Microstructural and Mechanical Properties of Welded Joints in Tig, Mig and Friction Stir Welding –Review

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Abstract
In the manufacturing industry today, welding is a very important process needed for fabrications and revamping metal products. Researchers continually look for the best types of welding to be used for various joints. A lot of experiments had been carried out varying welding parameters and studying its effects. This paper basically reviews the residual stress effects on the welded joints of Steel, Magnesium and Aluminium alloy with their experimental analysis. The performances comparison of TIG, MIG and Friction Stir welding were also considered through check of their microstructure, mechanical property, young modulus, stress and yield stress of their welded joints. This has been able to show different behaviours resulted from various welding mode of a welded joint.

Keywords: TIG; MIG; Stir Welding; Microstructure; Characterization

1.0 Introduction
Weld joints are points where two or more metal pieces can be joined together, characterized by the geometry of the metal under consideration. Friction stir welding is a solid state joining process developed as a welding technique for use in high-strength compounds that have been challenging to connect with conventional techniques. There are five types of joints: butt, corner, edge, tee and lap. Butt joints are the most common and simplistic as materials are placed in the same plane prior to welding, which is prevalent in automated welding processes such as Submerged Arc Welding[1]. Butt weld joint is best formed using either TIG or MIG welding processes due to their ability to naturally join metal parts.

The weld's properties, such as its corrosion and strength resistance, are determined by the various types of welded electrodes used for creating the weld. The most powerful butt weld is the one with the least imperfections[2]. Lap joints are used for welding together materials of varying thickness, one of the pieces being joined overlapping the other, it is a fillet weld joint and can be used with various welding techniques. Edge welding joints is a type of welding groove commonly used in welding sheet metal parts with flanging edges while corner welding joints being the most popular welding joints in the industry, it is a type of joint in which the two parts that make up the joint come together at right angles to form a L shape[3]. Friction stir welding is a solid-state joining process that uses a non-consumable tool to join work pieces that face each other without melting the work piece material and are performed at multiple speeds. The aim of this paper basically is to review the residual stress effects on the welded joints of Steel, Magnesium and Aluminium alloy with their experimental analysis. Also the performances comparison of TIG, MIG and Friction Stir welding to be considered.
**2.0 Literature Review**

**2.1 Magnesium and aluminum TIG welded joint**
Magnesium and aluminum with dimensions 100 mm by 40 mm by 3 mm for the sample tray were the materials used in this experiment. The solderability research on Aluminum 6063 is carried out in Gas Tungsten Arc and Electron Beam on several moulds[4]. A WSJ-500 type machine was used for TIG welding. This solder was used for welding workpiece attached to the solder panel. The solder had a current of 120A, a voltage of 25U/V, a v-mm⁻¹ and a wind of 12Ar/L min⁻¹. A critical and immense observation was made of ten percent of HNO₃ solution for alcohol sampling and metallography, and electron microscope imaging and morphology and microstructure close to the fusion area. In order to assess the allocation of micro-hardness close the ignition area, the micro-hardness experiment was also used. In order to assess this, the Shimadzu micro sclerometer form used a charging of 15 g and 10s. During this experiment it was observed that the arrangement near the weld metals is a vertically arranged crystal which grows into the solder metal with almost half the length of the columnary crystals in the width of the fusion zone. The heat-affected area microstructure and sold metal for the welded joint Mg / Al TIG was used in scanning electron microscope[5]. The results indicate that dendrite crystals are comprised of microstructures and it is likely that the Al-Si eutectical scheme is made up of the Al, Fe, and Si sold wire. In a large range from the fusion line, the impact of the heat welding process on the magnesium substratum was smaller. The outcome of the experiment indicates that the sealing material and the substrate are flagrantly fused, as the substrate is mainly affected by the heat process of soldering and the minute dendrite droplets. HM 275-300 were the Mg lateral fusion area, while HM 160-200 was the aluminum lateral fusion area. However, the hardness of the metal is HM 60-100. A wave model indicates the fracturing surface and comprises of a glossy, never-ending plane. The TIG welding fracture in which a hydrogen gas falls on the side of the Mg is typically morphological[6].

**2.2 Magnesium alloy Analysis of Magnesium alloy Stir welded joint**
After friction stir welding, the magnesium alloy characteristics AZ31B were examined and assessed. Also the size of the grain was closely observed and after the stir soldering of the friction, a decreases in micro hardness in the welded area of approximately 70HV in the metal base and 50HV in the stir zone center were discovered. With a lower heat source, the welding velocity increased and the power output and the ultimate strength of the tensile were increased. However, a lower turning speed of 500 rpm led in a higher output than an increase of 1000 rpm[7] of spinning speed. AZ31B Friction Stir Welding magnesium alloy microstructural and mechanical characteristics. The Friction Stir welding method is a stationary bonding method using a non-consuming device for raising workpieces facing together without removing the substance from the workpiece. Friction stir welds at different rates including 1800rpm, 1400rpm, 11200 rpm, 900rpm, and with different instruments at steady welding rates of 40mm /min, 2.5-degree tilt angles and 5KN axial strength. After observing the effect of rotating speed on the microstructure and the instrument-material of the joint produced using 11200 rpm SS toolmaterial compared with 1800rpm, 1400rpm and 900rpm with high speed steel[8], higher mechanical properties and less residual stress were obtained along with the reduced occurrence of defects.
The sample testing was segmented to the suitable size and subsequently refined using different types of emery documents. The raw materials for the experiment were 70ml of ethanol, a uniform 4.2 g picric acid reagent, 10ml acetic acid and 10ml diluted water to detect the microstructural elements in the sold joints. The analyzes of the micro-structural assessment were carried out using a light optical microscope with a weight-percentage estimate in order to produce an image analysis for a large magnification. The 15-Sec timing was used with a 100 G load Vickers hardness tester for measuring microhardness characteristics[9]. The joint elongation, traction resistance and capacity of the aircraft tensile specimen were assessed in accordance with theE8/ESM-11 standard (ASTM). The experiment for the traction tests was critically analysed by a 100KN electrochemically regulated universal testing machine. The tensile experiments led to the derivation of magnesium alloy and the FSWed joint at room temperature and machining of three specimen joint units one by one for one medium. The effect toughness of the welding metal and stir area is performed at room temperature using the 300 J pendulum style impact test device and is assessed in accordance with ASTM norm, by the preparation of the carpy effect samples (E23-06) [10].

2.3 Experimental analyses of 6061-T6 aluminum alloy with 6082-T6

Moreira[11] investigated the mechanical and metallurgical characterization of AA6061-T6 AA6082-T6 friction stir welding joints. An experiment was conducted to analyze aluminum alloy 6061-T6 with 6082-T6, which included tests such as microstructure testing, tensile testing, bending testing and micro-hardness testing. Tensile strength characteristics were produced showing a weld metal bending test where the approximate finite element model of the joint was taken into consideration. Tensile tests reveal intermediate properties of dissimilar joints and the experiment also shows when dissimilar friction welded joints display intermediate mechanical properties in comparison with base metal[12].

Tensile tests were performed on ASTME8-M[ 13] to determine the young modulus, stress and yield stress of the base materials and materials that were welded, 3 mm thick samples were laid out diagonally to weld line. A 25 mm gage length and 1mm / min cross-head speed with a 60 mm reduced section length and 12.5 mm width, with a 200 mm general sample length and a 20 mm grip width section. These specimens were obtained using CNC machining[14]. Hardness profiles can help weld microstructure and mechanical properties. Micro hardness tests conducted on a cross section at 90 degrees to the weld line at mid-thickness crossways to the weld zone in the district of the weld area to illustrate the hardness profile. Results using a universal traction testing machine; HSLA steel grade has been tested at a force of 3.5KN, a current of 9kA has been used and a number of 20 cycles with a diameter of 6mm[15]. A 590R steel grade was tested at a 5.5KN force using a 9kA current and a 5.9 mm diameter 20cycles[16]. A force of 3.5KN, a current of 8Ka, with a cycle number of 20 and a diameter of 5.4 mm were used to test the steel grade DP600. A DP780 steel grade was tested using a 9kA current with 15 cycles and a diameter of 6.4 mm. TRIP 780 steel grade was tested using a nugget of 5.6 mm diameter with a force of 4.5kN and a current of 8 and a cycle of 20. Alloying elements such as carbon, manganese, molybdenum, chromium and silicon have been added to the steel grade[17]. It was observed during mechanical testing that there was a overlap at static strain rates that caused a disruption in the loading cycle. The test speeds for static, impact and intermediate speeds are connected. The standardized results show TRIP780 closely behind then 590R as the highest load carrying capacity of the impact, intermediate and static test with
DP780. HSLA, however, performed better than DP600, DP780, 590R in which a failure load of 0.9 approached. These results were observed by (Ewing et al., 2010) because with base metal strength it showed increased failure loads for HSLA[18].

At the weld edge line location, it was observed that the tensile tests obtained a minimum value of hardness. On the alloy plate side of the AA6082-T6, lowest values of all joints were displayed by the dissimilar joint hardness profile, this refers to the rupture location when tensile testing similar joints. However, in the nugget zone, all three joints showed familiar values[19].

3.0 Effects of welded microstructure on welded joints
The effects of the welded micro structure on the static performance and impact of spot welded joints in state-of - the-art steel[20] were examined in detail by dividing paths into points of welded joints. The impact results of resistance spot welded joints are analyzed using an impact assessment and quasi-static test. Quasi static testing is a type of test performed with a universal traction test, with the use of a instrumented drop-down tower[21] for impact testing. Welded structures must be addressed, for example, the effect of a stress rate on joint strength and failure mode. This study investigates sections of theels moderately fractured to have a detailed fracture path during static loading. The relationship between mechanical characteristics and the fracture track was developed using microstructures seen in the fusion zone and the heat zone concerned, to achieve an appropriate impact performance[22].

3.1 Tensile analysis of alloy steel
Ewing et al. [23] investigated high-performance low-alloy steels and galvanized tensile strength welds. There have been single speed trials of 4.5x 10^-5 and 6.7 m / s. An overview of the outcomes with a higher sample velocity is shown, while the error rates of the key failure methods have stayed continuous for all solder cycles. Furthermore, the resistance of base metal was increased by an rise in error forces. It was observed that comprehensive galvanizing techniques for the spot-sweat HSLA sample did not affect the error costs statistically significantly. In a research for spot welds, Peterson and Orth[24] carried out a single grade tempP590 thickness experiment for the impact of temperature and velocity. Test temperatures ranked between —75 °C and —400°C and test velocity between 1,3x10^-4 and 12.7 m/s. The findings, however, showed no difference in transfer temperature at various load prices. During elevated trials, a drop in energy is noted as a result of the fabric ductility reduction in the weld microstructure. Impact tests have been conducted in order to imitate circumstances encountered in the implementation of automotive pitches[25] on an instrumented drooping weight effect tester. Compression, strength, biaxial voltage and uniaxial stress testing are part of the weight assessment capacities. Intensive research of the fracture border and failure routes details the impact of these test prices on the elongation, insufficient loads and energy absorption. There were three overlapping shear trials with the following sample speeds: static (8.3x10^-7 m / s), medium (1.7x 10^-3 m / s) and effect (5.36 m / s)[26].

There is a sharp decrease in displacement if it moves from medium to effect. This research illustrates how an rise in stress levels can result in an rise in fluid pressure which restricts the duration of the place weld material[27]. For this test, the materials used included a minimum density of 1.0 to 1.2 mm. The severe stability of the tensile was between 5.4 mm and 6.4 mm, which improved parameters to make the failure loads possible by generating a greater schedule
to compare immediately with each weld length material[28]. The results indicate that increased tensile shear sample rates contributed to an rise, but there was no relation between basic steel resistance and loads of weld failure. However, when tearing was noted at impact test rates, tearing was noted and energy absorption from place welds could be improved[29].

4.0 Assessment of Stir welded stainless steel ferritic joints

Assessment of microstructure, hardness, tensile strength and impact strength of friction stir welded stainless steel ferritic joints experimentation[29] shows that tensile testing indicates welded metals that are overmatched with base metal. The study involved several tests that included friction stir welded 409 M stainless steel joint, micro hardness, transverse tensile, impact and bend tests. Critically analyzed the microstructure and mechanical characterization. Due to the rapid cooling rate and high induction of weld strain, frictional stirring resulted in plastic deformation[30]. However, the joints exhibit appropriate toughness of impact. The stainless steel grade 409 M is often supplied in anesthetized and annealed condition whereby the last annealing process is carried out at a temperature range of 700 degrees Celsius and 750 Celsius following cold rolling or air cooling[30]. Modifications are made in the mechanical properties of the weld due to the more advanced weldability of 12% of chromium ferritic stainless steels than conventional stainless steel, which influences the grain growth of the steel due to the heat-affected zone[31]. Park et al.[32] examined the mechanical properties and microstructural evolution of the friction stir welded 430 stainless steel, whereby the joints were produced at a rotating speed of 550 rpm and a welding speed of 80mm / min, and it was observed that the steeper elongated base material was replaced by a duplex microstructure of ferrite and martensite, resulting in an enhanced mechanical projection. This study is used to estimate the 409 M grade stainless steel joint performance and behavior[33].

Thomas et al.[34] made use of bobbin tool design to connect 8 mm thick 12 chromium ferritic stainless plates and showed that sound welds were produced using 584rpm and 75mm / min rotating speeds. During tensile tests, joints were found to fail in the plate away from the weld. Using a vacuum spectrometer, as-received 4 mm thick base material was used in this experiment with the chemical composition acquired. The welding machine originated in India, named RV machine tools with 50 mm / min welding speed and 1000rpm rotational speed. The 33.5kN axial force used tungsten alloy as a 3.7 mm pin-length tool material. To further investigate the joints, these parameters were used[35]. In order to evaluate the transverse tensile properties of the joints alongside notch specimens, two separate tensile samples were arranged to evaluate the joints ' notch tensile strength and notch strength ratio[36]. For the stir zone, minute tensile samples that had covered gauge lengths characterized the tensile properties. These tests were tested using a 100kN force electrochemically controlled universal testing machine. The amount of energy absorbed in fracture can be defined as toughness of impact. The specifications of the ASTM E23-04 impact test research have been monitored to prepare the impact samples. The weld's hardness was experimented on using a Vickers micro hardness testing machine with a load of 0.5 N and a timing of 15 seconds. Microstructural structure observation was performed using an optical microscope with software to display images for analysis[38]. At increased magnification, the fractured surfaces of the impact test samples and the tensile samples were critically observed using a scanning electron microscope to closely observe the morphology of the fracture and the nature of the fracture[38]. The base metal displays a microstructure of randomly distributed abrasive ferrite grains about 30 micrometers
in diameter. The base metal's ultimate tensile strength is 536MPa and the welded friction joint is 574MPa with failure occurring in the base metal region[39].

4.1 Characterization of the stir zone's tensile properties
Characterization of the stir zone's tensile properties was covered by minute tensile samples. In this scenario, the yield strength of 0.2 percent offset is 702MPa and the final tensile strength is 906MPa. 409 M joint is lower than the percentage of weld nugget elongation compared to base metal. The stir zone micro-hardness test resulted in a range from 320HV to 382HV depending on the size and phases of the grain. The impact toughness of the FSW joint was calculated to be 34J[40]. In addition, the weld's HAZ region is 30J and the weld centerline is 28J. Experimentation in this study shows that most tensile specimens fail in a ductile manner as dimples are observed during tensile loading application. However, the rapid growth of grain during the cooling process at increased temperature with subsequent delicacy and substantial transformation of austenite and martensite resulting in substantial grain refinement and toughness enhancement[41].

Because of the material's stress / strain characteristics, work hardening influenced the specimen's microstructure configuration and this led to plastic deformation[42]. It is important to note that Wright and Wood and Floreen and Hayeden have demonstrated that duplex ferrite-martensitic microstructure-based Fe-Cr-Mn and Fe-Cr-Ni systems have superior impact resistance to either fully martensitic steels or complete ferritic steels of familiar composition.

Results show that the transverse tensile strength of the weld metal is 57% higher than that of the compound. Ultrasonic weld joints testing uses mechanical vibrations that are similar to sound waves but with a higher frequency to test butt welded joints[44]. Ultrasonic beam is directed to the exact location of the test object. A transducer is excited by a high frequency voltage that causes a crystal to vibrate mechanically. A couplant is a coupling fluid that transmits these vibrations to, often made of film oil. There is a reflection sent back to the point of origin where the waves strike a discontinuity in the test piece. The test piece is shown on a cathode oscilloscope with a trace[45]. The distance measurement is made possible so that discontinuities can be detected, located and evaluated due to the sound velocity being almost constant through a given material. In spot welds, this test is very common[47]. The most beneficial feature of this test is the ability to determine a welded discontinuity's exact position. This testing method can be used for ferrous metals as well as non-ferrous metals.

4.2 TIG, MIG and Friction Stir Welding performance comparison.
Taban and Kalue[47] conducted an investigation between the comparison of 5086-H32 aluminum alloy combined performance and the characteristics or properties of this aluminum alloy microstructure through TIG, MIG and friction stir welding process welding processes. In this experiment, it was discovered that the dual-pass friction of the 5086-H32 aluminum alloy, which was stir welded, had greater characteristics than that of the TIG and MIG welded joints after evaluation of tests carried out, such as the evaluation of welds performed by the performance of the examined microstructure with a light optical microscope and the transmission. In addition, EDX analyzes and bend tests were investigated. EDX analyzes were conducted at TMAZ, WM, BM at the friction stir welds. Micro hardness measurements were carried out using line analysis also known as line analysis, at a depth of 2 mm from the front.
and back of the individual cross section of the weld, below a test load of about 300 g. Using the bend test standard EN 895 and EN 910, transverse tensile testing and mechanical testing for the aluminum alloy were all performed. Scanning electron microscope using light microscope, however, was used to define the fracture mode of welded joints using light microscope[48]. TIG and MIG welded joints were found to be approved due to discontinuities and lack of crack in the detected surfaces where distortion rates revealed a measurement of 7.7 mm for metal inert gas welding plates and 6.65 mm for tungsten inert gas welding plates with a distortion rate above FSW joints at 1.1mm[49]. The experiment also revealed that FSW joints were more appropriate than fused joints. The FS welded specimens did not reveal any defects. In addition, electron microscope scanning showed permeability in tungsten inert gas (TIG) and metal inert gas (MIG) that caused the strength values to decline[50].

[51] investigated the characteristics of welded Al5083 and pure copper sheets lap joints on microstructure and mechanical properties. In addition to a scanning electron microscope, the use of an optical microscope was used to reveal the microstructure of the weld area. The effects of the joint properties were also discovered by using an energy dispersive X-Ray EDX together with map tests to reveal the intermetallic compound. Shear tensile tests were carried out at the right angle to the welding direction to reveal the mechanical properties[52]. The weld was cut wide by 18 mm and long by 130 mm. From the parameter of individual welds, three separate specimens were collected. For the distribution of micro-hardness tests using a vicker's hardness test probe, 100 g were applied for 10 seconds to the area where the cross section is located in the right-angle direction of the weld. Results show that both the temperature of the weld and the quantity of material flow and strains affected the values of separate weld areas regarding hardness. In addition, the copper joint was observed to have the maximum hardness due to the fine grain dimensions. Increasing process temperature resulted in decreasing tensile stress, resulting in increased amounts of copper-to-aluminum sheet diffusion particles, micro crack numbers, and intermetallic compounds[53].

5.0 Conclusion
Welding is applied in every industry whether big or little, and it’s a major method of manufacturing and revamping metal products because it is generally economical, efficient and reliable as a means of fitting together metals. The performances comparison of TIG, MIG and Friction Stir welding that showed the behaviour of tensile and impact of aluminum, magnesium and steel alloy weld joints created were found that gas flow rate, welding speed and welding current played an important role in producing precise and uniform welds. It was also asserted that the selection of parameters to use depends on material type, strength required and specifications of the welding machine to be used. This has been able to establish the role that various welding mode play in the life span of a welded joint and an increasing process temperature brought about a decreasing tensile stress whereby an increase in temperature resulted in increased amounts of the diffusion particles into the core region of welded joint.

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