A Review on Thin Plates Joining Method Using Arc Welding as The Heat Sources

S. D. Sabdin, N. I. S. Hussein, M. K. Sued

1Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA

*Email: saifulkdh@yahoo.com
Phone: +60192146061

*Corresponding author: saifulkdh@yahoo.com

Abstract: Innovations and developments in arc welding processes are mainly to increase productivity without losing the quality of the weldment. In order to protect the quality and the cost, using light material has become an interest among industries. One of the purposes of the developments in thin plate welding technology is to minimize the cost and the weight. Welding distortion resulted from residual stress and it can cause problems in terms of dimensional tolerance and manufacturing integrity in the assembled structure. This can also increase the cost and delay the production schedule due to the required secondary process after welding. In this paper, methods for thin plate welding process were reviewed. It was evident that experimental and numerical modeling has been employed on evaluation of welding parameters and its effect to the weld performance and characteristic. This paper also aims at outlining the recent findings from laser welding, MIG/MAG and TIG welding in regards to the thin plate welding. MIG/MAG welding is one of the most applied processes in industry of automobile, food, aerospace and naval, both in manual and robotized system. The most significant findings emerged from this study is that output responses are related to heat source, deformation of welded joint, thermal and physical properties. Some recommendations and future research methods are also proposed.

Keywords: Thin plate, Arc welding, Steel, Aluminum, Automotive

1. Introduction

In car industries, thin plate parts are generally utilized. Amid amassing process, welding innovation is normally utilized due to high profitability without losing the nature of the joined. This has been a focus of competitive market worldwide. However, for current technology, one of the challenges is joining thin plate materials especially in the automotive industries. Relatively, Welding distortion regularly happens in thin plate welded structures because of its low firmness. The distortion causes issues in the gathering procedure as well as in the nature of the last item. Dean Deng and Hidekazu Murakawa [1] reported on finite element method (FEM) is used to is utilized to recreate welding distortion in low carbon steel butt-welded joint with 1 mm thickness. They utilized the versatile FEM with those anticipated by the thermo-elastic–plastic to checked that the characteristic strain technique can successfully foresee the welding distortion in thin plate butt-welded joint. [Formatting Citation]. Nabil Arif et al. [1] talked about the joint-hole powerlessness of thin sheets with changing holes, the model can likewise be utilized to foresee required parameters progressively and refreshing them to the welding power supply to car bodies and to build their toughness while decreasing their weight. [2]. Long et al. [3] announced in expectation of welding bends, thermo-elastic–plastic FE techniques and the geometrical model were utilized in the research for the welding simulation of butt joint in thin plates.

They discovered that correlation of FE simulation from the current experimental forecasts demonstrates that the exact conditions significantly the welding distortion in thin plates. [3]. In term of modelling, welding heat source is expected as a point and a line in the beginning times of welding demonstrating. Amid this underlying stage warm exchange depended on conduction models and later convection models are created which observed to be more exact particularly in and around the weld pool [4]. There is a need to develop prediction on the unwanted welding distortion of thin material. The reasons are that residual stress and distortion can cause issues as far as dimensional resistance, fabricating honesty in the amassed structure, and increment the expense. Some factors that influence distortion can be categorized into process and design-related. In term of the processes involved, the variables are heat input, welding speed and sequence. Depending on application of welding thin materials, different distortion control methods are used to provide more solutions that are adequate. For instance, to approach stringent clamping, tacking and riveting. Understanding their capability and limitation of all these distortion control methods is critical in order to achieve a successful welding fabrication project.
2.0 Literature Review

2.1 Material and Application

In automotive industries, the plate thickness in welding is rarely exceeding 2.5mm. In some case of thin parts (up to 1.5mm) an overheat the joint and may cause undercuts of the edges of welded sheets [5]. Be that as it may, there are extremely restricted writing portraying the forecast and the estimation of welding distortion and disfigurement in the slight plate welded structures particularly under 3.0 mm of thickness of plate or wall. Lu et al. [6] the basic plate is a structural element dimensions might be classified thin and thick. Steele et al. [7] described plates thickness on the theory three-dimensional theory of elasticity.

2.1.1 Similar Material

Recently, for the past 10 years, researcher’s attention has focused on the provision of similar material in welding process and method. Mainly, aluminum is utilized as a material for lightweight structures, or, in other words utilized particularly in transport, sustenance and aviation businesses [8]. For the most part, the analyst’s worry is on the developing interest for new uniting advances with low distortion and high creation productivity. Shrivastava et al. [9] focused on two processes of aluminum 6061-T6 using 5 mm thick for FSW and 7.1 mm thick for GMAW. These two processes were chosen to maximize tensile force that sustained by the joints during tensile testing. Welding aluminum alloy high strength aluminum (Al-2024) thickness 3.2 mm with cold metal transfer (CMT) process have been examined for characteristics of the synergic by Pickin et al. [10]. Dean Deng et al. [11] experimented on thin mild steel (low carbon steel) 1 mm sheet joint to measure welding deformation in the thin plate butt-welded joint by GMAW.

2.1.2 Dissimilar Material

Murakami et al. [12] studied on cold rolled plain carbon steel sheet (SPCC) and industrial pure aluminum sheet (A1050P-H24) for a plate with the thickness of 2 mm and the outcome was the thickness of the intermetallic compound layer at the interface expanded with diminishing the welding speed, and expanded as the pointing position moved aluminum to steel side. Schultz et al. [13] studied two sample sheets in which each thickness of 1 mm with different base materials AA 5083 and AA 6082 and made a comparison to the gap bridging ability. Basaks et al. [8] investigate on joining of aluminum to steel by regular combination welding strategies is troublesome because of the vast contrasts in thermo-physical properties, for example, dissolving point, warm conductivity and warm extension which prompt high distortion and residual stress. Aluminum alloy (AA6061-T6) of 2 mm thickness and high strength grade galvanize healed IF (HIF-GA) steel sheet of 1mm thickness. Zhang et al. [8] reported on (AA2139–TiAl6V4) aluminum alloys and titanium alloys spot joints produced by ultrasonic welding. The investigation was related to the weld thermal cycle for aerospace industries. Examines on both joint comparative and disparate 5083-H111 and 6082-T651 aluminum amalgams (6mm) were especially utilized in ship building businesses particularly for their high erosion obstruction and moderate quality, and it was welded utilizing Pulsed Robotic Cold Metal Transfer (CMT) and Metal Inert Gas (MIG) innovation [15].

2.2 Welding Process

2.2.1 Laser welding

Laser welding has been used by the automotive industries for forty years. Several attempts have been made to industry in seeking weight reductions for large steel structures. This laser-based welding process as heat source is utilized to high strength steels and thin plate structures together. The specialists’ discoveries on weakness quality of welds in thin plate structures with plate thicknesses underneath 5 mm is seen to have substantial variety, which conveys difficulties to exhaustion quality evaluation [16]. The analyst’s [17] worry on for the impact of weld geometry that is dismissed in like manner exhaustion quality appraisal on thin plate 3 mm. Limalampi et al. [17] saw that hub misalignment in restricted laser half and half welds may cause a noteworthy indent worry in which it might expand the root side decreasing the exhaustion quality significantly in the basic and ostensible pressure framework. Kawahito et al. [18], focused on thin plate using laser welding for high shaft quality is especially worthwhile for aluminum composites. Laser welding on thin plate is a offers quick welding velocity, deep penetration, and less heat input [19]. Laser welding is progressively used in different modern fields and is rising as a basic creation strategy in the car business yet these techniques are typically confined to welding of specific materials with unique outline necessity, for example, microelectronic and aviation parts.

2.2.2 GMAW

Gas tungsten arc welding (GTAW) uses a non-consumable tungsten anode to create the welding process. Widely GTAW is used to weld thin areas of non ferous metals and tempered likely aluminum, magnesium, and copper amalgams [20][21].Tchoumi et al. [22] studied GTAW welding on thin plate and finding the local melting and solidification of the parts to be gathered amid welding is one of the troubles experienced amid the get together process, bringing about expansive disfigurements that frequently require fixing tasks. GTAW process is the most famous process to increase the production time for the assembly of metal parts. Mousavi et al. [23] used GTAW process to analyzed the effect of the grooved angle on residual stress distribution. GTAW process more often low profitability process, can expand its potential if the efficiency can be expanded [17]. GTAW welding is conceivable to create fantastic welding joints in an extensive variety of parent materials example carbon steels, treated steels, Ni, Ti, Cu or Mg compounds, in which the nonattendance of imperfections, distortion, vapor and low hydrogen levels are required. GTAW is typically performed in the manual variation where welding current are lower for more slender sheets ≤ 3mm needed manual. However, it is also one of the slower methods of arc welding.

2.2.3 GMAW

In recent years, as the industries have strive to become more efficient and succeed, there has been renewed interest to improve quality and to overcome the limitations of development of manufacturing process on thin plate. Present conventional Gas Metal Arc welding (GMAW) which led to the development of pulsed arc technologies. Shrivastava et al. [9] focused on GMAW processes to quantitatively and compare the energy consumption associated with the creation of full-penetration welds on aluminum and a life cycle assessment (LCA). This process to determine and compare the environmental impact of between process GMAW and Flux cored arc welding (FCAW). Tsai et al. [16] studied the distortion mechanisms and the effect of welding sequence on panel distortion thin plate. Pickin et al [10] Investigated on conventional GMAW on particular alloy system produces solidification cracking at dilution ratios of 40–50% using the Al-2319 filler 2.4 methods for thin plate. Long et al. [3]
GMAW welding gives high joint effectiveness in volume generation and light-weight plans by welding thin plates of high-quality steels with different thicknesses to make complex gatherings. Furthermore, the low energy on GMAW welding process is a standout amongst the most point of view strategies for joining thin panel components in car industry.

Nowadays, car body panel becoming increasingly thin as low as 0.2 mm for composite and sheet plate. New variant of technology for conventional GMAW. Present the concept based on using low arc energy welding techniques using gas shielding and mechanism. Which is known as cold metal transfer (CMT), Coldarc and surface tension transfer (STT) are next variants of GMAW welding to solve problem occurring when joining thin, high resistance steel sheets, coated and non-coated, stainless steel metal sheets and those made of aluminium alloy. Consequently, several GMAW welding systems technique with controlled heat input were introduced. STT produced by Linconl technology makes welds require low heat input is much easier without overheating or burning through, and most importantly it minimized the distortion [25]. The CMT innovation recognizes the short circuiting and decreases the welding current. More to empower the bead exchange, which is normally bolstered by the squeeze impact, the wire is withdrawn from the liquefy pool. Otherwise, the stagnating occurs with low power and reduces spatter formation, heat input and dilution is presented by Fronius [26]. Another method is the ColdArc innovation introduced by EWM. Rather than the CMT innovation no control of the wire sustaining framework is required. The ColdArc is furnished with an advanced flag preparing unit, which permits distinguishing the short. This offers the likelihood to join flimsy sheets or disparate materials (Steel/Aluminum, Titanium/Aluminum) without monstrous fragile intermetallic stages and to dodge or limit scatter arrangement [27]. Therefore, the researches should focus on learning and practical application for new technologies using ColdArc on thin plate.

2.3 Method of Study

2.3.1 Modeling
To apply Finite element (FE) techniques utilizing strong mechanics to displaying the welding procedure, the exact recreation of the welding heat source created by the welding light has an essential impact in delivering dependable warmth contributions to the FE show. This would permit a precise reproduction of temperature circulations and varieties, which thusly decide material properties, welding twists and leftover worries of the welded structure. Tchoumi et al. approached 3D finite elements as a model to develop and analyze the thermo mechanical behavior of 316L steel during the TIG welding process. The mobile welding source was represented with a Gaussian profile of thin plate [22]. Previous researches [28], [29] suggested that elastic FE method based on inherent strain theory is an effective approach to predicting welding distortion in production of thin plate structures. Liang et al. used finite element method to reenact welding disfigurement in an extensive or complex structure, the estimations of innate miss happenings in each run of the mill joint must be known before run actual process. Deng et al [30] on his study, combined thermos elastic plastic finite element method (FEM) and large deformation elastic FEM based on inherent strain theory and interface element method to predict method of welding distortion.

Seyyedian Choobi [31] approached welding induced angular distortions in steel plates and it was predicted using artificial neural networks using Matlab. Targ et al. [32] in order to overcome these problems, proposed to determine the optimal process parameters by using a modified Taguchi method while Juang et al [33] used a combination of a neural network with a fuzzy clustering technique. Cao et al. combined main effects of various process variables on the joint strengths pertaining by ANOVA analyses are shown in Figure 1. Verhaegen [34] created an exhaustive and basic survey of experimental recipes in expectation of significant distortion types including longitudinal shrinkage, transverse shrinkage and angular distortion. Confinements and states of utilizing these equations were additionally illustrated. Equation to anticipate mutations in various materials with contemplations of or of welding rate and plate thickness were given. Be that as it may, most of equation surveyed was constrained to applications utilizing generally thick plates. To make comparisons of experimental data with the simulation results obtained by this investigation, the formula produced by Okerblom [34] is selected to predict longitudinal shrinkage as shown in Eq. (1). However, the use of this formula is limited to processes with fast welding speed.

\[
\delta_L = \frac{0.335 \kappa \Delta T}{\rho \nu_p} = 17.40 \times 10^{-3} (2)
\]

Where \(\delta_L\) is the longitudinal shrinkage; \(Q\) is the energy input which is determined by welding current, voltage and efficiency. \(A\) is the cross-sectional area of the plate to be welded; \(v\) is the welding speed; for the material properties of the plate, \(a\) is the coefficient of thermal expansion, \(q\) is the density, \(\epsilon_p\) is the specific heat. For the transverse shrinkage prediction,

Capel’s formula [31] based on measurements of the transverse shrinkage of butt welds in 6.4mm thick plates for carbon steel is selected. Where \(\delta_T\) the transverse shrinkage and \(S\) is the thickness of the plate (2).

Figure 1 Contour Interacting effect galvanized mild steel by [35]. (a) wire-feed speed × welding speed, (b) wire-feed speed × deviation distance, and (c) welding speed × deviation distance on the strength of CMT.
2.3.2 Experimental Procedures

The experimental method is the most frequently used method by all researchers in conducting their studies. Included in the welding field in finding the certainty and accuracy of the test is carried out.

Masubuchi [36] talked about systematic and test results from transverse shrinkage in butt welds. Various researcher hypothetically or tentatively has attempted to foresee the warm and mechanical reactions of welding structure to discover approaches to anticipate welding remaining pressure and twisting in rehearsing modern preparations [37]. For the most part producing strategy improvement is to keep away from unfavorable welding distortions, and this can be practiced by an iterative trial methodology in present day fabricating. However, it was impractical due to its huge amount of cost. To determine the effect of thin plate, the researcher made a comparison between method numerical and experiment to identified welding distortion. Murakawa et al. [29] approach in experiment welding bead on plate welding as research objective on thin plate thickness 2.28 mm for evaluate magnitude of inherent deformation. This researcher using experiment to measure fatigue strength by laser-hybrid welded butt joints thick plate 3 mm actual weld geometry and the notch stress approach [38]. Desired low level with developed to increase welding productivity and maintaining base metal heat input by double electrode gas metal arc welding and focused approximately 10 mm for the length of the main arc welding established between the tip of the main welding wire and the work piece [39]. Nabeel Arif et al. conducted experiment using different types of wires to validate the predicted results and the range of the joint gap that can be bridged effectively [40]. Holub et al. studied on experiment multi-pass SAW welding into narrow gap 15 mm to verify of a suitable welding consumable using low alloy material [41]. Holub et al. approach MMAW with Ar and Ar+O2 mixtures. He found that an increase in the oxygen content in the shielding gas reduces the values of the current transition and reduces the size of the droplet at the globular/spray transition. It has also been reported that in argon/argon–oxygen gas mixtures, the stainless-steel wires behave is very similar to mild steel. Liinalampi et al. arranged experiment for the angle between the two welding guns less than 40 degree and approximately 5 mm and 25 mm for the distance from the tip of the bypass welding wire to the work piece.

Zhang et al. approached variable parameter on welding time, which ranged from 0 s to 4 s in his study for ultrasonic welding. Schultz et al. focused on experiment thin sheet aluminium by laser beam welding on the influence of the welding speed and wire feed speed parameters. Pickin et al. studied on contrast to the GMAW welding of thin steel sheet, cold metal transfer traditional short circuit/dip transfer to the bead on plate welds on material Al-2024 base material and parameter for wire feed settings from 4.5 mmmin<sup>-1</sup> to 7.5 mmmin<sup>-1</sup> with travel speed was set at 5mm s<sup>-1</sup>. Feng et al. arranged GMAW welding on AlSi5 alloy thin plate 1 mm pure aluminium with wire in 1.2mm flier wire diameter and using pure argon for their research. Koleva et al. focused on experiment to investigate the influence from the main surface of the magnetic lens to the focus point using electron beam welding (EBW) set as welding velocity and distance to develop models. S. Basak et al. studied friction stir welding (FSW) as a solid-state joining technique to thin plate aluminium alloys.

![Figure 2 Sample Setup by [35]. Schematic Experiment of thin plate sheet lap joint (a) plane, (b) side view of the welding torch with respect to the sample, and (c) specimen machined from the joint (mm).](http://www.fazpublishing.com/jiei)
1) Recently, the focus of the researchers and industry is to study the comparison of thick (≥ 3mm) material and thin (≤ 3mm) material because of its welding technologies process is quite established.

2) 2) MIG (Cold Metal Transfer) (CMT), Surface Tension Extraction (STT) and Cold Arc are the technologies introduced for low heat use on thin plates and penetration welding. This is used to achieve high productivity and minimize production costs. MIG or GMAW has proven to be a high-potential technology that has been upgraded to increase production at a cheaper price to ensure welding quality standards when compared to traditional and modern technology.

3) Two types of basic method was research approach numerical (FE) and (DOE) Design of experiment method to investigate the distortion and residual stress on welding process.

4) Commonly, researchers’ parameter and concern in their study on MIG process is heat input, voltage, current, welding sequence, gap of plate, wire feed, welding speed and gas.

Acknowledgement
The authors would like to thank the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Advanced Technology Training Center (ADTEC) Batu Pahat and Scientific and Industrial Research Institute of Malaysia (SIRIM), Shah Alam for their technical support throughout this research work. The first author gratefully acknowledges the scholarship support provided by the Public Service Department Malaysia, under the Hadiah Latihan Persekutuan (HLP) programmed.

References


