Effect of Crack on Bending Process for S55c Carbon Steel with Ultrasonic Testing On Zero Degree Probes

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Abstract. Bending force and fatigue-induced crack is a generally assured trouble in industrial pipe line achieving their original design life. An amount of high-profile accidents has been covered in the past that involved bending and fatigue harm in structures. Such that incidences frequently encounter without prior warnings ascribable deficiency of proper crack monitoring method. Called for to discover and monitor the bending and fatigue crack, ultrasonic (UT) and acoustic emission (AE) technique, has been encountering growing concerns recently. This paper presenting the measurement and effect of bending test at carbon steel plate with different length and defect’s depth by using ultrasonic testing with considering the defect size at failure point. The zero-degree probe and 4MHz excitation frequency is used in UT measuring for condition of S55C carbon steel plate within before bending process and after bending process. From the result show that effect of bending force will increase the velocity (m/s), gain (dB), beam path (mm) and thickness plate (mm) based on the defect sizes. The increasing of four parameters can be explained namely 0.19% - 0.3% velocity, 17% - 20% gain, 10% - 12% beam path and 5.0% - 7.5% thickness of plate.

1. Introduction

Traditional design of plate elements in built up members and assemblies such as the web of I-girders, box girders, rail cars, ship hulls etc., depend on limit states defined by codes (AASHTO, AISC, ADM, etc.) based on the section’s properties. For economic viability and weight reduction, it is not uncommon to use allowable loads beyond the limit states[1]. Conditions that promote and/or accentuate out of plane movement of plate elements promotes the development of secondary bending stresses along supported boundaries. These additional bending stresses must be properly accounted for when the structure is exposed to cyclic loading or fatigue. Commonly utilized details like web to flange and web to diaphragm fillet welds of plate and box girder type structures may be prone to the development of panting fatigue [2][3].

Previous studies have been used to develop a basis for current fatigue design provisions and standards [1][4]. However, the vast majority of the fatigue studies have been conducted on built up beams with plate elements loaded in their plane. Results from such experiments have been used as a
basis upon which lower bound S-N curves for design were developed. While the web to flange and flange to diaphragm fillet welds would be classified as categories B and C for membrane stresses by current U.S. design specifications, it is unclear as to the proper classification when significant through thickness bending is present. A few studies have examined the problem of plate panting or breathing and the resulting effect on fatigue life. However, design recommendations and procedures are lacking. In the late 1960’s, Mueller and Yen examined web breathing on the fatigue performance of welded plate girders [1].

Calculation of in-plane membrane stresses using simple beam theory did not predict actual measured stresses and did not predict the observed fatigue behaviour. Rather, fatigue cracking along the girder web to flange fillet welds resulted from out of plane bending of the web. Others working on panting fatigue cracking due to secondary stresses have suggested limiting slenderness or reducing allowable web shear to below initial buckling strengths [5][6][7]. In each case, secondary or out of plane bending stresses were detrimental to fatigue life. Paterson et al, completed fatigue tests of several box girders susceptible to panting condition [8].

Furthermore, in oil and gas industrial the bending and fatigue force on pipes is quickly challenging for the petroleum liqoute material distribution. The welding joint is the critical part and frequently being inspective to avoid any problem especially on pipe leakage that can be effect on distribution process. In pipes conditioning measurement non-destructive testing (NDT) techniques were widely implemented. Ultrasonnic methods are used reliably in these applications. Additionally, the interaction of the sound wave with the medium provides insight into the material microstructure. Thus, this paper will focus on the uses of ultrasonic methods for material characterization. The principles of ultrasonic testing are explained in the following section.

2. Previous Work

2.1. Stress Intensity Factor (SIF)

The stress intensity factor describes the stress conditions around a crack tip. The local stress field, defect condition and material properties are the main parameters upon which the fatigue performance of welded details depends[9][10]. The accurate prediction of the stress intensity factor is necessary in order to evaluate fatigue crack growth and the fatigue performance of the welded details. Generally, it depends on the type of loading, the geometry (crack geometry, weld profile and cross section) and the residual stress conditions at the crack tip. There are several methods that have been used to determine the stress intensity factor as recorded in the literature. The following Table 1 categorizes them in a group.

| Theoretical Methods                  | Numerical Methods                      | Experimental Methods       |
|--------------------------------------|----------------------------------------|-----------------------------|
| Westergaard semi-inverse method      | Weight Function (Green’s function)     | Photo elasticity            |
| Method of Complex potentials         | Boundary Collocation                   | Fringe                      |
|                                      | Alternating Methods                    | Holography                 |
|                                      | Integral Transforms                    | Caustics and combinations of these methods |
|                                      | Continuous Dislocation                 |                             |
|                                      | Finite Element Methods                 |                             |

Elena Atroschchenko [12][13] developed an exact analytical solution for the stress intensity factor (SIF) for an elliptical crack embedded in an infinite elastic body subjected to an arbitrary stress field. At first, she derived the analytical weight function for an elliptical crack embedded in an infinite elastic body. This weight function was subsequently used in the alternating method to obtain the SIF in a semi-infinite body subjected to an arbitrary applied stress field. This solution for the SIF can be used in various engineering problems including pressure vessels, welded structures and components under fatigue loading. Analytically, Sneddon [14] studied planar cracks, using a circular shape
embedded in an infinite body. The loading condition was symmetric with respect to the centre of the crack [15][16]. For crack opening displacements, he transformed the mixed mode boundary conditions in the crack plane into a pair of dual integrals equations. Using these integrals, he found the stresses and displacements for the cracked body. [17][18] The analytically predicted the stress intensity factor using the stress concentration distribution along a perspective crack path which he developed first by finite element analysis. He subsequently used the Green’s Function proposed by Albrecht [19][20] by establishing the resulting correction curve for fillet-weld and groove welded details using the stress decay originating from either axis of an elliptical hole in an infinite plate.

Later the developed formulae for proper ellipse shape and size depending on the detail type and specific values of geometric parameters to predict the stress intensity factor for arbitrary geometries.

A. F. Grandt, Jr. and G. M. Sinclair [21] studied the SIF solution for plates under bending. The cracked plate was modelled as a two-dimensional beam containing a spring to find the stress intensity factor at the point of intersection of a semi-elliptical crack with a free boundary. In their studies, they provided results for various crack shapes and sizes and used polymethylmethacrylate, a transparent polymer, to calibrate the crack growth rate and stress intensity range for surface flaws in bending. Z. Kassir and Sih [22] expanded on the idea of Sneddon’s approach [14] by applying Fourier expansion of the stress field, crack opening displacements and the SIF in polar coordinates [12]. The SIF was found by solving the dual integral equation obtained by Fourier expansion. Kiciak et.al. [19] developed a weight function to calculate the stress intensity factors for complex stress fields consisting of external loads and residual stresses usually experienced in shot peened and case hardened notched machined components and high pressure vessels. Their generalized weight function can also be used to calculate the crack opening displacement field. Glinka and Shen [23] developed weight functions and neural network method for cracks structure. This method requires two reference stress intensity factors to be known. They used the general weight function expression and its characteristic properties for the determination of the unknown weight function parameters. Several weight functions derived by this method were compared to exact analytical weight functions available in the literature and the differences were less than 2%.

Tan and Fenner [12] used the Boundary Integral Equation method to analyse semi-elliptic surface cracks in pressurized thick-walled cylinders. They treated the case for ratios of external to internal cylinder radii of 2 and 3, with maximum crack depths ranging from 20% to 80% of the wall thickness. The expansion method on the stress field and unknown crack opening displacements were studied by Martin[24][25] in orthogonal Gegenbauer polynomials [12]. He transformed the boundary conditions in the crack domain into a system of linear algebraic equation to find constant, linear and quadratic stress fields based on which he found the stress intensity factor.

Fatigue is the process of cumulative damage under which a crack can form and grow in repetitive or cyclic loading. Fatigue damage typically occurs in a region of a stress (strain) riser, where the local stress exceeds the yield stress of the material[26]. A favorable condition typically exists on the surface of the component to initiate the crack and then the crack will grow under the cyclic loading until it fails [26][27]. The life of a component subjected to fatigue is composed of a crack initiation period and a crack growth period. There is no clear cut delineation of the boundary between these two periods, but crack initiation and crack growth are a consequence of cyclic slip which implies plastic deformation or dislocation activities along the grains of the material [28]. Steps which comprise the fatigue life are shown in Figure 1.

Figure 1: Factors Related to Different Phases of Fatigue Life [28]
2.2. Stress Concentration Factor

The definition of stress concentration is “the ratio between the peak stress at the root of the notch and the nominal stress without it” [29], i.e. it is the relation between the local maximum stress and the applied nominal stress if a discontinuity or notch exists. The geometry of the notch configuration i.e. the shape of the notch plays important role for the severity of the stress concentration [29].

\[ K_t = \frac{\sigma_{\text{peak}}}{\sigma} \] \hspace{1cm} (1)

For an elliptical hole in an infinite plate, the stress concentration can be shown by Figure 2 and can be described [26] as

\[ K_t = \frac{\sigma_{\text{peak}}}{\sigma} = \left(1 + \frac{2u}{\rho}\right) = 1 + \frac{2u}{\rho} \] \hspace{1cm} (2)

After rearranging

\[ \sigma_{\text{peak}} = \sigma_{\text{nominal}} \left(1 + \frac{2u}{\rho}\right) \] \hspace{1cm} (3)

Figure 2: Strip with Central Hole as Prototype of a Notched Part [29]

Where \( \rho = \frac{L}{2} \) is the tip radius of the major axis. From the above equation it is noted that a small notch root radius \( \rho \) will give higher stress concentration factors, \( K_t \) and a large radius will produce a lower \( K_t \) [29]. The stress concentration factor for an elliptical hole will show on Figure 3

Figure 3: Stress Concentration Factor for an Elliptical Hole [26]
3. Methodology

The twelfth carbon steel plate is prepared in bending test. Two thing are considered on carbon steel plate preparing there are width and depth of defect. In experimental the depth of defect being set on 1mm until 6mm and defect width are 15mm until 35mm and sizes of plate is constantly which in 210mm x 40mm. In this preparation the carbon steel plate been cutting by using bandsaw machines. After carbon steel plates prepared, the next process is make the defect using CNC machine respectively fives plates with the same depth, six plates with the same length and one plate with no defect. The next process is to inspect all the plates before doing bending test, and the parameter being tested is this is sizing defect, velocity, depth of defect, gain and the signal amplitude of plates. After the bending test is done the UT inspections is do it again based on the bending force at the plates and the data was comparing data for before and after bending test. Figure 4 show the flow chart of plate fabrication and bending test measuring by using UT.

![Flow Chart](image)

Figure 4: Process Flow for Bending on UT Inspection

The criterial of carbon steel used is 2.1% content carbon composition named as S55C carbon steel material. The term "carbon steel" may also be used in reference to steel which is not stainless steel; in this use carbon steel may include alloy steels. As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile. Figure 5 (a) is carbon steel plates which is the materials of this project. This carbon steel plates will cut into six parts with 210mm length and 40mm wide each part like shows in Figure 5 (b).

![Carbon Steel Plates](image)

Figure 5: (a)Carbon Steel Plates (10mm depth), (b) Dimension of Carbon Steel Plates
The band saw machine is used for cutting plates based on size are needed. This machine will cut the plate for 210mm length 40mm width. Figure 6 show the band saw machine in cutting process. The speed for band saw machine is setting on medium speed to ensure that the finishing cutting on carbon steel plate is smooth and the dimension result are accurately.

![Figure 6: Band saw machine](image1)

Figure 6: Band saw machine

Figure 7 show the process of cutting plates using bandsaw machines. The coolant is used in cutting process to avoided the blade are broken. From here the minimum radius of a curve is determined according width of the band and kerf. On this bandsaws machine there have two rotating wheels in the same plane, one is powered by single phase motor and the rest by distributing load. The blade itself can come in a variety of sizes and tooth pitches, which enables the machine to be highly versatile and able to cut a wide variety of materials including wood, metal and plastic.

![Figure 7: Cutting Process of Band saw Machine](image2)

Figure 7: Cutting Process of Band saw Machine

After the cutting process is done, for next step is to levelling the carbon steel plate angle and surface by using milling machine besides to ensure the plate surface is clean and smooth. In this process, the milling machine will be levelling the surface of plate from 10mm thickness until 7mm based on Figure 8 (a) and width of plate from 40mm and until 29mm. The process of width reduction is show on Figure 8(b). Figure 8(c) and Figure 8(d) show the dimension’s measurement (thickness, width and length) by using Vernier.

![Figure 8](image3)
Each plates are being measured to ensure the dimension of plate is same and the third process is applying the defect on the plate. All specimens or plate will be make the artificial defect based on sizes defect and also the depth of defect. The CNC machine (Computer Numerical Control) is used in this process. CNC is an automation of machine tools by means of computers executing pre-programmed sequences of machine control commands. This is in contrast to machines that are manually controlled by hand wheels or levers, or mechanically automated by cams alone. In modern CNC systems, the design of a mechanical part and its manufacturing program is highly automated. The part's mechanical dimensions are defined using computer-aided design (CAD) software, and then translated into manufacturing directives by computer-aided manufacturing (CAM) software. The resulting directives are transformed (by "post processor" software) into the specific commands necessary for a particular machine to produce the component, and then loaded into the CNC machine. Figure 9(a) is the milling CNC machine and Figure 9(b) is the example of artificial defects has been made by using CNC machine. In addition, after all the preparations of carbon steel plates finish, the next process is to apply bending test by using bending machine. Figure 9(c) shows the bending machine.

Figure 8: (a) Milling process of thickness plate, (b) Milling process of wide plate, (c) Specimens from thickness 10mm to 7mm after milling process, (d) Specimens wide form 40mm to 29mm after milling process.

Figure 9: (a) CNC milling machine (Computer Numerical Control), (b) Example defects, (c) Bending test machine.
The bending test is a simple test that can be used to evaluate both the ductility and soundness of a material. The bending test uses a coupon that is bent in three points bending to a specified angle. Bending tests deform the test material at the midpoint causing a concave surface or a bend to form without the occurrence of fracture and are typically performed to determine the ductility or resistance to fracture of that material. Unlike in a flexure test the goal is not to load the material until failure but rather to deform the sample into a specific shape. The test sample is loaded in a way that creates a concave surface at the midpoint with a specified radius of curvature according to the standard in relation to which the test is performed. Bending tests are as popular as tensile test, compression test, and fatigue tests.

Figure 10 shows the compression probes and also called by zero-degree probe. Zero-degree probe was used in this project to determine the crack from the crack accept until the crack would not be accept. It also used for identified the condition or criteria for testing plate either acceptance or rejecting. The zero-degree probes contain twin crystal. This probe usually used for checking the thickness and also used for crack identification. Different frequencies probe was used to differentiate the echo performance signal in ultrasonic testing set. Table 2 shows the details of zero-degree probe and Frequency used is 4MHz for set up.

![Zero-degree probe](image)

**Figure 10: Zero-degree probe**

| Type of probe | 0° probe or compressional probe |
|---------------|---------------------------------|
| Model         | MSEB 4                          |
|               | 57462                           |
|               | 56743                           |
| Frequency     | 4MHz                            |
| Diameter      | 3.5x10                          |
| Brand         | USM GO                          |
| Single/Double Crystal | DOUBLE                      |

### 4. Experimental Setup

#### 4.1. Ultrasonic Measurement on Plate

Ultrasonic thickness measurement is a method of performing non-destructive measurement which is gauging of the local thickness for the solid element that are typically made of metal. The concept of ultrasonic testing is based on the time taken start from signal transmission until signal feedback for the surface inspection. This type of measurement is typically performed with an ultrasonic thickness gauge. Figure 11(a) and (b) shows the inspections process before and after applied bending test on the carbon steel plates.
Procedure to use the ultrasonic tester is by going on to calibration menu for setting the right velocity material for the step wedge. Before the calibration process is going on, the couplant should being applied at step wedge surface and after that the probe’s surface are attached on the step wedge surface. From here the appropriate signal will obtain according the depth of step wedge used. The calibration of zero-degree probe can be set by visually or for more accurate calibration use the gate control to obtain the digital read out of the signal depth and always confirm the calibration on a second thickness.

The measurement does not need to be affected by these since the first recorded return will normally be the head of the emitted wave traveling at the shortest distance which is equivalent to the thickness of the sample. All other returns can be discarded or might be processed using more complicated strategies. When scanning for defects the scanning pattern to be used is sometimes dependant on the size of defect sought. The two main factors to consider are the pitch or overlap and the pattern or direction of scanning. If the pitch is less than the size of the probe, then the scan will overlap. If the pitch is greater than the size of the probe, then there will be a gap between the scans. Whether there is a gap between the scans or not a may depend on the size of defect sought and the size of the test piece.

For the length sizing discontinuities larger than the beam width there is 6dB drop method. However, peaking the signal then moving laterally to 50% signal height can often under size the length.

4.2. Bending Testing Process

The ductility of metallic materials helps provide a visual indication of the ductility of the material. The guided bend test method requires the specimen to be loaded at its center point with a mandrel or plunger while being supported at the ends. The specimen is bent to a predetermined angle or until the specimen fractures. The convex side of the specimen is visually inspected for cracks or defects, and failure is determined by the size of the cracks and imperfections allowed by the material specification. Figure 12(a) and (b) show the specimens from start bending until finish bending.
According on bending test shows that the differences of value is based on the specimen’s condition there are the plate with no defect, the plates with same depth of defect but different length of defect, and the plates with the different depth of defect but the same length of defect. Figure 13 show the specimens with (a) no defect, (b) 25mm length and 1mm depth of defect, (c) 25mm length and 6mm depth of defect and lastly (d) 15mm length and 5mm depth of defect after bending test.

From this test, the specimens with contain no defect does not take long time to bend in bending process. Instead, the specimens of the same dimension with different defect depth hardly to be band compared with no defect and also the specimens containing defect taking long time to reach the break point in bending process. In the other word, the deeper of defect will affect the time taken for bending process.

Figure 13: (a) No defect, (b) 2.5mm x 25mm x 1mm defects specimens, (c) 2.5mm x 25mm x 6mm defects specimens and (d) 2.5mm x 15mm x 5mm defects specimens

5. Results and Discussion

5.1. Result of Ultrasonic Testing Inspections Before and After Bending Test

Figure 14 (a) and (b) shows the sample of thickness for UT measurement before and after bending test and the parameter has been measuring and analysis including sizing defect (6dB) (mm), depth of defect (mm), velocity (m/s), gain (dB), signal amplitude (%), beam path (mm) and thickness plate (mm). Figure 14 (c) show the sample graph of bending test by based on tensile strength (mm/mm) and flexure stress at tensile strength [MPa].
The analysis of bending process is applying at 6 plate with different width and 6 plate with different depth of defect respectively width (no defect, 15mm, 20mm, 25mm, 30mm, 35mm) and depth of defect (1mm, 2mm, 3mm, 4mm, 5mm and 6mm). Table 3 below show the result of ultrasonic measurement for normal and after bending plate and also the value of bending specimen.

Table 3: UT Measuring Before and After Bending Process

| Condition After Bending | Size defect (mm) | Depth defect (mm) | Velocity (m/s) | Gain (dB) | Signal Amp (%) | Beam path (mm) | Plate Thickness (mm) |
|-------------------------|------------------|-------------------|----------------|-----------|---------------|-----------------|----------------------|
| Before 0                | 0                | 0                 | 6006           | 43.6      | 48            | 7.17            | 7.17                 |
| After                   | 0                | 0                 | 6042           | 48.0      | 66            | 7.40            | 7.40                 |
| Before 15               | 5                | 6030              | 50.4           | 22        | 2.59          | 7.03            |                      |
| After                   | 19               | 6042              | 65.8           | 11        | 2.61          | 7.36            |                      |
| Before 20               | 5                | 6030              | 50.8           | 36        | 2.50          | 7.26            |                      |
| After                   | 23               | 6042              | 60.0           | 10        | 2.77          | 7.31            |                      |
| Before 25               | 5                | 6030              | 53.4           | 33        | 2.47          | 7.12            |                      |
| After                   | 30               | 6042              | 60.0           | 26        | 2.61          | 7.36            |                      |
| Before 30               | 5                | 6030              | 49.6           | 38        | 2.41          | 7.02            |                      |
| After                   | 35               | 6042              | 63.2           | 18        | 2.64          | 7.36            |                      |
| Before 35               | 5                | 6030              | 46.0           | 34        | 2.43          | 6.90            |                      |
| After                   | 40               | 6042              | 60.0           | 11        | 2.82          | 7.17            |                      |
| Before 25               | 2                | 6030              | 46.0           | 58        | 5.80          | 7.03            |                      |
| After                   | 26               | 6042              | 53.2           | 57        | 7.11          | 7.00            |                      |
Before & After comparison of 25 mm x 20 mm x 5 mm plate thickness at bending point are increases until 6.6% and it also increasing the size of defect until 56%. The signal velocity is constantly within before 6030 m/s and after bending 6042 m/s for each testing. By looking on the signal amplitude and depth defect, the value before is high compare to after bending until 72% for signal amplitude and 50% for depth defect and it inversely proportional with beam path, gain value, size defect and plate thickness for before and after bending process.

Table 4 show the bending result according bending test. The 11 plate are testing based on the size defect and depth of defect. The higher load at tensile strength is plate with size defect 2.5 mm x 20 mm x 5 mm there is 4258.09863 N and the lower is at plate defect dimension on 2.5 mm x 25 mm x 5 mm within 1625.33228 N.

Table 4: Bending Measurement According Bending Test

| Size Defect (mm)                  | Modulus (automatic) [MPa] | Flexure (Extension) at Tensile strength [mm/mm] | strain at Tensile strength [MPa] | Flexure stress at Tensile strength [MPa] | Load at Tensile strength [N] |
|----------------------------------|---------------------------|----------------------------------------------|---------------------------------|----------------------------------------|----------------------------|
| No defect                        | 17583.71789               | 0.05993                                      | 422.04260                       | 3028.90186                             | 5022.7612                          |
| 2.5 mm x 15 mm x 5 mm            | 11616.62359               | 0.05234                                      | 362.66690                       | 2602.77612                             | 5022.7612                          |
| 2.5 mm x 20 mm x 5 mm            | 33320.44800               | 0.05579                                      | 593.31702                       | 4258.09863                             | 5022.7612                          |
| 2.5 mm x 25 mm x 5 mm            | 9672.83746                | 0.05222                                      | 275.74084                       | 1978.92798                             | 5022.7612                          |
| 2.5 mm x 30 mm x 5 mm            | 7112.75669                | 0.05736                                      | 252.53998                       | 1812.42078                             | 5022.7612                          |
| 2.5 mm x 25 mm x 1 mm            | 7262.06813                | 0.05740                                      | 255.08971                       | 1830.7160                              | 5022.7612                          |
| 2.5 mm x 25 mm x 2 mm            | 6008.92915                | 0.05720                                      | 231.69978                       | 1662.85559                             | 5022.7612                          |
| 2.5 mm x 25 mm x 3 mm            | 6942.32562                | 0.05732                                      | 241.10907                       | 1730.38379                             | 5022.7612                          |
| 2.5 mm x 25 mm x 4 mm            | 9705.26847                | 0.05892                                      | 356.45660                       | 2558.20630                             | 5022.7612                          |
| 2.5 mm x 25 mm x 5 mm            | 6155.90199                | 0.05752                                      | 226.47134                       | 1625.33228                             | 5022.7612                          |
| 2.5 mm x 25 mm x 6 mm            | 6355.90199                | 0.06752                                      | 236.47144                       | 1635.43238                             | 5022.7612                          |

5.2. RSM ANOVA Analysis

The Response Surface Methodology (RSM) has be made to know the correlation between a few parameters in this research. The three parameter being analysis including signal amplitude, depth defect and gain are affected when bending process are beginning.

5.2.1. Before Bending Process

Table 5 show the RSM for steel plate before bending process. The relation of Table below can be relating on mathematical modelling equation 4 and 5 where A representing on Depth Defect and B for Gain. From here the higher amplitude signal can identified when the gain is in range 43.60dB until 47.90dB and depth defect on 1mm until 3.75mm. The signal amplitude will be low when the defect size lest than 1mm in gain 47.91dB until 60.80dB. The value of amplitude is show on Figure 15. From here the red color of graph representing the very high signal and blue is very low signal.
Table 5: ANOVA for Response Surface Quadratic Model Before Bending Test

| Source     | Sum of Squares | df | Mean Square | F Value | p-value | Prob > F |
|------------|----------------|----|-------------|---------|---------|-----------|
| Model      | 2870.69        | 5  | 574.14      | 6.71    | 0.0134  | significant |
| A-Depth Defect | 1826.83      | 1  | 1826.83     | 21.35   | 0.0024  |           |
| B-Gain     | 2165.80        | 1  | 2165.80     | 25.31   | 0.0015  |           |
| AB         | 2208.40        | 1  | 2208.40     | 25.81   | 0.0014  |           |
| A²         | 1565.24        | 1  | 1565.24     | 18.29   | 0.0037  |           |
| B²         | 237.16         | 1  | 237.16      | 2.77    | 0.1399  |           |
| Residual   | 599.00         | 7  | 85.57       | 6.08    | 0.1473  | not significant |
| Lack of Fit| 562.00         | 5  | 112.40      | 6.08    | 0.1473  | not significant |
| Pure Error | 37.00          | 2  | 18.50       |         |         |           |
| Cor Total  | 3469.69        | 12 |             |         |         |           |

Final Equation in Terms of Coded Factors:
Signal Amplitude = -85.93+176.83*A-208.59*B+194.43*A*B-57.90*A²-29.29*B²  
(4)

Final Equation in Terms of Actual Factors:
Signal Amplitude = +953.98844-266.20415*Depth Defect-10.29701*Gain+7.00650*Depth Defect*Gain-9.26374*Depth Defect²-0.23776*Gain²  
(5)

Figure 15: 3D graph for Correlation between Signal Amplitude, Depth Defect and Gain before Bending Process

5.2.2. After Bending Process
The value of signal amplitude for defect identification totally changer between before and after bending process. It will show on Table 6 for RSM after bending process. From here the Sum of squared for depth defect are reducing until 18 times and it follows on the gain to until 4 times reduction. All changer are shows in Mathematical modelling on equation 6 and 7. According on Figure 16 show the maximum amplitude will identify on depth defect range 3.00mm until 6mm at gain 46.00 dB until 55.90dB. The another maximum amplitude will be find on depth defect 0.00mm until 1.50mm where the gain range is 55.90dB until 65.80dB.
Table 6: ANOVA for Response Surface Quadratic Model After Bending Test

| Source          | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|-----------------|----------------|----|-------------|---------|-----------------|
| Model           | 5726.15        | 5  | 1145.23     | 15.89   | 0.0011 significant |
| A - Depth Defect| 98.26          | 1  | 98.26       | 1.36    | 0.2812          |
| B - Gain        | 628.52         | 1  | 628.52      | 8.72    | 0.0213          |
| AB              | 754.64         | 1  | 754.64      | 10.47   | 0.0143          |
| A^2             | 1819.64        | 1  | 1819.64     | 25.24   | 0.0015          |
| B^2             | 434.05         | 1  | 434.05      | 6.02    | 0.0439          |
| Residual        | 504.62         | 7  | 72.09       | 1.58    | 0.3693 not significant |
| Lack of Fit     | 341.87         | 4  | 85.47       |         |                 |
| Pure Error      | 162.75         | 3  | 54.25       |         |                 |
| Cor Total       | 6230.77        | 12 |             |         |                 |

Final Equation in Terms of Coded Factors:
Signal Amplitude =+31.80+11.09*A-42.03*B-122.79*A*B+74.81*A^2+52.53*B^2 \hspace{1cm} (6)

Final Equation in Terms of Actual Factors:
Signal Amplitude =+973.31586+155.52512*Depth Defect-39.37052*Gain-3.68741
* Depth Defect * Gain+8.31205*Depth Defect^2+0.42638*Gain^2 \hspace{1cm} (7)

Figure 16: 3D graph for Correlation between Signal Amplitude, Depth Defect and Gain after Bending Process

6. Conclusion

The bending process will give a high effect especially on the material thickness, gain, beam path, material velocity and signal amplitude. Based on the result show that the plate without defect are easier to bend compare with the defect plate. The surface layer is the most affected part during a bending operation and therefore it is of primary interest for the determination of the bendability. The surface finish is of great importance and both damages and rust on the surface exposed to stress during the process reduces the bendability. Each scratch or defect that occurs at the exterior of the bend is regarded as an initiation of fracture and cracking generally occurs where the surface has been exposed to most strain. There is only one single critical imperfection needed in order for fracture to start. It is therefore not an average number of defects on the surface that determines the probability for a fracture. Former studies have shown that the local strain at a bend test can be tripled if the plate is
scratched or has an indication of a fracture. Thus, it is important to ensure that the surface is flawless from all kinds of fracture indications.

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