IMPLEMENTATION OF FRICTION STIR WELDING IN 3003 ALUMINUM PLATES INSPECTED BY ULTRASONIC TESTING

TESIS

MAESTRO EN CIENCIAS CON ESPECIALIDAD EN SISTEMAS DE MANUFACTURA

Instituto Tecnológico y de Estudios Superiores de Monterrey

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Ing. Tomás Lamuño Encorrada

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PRESENTADA AL PROGRAMA DE GRADUADOS EN INGENIERÍA

ESTE TRABAJO ES REQUISITO PARCIAL PARA OBTENER EL GRADO ACADEMICO DE MAESTRO EN CIENCIAS CON ESPECIALIDAD EN SISTEMASDE DE MANUFACTURA

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Diciembre de 2010

To my family for the unconditional support they have always given me, thank you mom and dad for trusting me. To my sisters whose are my pillars to follow.

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To my family, my colleagues and friends who have shared this process and that always gave me encouragement in difficult times.

And thanks to my parents because they've got here.

Thank you

Tomás Lamuño Encorrada

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Asesor de la tesis: Dr. Juan Oscar Molina Solís

In this thesis, the Friction Stir Welding parameters and how they affect the functionality of the weld are analyzed. The parameters, the type of tool used to weld, welding speeds of rotation and transverse, are interrelated to obtain a functional welding,

To find out the quality of the weld an ultrasonic testing was made, with which it can be seen from the construction of a block pattern for measurement to the assessment and analysis of the ultrasonic test. This test was held in concordance with the ASTM standards, which gave as a result a couple of specimens with different discontinuities.

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1. Introduction

1.1 Friction-stir welding (FSW)

Friction-stir welding (FSW) is a solid-state joining process (meaning the metal is not melted during the process) and is used for applications where the original metal characteristics must remain unchanged as far as possible. This process is primarily used on aluminum, and most often on large pieces which cannot be easily heat treated post weld to recover temper characteristics. It was invented and experimentally proven by Wayne Thomas and a team of his colleagues at The Welding Institute (TWI) UK in December 1991. TWI holds a number of patents on the process, the first being the most descriptive (1).

The method is based on the forged aluminum components without the temperature exceeds the melting point of the material. This is achieved by using of a rotating tool moving along the board uniting components by setting. After curing, the junctions are free from tensions greatly and offer an area perfect union because the welding was carried out from a side. Thus the need for additional work is reduced to least. Using this method, the full board is only formed by the original material, no filler material and impurities.

Application areas suitable for FSW

- Shipbuilding.
- Offshore oil platforms.
- Aerospace.
- Rail wagons, trams, underground trains.
- Automotive industry.
- Brewing Industry.
- Construction of bridges.
- Production of electric motors.
- Defense industry.
- Elements of cooling.

1.2 Non Destructive Evaluation

The NDE are trials or non-destructive testing, which are made to materials, be they metals, plastics (polymers), ceramics or composites. (2) Such trials generally used to determine certain physical or chemical property of the material in question.

The main applications are found in the NDE:

- Detection of discontinuities (internal and surface).
- Determination of chemical composition.
- Leak detection.
- Measurement of thickness and corrosion monitoring.
- Adhesion between materials.
- Inspection of welded joints.

The NDE are very important in the continued industrial development. Thanks to them is possible, for example, determine the presence of defects in materials or welds equipment such as pressure vessels, where catastrophic failure can represent huge losses in money, human life and damage to the environment. The ultrasonic test is based on the generation, propagation and detection of elastic waves through the materials (3).

The sound or vibration, in the form of elastic waves, propagates through the material until it completely loses its intensity or until encounters an interface, namely some other material such as air or water and, consequently, waves can undergo reflection, refraction, distortions. This can result in a change in intensity, direction and angle of wave propagation original.

Thus, it is possible to apply the method of ultrasound to determine certain characteristics of materials such as:

- Speed of wave propagation.
- Grain size in metals.
- Presence of discontinuities (cracks, pores, laminations, etc.).
- Adhesion between materials.
- Weld Inspection.
- Measurement of wall thickness.

As can be seen with the ultrasound method is possible to obtain an assessment of the internal condition of the material in question. However, the ultrasound method is more complex in practice than theory, which requires trained personnel for implementation and interpretation of signs or test results (4).

1.3 MOTIVATION

In regard to the FSW is a very recent technology no more than 20 years, so there is a wide range of work to develop new methods and processes, which means you have an opportunity to contribute to the analysis of this system welding to be increasingly employed in the industry but has many uses.

In today's world we have different ways to get the data to determine the flaws in the material, but the preventive study materials before they fail is a world explored but is not highly developed, usually when some part fails is when for the error and corrected, in contrast with non-destructive tests can be done a study preventive and detect faults before they occur.

1.4 OBJETIVE

The objective of this work is to determine the value of the parameters in operation on the Friction Stir Welding, such as transverse speed, rotational speed, load applied and tool design, affect the friction stir welding. For this purpose different samples with different welding parameters were used to achieve a functional weldment, which were inspected by ultrasonic testing.

Welded materials present changes in the microstructures respect to original plates. Through these features is possible to observe internal defects but it is necessary to destroy the joined sample and it only shows features of a plane.

It is intended that the Ultrasonic Testing can provide the flaws that occur on the weld and its location without having to destroy the sample, because the UT lets us to examinate completely the welded and affected zone along longitudinal axe of a non-destructive way.

1.5 CONTRIBUTION

If successful in research and build the prototype for the test, the laboratory will be expanded. Be recognized that the error is occurring in the micro-structure.

Knowledge of the rules may help reduce the time requested. Since that show how the material is affected from a different point of view that is currently done in laboratories.

1.6 TECHNOLOGY TRENDS

Currently within the technology for nondestructive testing has been increasing throughout the aerospace industry, since most of the time these faults are undetectable, which makes preventive maintenance in the aerospace industry to address failures to identify micro structure (5).

Considering these points and facing the trend of not being able to wait until problems arise from failures to stop macro metric for the exchange of parts needed to obtain a common and easiest method to have a broader preventive maintenance.

Friction stir welding technology has been a major boon to industry advanced since its inception. In spite of its short history, it has found widespread applications in diverse industries. Hard materials such as steel and other important engineering alloys can now be welded efficiently using this process.

Significant progress has also been made in the fundamental understanding of both the welding process and the structure and properties of the welded joints. The understanding has been useful in reducing defects and improving uniformity of weld properties and, at the same time, expanding the applicability of FSW to new engineering alloys. With better quantitative understanding of the underlying principles of heat transfer, material flow, tool-work–piece contact conditions and effects of various process parameters, efficient tools have been devised. At the current pace of development, FSW is likely to be more widely applied in the future.

2. Literature Survey

2.1 Friction Stir Welding

There are around 2000 patents on FSW of which is searched to find those that affect the issue proposed for greater scope and understanding of welding by this method (6).

There are several magazines published on materials, there is specializing in what is solder, which were obtained some items of this section of research to find the data and understanding of the FSW.

According to the patents found there are several devices to the FSW, at which sought to make a design according to the literature found to obtain samples for characterization.

In FSW as shown in Figure 1, a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe (nib or pin) is rotated at a constant speed and fed at a constant traverse rate into the joint line between two pieces of sheet or plate material, which are butted together. The parts have to be clamped rigidly onto a backing bar in a manner that prevents the abutting joint faces from being forced apart. The length of the nib is slightly less than the weld depth required and the tool shoulder should be in intimate contact with the work surface. The nib is then moved against the work, or vice versa.

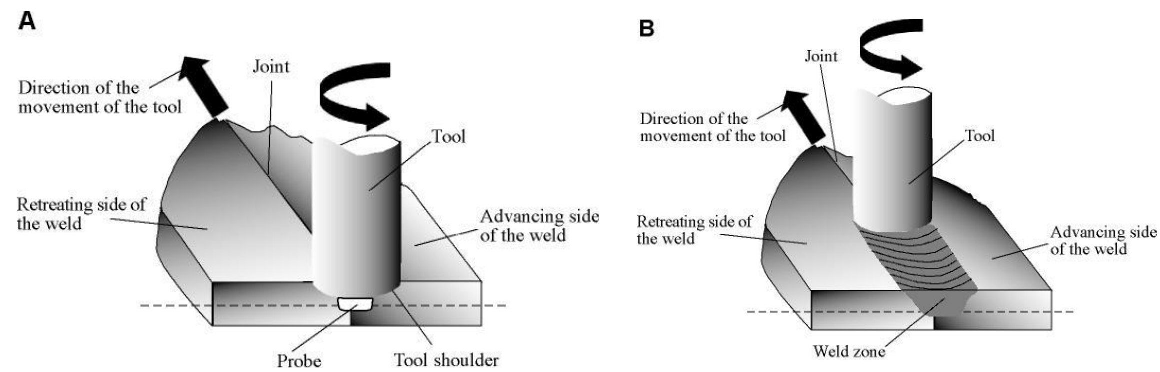


Figure 1 (A) Schematic diagram of the FSW process: (B) The progress of the tool through the joint, also showing the weld zone

Frictional heat is generated between the wear-resistant welding tool shoulder and nib, and the material of the work pieces. This heat, along with the heat generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without reaching the melting point allowing the traversing of the tool along the weld line in a plasticized tubular shaft of metal.

This heat causes the latter to soften without reaching the melting point and allows traversing of the tool along the weld line. The plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged by the intimate contact of the tool shoulder and the pin profile. It leaves a solid phase bond between the two pieces. The process can be regarded as a solid phase keyhole welding technique since a hole to accommodate the probe is generated, then filled during the welding sequence (6).

As the pin is moved in the direction of welding, the leading face of the pin, assisted by a special pin profile, forces plasticized material to the back of the pin while applying a substantial forging force to consolidate the weld metal. The welding of the material is facilitated by severe plastic deformation in the solid state, involving dynamic recrystallization of the base material (7).

2.1.1 Tool Design

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed.

It is desirable that the tool material is sufficiently strong, tough and hard wearing, at the welding temperature. Further it should have a good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H12 has proven perfectly acceptable for welding aluminum alloys within thickness ranges of 0.5 – 50 mm (8) but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium.

The majority of tools have a concave shoulder profile which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool as shown in Figure 2.

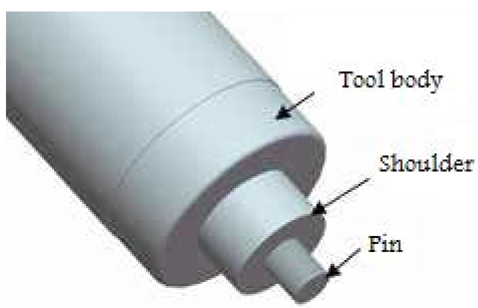


Figure 2 Tool Design

Tool design influences heat generation, plastic flow, the power required, and the uniformity of the welded joint. The shoulder generates most of the heat and prevents the plasticized material from escaping from the work–piece, while both the shoulder and the tool–pin affect the material flow.

Improvements in tool design have been shown to cause substantial improvements in productivity and quality. TWI has developed tools specifically designed to increase the depth of penetration and so increase the plate thickness that can be successfully welded. An example is the ‘whorl’ design that uses a tapered pin with re-entrant features or a variable pitch thread in order to improve the downwards flow of material. Additional designs include the Triflute and Trivex series (9) (10).

The Triflute design has a complex system of three tapering, threaded re-entrant flutes that appear to increase material movement around the tool. The Trivex tools use a simpler, non-cylindrical, pin and have been found to reduce the forces acting on the tool during welding.

The Triflute tool uses an alternative system with a series of concentric grooves machined into the surface which are intended to produce additional movement of material in the upper layers of the weld.

The table 1 reveals the common tools for friction stir welding at TWI (6).

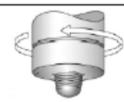
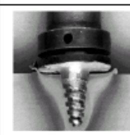
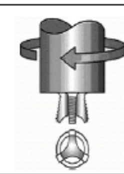
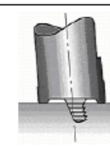
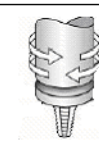
Tool	Cylindrical	Whorl™	MX triflute™	Flared triflute™	A-skew™	Re-stir™
Schematics						
Tool pin shape	Cylindrical with threads	Tapered with threads	Threaded, tapered with three flutes	Tri-flute with flute ends flared out	Inclined cylindrical with threads	Tapered with threads
Ratio of pin volume to cylindrical pin volume	1	0.4	0.3	0.3	1	0.4
Swept volume to pin volume ratio	1.1	1.8	2.6	2.6	depends on pin angle	1.8
Rotary reversal	No	No	No	No	No	Yes
Application	Butt welding; fails in lap welding	Butt welding with lower welding torque	Butt welding with further lower welding torque	Lap welding with lower thinning of upper plate	Lap welding with lower thinning of upper plate	When minimum asymmetry in weld property is desired

Table 1 Tool Design by TWI

2.1.2 Welding forces

During welding a number of forces will act on the tool:

- A downwards force is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases the vertical position of the tool are preset and so the load will vary during welding.
- The traverse force acts parallel to the tool motion and is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool it might be expected that this force will decrease as the temperature of the material around the tool is increased.
- The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the weld.
- Torque is required to rotate the tool, the amount of which will depend on the down force and friction coefficient (sliding friction) and/or the flow strength of the material in the surrounding region (sticking friction).

In order to prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle should be modified so that the forces acting on the tool are as low as possible.

There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the welding speeds and the heat input during welding is complex but, in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cool then voids or other flaws may be present in the stir zone and in extreme cases the tool may break.

At the other end of the scale excessively high heat input may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases.

The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be a critical parameter for ensuring weld quality (11). Plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2-4 degrees (Figure 3), such that the rear of the tool is lower than the front, has been found to assist this forging process.

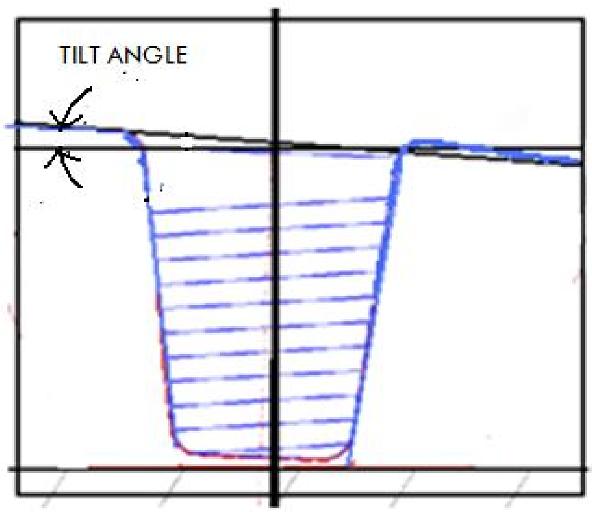


Figure 3 Tilt diagram

The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Given the high loads required the welding machine may deflect and so reduce the plunge depth compared to the nominal setting, which may result in flaws in the weld. On the other hand an excessive plunge depth may result in the pin rubbing on the backing plate surface or a significant under match of the weld thickness compared to the base material. Variable load welders have been developed to automatically compensate for changes in the tool displacement while

TWI has demonstrated a roller system that maintains the tool position above the weld plate.

2.1.3 Microstructure features

The solid-state nature of the FSW process, combined with its unusual tool and asymmetric nature, results in a highly characteristic microstructure. The microstructure can be broken up into the following zones (Figure 4):

- The stir zone (SZ) is a region of heavily deformed material that roughly corresponds to the location of the pin during welding. The grains within the stir zone are roughly equiaxed and often an order of magnitude smaller than the grains in the parent material. The precise origin of these rings has not been firmly established.
- The flow arm zone (FAZ) is on the upper surface of the weld and consists of material that is dragged by the shoulder from the retreating side of the weld, around the rear of the tool, and deposited on the advancing side.
- The thermo-mechanically affected zone (TMAZ) occurs on either side of the stir zone. In this region the strain and temperature are lower and the effect of welding on the microstructure is correspondingly smaller. Unlike the stir zone the microstructure is recognizably that of the parent material, albeit significantly deformed and rotated. Although the term TMAZ technically refers to the entire deformed region it is often used to describe any region not already covered by the terms stir zone and flow arm.
- The heat-affected zone (HAZ) is common to all welding processes. As indicated by the name, this region is subjected to a thermal cycle but is not deformed during welding. The temperatures are lower than those in the TMAZ but may still have a significant effect if the microstructure is thermally unstable. In fact, in age-hardened aluminum alloys this region commonly exhibits the poorest mechanical properties (12).

Figure 4 Microstructure diagram

2.1.4 Advantages and disadvantages

In general, FSW has been found to produce a low concentration of defects and is very tolerant to variations in parameters and materials (6).

The solid-state nature of FSW immediately leads to several advantages over fusion welding methods since any problems associated with cooling from the liquid phase are immediately avoided. Issues such as:

- Porosity
- Solute redistribution
- Solidification cracking
- Liquation cracking

Nevertheless, FSW is associated with a number of unique defects.

- Insufficient weld temperatures
- Due to low rotational speeds or high traverse speeds
- Lack-of-penetration defect

This may result in long, tunnel-like defects running along the weld which may occur on the surface or subsurface. Low temperatures may also limit the forging action of the tool and so reduce the continuity of the bond between the materials from each side of the weld.

A number of potential advantages of FSW over conventional fusion-welding processes have been identified:

1. Good mechanical properties in the as welded condition
2. Improved safety due to the absence of toxic fumes or the spatter of molten material.
3. No consumables - A pin made of conventional steel can weld over 1000m of aluminum and no filler or gas shield is required for aluminum. (13)
4. Easily automated on simple milling machines - lower setup costs and less training.
5. Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
6. Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
7. Low environmental impact.

However, some disadvantages of the process have been identified:

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques although this may be offset if fewer welding passes are required.

2.2 Ultrasonic

NDT has been practiced for many decades, with initial rapid developments in instrumentation spurred by the technological advances that occurred during World War II and the subsequent defense effort. During the earlier days, the primary purpose was the detection of defects. As a part of "safe life" design, it was intended that a structure should not develop macroscopic defects during its life, with the detection of such defects being a cause for removal of the component from service. In response to this need, increasingly sophisticated techniques using ultrasonic, eddy currents, x-rays, dye penetrate, magnetic particles, and other forms of interrogating energy emerged.

In the early 1970's, two events occurred which caused a major change in the NDT field. First, improvements in the technology led to the ability to detect small flaws, which caused more parts to be rejected even though the probability of component failure had not changed. However, the discipline of fracture mechanics emerged, which enabled one to predict whether a crack of a given size will fail under a particular load when a material has fracture toughness properties are known. Other laws were developed to predict the growth rate of cracks under cyclic loading (fatigue). With the advent of these tools, it became possible to accept structures containing defects if the sizes of those defects were known. This formed the basis for the new philosophy of "damage tolerant" design. Components having known defects could continue in service as long as it could be established that those defects would not grow to a critical, failure producing size (14).

Many ultrasonic flaw detectors have a trigonometric function that allows for fast and accurate location determination of flaws when performing shear wave inspections. Cathode ray tubes, for the most part, have been replaced with LED or LCD screens. These screens, in most cases, are extremely easy to view in a wide range of ambient lighting. Bright or low light working conditions encountered by technicians have little effect on the technician's ability to view the screen. Screens can be adjusted for brightness, contrast, and on some instruments even the color of the screen and signal can be selected. Transducers can be programmed with predetermined instrument settings. The operator only has to connect the transducer and the instrument will set variables such as frequency and probe drive.

Along with computers, motion control and robotics have contributed to the advancement of ultrasonic inspections. Early on, the advantage of a stationary platform was recognized and used in industry. Computers can be programmed to inspect large, complex shaped components, with one or multiple transducers collecting information. Automated systems typically consisted of an immersion tank, scanning system, and recording system for a printout of the scan.

2.2.1 Wave Propagation

UT is based on time-varying deformations or vibrations in materials, which is generally referred to as acoustics. All material substances are comprised of atoms, which may be forced into vibration motion about their equilibrium positions. Many different patterns of vibration motion exist at the atomic level; however, most are irrelevant to acoustics and ultrasonic testing.

In solids, sound waves can propagate in four principle modes that are based on the way the particles oscillate. Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as plate waves. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear waves is illustrated below (14).

In longitudinal waves, the oscillations occur in the longitudinal direction or the direction of wave propagation. Since compression and dilatational forces are active in these waves, they are also called pressure or compression waves. They are also sometimes called density waves because their particle density fluctuates as they move.

In the transverse or shear wave, the particles oscillate at a right angle or transverse to the direction of propagation. Shear waves require an acoustically solid material for effective propagation, and therefore, are not effectively propagated in materials such as liquids or gasses. Shear waves are relatively weak when compared to longitudinal waves (Figure 5). In fact, shear waves are usually generated in materials using some of the energy from longitudinal waves (14).

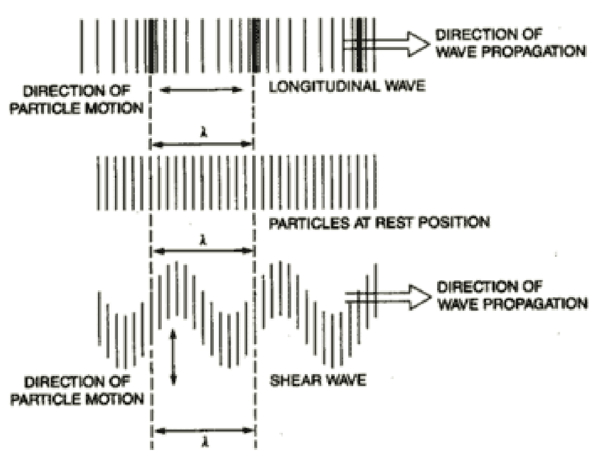


Figure 5 Wave types

2.2.2 The Speed of Sound

Hooke's Law, when used along with Newton's Second Law, can explain a few things about the speed of sound. The speed of sound within a material is a function of the properties of the material and is independent of the amplitude of the sound wave. Newton's Second Law says that the force applied to a particle will be balanced by the particle's mass and the acceleration of the particle. Mathematically, Newton's Second Law is written as $F = m*a$ Hooke's Law then says that this force will be balanced by a force in the opposite direction that is dependent on the amount of displacement and the spring constant $F = -k*x$ therefore, since the applied force and the restoring force are equal, $m*a = -k*x$ can be written. The negative sign indicates that the force is in the opposite direction (15).

Since the mass m and the spring constant k are constants for any given material, it can be seen that the acceleration a and the displacement x are the only variables. It can also be seen that they are directly proportional. For instance, if the displacement of the particle increases, so does its acceleration. It turns out that the time that it takes a particle to move and return to its equilibrium position is independent of the force applied. So, within a given material, sound always travels at the same speed no matter how much force is applied when other variables, such as temperature, are held constant.

2.2.3 Properties of material affect

Of course, sound does travel at different speeds in different materials. This is because the mass of the atomic particles and the spring constants are different for different materials. The mass of the particles is related to the density of the material, and the spring constant is related to the elastic constants of a material. The general relationship between the speed of sound in a solid and its density and elastic constants is given by the following equation:

$$V = \sqrt{\frac{C_{IJ}}{\rho}} \qquad \text{Equation 1}$$

Where V is the speed of sound, C is the elastic constant, and p is the material density. This equation may take a number of different forms depending on the type of wave (longitudinal or shear) and which of the elastic constants that are used (15).

The typical elastic constants of materials include:

- Young's Modulus, E: a proportionality constant between uniaxial stress and strain.
- Poisson's Ratio, n: the ratio of radial strain to axial strain
- Bulk modulus, K: a measure of the incompressibility of a body subjected to hydrostatic pressure.
- Shear Modulus, G: also called rigidity, a measure of a substance's resistance to shear.
- Lame's Constants, l and m: material constants that are derived from Young's Modulus and Poisson's Ratio.

When calculating the velocity of a longitudinal wave, Young's Modulus and Poisson's Ratio are commonly used. When calculating the velocity of a shear wave, the shear modulus is used. It is often most convenient to make the calculations using Lame's Constants, which are derived from Young's Modulus and Poisson's Ratio.

It must also be mentioned that the subscript ij attached to C in the above equation is used to indicate the directionality of the elastic constants with respect to the wave type and direction of wave travel. In isotropic materials, the elastic constants are the same for all directions within the material. However, most materials are anisotropic and the elastic constants differ with each direction. For example, in a piece of rolled aluminum plate, the grains are elongated in one direction and compressed in the others and the elastic constants for the longitudinal direction are different than those for the transverse or short transverse directions.

Examples of approximate longitudinal sound velocities in materials are:

MATERIAL	VELOCITY (inch/µs)
Aluminum	0.248
1020 steel	0.232
Cast iron	0.220

Table 2 Longitudinal sound velocities

Examples of approximate shear sound velocities in materials are:

MATERIAL	VELOCITY (inch/µs)
Aluminum	0.121
1020 steel	0.128
Cast iron	0.136

Table 3 Shear sound velocities

When comparing longitudinal and shear velocities, it can be noted that shear velocity is approximately one half that of longitudinal velocity. (16)

2.2.4 Acoustic Impedance

Sound travels through materials under the influence of sound pressure. Because molecules or atoms of a solid are bound elastically to one another, the excess pressure results in a wave propagating through the solid (17).

The acoustic impedance (Z) of a material is defined as the product of its density (**p**) and acoustic velocity (**V**).

$$Z = \rho * V \qquad \text{Equation 2}$$

Acoustic impedance is important in

- The determination of acoustic transmission and reflection at the boundary of two materials having different acoustic impedances.
- The design of ultrasonic transducers.
- Assessing absorption of sound in a medium.

2.2.5 Frequency

Each ultrasonic operational frequency has its own unique characteristics. These characteristics can be used to determine which frequencies might be best suited to a given application (18).

Ultrasonic testing involves frequencies of 500 KHz to 20 MHz, although higher and lower frequencies (> 20 KHz) are also used.

2.2.6 Couplant

Couplant, usually a liquid or semi liquid, is required between the face of the search unit and the examination surface to permit the transmission of ultrasonic waves from the search unit into the material under examination. Typical couplants include glycerin, water, cellulose gel, oil, water-soluble oils, and grease (19).

2.2.7 Calibration

Calibration refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment. In ultrasonic testing, several forms of calibration must occur. First, the electronics of the equipment must be calibrated to ensure that they are performing as designed. This operation is usually performed by the equipment manufacturer and will not be discussed further in this material. It is also usually necessary for the operator to perform a "user calibration" of the equipment. This user calibration is necessary because most ultrasonic equipment can be reconfigured for use in a large variety of applications. The user must "calibrate" the system, which includes the equipment settings, the transducer, and the test setup, to validate that the desired level of precision and accuracy are achieved. The term calibration standard is usually only used when an absolute value is measured and in many cases, the standards are traceable back to standards at the National Institute for Standards and Technology (14).

In ultrasonic testing, there is also a need for reference standards. Reference standards are used to establish a general level of consistency in measurements and to help interpret and quantify the information contained in the received signal. Reference standards are used to validate that the equipment and the setup provide similar results from one day to the next and that similar results are produced by different systems. Reference standards also help the inspector to estimate the size of flaws. In a pulse-echo type setup, signal strength depends on both the size of the flaw and the distance between the flaw and the transducer. The inspector can use a reference standard with an artificially induced flaw of known size and at approximately the same distance away for the transducer to produce a signal. By comparing the signal from the reference standard to that received from the actual flaw, the inspector can estimate the flaw size.

2.2.8 Wavelength and Defect Detection

In ultrasonic testing, the inspector must make a decision about the frequency of the transducer that will be used. As we learned on the previous page, changing the frequency when the sound velocity is fixed will result in a change in the wavelength of the sound. The wavelength of the ultrasound used has a significant effect on the probability of detecting a discontinuity. A general rule of thumb is that a discontinuity must be larger than one-half the wavelength to stand a reasonable chance of being detected.

Sensitivity and resolution are two terms that are often used in ultrasonic inspection to describe a technique's ability to locate flaws. Sensitivity is the ability to locate small discontinuities. Sensitivity generally increases with higher frequency (shorter wavelengths). Resolution is the ability of the system to locate discontinuities that are close together within the material or located near the part surface. Resolution also generally increases as the frequency increases (20).

The wave frequency can also affect the capability of an inspection in adverse ways. Therefore, selecting the optimal inspection frequency often involves maintaining a balance between the favorable and unfavorable results of the selection. Before selecting an inspection frequency, the material's grain structure and thickness, and the discontinuity's type, size, and probable location should be considered. As frequency increases, sound tends to scatter from large or course grain structure and from small imperfections within a material. Cast materials often have coarse grains and other sound scatters that require lower frequencies to be used for evaluations of these products. Wrought and forged products with directional and refined grain structure can usually be inspected with higher frequency transducers.

Since more things in a material are likely to scatter a portion of the sound energy at higher frequencies, the penetrating power (or the maximum depth in a material that flaws can be located) is also reduced. Frequency also has an effect on the shape of the ultrasonic beam. Beam spread, or the divergence of the beam from the center axis of the transducer, and how it is affected by frequency will be discussed later.

It should be mentioned, so as not to be misleading, that a number of other variables will also affect the ability of ultrasound to locate defects. These include the pulse length, type and voltage applied to the crystal, properties of the crystal, backing material, transducer diameter, and the receiver circuitry of the instrument.

2.2.8 Detection of discontinuities

The essential "tool" for the ultrasonic operator is the probe, the piezoelectric element, excited by an extremely short electrical discharge, transmits an ultrasonic pulse (Figure 6). The same element on the other hand generates an electrical signal when it receives an ultrasonic signal thus causing it to oscillate. The probe is coupled to the surface of the test object with a liquid or coupling paste so that the sound waves from the probe are able to be transmitted into the test object (16).

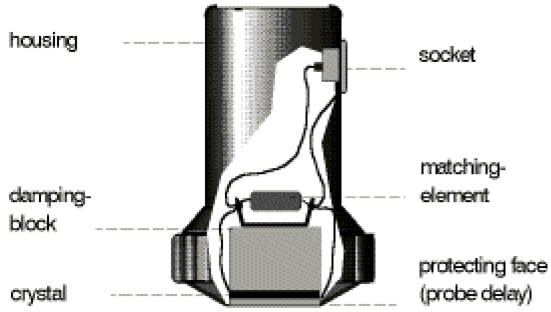


Figure 6 Straight-beam probe

The operator then scans the test object into different types of probes such as longitudinal waves in straight beam probe and shear waves in the angle beam probe (Figure 7).

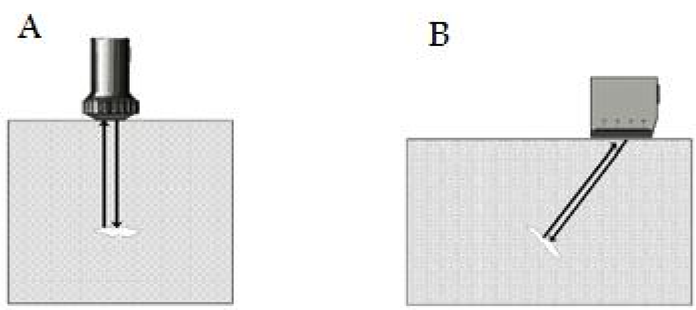


Figure 7 (A) Plane flaw - straight-beam probe (B) Plane flaw - angle-beam probe

The operator moves the probe evenly to and fro across the surface. In doing this, he observes an instrument display for any signals caused by reflections from internal discontinuities.

The shape of the sound beam plays an important part in the selection of a probe for solving a test problem. It is often sufficient to draw the acoustic axis in order to show what the solution to a test task looks like (Figure 8) A volumetric discontinuity (hollow space, foreign material) reflects the sound waves in different directions (16).

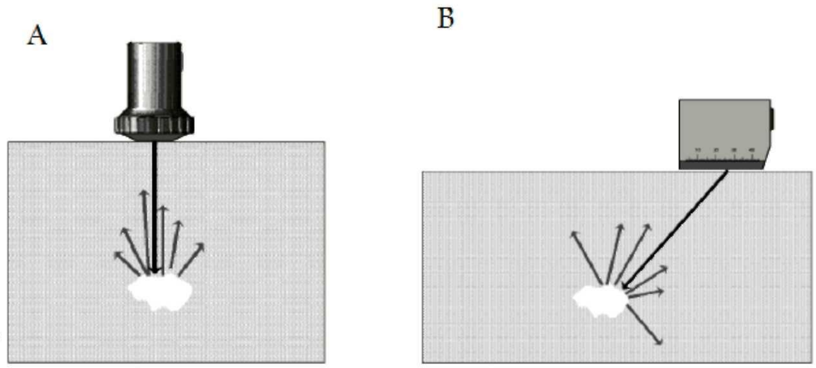


Figure 8 Volumetric discontinuity (A) straight-beam probe (B) angle-beam probe

The portion of sound wave which comes back to the probe after being reflected by the discontinuity is mainly dependent on the direction of the sound wave.

2.2.9 Techniques

2.2.9.1 Pulse eco testing

This technique is based on the physical effect echo: The sound waves are reflected from boundaries of different materials.

The transducer emits signal and also detects the echo of the reflection of the sonic wave striking the boundary of different materials (Figure 9). Between greater the difference in acoustic impedance of the material, the greater reflected power.

Through the echo delay can know the thickness of the material or distance and shape of the discontinuity using the formula (17).

$$T = V\left(\frac{t}{2}\right) \quad \text{Equation 3}$$

Where V is the speed of sound, T is the distance to boundary, and t is the time.

Figure 9 Pulse eco

2.2.9.2 Resonance testing

Acoustic measurement technology is very sensitive; even minor changes in the oscillatory behavior of mechanical structures can be detected. Resonance analysis is a qualitative process that compares the actual oscillatory situation with the target one derived from a learning base. This learning base is established by using defined standard parts.

It uses the physical effect known in which a body, having been excited in some ways characteristic vibrations and frequencies as shown in Figure 10. These vibrations when passing through the test object leaves a "fingerprint" which can be captured by a sensor and then graphically exposed (18).

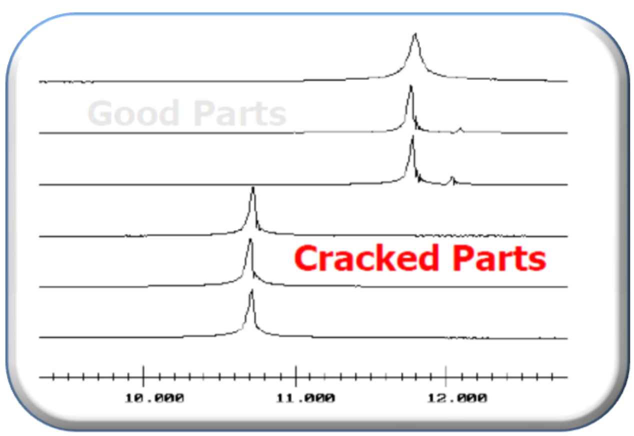


Figure 10 Resonance testing

2.2.9.3 through transmission

This technique is based on energy attenuation of ultrasonic wave when passing through the material and crashed into higher acoustic impedance discontinuities.

The propagation of ultrasonic energy is influenced by the damping and dispersion that occur:

- The microstructure of the material.
- Modulus of elasticity and density of the material.
- The different stages of material including discontinuities.
- Grain boundaries.

To characterize the attenuation to interpret the results requires knowledge of a large number of thermo-physical parameters which in practice is difficult to quantify.

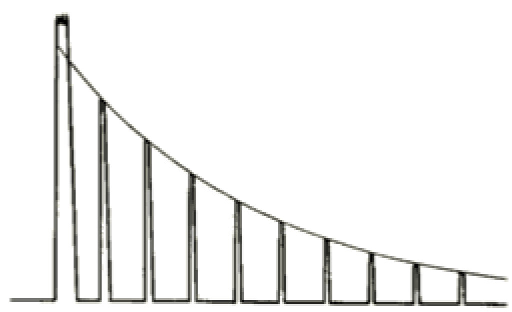


Figure 11 Attenuation

Significant variations in the characteristic micro structural and mechanical properties generally produce only a relatively small change in velocity and attenuation of the wave (Figure 11).

2.2.9.4 Phased Array

The technology called Phased Array transducers using arrays composed of small elements (64-128) piezoelectric crystals. Its key advantage is that each of these crystals can be activated electronically and individually to generate a slight vibration. The union of these small vibrations leads to the principal.

The controlled activation of small piezoelectric device can run a simple wave, matching onset times of the crystals (Figure 12). Similarly, this type of transducers allows a dynamic approach in both transmission and reception.

Phased array technology also allows the replacement of multiple probes and even mechanical components. Inspecting a part with a variable-angle beam also maximizes the detection of the fault (18).

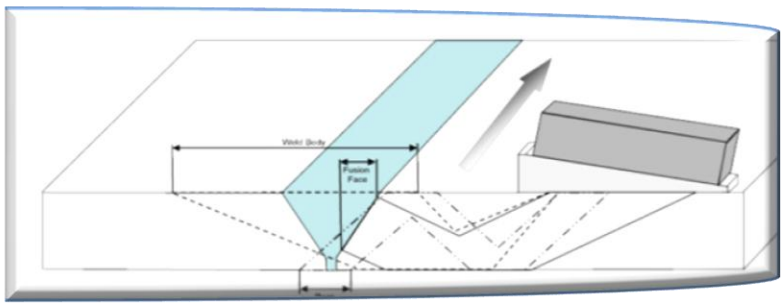


Figure 12 Phased Array

2.2.10 Advantages and disadvantages

Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

- It is sensitive to both surface and subsurface discontinuities.
- The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- Only single-sided access is needed when the pulse-echo technique is used.
- It is highly accurate in determining reflector position and estimating size and shape.
- Minimal part preparation is required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses, such as thickness measurement, in addition to flaw detection.

As with all NDT methods, ultrasonic inspection also has its limitations, which include:

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.

- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
- Linear defects oriented parallel to the sound beam may go undetected.
- Reference standards are required for both equipment calibration and the characterization of flaws.

The above provides a simplified introduction to the NDT method of ultrasonic testing. However, to effectively perform an inspection using ultrasonic, much more about the method needs to be known.

3. Experimental Set-up

3.1 FSW Experimental methodology

3.1.1 Tool design

The first was the design of the tool, for which seek of information on the best steels for tooling available in the local market, still the best option the family of steels H11-H16. This family of steels has good resistance to loss of hardness due to its medium content of chromium, supplemented with the addition of carbide forming elements such as tungsten, molybdenum and vanadium. The low carbon content and low content of alloying elements promote a hardness of 40-50 Rockwell C. High contents of tungsten and molybdenum increase hardness and resistance red hot, but small amounts decrease its strength (21).

The Table 4 shows the composition of different steels.

Chromium Hot Work Tool Steels (Group H11-H16)								
Designación	**C**	**Mn**	**Si o Ni**	**Cr**	**V**	**W**	**Mo**	**Co**
H11	0.35	-----	-----	5.00	0.40	-----	1.50	-----
H12	0.35	-----	-----	5.00	0.40	1.50	1.50	-----
H13	0.35	-----	-----	5.00	1.00	-----	1.50	-----
H14	0.40	-----	-----	5.00	-----	5.00	-----	-----
H15	0.40	-----	-----	5.00	-----	-----	5.00	-----
H16	0.55	-----	-----	7.00	-----	7.00	-----	-----

Table 4 Group H11-H16

For this propose was occupied the H12 steel, which was found in the local market for sale at retail.

Different models were designed tool according to what could be done in the laboratories of manufacturing the Tecnologico de Monterrey, where the design of a cylindrical threaded tool, the model that was used is on figure 13.

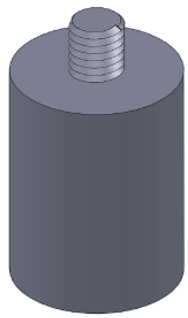


Figure 13 3D Model of the Tool

Tools were made with different threads to test each of them as shown in the Table 5 and Figure 14.

TOOL	DIAMETER OR THE SHOULDER (mm)	DIAMETER OF THE PIN(mm)	PIN LENGTH	THREADS
1	9.30	4.32	8.13	UFN
2	8.20	6.00	8.13	UFN
3	6.30	3.40	8.13	UFN

Table 5 Tools

Figure 14 Tools

Hence, heat treatment was made according to the specification sheets for this family of steels, which consisted in a pre heated the tools to 600 °C for 20 minutes, and then from there move to a austenitizing temperature of 1120 °C for 45 minutes to quenching on oil SAE 40 at environment temperature with agitation of the part within it, and then took the tools to a double tempering at 600 °C for 30 minutes between each tempering the tool was cooled on air at environment temperature for 15 minutes.

The temper of 600°C was made to have any change in microstructure of the tool, because the work temperature is about to 400 to 500 degrees.

After completion of the hardness heat treatment were taken to see the results from them giving the following results in Table 6.

Radius	HRC
1	37
0.75	42
0.5	44
0.25	45
Center	47

Table 6 Tool hardness

3.1.2 Welding parameters

The weld material was 3003 aluminum alloy plates is an alloy with good corrosion resistance and moderate resistance.

- 3003 aluminum alloy is easily machined and is considered a good machinability alloy between aluminum similar.
- Heat treatment, the 3003 aluminum alloy is not heat treatable. The temperature range for hot work is 510-260 C. In this range the alloy is easily hot worked.
- Annealing during or after cold working, is 400 C, giving adequate time for thorough heating, followed by air cooling.

The FSW process was developed from the adaptation of a universal milling machine with rotation speeds of 1115, 1750 and 2750 rpm and feed rate, with 500 mm-race.

Butt-welded joints along the direction of forming the material, were made on plates cut from extruded profiles, Aluminum 3003, whose chemical composition is in Table 7.

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
96-97	0.6	0.7	0.05-0.2	1.0-1.5	0	0	0.1	0

Table 7 Chemical composition of Aluminum 3003

The plates were machined to obtain the contact surface between them with the slightest imperfection as possible and to avoid possible errors porosities by poor coupling between them.

Once the plates were placed at the top cut on a common shaft, the rotary pin sinks into the work pieces until the shoulder of the tool is in intimate contact with the work surface.

After the bolt is inserted, it moves in the direction of welding. As the tool moves along the seam, the heated and softened material flows around the bolt to the rear where it is consolidated to create the weld. The result is a solid state welding and high quality. The tool axis is usually tilted a few degrees (2 º or 3 º) from the vertical, to facilitate the consolidation of the weld.

The FSW process variables to be taken into account in the characterization in this project were the feed rate or welding (Va), and pin rotation speed (Vr), so that relations of rotational speeds /progress were used between 4 and 16 rev / mm, seeking to determine the optimum system operation, with the minimum possible deterioration of mechanical properties in the welded joint and ensure complete healing of the union. The welding conditions tested are presented in Table 8.

Sample	Tool	Tool Velocity (rpm)	Traverse Velocity (mm/min)	Tool spin
1	1	1,115	25.4	CW
2	1	1,115	25	CW
3	1	1,115	27	CW
4	2	1,115	22	CW
5	2	1,115	30	CW
6	3	1,115	26	CW
7	3	1,750	24	CCW
8	1	1,750	20	CCW
9	3	1,750	23.5	CW
10	2	1,750	24.6	CCW
11	2	1,750	25.7	CW
12	1	1,750	23.2	CCW
13	2	2,700	21.6	CW
14	1	2,700	25.2	CW

Table 8 Welding conditions

SAMPLE	TOOL VELOCITY (rpm)	TRAVERSE VELOCITY (mm/min)	TOOL SPIN
1	1600	60	CW
2	1360	60	CW
3	1300	60	CW
4	1000	50	CW
5	960	25	CW
6	1600	40	CW

Table 9 CNC´s Welding conditions

The results of the Table 9 represent those achieved in the CNC for these samples had the same tool and the spin tool was CW.

3.1.3 Mechanical testing

Welded plates representative samples were taken for mechanical testing by tension tests, hardness of welded joints.

The hardness obtained in the samples is shown in Table 10.

HARDNESS VICKER			
SZ	FAZ	TMAZ	HAZ
359	130	165	257

Table 10 Hardness of samples

The objective of the tensile test is to investigate the behavior of the material. The samples to be investigated are pure aluminum and aluminum with FSW. From performing the Tensile Test the following properties will be determined; young's modulus, yield stress, ultimate tensile stress, percentage elongation at fracture, percentage reduction in cross-sectional area at fracture and fracture stress. This experiment is used to determine a material's properties.

The two specimens will take the rectangular form with these dimensions 1 inch by 0.200 inch; the test will be done on the universal machine of materials laboratory. . The machine will exert a tensile force on the specimen causing it to extend. The force exerted to create each increment of extension is displayed on the machine along with the total extension.

PROPERTY	ALUMINUM 3003	
	BASE	FSW
YOUNG´S MODULE (GPa)	72	
YIELD STRESS (MPa)	50.27	37.75
ULTIMATE TENSILE STRESS (MPa)	130.8	82.78
ELONGATION	11.25%	6.68 %

Table 11 Aluminum proprieties

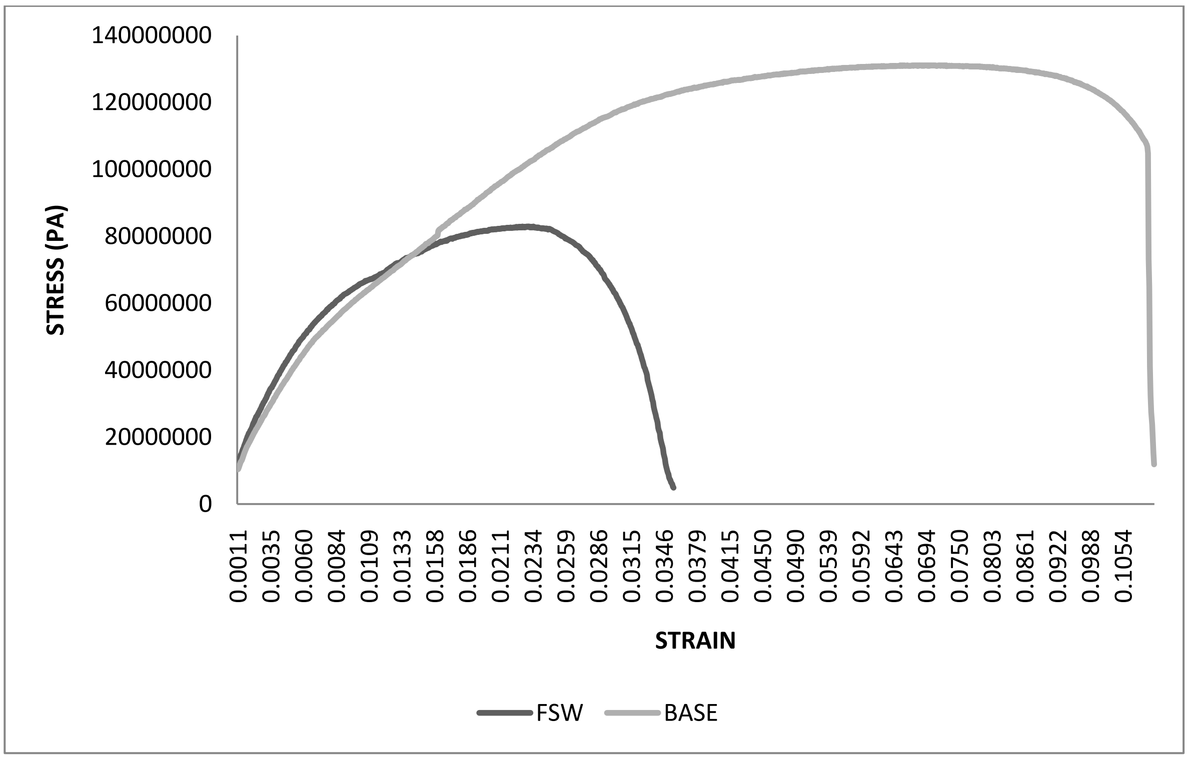


Figure 15 The Stress-Strain graph

3.1.4 Fracture behavior

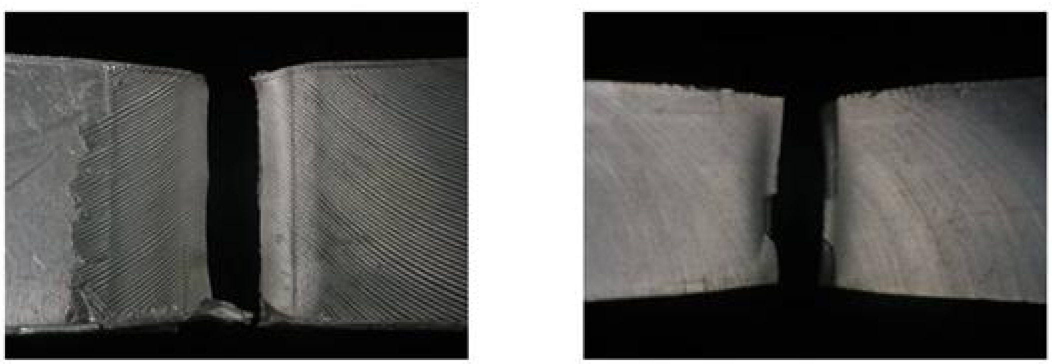
A factor that determines the amount of brittle or ductile fracture that occurs in a material is dislocation density. The higher the dislocation density, the more brittle the fracture will be in the material. The idea behind this theory is that plastic deformation comes from the movement of dislocations. As dislocations increase in a material due to stresses above the materials yield point, it becomes increasingly difficult for the dislocations to move because they pile into each other. So a material that already has a high dislocation density can only deform but so much before it fractures in a brittle manner. The last factor is grain size. As grains get smaller in a material, the fracture becomes more brittle.

So the samples have a brittle fracture, and have two types of fractures seen: transgranular and intergranular.

In transgranular fracture, the fracture travels through the grain of the material. The fracture changes direction from grain to grain due to the different lattice orientation of atoms in each grain.

Intergranular fracture is the crack traveling along the grain boundaries, and not through the actual grains. Intergranular fracture usually occurs when the phase in the grain boundary is weak and brittle.

In Figure 16 shows two images the A is from the sample with FSW and the B is on base material.



A B

Figure 16 Samples after the tensile test A) FSW B) BASE

In Figure 17 A is referred to the Figure 16 A on the left of fracture, it shows two zones of fracture, one is practical the same of the Figure 18, the other one is above the figure that seem to have a intergranular fracture. Figure A is showing a crack at a thread root on the failed bolt.

The B is the right side of the fracture that appears to have to more transgranular fracture in the up zone of the fracture at the above part of the fracture has an intergranular behavior.

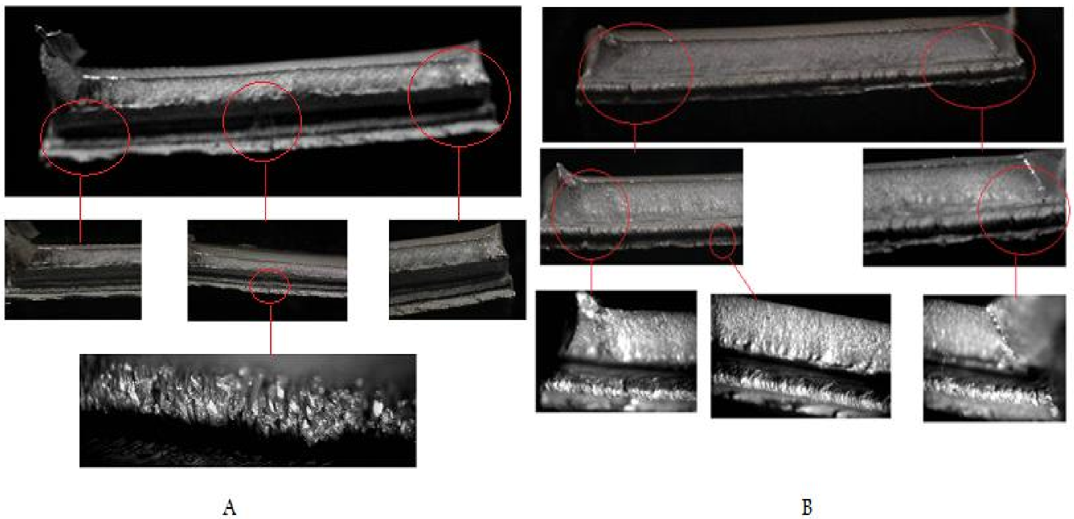


Figure 17 Fracture behavior on FSW sample

Figure 17 is an overall view of the fracture surface of the failed bolt. The surface appears to have tiny facets, which are characteristic of a brittle fracture.

To explain how the fracture goes like a peak in the bottom of the sample is because how the FSW altered the microstructure; the weld penetrates deep into the joint of the two plates so the propagation of the failure seems to follow the deep penetration (22). The fracture here and over the rest of the surface is totally brittle, with no signs of ductility. No fatigue striations were found.

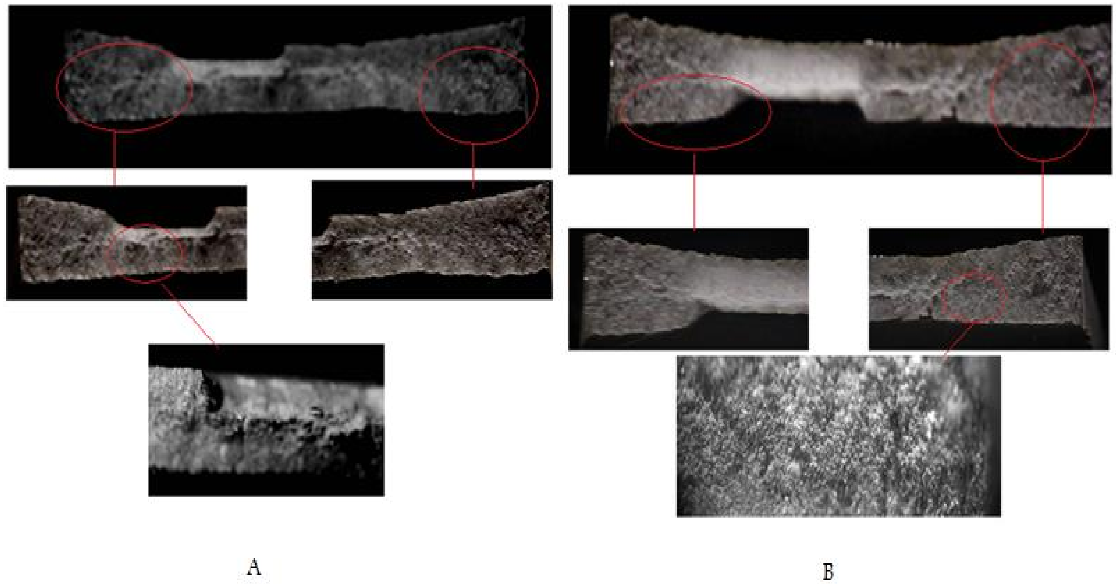


Figure 18 Fracture behaviors on BASE sample

In the cast Al–Si alloys, friction stir welding breaks up the large silicon particles in the nugget and the TMAZ; as a consequence, the fracture is located in the base plate during cross-weld tensile tests because in this case, it is the coarse silicon particles which control failure (23).

3.1.5 Microstructure behavior

The microstructure evaluation was performed in planes transverse to weld using optical metallographic analysis in Figure 19 is the sample that was used.

The different microstructures zones are shown in Figure 4 and physical proprieties can be seen in the next microstructures of samples welded with FSW in Table 9.

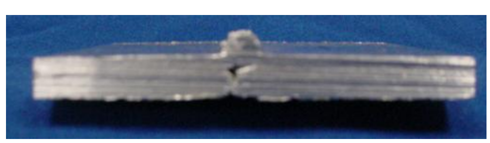


Figure 19 Sample for Microstructure behavior

The alloy 3003 sheet, hot rolled, the longitudinal section shows stringer of oxide from an inclusion in the cast ingot and particles of phase that contains manganese (Figure 20).

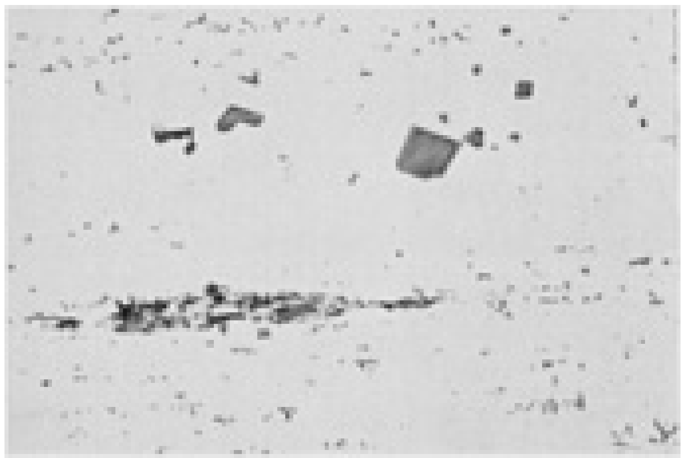


Figure 20 Microstructure aluminium 3003 as polish (24)

At Figure 21 shows the SZ and the TMAZ as polished attack at 50x at left side of the Figure is the TMAZ in the middle of the figure is the border between the TMAZ and the SZ.

Figure 21 Microstructure aluminium 3003 SZ and TMAZ as polish 50x

At Figure 22 shows the SZ before the chemical attack at 100x can be see the some angle in the flow lines.

Figure 22 Microstructural aluminium 3003 SZ as polish 100x

At Figure 23 shows the HAZ before the chemical attack at 100x in this can be see that there is no significant change in the size or the flow of the rolled.

Figure 23 Microstructural aluminium 3003 HAZ as polish 100x

At Figure 24 shows the SZ and the FAZ before the chemical attack at 100x at the top left corner can be see the inclusion of manganese and small porosities that are in the FAZ.

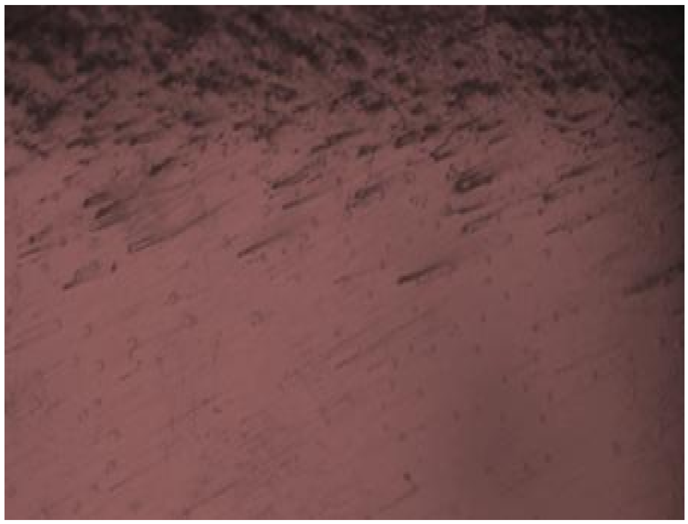


Figure 24 Microstructural aluminium 3003 FAZ and SZ as polish 100x

At Figure 25 shows the SZ and the TMAZ with Keller´s reagent at 200x the right side of the figure is the SZ and the border between the two zones is in the middle forming a space with small concentrations of inclusions. It is shown dispersion of insoluble particles of Fe and Mn.

Figure 25 Microstructural aluminium 3003 SZ and TMAZ Keller´s reagent 200x

At Figure 26 shows the TMAZ with the chemical attack at 200x the inclusion of manganese are shown as well the directions of the grains.

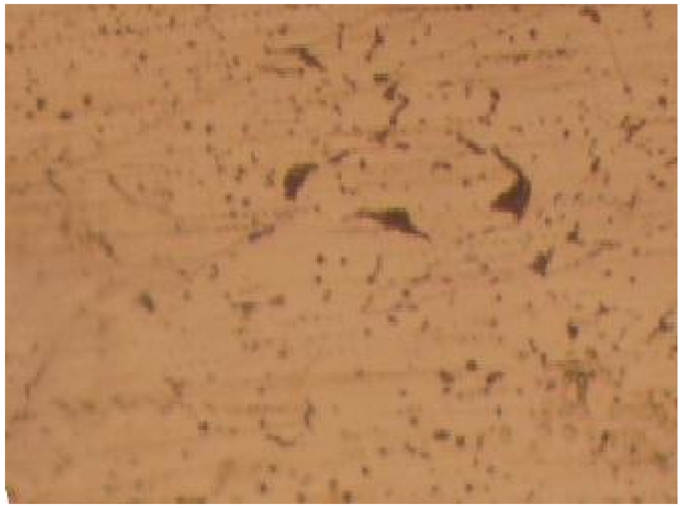


Figure 26 Microstructural aluminium 3003 TMAZ Keller´s reagent 200x

At Figure 27 shows the SZ with the chemical attack at 200x in the SZ have an angular grain structure the inclusions of manganese are small than the TMAZ inclusion´s.

Figure 27 Microstructural aluminium 3003 SZ Keller´s reagent 200x

At Figure 28 shows the FAZ and the SZ with the chemical attack at 200x the concentration of the inclusions are in the top of the weld.

Figure 28 Microstructural aluminium 3003 FAZ and SZ Keller´s reagent 200x

3.2 Ultrasonic

3.2.1 CALIBRATION FOR PULSE ECHO OF STRAIGHT BEAM.

In this case, it had the need to develop a reference plate to calibrate the ultrasound equipment. To establish a standard plate using the same material this carried out the test measurements.

Covered the following criteria:

They drafted a 3003 aluminum plate .250 inch thickness known dimensions, since the calibration blocks should have the same physical, chemical and material structure inspected. It was pierced in the plate getting three reference holes (Flat bottom holes) of 0.08 inch.

Reference standards can be a block or set of blocks with artificial discontinuities and / or thickness known.

The Figure 29 shows the dimensions of those holes. The depths of the holes are shown in Table 11. It inspects the back where the holes are not there.

Hole	Dimension (Inch)
1	0.210
2	0.120
3	0.060

Table 12 Hole dimension

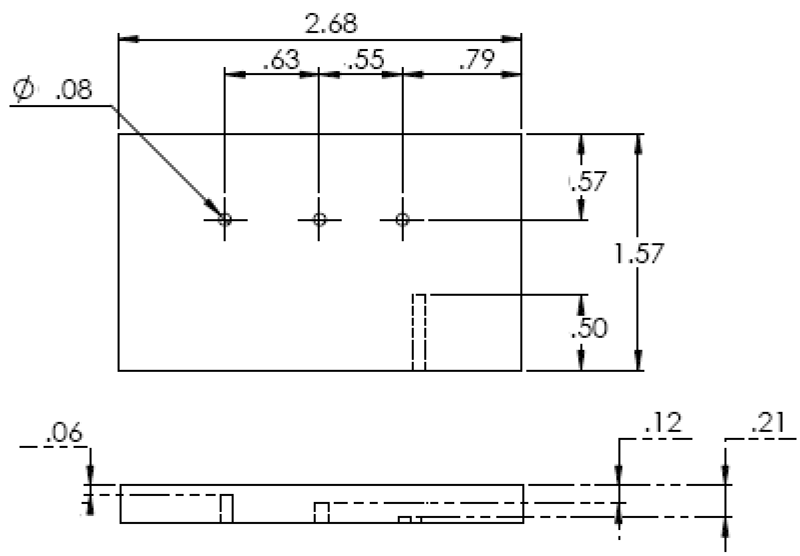


Figure 29 3D model of reference plate measurements in inches

In Figure 30 can be see the first hole.

Figure 30 First hole inspection

In Figure 31 can be see the second hole.

Figure 31 Second hole inspection

In Figure 32 can be see the third hole.

Figure 32 Third hole inspection

After the ultrasound beam strikes the discontinuity, the other pulses are replicas of the discontinuity which is the attenuation.

3.2.2 CALIBRATION FOR PULSE ECHO OF BEAM ANGLE.

We do not have a pattern that has two holes perpendicular to the cross section of the board; therefore we will use a pattern with a single hole with known location. Figure 33 shows the layout of the location and its 3D model.

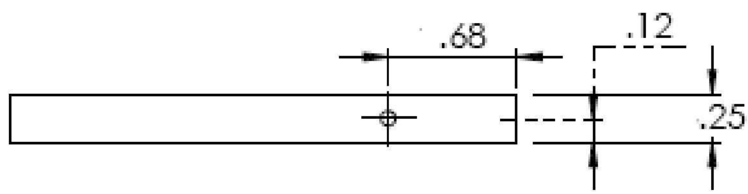


Figure 33 3D model and layout for pattern in shear beam

Calculate the distances SA and PA by trigonometry to shoe for the 45° and 60° for the first leg.

The depth to which is the hole is removed according to the machining process that was taken and results in a DA = 0.120 inches.

Since DA is calculated the following measures to two different types of shoes to each other at 45° and 60°.

45°

$$SA = DA / Sen\beta \qquad PA = \sqrt{SA^2 - DA^2}$$

$$SA = 0.12 / Sen(45) \qquad PA = \sqrt{(0.1697)^2 - (0.12)^2}$$

$$SA_{45^o} = 0.1697'' \qquad PA_{45^o} = 0.12''$$

We set the distance DA, SA and PA in the pattern and place the probe at a distance PA = 0.120 inches of discontinuity as shown below in Figure 34.

Figure 34 DA pattern

Each of the legs are defined in a different color, Leg 1 records discontinuity

The instrument detects the discontinuity in the first leg as shown in the figure 35:

Figure 35 Shear beam detection

To make the display the value of SA = 0169 inches is changed the value of the PROBE DELAY leaving this to a value of 4.5062 mS velocity 0.1538.

Thousandths are rearranged by the sensor also managing to add more gel in the second leg to see the cross section of material.

SA= 0.169 inches

DA=**PA**= 0.119 inches

3.2.3 Analysis of the welds

In a first step, visual inspections in all samples, resulting in some samples were discarded. From there took place the ultrasound for the remaining samples, as were samples with different discontinuities, so that only represent the most characteristic samples in this work.

The analysis report was made in base of the ATSM standard E164 &E587 a sketch of the sample to be tested are in Figure 36.

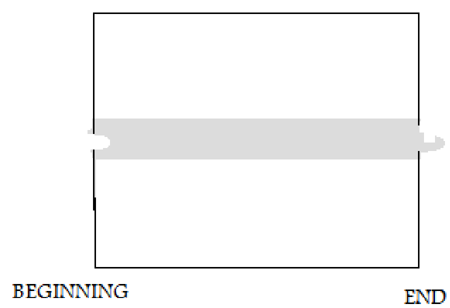


Figure 36 Sketch of the sample

The FSW is examined under the technique 1, measurements were made in inches and with an angle of 45 degrees in shear mode, the probe has a frequency of 2,25Mhz, the couplant used was SAE 20 oil by the type of roughness that presented in the finish of the sample (25).

The technique 1 is the button passing around the surface near the weld separation given to the readings with the second and third leg to rule out noise by the coupling between the plunger and the sample tested (Figure 37).

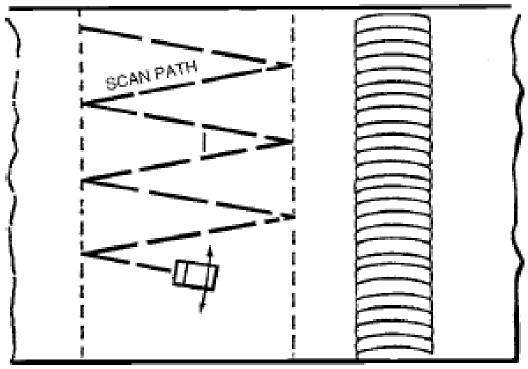


Figure 37 Technique 1, for Examining Butt Welds with Angle Beams (19)

The Figure 38 shows how the different readings are taken for analysis of the welding, the main variables PA, DA and SA. It will be using the second and third leg to eliminate any noise that causes a bad reading.

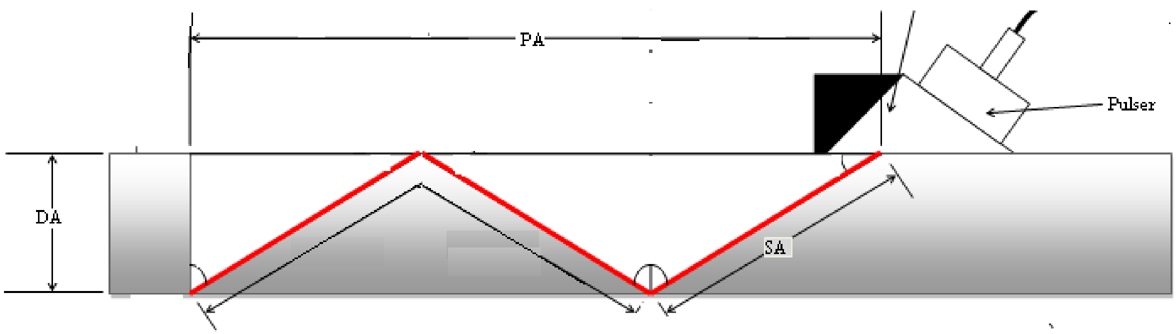


Figure 38 Diagram of legs in shear UT

Some of the failures that we encounter are corner, normal plane, laminar, incomplete penetration, incomplete fusion, slag, porosity and cracks. On Figure 39 are some sketches of these failures.

Generally, laminations should be detected and evaluated by the straight-beam technique. Angle-beam shear waves applied to weld testing will detect incomplete penetration.

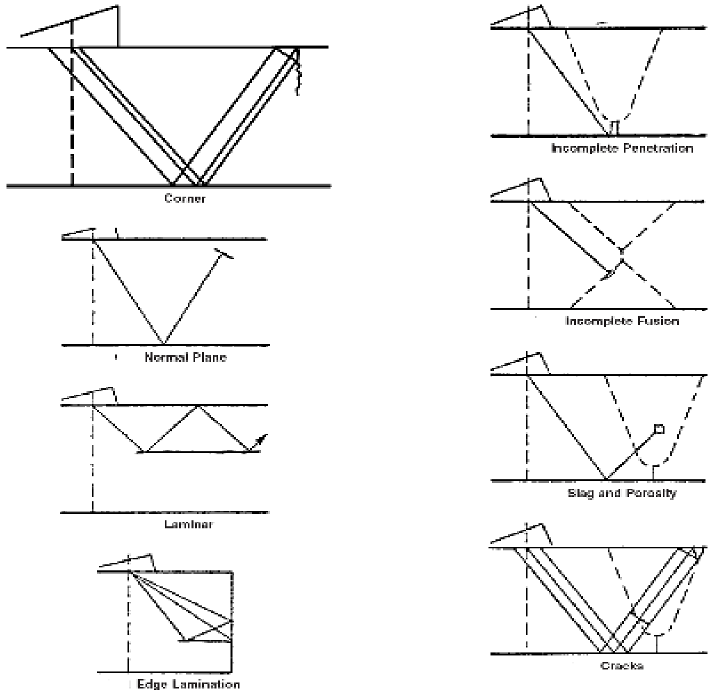
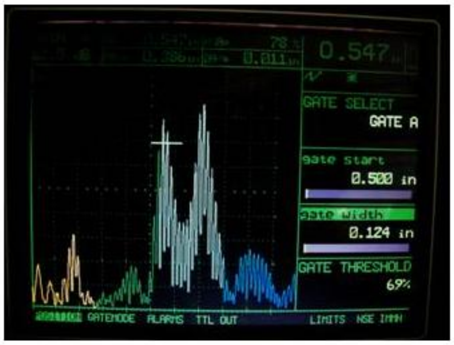


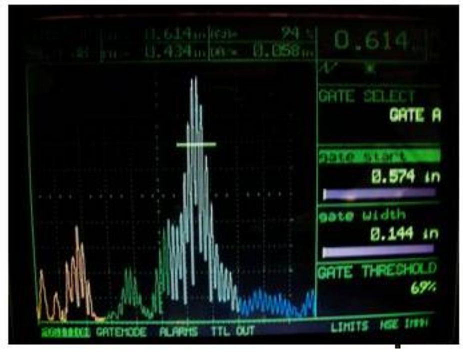
Figure 39 Types of failures (25)

Analysis sample 3 CNC

The Figure 40 shows three different images of the same discontinuity being seen on the ultrasound equipment, all measurements were done with the third leg to enable a comparison of how the discontinuity is. The peaks in the graphs represent the discontinuity and removed the parameters according to measurements made by ultrasound. It can be see that the plane of the reflector is perpendicular to a material surface and by direct reflection if the ultrasonic beam is normal to the plane of the reflector at the beginning of the third leg until the finish of it.



A



B

C

Figure 40 Sample 3 table 9 discontinuities at the third leg A) Beginning B) Middle C) End

According to the parameters of the UT can see how the material behaves, the DA parameter indicates that the height at which the discontinuity begins at the beginning and how we turn from it, as shown in the parameter PA, is continued until we to the point where we see that the discontinuity is presented dare the full width of the material (Table 12).

According to that seen in the gain parameter, it appears that the fault is continuous which requires a very small change to optimize the discontinuity according to the closeness you are.

IMAGES	DA	PA	SA	GAIN
A	0.011	0.386	0.547	52.5
B	0.058	0.434	0.614	53
C	0.119	0.495	0.700	55

Table 13 Parameters of UT sample 3 table 9

This analysis gives us the piece has a flaw that is in all material, which indicates a crack running through the material at which the weld has to be rejected.

Analysis sample 5 CNC

The Figure 41 shows three different images, the image A is taken at the beginning of the sample; this means that this side is where it started to weld (Figure 36), which marks a flaw in the third leg. Image B was taken from the final side of the weld and mark a discontinuity at the end of the second leg, and image C does not mark any apparent discontinuity.

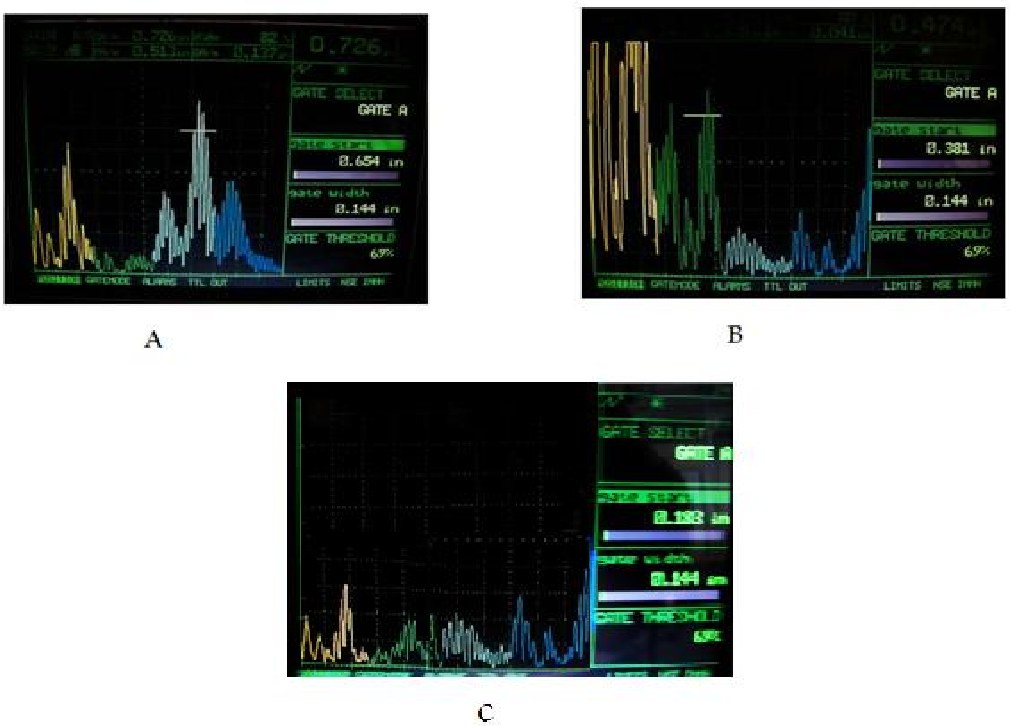


Figure 41 Sample 5 table 9 discontinuities A) At the beginning of FSW B) At the end of FSW C) at the middle

In the beginning of the weld has a discontinuity greater than the end of it, this is because we have barely begun to FSW heat and material flow is not optimal for welding, while in the middle of the weld have a section free of defects for the optimal control of welding variables and re-fine defects smaller than the first due to lack of material because it is reaches the edge of the sheet.

IMAGES	DA	PA	SA	GAIN
A	0.137	0.513	0.726	58.8
B	0.041	0.335	0.474	72
C	0	0	0	75

Table 14 Parameters of UT sample 5 table 9

In accordance with the parameters obtained in the ultrasound (Table 13) we see that the image DA A discontinuity appears in the middle of the depth and occurs with a low gain which shows that the discontinuity is large, the image B discontinuity occurs in the second leg at the end of the width of the sample, which required a greater gain to be detected and the image C shows that there is no change in measurements which can be determined at that area.

The analysis of this sample reveals that in the beginning of the weld have three zones, two which have faults and one not, so it follows that at the beginning and end of the FSW is that present the greatest number of defects in different circumstances. In the beginning of welding discontinuities are incomplete fusions while in the end welding discontinuities have porosity.

Analysis sample 6 CNC

Figure 42 shows a defect in the second leg that shows a flaw in the material.

Figure 42 Sample 6 table 9 discontinuities

As shown in Table 25, the UT parameters make known the location of the discontinuity surface being almost since the DA is very low, and as the gain is high, one can deduce that the discontinuity is small.

DA	PA	SA	GAIN
0.055	0.321	0.454	60

Table 15 Parameters of UT sample 6 table 9

With the analysis can be determinate that the flaw in the figure 51 is a slag inclusion by direct reflection because the beam angle is chosen to be normal to the plane of the weld preparation.

4. Conclusion

Friction stir welding technology has been a major boon to industry advanced since its inception. In spite of its short history, it has found widespread applications in diverse industries.

The fundamental understanding of both the welding process and the structure/properties of the aluminum 3003 into the welded joints has been useful in reducing defects and improving uniformity of weld properties.

FSW does not seem to have an advantage with respect to the strength of the fusion zone. The TMAZ is somewhat softer than the fusion zone because the latter dynamic recrystallization into a fine grain structure.

Different tools and were designed according to the given experiment, it was found that the tool 1 showed the best results, and this is made of H12 steel heat treated under a preheated, a quenching and double tempered at 600 Celsius.

It is able to obtain several alternative sets of welding parameters involving combinations of the welding speed, rotational speed and tool. For this work the best parameters were 25 mm/min, 960 rpm and tool 1.

Over the years, ultrasound examination has taken the lead X-ray examination in a variety of applications, thanks to a number of advantages that account.

Optimum ultrasonic reflections at defects in aluminum 3003 alloy FSW can be obtained by using angle ultrasonic method. The echo signals resulting from welds show a good detectability to small weld defect.

Considerations for UT:

- For each transducer will have to adjust the frequency at which it works
- For each material has a different speed of ultrasonic propagation
- The opening or closing speed makes the echoes shown
- We must learn to visualize and maximize up signals before the gain
- To get a good measurement is to meet 80 percent of the signal to eliminate noise signals

- It is important to see the wide gate to get a better measurement
- The outputs are concerned according to the sampling requirements
- In reading angle beam need to know how this leg to get a good read
- In beam angle for each pad (30 °, 45 °, 60 °, 70 °) must be calculated under the parameters trigonometry
- Excessive use can cause false readings
- The viscosity helps minimize noise coupling in reading

Future work

Weld different materials, such as aluminum with another material and see how it behaves in each case welded joint

A different design tools in order to determine the best tool according to the properties of the material to be welded, as well as getting a better weld.

A modeling of heat generated according to the tool used and the material to be welded, this implies that is a factor affecting the development of welding defects (Douglas C. Hofmann and Kenneth S. Vecchio).

A modeling of the residual stress prediction, the presence of residual stress in a weld plate affects its distortion behavior and ability to sustain applied loads while maintaining structural integrity (A. P. Reynolds, Wei Tang, T. Gnaupel-Herold).

A modeling material flow according to the tool, this would serve to determine the arrangement of material and to check with the microstructure that is what happens in reality (P. A. Colegrove and H. R. Shercliff).

Make a non-destructive inspection using X-rays to find the similarities between the discontinuities seen on ultrasound and radiography.

Evaluate the behavior of the welded material according to the direction of grain that shows the plates, these results in different properties in the material.

Annex A set up calibration procedure

FOR PULSE ECHO OF STRAIGHT BEAM

Open the main menu and defined the rage four times the width of the sample (Figure 43).

Figure 43 Main menu of kraufkramer

On main menu open the submenu basic then open submenu config then defined the material (Figure 44).

Figure 44 Config submenu of kraufkramer

Return to main menu open submenu basic and go to submenu results

On results put the parameters to see (Figure 45).

- READING 1: SA
- READING 2: OFF
- READING 3: A%A
- READING 4: OFF

Figure 45 Results submenu of kraufkramer

SA: distance traveled by the ultrasonic beam to collide with a interface as shown in Figure 46.

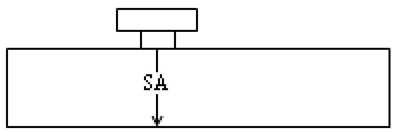


Figure 46 Demonstration of SA

On submenu plsrcvr go to receiver (Figure 47).

- Frequency of the probe used.
- Type-wave rectified.
- Probe Type:
  - DUAL ON .- transducer probe with separate transmitter and receiver transducer.
  - DUAL THROUGH.- two transducer probes a transmitter and another receiver transducer.
  - DUAL OFF - probe with a transducer that is sender and receiver.

Figure 47 Receiver submenu of kraufkramer

The ultrasound beams straight out of the tube and enters the material (upper interface) and reaches the bottom interface which generates an echo that returns to the soda which is found and registered on the screen. This is called a cycle.

The straight beam of ultrasound performed several of these cycles fading in each of them.

As the range of the screen is 1 inch, then we see four pulses, each of them is the return of the ultrasound beam and the probe .250 inch should be spaced the thickness of the plate being inspected (Figure 48).

Figure 48 First calibration into the kraufkramer

The steps to calibrate the equipment for plate thickness measurement are:

In the main menu and go to PROBE DELAY signal delay (increasing the number of mS) to the point where the signal peak of the echo from the bottom interface is located approximately 0243 'of the grid of the screen (Figure 49).

When you run this operation four echo pulses, the same distance apart from each other (≈ 0243), they will see on the screen. The echoes are attenuated in each cycle.

Figure 49 Calibration of time delay

If necessary, increase the dB until the first pulse reaches a height of 80% of the reticule on the screen.

In the main menu AutoCAL open the menu and go to SET UP (Figure 50).

Figure 50 Autocal submenu of kraufkramer for first reference

Back to the main menu and increase the pulse dB to 3 reaches a height of 80% of the reticule on the screen (Figure 51).

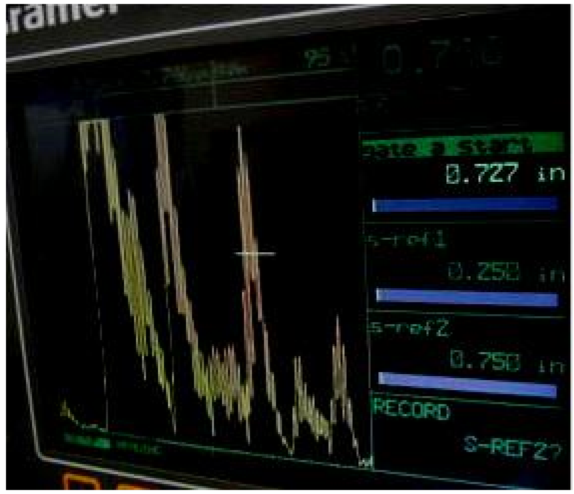


Figure 51 Autocal submenu of kraufkramer for second reference

FOR PULSE ECHO OF BEAM ANGLE.

Return to Main Menu to open the menu and go to SETUP TRIG (Figure 52).

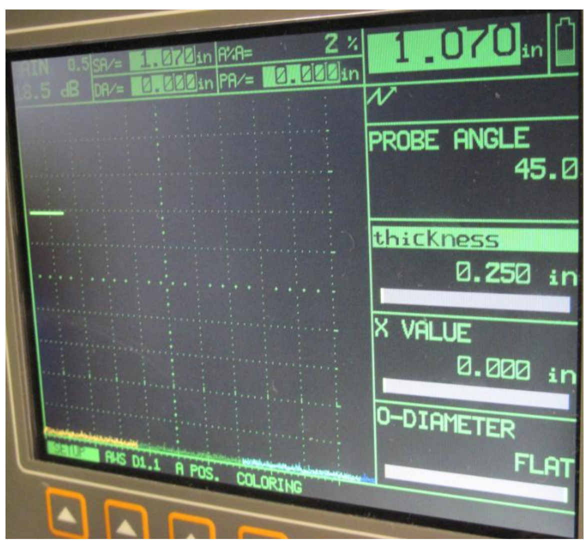


Figure 52 Submenu Set up trig of kraufkramer

- PROBE ANGLE: 45° This is because we are going to calibrate using a 45° shoe.
- O-DIAMETER: FLAT This is because the area of the probe will make contact with the specimen does not have radio.
- In these case with a 45°(Figure 53):

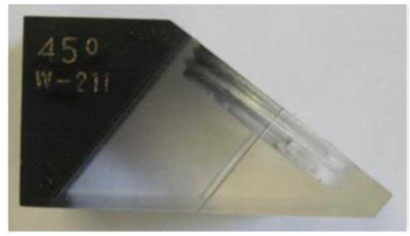


Figure 53 Beam Shoe

$$\text{LEG LENGTH} = \text{SA} = \frac{t}{Cos\beta} = \frac{0.25}{Cos45^o} = 0.3535534$$

$$\text{RANGE} = 3(0.3535534) = 1.061\,\text{inch.}$$

Figure 54 describes the parameters SA, DA and PA.

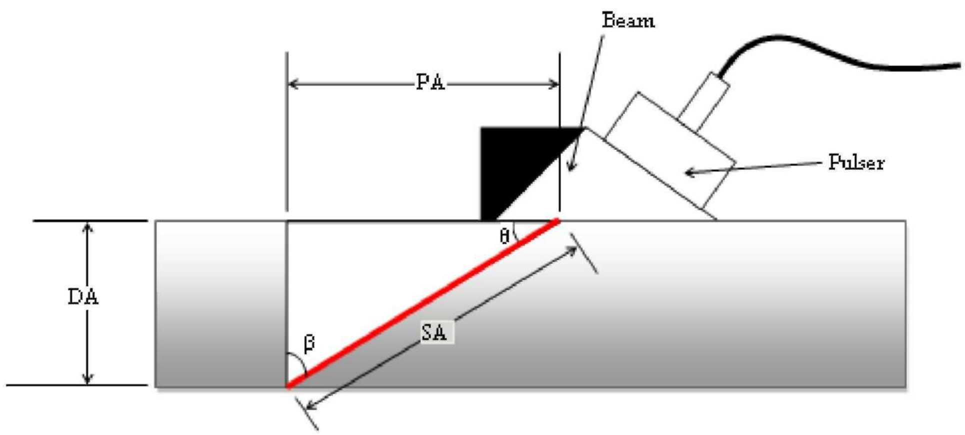


Figure 54 Shear beam parameters

In the main menu to open the basic menu within this menu, go to config and define the material that will work in our case is aluminum but when using angle beam ALUMINUM S (Figure 55) choose which is half the speed aluminum

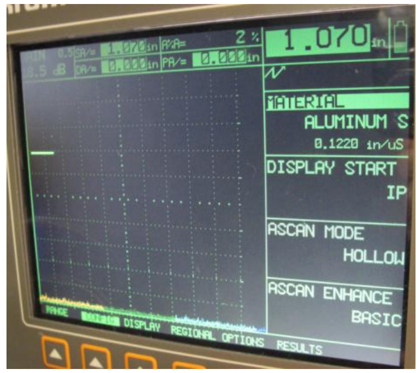


Figure 55 Shear velocity

The parameter that the instrument displays on the screen is SA.

The DA and PA parameters are calculated by the instrument to display the checkboxes selected (Figure 56).

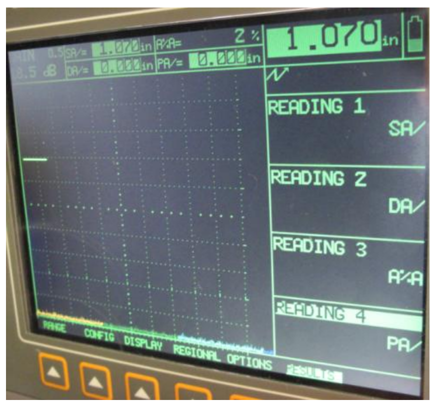


Figure 56 Parameters of shear beam

Annex B Standards ATSM

E 164 – 08 Standard Practice for Contact Ultrasonic Testing of Weldments

E 317 – 06a Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E 587 – 00 (Reapproved 2005) Standard Practice for Ultrasonic Angle-Beam Examination by the Contact Method

E1316 – 10ª Standard Terminology for Nondestructive Examinations

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