Reliability Based Design Approach for Development of Friction Stir Welding Fixture

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Abstract. Friction Stir Welding (FSW) is a solid state welding process invented by The Welding Institute (TWI) in 1991. High speed rotating tool with small pin forced to deform work piece material using thermo mechanical action. A small pin with shoulder of tool is plunged into the work piece with axial pressure and traversed along the line of joint. During the welding process, axial force, lateral forces, traverse force and torque are applied on the workpiece which lead to distortion of workpiece materials and fixture; hence design of the fixture should be reliable for proper positioning of workpiece. In this Paper, Types of Probable failures, Cause and Effect analysis, Pre-requisites and reliability based design approach for development of FSW fixture have been discussed in brief. Further modified design was prepared in AutoCAD and FSW fixture is fabricated. Some successful trials are also carried out for testing for reliability. Results shows FSW fixture is reliable to carry out friction stir welding process.

Keywords: FSW fixture failure · Cause and effect analysis · Reliability based design

1 Introduction

Friction Stir Welding (FSW) is a solid state welding process invented by The Welding Institute (TWI) in 1991. High speed rotating tool with small pin forced to deform work piece material using thermo mechanical action [3, 5]. Heat generated by the thermo-mechanical action is used to soften the material without reaching its melting point followed by stirring mechanism to produce welds. A small pin with shoulder of tool is plunged into the work piece with axial pressure and traversed along the line of joint Fig. 1. The major functions of the rotating tool are: (i) To generate heat for softening of materials, and (ii) stirring and trailing of materials to be welded.tool rotation and translation causes material movement along the pin towards the back of the pin [1]. During FSW process, the material goes into the severe plastic distortion at elevated temperature, producing fine and equaxed recrystallized grains [2]. Generally materials used for the process are of different thickness from 1 mm to 12 mm. During the

V. K. Gunjan et al. (Eds.): *ICRRM 2019 – System Reliability, Quality Control, Safety, Maintenance and Management*, pp. 60–66, 2020.
https://doi.org/10.1007/978-981-13-8507-0_10

welding process, large axial force is applied on the workpiece hence design of the fixture for holding workpiece should be reliable for proper positioning of workpiece. Figure 2 shows types of forces acting on the workpiece during the friction stir welding.

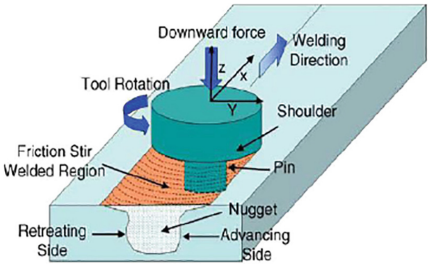

Fig. 1. Friction stir welding process

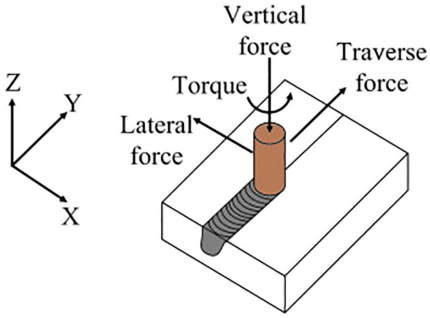

Fig. 2. Forces developed during FSW

2 Pre Requisite for Design of FSW Fixture

During the design of FSW fixture, A Major issues is the high temperature produced during thermo mechanical action between tool and workpiece. In this situation, workpiece material is likely to remain stuck to the baseplate deteriorating quality of the weld and the reliability of the fixture. The design of the FSW fixture should be such that it should be able to carry the forces and keep the workpiece material stable during the process [6, 7, 9]. Proper stability during the process is very important concern to avoid any distortion or sudden vibrations which affect the quality of the weld [8].

Following are the possible failures of FSW fixture during the process;

1. **Workpiece Misalignment:** Workpiece to be welded will get misaligned if not fixed properly inside the fixture.
2. **Workpiece Buckling:** Workpiece may undergo buckling due to axial, lateral forces and torque during the process
3. **Thermal Expansion:** Workpiece undergoes thermal expansion due to elevated temperature produced by thermo-mechanical action.
4. **Thermal Loss:** During the FSW, thermal must be avoided in order to keep workpiece material at elevated temperature zone.
5. **Improper Intermixing of Material:** Workpiece is required to be maintained in optimum temperature range in order to keep materials not below or above the plastic zone. Below plastic zone, materials will not intermix/stirred properly. Above plastic zone, materials may reach its melting point lead to failure of weld.
6. **Plunging:** Tool along with pin may not plunge properely inside the workpiece if sufficient axial force not applied and workpiece should be rigidly fixed inside fixture.
7. **Clamping:** Clamps may get misaligned if not fixed properly on the fixture.

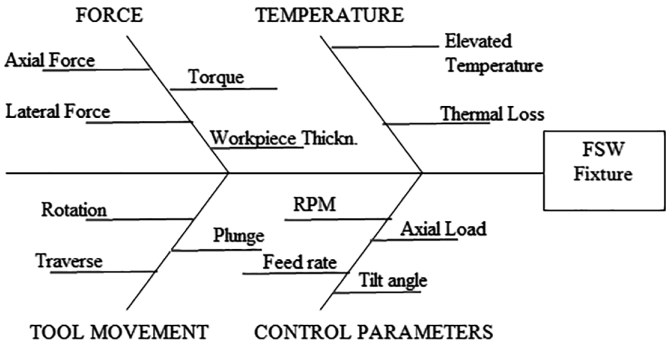

Fig. 3. Cause and effect (Fishbone diagram) diagram of FSW fixture

Figure 3 shows factors affecting weld quality and reliability of FSW fixture by the cause and effect diagram.

3 Reliability Based Design Approach of FSW Fixture

Reliability is the efficiency of the product or system that will continue to work normally over a specified interval of time, under specified conditions. The overall reliability of a system or product is described by the combination of the reliabilities of the individual components [10]. If the failure of any component will lead to the total failure of the system, then design is said to be in series reliability. In contrast better combination of components is that in which failure of all components lead to total failure of the system. Such a combination is said to be in parallel reliability. Figure 4 shows failure behavior of system or product over the time period. The highest failure rate observed during the premature phase [11]. This curve also known as "Bath Tub Curve".

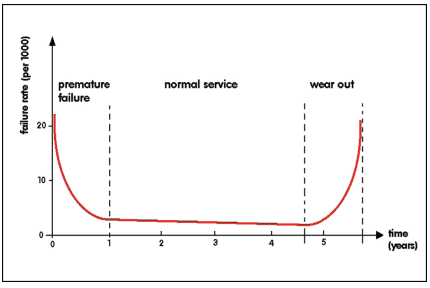

Fig. 4. Bath tub curve

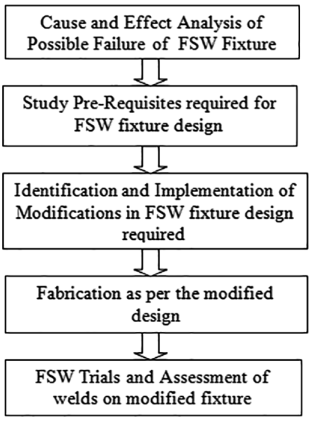

Fig. 5. Reliability based design approach

Figure 5 shows reliability based design approach for fixture required for the friction stir welding process.

Table 1 show improvements used as per the reliability based design approach for F SW fixture design.

Table 1. Improvement in FSW fixture as per the reliability based design approach

Sr No	Types of failures	Reliability based design approach for improvements in FSW fixture
1	Workpiece misalignment	Multiple clamping and dimensional accuracy has been maintained for proper alignment of workpiece
2	Workpiece buckling	Multiple and enough clamp length maintained in order to avoid buckling
3	Thermal expansion	Dimensional accuracy and high tolerance kept in order avoiding thermal expansion
4	Thermal loss	Thermal insulating material such as mica or bakelite is suggested to use as backup plate to avoid thermal loss
5	Improper material mixing	Thick fixture baseplate (40 mm) of mild steel is used to withstand against high axial load, frictional forces and elevated temperature
6	Improper plunging	High dimensional accuracy, tolerance and rigid fixture provide enough support for tool pin plunging
7	Improper clamping	Multiple and rigid clampings with proper dimensions are used to prevent misalignment from its position
8	Productivity	Arrangement has been provided to carry out two trials in single set-up
9	Fixture positioning	Universal FSW fixture design is used that can be used with any milling machine beds

4 Modelling and Fabrication of FSW Fixture

Figure 6 shows reliability based modified design of FSW fixture prepared in AutoCAD software. Figure 7 shows FSW fixture along with clamping developed using reliability design approach flexible to be used different kinds of milling machines at elevated temperature without misalignment and buckling of workpiece materials. Two trials can be carried out in single set up as shown in figure showing copper plates of 150 mm X75 mm X3 mm fixed on the fixture to increase productivity of FSW process. Base plate of large thickness of 40 mm is used in order to have rigidity to the fixture.

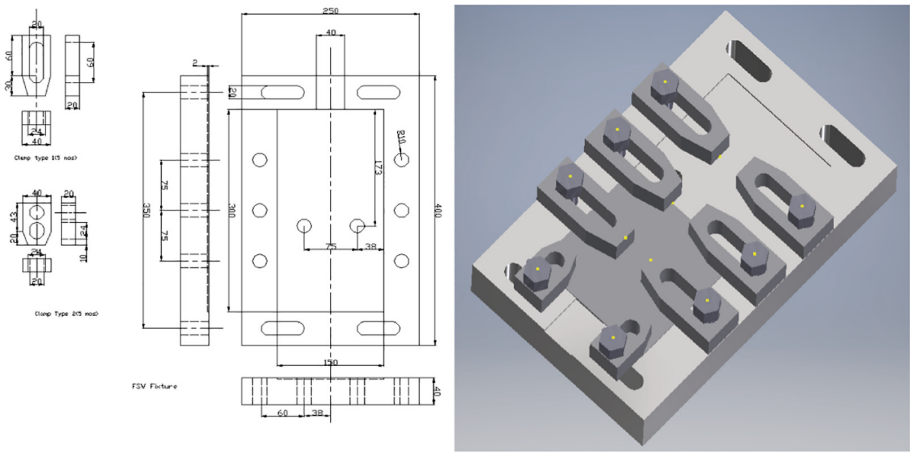

Fig. 6. Modeling of FSW fixture

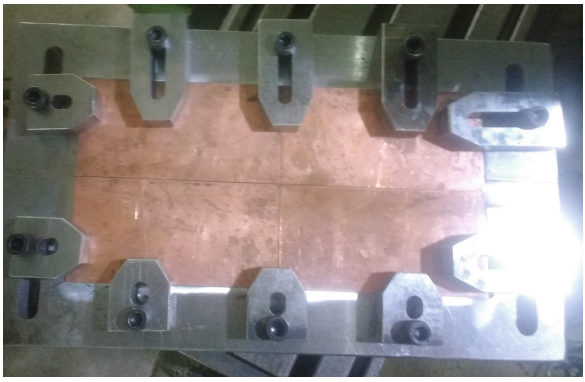

Fig. 7. FSW fixture with clamping

5 FSW Trials for the Weld Quality Assessment

Various Successful FSW trials without defects have been conducted between aluminum to aluminum and aluminum to copper at different levels of RPM, Weld Speed and Tilt Angle as shown in Figs. 8(a) and (b).

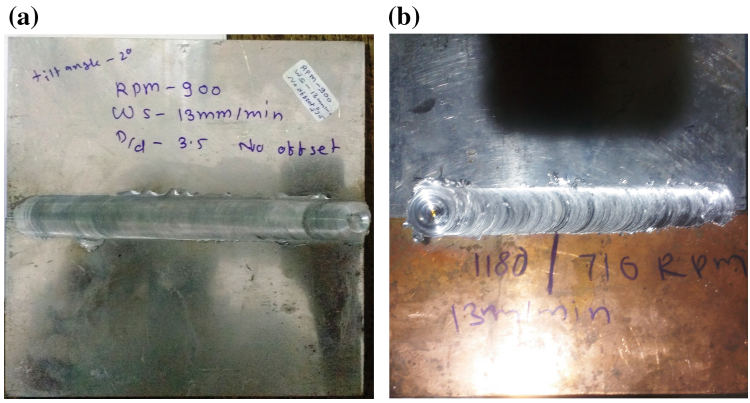

Fig. 8. (a) FSW of Al-Al (b) FSW of Al-Cu

6 Conclusions

In this paper, Reliability based design approach has been used for development of fixture for friction stir welding. Most of the design issues and probable failures are addressed from previous studies and some pre requisite are considered before designing of FSW fixture. Reliability based design approach further used considering pre-requisite to avoid possible failure of the FSW fixture. Modified design of FSW fixture has been prepared in AutoCAD and further fabricated as per design. Some successful FSW trials have been conducted which shows modified FSW fixture is reliable for carrying out friction stir welding process.

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