ultrasonic beam propagates from the probe through the water into the solid specimen, the beam exhibits refraction at the fluid-solid interface and results in a refocused length, X_m, inside the specimen. In immersion ultrasound inspection, the new focusing point is calculated by Eqn. 3 [14]:

$$X_w = F - X_m\left(\frac{C_m}{C_w}\right) \quad (3)$$

where, X_w is the water path, F in the focusing length of the probe, X_m is the path in the material, $C_m$is the sound velocity in the material and C_w is the sound velocity in water.
To stimulate the tranducer, it is used sinusial equation which it leads to the focused and so, it lead to increase the energy of waves. In the following

function, the central frequency is $f_c = 15$ MHz , which is defined as follows (Eq. 4)[14].

$$p(t) = e^{(-(\frac{t-T}{T/2}))} \times \sin(2\pi f t) \quad (4)$$

The interfaces between the water and aluminum sheets 5083 domains are the acoustic-structure boundary. Both right and left sides of the 2D model are selected to be perfectly matched layers. where T is the pulse period, and f is the frequency. It was given physical properties of applied materials in Table 1.

TABLE 1
Physical properties of materials

Sheets	Density (G/cm^3)	Poisson's ratio (V)	Young's modulus (GPa)
5083 aluminum Sheets	2.66	0.33	69

III. Simulation in Comsol Multiphysics software

Comsol Multiphysics software is used in this modeling. Comsol Multiphysics is a multipurpose software to analyze problems by using advanced numerical solution methods. Events analysis consisting of several different physics and also coupled events analysis are features and indicators of this software. The used pieces are two layers of aluminum sheet 5083, that are modeled. 2-D modeling is used to facilitate computations and calculations. The sheets thickness for used sheets is 1 mm for the upper sheet and 2 mm for the lower sheet and their overall length is 10 mm, according to Fig 1.

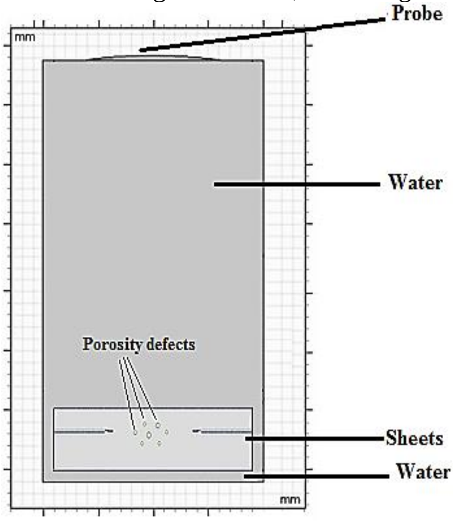

Fig 1. Primary model of peices in simulation

Signal stimulation in simulation is done by the probe. The probe is simulated for transmitting ultrasound waves as immersion. The most suitable position for the probe when sending ultrasonic waves must be defined in the simulation. This position is shown in Fig 1. The propagation of ultrasonic waves when the probe is placed on the main metal area and the wave hits the welded area and the porosity defect is shown in Fig 2. These are the primary waves that have entered the piece. These waves first enter the water from the upper surface of the part and after hitting the surface of the part, they hit the porosity defect and then they hit the bottom of the part. The transmission of waves is centrally (focused) simulated. For this reason, in simulation of probe to send waves, the waves are considered focused. The focused waves was the same in the experimental test. You can see the full propagation of the simulated waves as immersion in Fig 3.

A. Models Meshing

Meshing is an important step in simulation that directly affects numerical calculations. The principle of meshing is generally to control the largest size of the hole in the ultrasonic wave. The meshing is done for the 2-D model and the smallest size in the software is considered. Meshing is an important step in simulation that directly affects numerical calculations. Meshing is Splitting the domain into a number of smaller divisions do not overlap. The result of this division is a network (mesh) from cells. Mesh generation and meshing is one of the most important parts of any simulation. Meshing in Comsol Multiphysics software is easier than similar software. Because Comsol Multiphysics can offer an elementary mesh depending on the type of physics added to the problem, and the user will initially determine only the fine and coarse mesh size. The optimum mesh size for simulating the ultrasound test should be between λ/6 to λ/20. In this simulation, the mesh size was initially selected as λ/6, which did not yield an acceptable answer. Then the mesh size of λ/8 and λ/10 was selected and it was obtained an acceptable answer. To be sure, the mesh size λ/9 was also simulated which had a similar and acceptable response. To solve this problem, special networks are needed, which are formed manually using the tools available in the mesh section. Since the nature of Comsol Multiphysics software is computational, it is possible to embed mesh in Comsol Multiphysics from other mesh generation software.

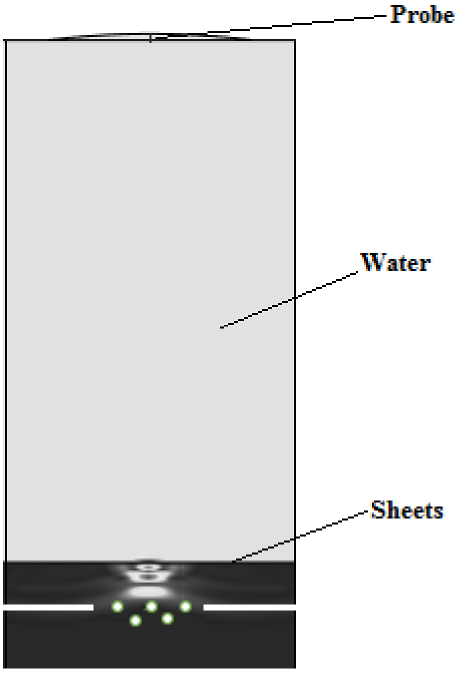

Fig 2. Waves propogation in sheet and its effect on porosity defect

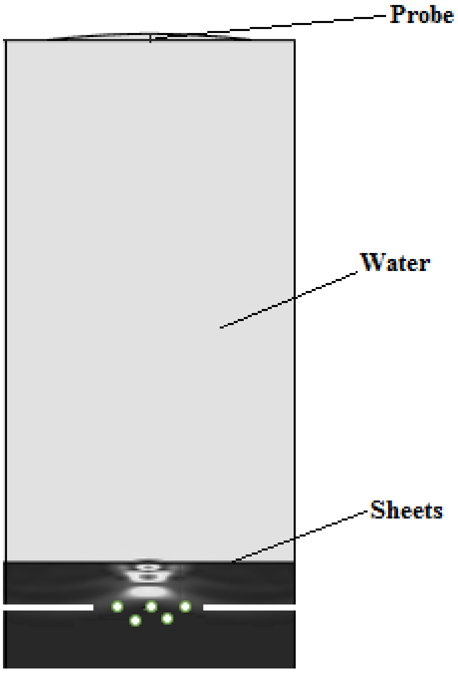

Fig 3. Full propogation of waves in sheet and its effect on porosity defect

B. Simulation of porosity defect in sheets

Simulation of waves are performed as focused. Defective echoe was observed according to the simulation in similar sheets of the 5083 Aluminum, the larger the porosity of the defect diameter, the greater the echo amplitude of the response of the resulting defect. This result has been the same in the experimental discussion that the simulation results are consistent with the experimental those. You can see results the echoes of the simulated porosity in Fig. 4 and Fig. 5.

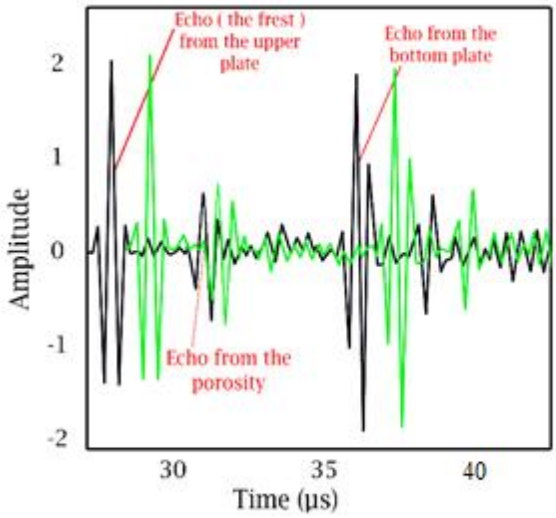

Fig 4. Echoes of porosity defect signal for two aluminum sheets 5083 and echoes of porosity defect for two aluminum sheets 5083 when porosity diameter increases

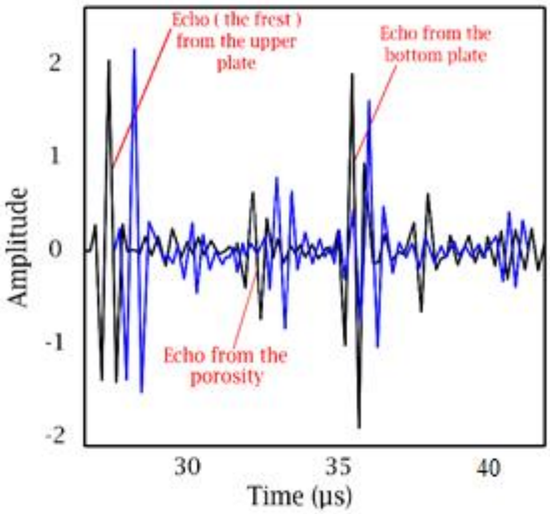

Fig 5. Porosity signal echo for two aluminum sheets 5083 and porosity signal echo for two aluminum sheets 5083 when porosity diameter increases

C. Experimental test

In the present experiment, 5 spot welds are applied on the sheets. Upper sheet thickness is 1 mm, bottom sheet thickness is 2 mm, sheet length is 100 mm and nugget width is also 4 mm. Ultrasound test, weld width and porosity defects are examined. During welding, the surface must be free of any contamination. If the surface is contaminated, you will develop porosity. The defect can be caused contamination by a thin layer of oil or dust between the two sheets. According to several welding tests on 5083 aluminum sheets, realized that, welding and gas welding have a good ratio, welding and arc welding have an excellent ratio, spot welding and spot welding have an excellent ratio and solder of these sheets are weak. In this test, due to the excellent welding ratio and spot welding machine for 5083 aluminum sheets, it was used spot welding for connection. You can see a schematic of the test sheet in Fig 6.

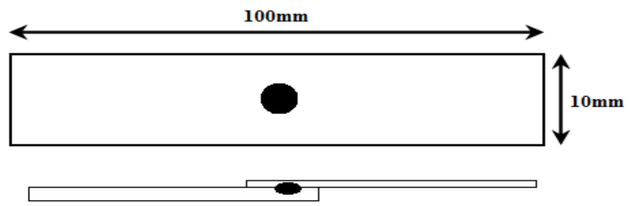

Fig 6. Test pieces of similar sheets 5083 aluminum

D. Ultrasonic A-scan experiment on spot welding

Each probe has a focal distance that is specified by its manufacturer and it's marked on it. Probe used the 15-MHz immersion probe manufactured by Panametrics USA has a 1-inch focal length. It means that if there is nothing in the path of ultrasound except water, the waves will be focused 1 inches ahead of the probe surface. For inspection, the focal length must be determined so that the focal point of the waves is focused at the porosity defect. The reason is that the porosity defect is a small defect and it doesn't reflect itself well, as a result, the probe focal point has the most acoustic energy at the defect site and it is predicted to be a detectable signal. Fig. 7 shows the probe focal length and the probe focal length in the segment.

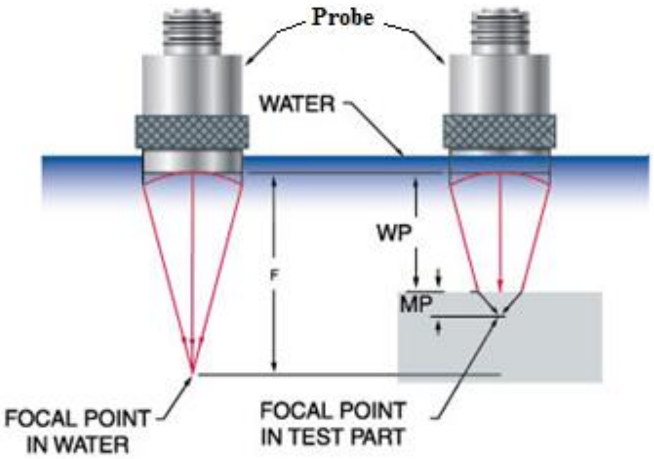

Fig 7. probe focal length and probe focal length in sheets

F: Probe focal length
WP: Distance from probe level to piece level
MP: Distance from surface to defect

It is important to calculate obtaining the first echo from the surface by the wave hitting the surface of the piece and the next echo from the wave hitting the porosity defect in order to detect this defect. The amount of time calculation is used for simulation to determine the percentage of error in experimental and simulation work. To calculate where the signals appear in the oscilloscope, the time intervals must be multiplied by two with regards to that go-to and return distances of the ultrasound waves are displayed. According to the description of the echo model, the slightest change in the geometric shape of each defect can affect the reaction of the waves and change the shape of the echo. Therefore, by recognizing the types of models and matching each echo on the image screen, the geometric shape of the defect will be recognizable. In general and principally, before starting any ultrasound test, all aspects and influential factors should be studied and the test should be performed based on accurate information. Of course, it is necessary to mention that the thicker the two sides of the joint, the greater the width of the weld and the possibility of sending waves to the entire welding area will not be possible. After describing the characteristics and model of the echoes, the signals obtained from the calculations are performed for the 5083 matched aluminum sheets where the first BW signal appears at 28.5 µs and the fault signal appears at 31.64 µs. The larger the porosity of the defect, the greater the intensity and amplitude of the reaction of the resulting waves. It is clear from the figure that the larger the echo porosity, the greater the reaction amplitude. Fig. 8 shows the time of occurrence of the obtained signals from the experimental work for the matched 5083 aluminum sheets, which is consistent with the calculations performed. Fig. 9 shows an image of the A scanning test system.

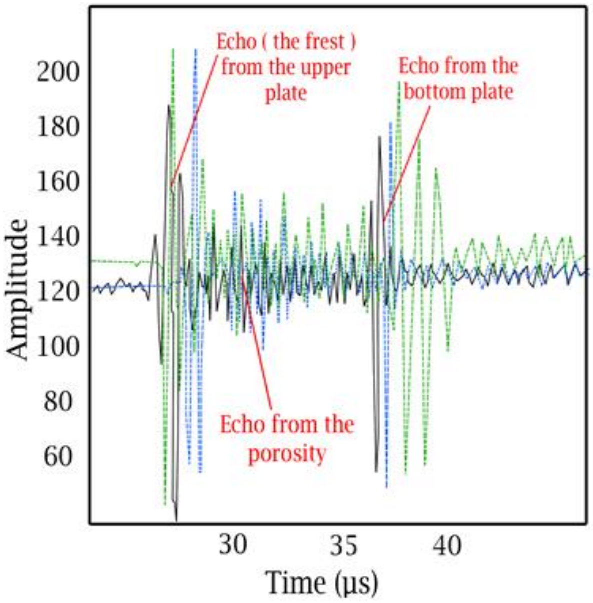

Fig 8. Echo of porosity defect signal for Two 5083 aluminum sheets

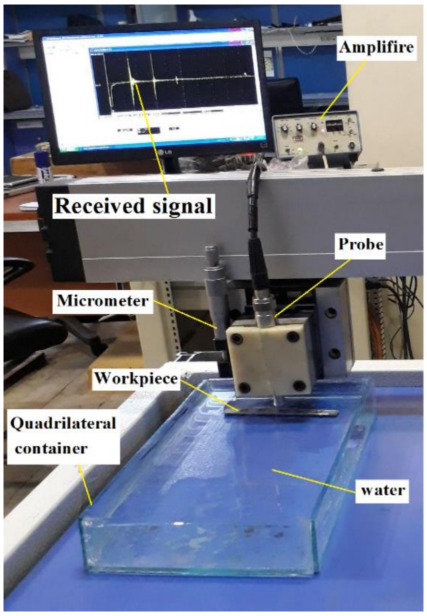

Fig 9. A-scan siystem

E. Ultrasonic C-scanning experiment on spot welding

C-scanning system shows the full view of all the points irradiated in the above image. In older devices, the screen only indicated changes within the tested components by black degree, but in advanced devices, the results of the waveforms response were reflected in color images with varying density on the image plane. They are recognizable and interpretable ease in position and characteristics [15]. The C-scan test was also performed to ensure the defects, and the defects were more clearly detectable and interpretable. You can see an example of the fragments on which the C-scan test was performed in fig. 10.

Fig 10. An example of a C-scan test on three porosity sample for porosity

F. Influence of defect echo amplitude on received waves and relative error average diagram

The test values for the 5 spot welding samples are shown in diagrams like Fig. 11, in order to compare the ultrasonic test and radiographic test for the size of the porosity defects by tests for sheets. Respectively, Du is the value of the weld nugget diameter by ultrasonic test, Dm is the radiographic measurement for the weld nugget diameter, Dp is the size of the porosity in the ultrasonic test waves are that determined by the received signals. Using the amplitude obtained from the waves, the diameter of the porosity defect was obtained (the domain has a direct relationship with the size of the porosity defect diameter). And Dr is the size of the porosity in the radiographic test. Using the ultrasonic test, the intensity and amplitude of the response of the defect waves are determined by the received signals, The amplitude of the defect is obtained using the amplitude obtained from the waves (the amplitude is directly related to the defect depth size). The ultrasonic test values for the porosity diameters are in good agreement with those measured by the metallographic and radiographic tests []. The average relative error of the simulation test and the experimental test for sheets that can meet the industrial need for porosity defects is 1.3%. The mean relative error of diagrams for sheets that can meet the industrial need for porosity defects is 1.2% (All sizes are in millimeters). This low error percentage indicates the exact test performed.

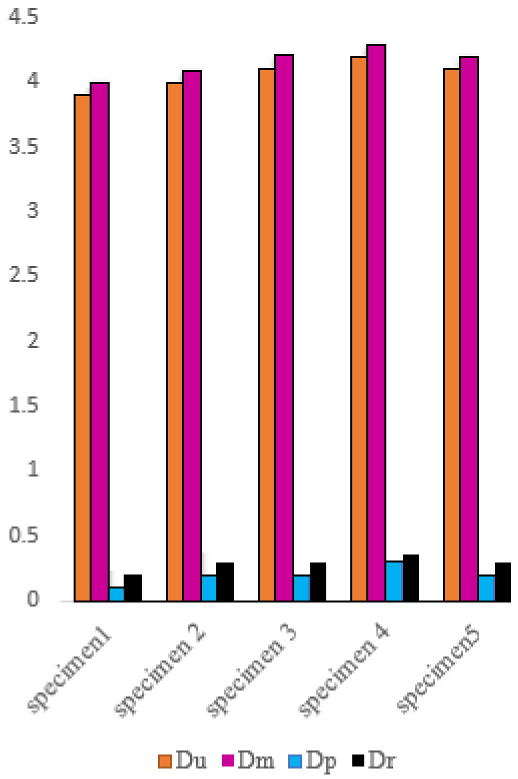

Fig. 11. Comparison of ultrasonic test and radiographic test for porosity defect and size of welded nugget on 5 aluminum sheets

G. Conclusion

In this article, it was mentioned why 5083 aluminum sheet was used instead of steel in the automobile, and like experiments and researches were done, these sheets will reduce the weight of automobile and thus decrease the fuel consumption of automobile and its impact on their speed. The results show that the waveform in A-scan has different amplitude in various locations of spot welding. In this paper, Comsol Multiphysics software is used for the simulation process of spot welding ultrasonic waves. It was investigated ultrasonic detection of spot welding with the presence of simulated porosity defect. Diameter of porosity defect in welded sheets and diameter of weld nugget were also measured by radiography test. With regards to the high frequency of the 15 MHz probe, the noise factor is an intruder for the porosity signal. Considering the comparison of the signals obtained from the experimental and simulation results on similar sheets, This result is obtained that larger the porosity defect diameter, the stronger the amplitude of the waves due to the defect response. The ultrasonic test values for the weld nugget and porosity were in good agreement with those measured in radiographic and simulation experiments. Accuracy in diagnosis and average relative error are noted that can meet the industrial need. Simulations of porosity defect were performed and it was good agreement between the echo received from the defect compared with the experimental echo.

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