Design of Fixture for Welding

Chanada Naksri 1, Somchai Chuchom2, Supapan Chaiprapat3

1Benjamarachutit Pattani School, Pattani 9400
2Faculty of Engineering, PSU, HatYai, Songkhla 90110
3Faculty of Engineering, PSU, HatYai, Songkhla 90110

Abstract. Defects commonly found in welding include distortion, overlapping, warping, and misalignment. Welders probably observe more frequent problems as such if lacking proper fixturing devices. Existing fixture designs are tedious to use, and they could induce even more defects. In this study, four design alternatives of a welding fixture were initially conceptualized from a survey of 25 experienced welders before the best one was selected based on reliability, rigidity, and ease of use. The design was made of SS400 steel because of its exceptional mechanical and thermal properties. A structural analysis was performed using the finite element method to evaluate the strength and stability of the design while in use. Experimental results revealed that this fixturing device could withstand forces exerted vertically from screw clamping. It could also tolerate high temperature from a welding arc and restrain the workpiece as deformed by the heat. This novel design will minimize set-up time, chances of defect formation, and a need for post-welding quality improvement.

Keywords: weld-attaching device, fixture, Finite Element Analysis (FEA), Analytic Hierarchy Process (AHP)

1. Introduction

A jig is a device used to locate the workpiece, while a fixture is designed to support and restrict workpiece movements during operation [1] [2]. On many occasions, fixtures also perform both locating and restraining functionalities[3]. They must be designed in such a way that allows a convenient, reliable, accurate, and quick set-up procedure, more importantly leaving as little workpiece deformation as possible. Jig-fixture, if properly designed, can help save a tremendous cost [4] [5] [6] [7]. Principles of fixture design typically consider the size and shape of a workpiece, material, processes, and economic impacts. The design must also take into account ease of use. Although it provides secure restraining, fixture operational complexity increases setting and handling times that eventually results in less productivity [8] [9]. Simplicity is, therefore, among important considerations the designer must be aware of.

In welding practice, material shrinkage and deformation are common problems resulting from exposure to a welding arc's high temperature. Various devices in the market, such as modular mechanical screws and clamps, magnetic devices, or jigs are used to restrain a workpiece at its nominal position and orientation. One often finds it difficult to accurately keep the workpiece in position while welding using the magnetic-powered tools. The magnetic force obviously cannot withstand the internal forces induced by heat, leading to the workpiece displaced from its intended position and orientation. Using the modular mechanical screws and clamps to orient the workpiece at its right angle is laborious and time-consuming. A device to assist in holding the workpiece while being welded is needed to minimize the defects that can visibly be detected: 1) distortion, 2) overlapping, 3) warping, and 4) misalignment. Besides, the device shall allow a
welding operator to put the workpiece in place in less time conveniently. It can also function as a training device for novice welders, or technical students, who lack skills and experiences.

In arc welding operation practice, tools are essential to get the job done correctly [10] fast, safe[11]. Also, the operation duration is the result of the cost [12]. The most common problem encountered in arc welding work is workpiece warpage due to the heat of the welding operation, welding twists and stresses under different mechanical boundary conditions, and welding distortion and residual stress at normal position. The study results showed that the mechanical boundary conditions mainly affected the weld [13]. Beginners and experienced welders encounter problems with welding and twisting. This is caused by the expansion and contraction of the weld metal and the adjacent metal during the heat treatment of the welding process. According to past research studies, it is found that most of the welding heat will cause the workpiece to warp and deform. Some studies use jig-fixture to solve the problem [4] with a finite element program to study the workpiece quality after welding using welding jigs. The result can reduce the problem of warping or deformation of the workpiece.

2. Materials and Methods

2.1 Study theories and research related to design a device to hold the welding work
2.1.1 Metal welding and the principle of Shield Metal Arc Welding (SMAW)
2.1.2 The design of the jig and fixture consists of
   1) The positioning and support of the pieces
   2) Principle of jig fixture
   3) Principle of basic jig fixture
2.1.3 Types of steel
2.1.4 Applying the Analytic Hierarchy Process (AHP)
2.1.5 Analyze the thermal properties of the designed fixtures

2.2 Studying the preliminary welding problems
2.2.1 Survey of the problem arising while performing manual arc welding was conducted using questionnaires, created and verified by welding experts from the institute for skill development, comprising 35 people who issued a test certificate for skill standards (Certificate); 6 people, 19 welding teachers, five welders, one welder student, and four business owners.
2.2.2 Analyzing the results from surveying the problems from welding operators to bring the problems that arise with the workpiece in the welding to be used to design and construct welding equipment.

2.3 Design of welding fixture
Welding fixture design focuses on holding the workpiece to resist the heat shrinkage in the welding work. Quick and convenient to use, including cost-effective use of materials and equipment and designed to reduce the problems of welding that can be visually tested, including 1) distortion, 2) overlapping, 3) warping, and 4) misalignment by designing 4-part sub-component workpieces with SOLIDWORKS program as follows:
   1) Five types of a clamping mechanism (a gripping mechanism)
   2) Three types of sub-base characteristics to hold the workpiece
   3) Two types of the angle rotation plate
   4) Three types of keypad or touchpad

2.4 Setting the importance of a subsection of equipment using AHP
The priority will be graded by three experts, with the qualifications of the specialist comprise
   1) The qualification must not be lower than the Diploma in industrial metal welding or industrial arts
   2) Work experience related to the job at least ten years
3) Welding inspector teachers in the public or private sector.
4) A person who has passed the labor skill standard test manual metal and welder branch level 1

2.5 Assembled grips from selected sub-parts to assess the satisfaction of the experts in 5 areas:
1) Equipment performance
2) Clamping time
3) Equipment cost
4) Equipment size and weight
5) Equipment construction time each issue has a full score of 100

2.6 Determining materials for welding aids
Material designation for welding aids will consider the production cost and the purchasing ability of users as the main. In addition, it must also consider the strength and durability to use. The most popular material is SS400 grade steel.

2.7 Analyze the thermal properties of the welding fixtures according to the design obtained
Using the clamping device simulation while clamping the workpiece at the steel pipe and square tube according to the size as shown in Table 1, which is the size available in the market. Moreover, it is a galvanized steel material clamped at an angle of 45, 90, and 180 degrees. In the analysis, the welding temperature is 10,000 °F, or 5537.78 °C. Type of edge weld connectors are determined as groove weld, single-sided, and weld specifications are specified according to American standards. E60 welding electrodes were used to determine the temperature, temperature gradient, and the heat flux on workpieces and fixture.

Table 1. Size of steel pipe and square tube used for testing

| STEEL PIPES (INCH) | SQUARE TUBE (INCH) |
|-------------------|-------------------|
| 1/2               | 3/4               |
| 3/4               | 1                 |
| 1                 | 1-1/4             |
| 1-1/4             | 1-1/2             |
| 1-1/2             | 2                 |
| 2                 | 2-3/8             |
| 2-1/2             | 2-1/2             |
| 3                 | 3                 |

3. Results and Discussion

3.1 Results of the preliminary study of welding problems
From the study of connection problems, it was found that the most common problems that can be visually tested are 1) distortion, 2) overlapping, 3) warping, and 4) misalignment. If there is a device that helps gripping while working, it can reduce the problem.
Table 2. Questionnaire results.

| Welding Problem | Steel square |               | Steel Pipe |               |
|-----------------|--------------|---------------|------------|---------------|
|                 | Problem      | No problem    | Problem    | No problem    |
|                 | encounter    | little        | moderate   | little        |
|                 | level        | very          |            | very          |
|                 | Total (person) |             | Total (person) |             |
| BUTT JOINT      | A            | B             |            |               |
| 1. Joint Not    |              |               |            |               |
| equal           |              |               |            |               |
| Figure 1.       | 4            | 3             | 8          | 20           |
| Number of people experiencing the problem (%) | 11 | 9 | 23 | 57 | 89 | 9 | 14 | 29 | 49 |
| 2. The workpiece is curved. |            |               |            |               |
| Figure 2.       | 3            | 7             | 6          | 19           |
| Number of people experiencing the problem (%) | 9 | 20 | 17 | 54 | 91 | 11 | 11 | 26 | 37 |
| 3. The workpiece may move out of the desired position when starting the arc welding. |            |               |            |               |
| Figure 3.       | 9            | 2             | 12         | 12           |
| Number of people experiencing the problem (%) | 26 | 6 | 34 | 34 | 74 | 6 | 23 | 23 | 49 |
| 4. The weld line has cracks. |            |               |            |               |
| Figure 4.       | 21           | 4             | 4          | 6            |
| Number of people experiencing the problem (%) | 60 | 11 | 11 | 17 | 54 | 11 | 17 | 17 | 17 |
The welding work is assembled at a 90 degree angle by 45 degree notched workpieces.

| Welding Problem | Steel square | Steel Pipe |
|-----------------|-------------|------------|
|                 | Problem encounter level | Problem encounter level |
|                 | No problem | little | moderate | very | Total (person) | little | moderate | very | Total (person) |

The workpiece is tilted or twisted.

1. **Type 1**

   - Number of people experiencing the problem (%): 20 6 31 43 80 3 9 29 60

   - Figure 6.

   - Figure 7.

2. **Type 2**

   - Figure 8.
| Problem | Steel square | Steel Pipe | Total (person) |
|---------|--------------|------------|----------------|
| Welding Problem | | | |
| Number of people experiencing the problem (%) | 9 | 17 | 26 | 49 | 91 | 3 | 9 | 40 | 49 |
| Problem encounter level | No problem | little | moderate | very | Total (person) | No problem | little | moderate | very |
| | | | | | | | | | |
| 2. The weld line has cracks. | 22 | 4 | 5 | 4 | 35 | 22 | 4 | 6 | 3 | 35 |
| | | | | | | | | | |
| Number of people experiencing the problem (%) | 63 | 11 | 14 | 11 | 63 | 11 | 17 | 9 | |
| 3. Joint Not equal | 7 | 6 | 14 | 8 | 35 | 4 | 7 | 17 | 7 | 35 |
| | | | | | | | | | |
| Number of people experiencing the problem (%) | 20 | 17 | 40 | 23 | 80 | 11 | 20 | 49 | 20 |
4. The workpiece may move out of the desired position when starting the arc welding.

**Figure 11.**

| Welding Problem | Steel square | Steel Pipe |
|-----------------|--------------|------------|
| No problem      |              |            |
| little           | 7            | 6          |
| moderate         | 13           | 11         |
| very             | 9            | 35         |
| Total (person)   | 35           | 35         |

Number of people experiencing the problem (%)

| Number of people experiencing the problem (%) |
|-----------------------------------------------|
| 20 17 37 26 80 6 20 31 43 |

T-JOINT

**Figure 12.**

| Welding Problem | Steel square | Steel Pipe |
|-----------------|--------------|------------|
| No problem      |              |            |
| little           | 4            | 1          |
| moderate         | 8            | 5          |
| very             | 12           | 13         |
| Total (person)   | 35           | 35         |

Number of people experiencing the problem (%)

| Number of people experiencing the problem (%) |
|-----------------------------------------------|
| 11 23 34 31 89 3 14 37 46 |

1. The workpiece is tilted or twisted.

**Figure 13.**
2. The weld line has cracks.

![Figure 14.](image)

| Welding Problem | Steel square | Steel Pipe |
|-----------------|--------------|------------|
| Problem encounter level | | |
| No problem | little | moderate | very | Total (person) | No problem | little | moderate | very | Total (person) |
| 19 | 6 | 7 | 3 | 35 | 18 | 7 | 6 | 4 | 35 |

Number of people experiencing the problem (%)

| | No problem | little | moderate | very | Total (person) |
|---|---|---|---|---|---|
| Steel square | 54 | 17 | 20 | 9 |
| Steel Pipe | 51 | 20 | 17 | 11 |

3. Joint Not equal

![Figure 15.](image)

| | No problem | little | moderate | very | Total (person) |
|---|---|---|---|---|---|
| Steel square | 5 | 5 | 17 | 8 | 35 |
| Steel Pipe | 1 | 8 | 14 | 12 | 35 |

Number of people experiencing the problem (%)

| | No problem | little | moderate | very | Total (person) |
|---|---|---|---|---|---|
| Steel square | 14 | 14 | 49 | 23 | 84 |
| Steel Pipe | 3 | 23 | 40 | 34 | 80 |

4. The workpiece may move out of the desired position when starting the arc welding

![Figure 15.](image)
From the table, it can be seen that the Practitioner will encounter most of the problems that may arise from the visual inspection. 1) The workpiece is tilted or twisted accounted for 86 percent 2) Joint Not equal accounted for 84 percent 3) The workpiece is curved accounted for 81 percent, and 4) The workpiece may move out of the desired position. When starting the arc welding with the workpiece accounted for 77 percent.

3.2 The results of the design of the welding fixture
As a result of the welding problem, the welding fixture sub-component was designed and shown in Table 3.

| Sub-component                                                                 | Type                           |
|-------------------------------------------------------------------------------|--------------------------------|
| 1) Characteristics of clamping mechanisms (a gripping mechanism) (A)          | (A) (1) spring                  |
|                                                                                | Figure 17.                      |
|                                                                                | (A) (3) toggle clamp            |
|                                                                                | Figure 18.                      |
|                                                                                | (A) (2) spiral                  |
|                                                                                | Figure 19.                      |
|                                                                                | (A) (4) magnet                  |
|                                                                                | Figure 20.                      |
| 2) Sub-base characteristics to hold the workpiece (B)                         | (B) (1) unperforated base       |
|                                                                                | Figure 21.                      |
|                                                                                | (B) (3) only edge               |
|                                                                                | Figure 22.                      |
|                                                                                | (B) (2) perforated base         |

Table 3. shows the sub-component of the device
3) Adjustable rotating plate (C)

- (C) (1) grooved
- (C) (2) not grooved

4) Keypad or touchpad (D)

- (D) (1) attached with fixture
- (D) (2) separate

Fixture component selection criteria used the AHP selection process, fixture design, and system design. The jig is a mnemonic device. For convenience, the focus is 1) efficiency, 2) speed of use of the equipment, and 3) equipment weight and cost. The results of the design of welding jigs selected components are 1) Characteristics of clamping mechanisms (a gripping mechanism) (A) (2) spiral because the gripping force can be controlled 2) Sub-base characteristics to hold the workpiece (B) (2) perforated base circular lightweight, non-slip surface 3) Adjustable rotating plate (C) (1) grooved The shape is more robust 4) Keypad or touchpad (D) (2) separate it can modify the equipment.

### 3.3 The results of prioritizing the sub-component by AHP

The prioritize the sub-component by AHP all four parts (A-D) found that the first sub-component, clamping mechanisms (A), the experts give top priority to the spiral (0.496) and toggle clamp (0.265), spring (0.130), and magnet (0.109) orderly. In the second sub-component, sub-base characteristics (B), the experts give top priority to the perforated base (0.601) next, unperforated base (0.245), and having an only edge (0.170). In the third sub-component, adjustable rotating plate (C), the experts give top priority to grooved one (0.750) and not grooved one (0.250). The fourth sub-component, the keypad or touchpad (D), the experts give top priority to separate one (0.833) and next attached with the fixture (0.167), which summarized the sub-components significance as shown in table 4.

**Table 4.** shows expert-graded sub-components

(A) Pattern 2
(B) Pattern 2
(C) Pattern 1
(D) Pattern 2

Figure 27.                      Figure 28.                     Figure 29.

(A) Pattern 2 Characteristics of clamping mechanisms (a gripping mechanism)
(B) Pattern 2 Sub-base characteristics to hold the workpiece
(C) Pattern 1 Adjustable rotating plate
(D) Pattern 2 Keypad or touchpad
3.4 Model of sub-component fixture that has selected

According to the satisfaction survey of 25 users, the model with the highest score was type 3, fixture vertically circular perforated base with 384 points, followed by type 4 fixture vertically perforated base with 379 points. Type 1 fixture horizontally circular perforated base 345 points, and Type 2 fixture horizontally and fixture with a square gripping 326 points, indicating that Pattern 3 as shown in Figure 30. Is the selected one according to analyze the thermal properties.

![Welding fixture](image)

Figure 30. Welding fixture

3.5 Results of thermal analysis of welding fixture according to model

From the thermal analysis of the welding fixture in both steel pipe and square tube at angles of 45, 90, and 180 degrees, it was found that the results were in the same direction, with the same welding temperature at the highest level (Max.) 5538 °C which was close to the set temperature of 5537.78 °C. The temperature gradient and the heat flux value increased with the size of the workpiece grew. Moreover, from the thermal analysis figure, it can be concluded that the welding heat does not affect the workpiece clamping device, as shown in Figure 31. Simulation of welding is electric welding. Simulate heating temperature at 10,000 °F or 5537.78 °C and clamping at 45, 90, and 180 angles using E60 welding electrodes. It may not be used for other welding types because the heat may change the jig may not be stable.
4. Conclusion
This research aims to design a welding fixture that can adjust angled using AHP to obtain the most suitable welding fixture assembly for the application. The thermal properties analyzed by Finite Element Analysis (FEA) were also used, it was found that the designed welding fixture was not affected by heat during welding. As a result, the fixtures can hold the workpiece efficiently as expected. Device results, especially Jig fixture designed to press the workpiece from the vertical with a twist the clamping force of 7-9 pounds can hold the workpiece to resist the shrinkage of welding and does not cause the workpiece to be deformed or damaged, which can be obtained from the design principles of the Jig fixture. For other research approaches or to further carry out this research, the end of gripping should be taken into account. Equipment weight, and by combining the device with a practical welding table, can perform more versatile and ergonomic work.

5. Acknowledgments
This thesis has been successful because people join hands so thank them all. Thank the advisor, Associate Professor Somchai Chuchom and Assistant Professor Dr. Supapan Chaiprapat, Professor from Department of Industrial Engineering Faculty of Engineering Prince of Songkla University. They both give useful advice to improve the research together with checking, correcting the mistake until this research becomes entirely correct.

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