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Design and development of Fixture for Friction Stir Welding

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Abstract: Friction Stir Welding being a solid-state process is free from defects generally occurs in fusion welding process. FSW of Stainless Steel is done on retrofitted vertical milling machine. For this welding operation a fixture is needed on which the plates which are to be butt welded is to be bolted. In this paper first fixture is designed using AutoCAD software keeping certain things in view like groove of fixture to be such that it accommodates both backing plate and metal plate to be welded, then development of fixture is done using AutoCAD drawing. Apart from this a five nos. of clamps is also manufactured for holding the plates firmly and subsequently a key is also manufactured for the purpose of fixing and balancing of plates to be welded.
Key words : FSW; fixture; clamps; key; shaping; milling; drilling

1. Introduction

Friction stir welding (FSW) was first invented by The Welding Institute (TWI), UK in 1991 as a solid-state joining process. It is the process that involves plunging a portion of a specially shaped rotating tool between the abutting faces of the joint. The relative motion between the tool and the substrate generates frictional heat that creates a plasticised_third-body region around the immersed portion of the tool. The contact of the shouldered region of the tool with the work pieces also generates significant frictional heat, as well as preventing plasticised material from being expelled. The tool is moved (relatively) along the joint line, forcing the plasticised material to coalesce behind the tool to form a solid-phase joint. At present, Friction Stir Welding has found various applications in a number of areas. Potential applications are space shuttle fuel tanks, aluminum decking for car ferries, manufacturing of compound aluminum extrusions and automotive structural components. Most of the applications are on aluminum alloys although several facilities have reported experiments on titanium alloys and steels. The process is not yet fully understood and further research is required to optimize this technology It is one of the emerging welding techniques and due to its advantages over fusion welding technique it has drawn attention of various researchers around the world. Apart from metallurgical and environmental benefits it has energy benefits as well, like only 2.5% of laser welding energy is needed for FSW.

1.1 Fixture development for FSW

FSW of Steel alloys requires a more careful design of both the fixture and the tooling with respect to FSW of aluminum alloys. As far as the fixture design is concerned , it is always regarded as the first problem to be overcome due to the high temperatures reached during the process; under such extreme conditions, the welded blanks are likely to remain stuck to the backplate compromising both the soundness of the joint and the integrity of the fixture itself. The fixture should be such that it should withstand the forces and rising temperature during welding process without

distortion in shape. FSW is performed on a retrofitted vertical milling machine. To support the metal plates to be joined, the fixture is designed and fabricated using different machining processes. The main purpose of a fixture for friction stir welding is to hold the workpieces in position during welding. However, there is limited published information that details the fixture design requirements. The main reason for having appropriate clamps or fixtures is to prevent the specimens from moving while being welded. Obtaining good stability during the process is important since any deflection or major vibration would affect the quality of the weld. Certain features should be kept in mind while designing the fixture.

The basic features which were kept in mind while designing the fixture are:

1. The design should be such that it should accommodate both backing plate and plate to be welded.
2. Clamps would also be required for proper holding of plates. So for that holes for clamps to be screwed should also be considered as suitable places while designing.
3. Key is also required for fixing and balancing the plates so that plates do not get displaced from their original position while performing FSW operation. So for that grooving at suitable area should also be considered while designing.
4. The design should be such that it should allow the fixture to be properly mounted over the bed of Vertical Milling Machine for welding operation.
5. Two holes at the centre line should also required so that temperature during welding can be measured using the thermocouple.

Considering above versatile features, the design of fixture was prepared using the AutoCAD software. Design as shown in Figure 1.1 was prepared by measuring the dimensions of the bed of vertical milling machine on which the welding was to be performed. Mild steel is the material used for manufacturing the fixture, clamps and key. Since Mild steel has high strength and toughness which is required to withstand unbalanced force and pressure during FSW operation that is why it was chosen for fixture development. The measurement of the fixture is in millimeter (mm).

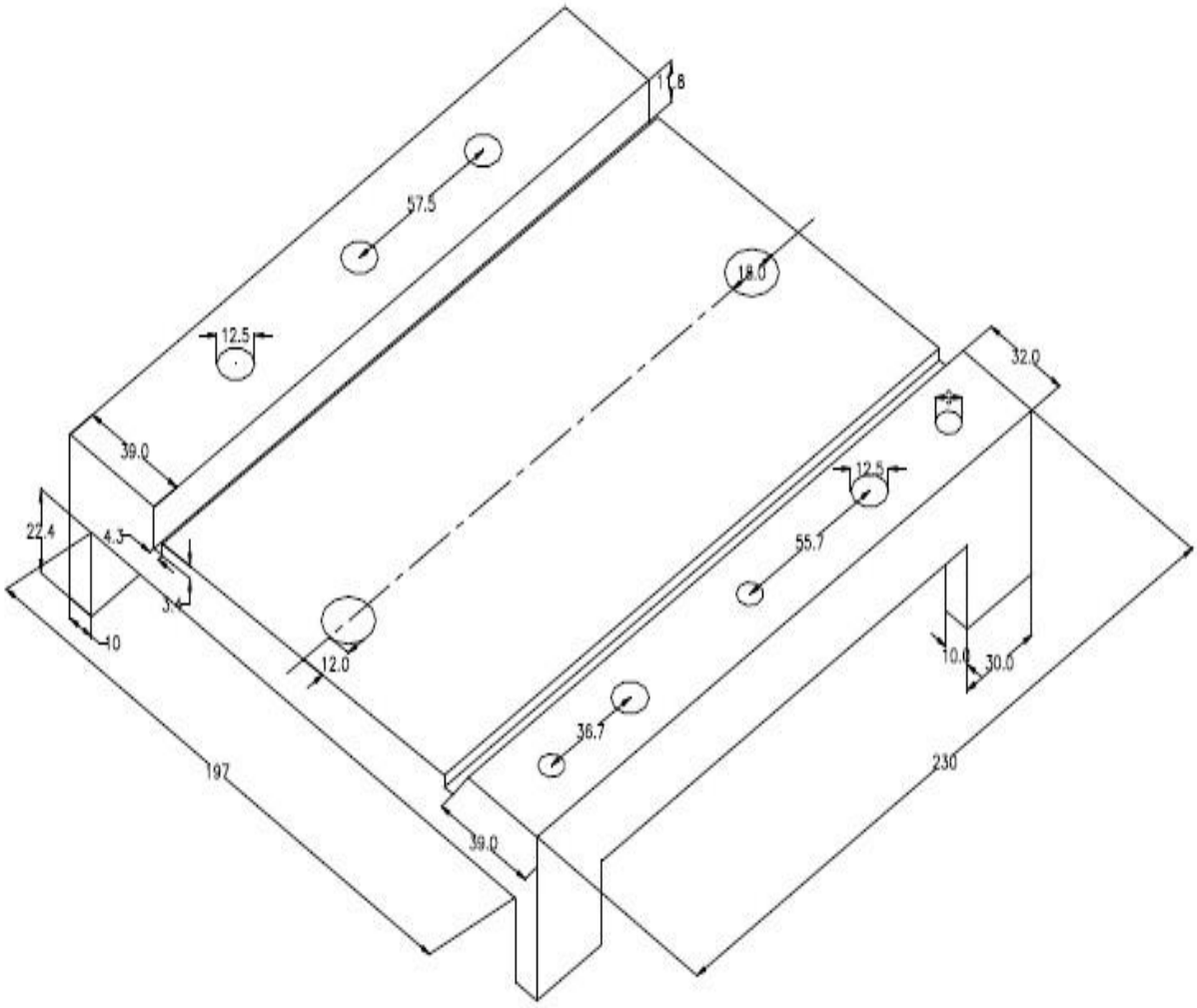

Figure 1.1- Dimensions of Fixture

After designing the fixture, its manufacturing was done that involved following operations:

1. *Milling operation on horizontal milling machine.*
   The milling operation was done to produce the sharp edges of the workpiece to be manufactured. Once equal edges of right angle were produced after machining, the measurement using scale and marking using red chalk was done. Climb milling process was used for milling. The tool used was high speed steel cutter.

2. *Shaping operation on shaper machine.*

In the shaping operation, shaper machine was used for creating the grooves on two positions separating with equal distances. The tool used was high speed steel tool.

3. *Drilling operation on drilling machine.*
   Drilling operation was done using tool bits of different sizes as per the design specification. Two holes at the centre were drilled using 18mm drill bit, Six holes of small diameter on either side were drilled using 9mm drill bit and remaining two holes were drilled using 12.5mm drill bit.

4. *Surface finishing is done using grinding operations.*
   Surface finish using surface grinder was used for removing the roughness and providing the desired tolerance .

After performing all these operations finally fixture is produced as shown in Figure 1.2.

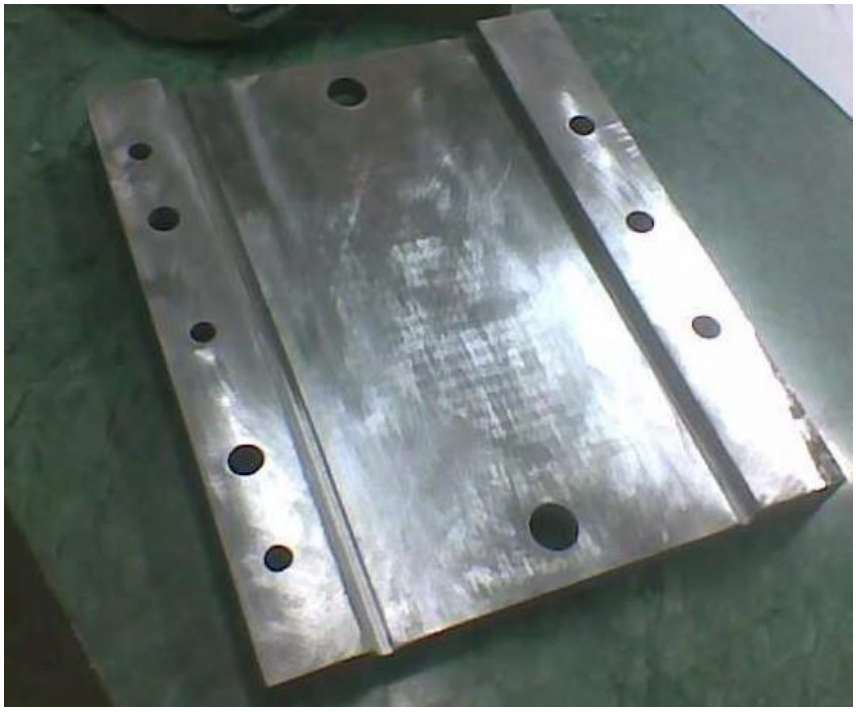

Figure 1.2- Developed Fixture

1.2 Clamping Requirements

The forces that act on the base plates as a result of transversal and rotational movement of the tool can be summarized and built into clamping design. The initial plunge of the tool, before welding feed (cold start), transfers forces to the base material. Firstly the tool generates a moment while rotating against the frictional surface of the base material. This frictional moment or shearing force is assisted by the downward thrust of the tool increasing the

linear force vector at every increment of rotation. The probe that is sunk into the joint line wants to push the two base plates apart. Movement of the tool through the joint line also produces translational forces that tend to push the plates in the x-axis direction. The magnitude of these forces will depend on the viscosity level reached as well as the feed rate also.

Thus Clamps are required for countering following things:

1. *Welding tool axial force and deflection*
   The forces in action during FSW are significant, and proper fixture design is critical to the success othe weld. The axial force applied to the welding tool, keeping it embedded in the workpiece, is commonly from 20kN to 60kN. This depends on the welding tool, workpiece alloy, thickness, travel speed, etc. This force must be controlled with minimal deflection, since it is necessary to control the position of the welding tool precisely in relation to the surface of the workpiece
2. *Easier to join or separate the workpiece*
   During the initial plunge of the welding tool into the workpieces load is transferred laterally to separate the plates along the joint line where large forces are required to prevent this separation. The magnitude of this force has not been published in any literature. In addition, during the course of welding plates tend to separate under the thermal expansion/contraction associated with passage of the welding tool. This produces an in-plane moment that opens the unwelded section in front of the welding tool. In the case of the plate separation due to the plunge of the welding tool at the start of the weld, restraining the plates laterally immediately adjacent to the plunge location is most effective. As the weld progresses, the thermal expansion that causes plate separation in front of the welding tool is most effectively counteracted by clamping at the end of the plate, producing the maximum in-plane moment to counterthe separation with minimal force
3. *Workpiece buckling due to thermal expansion*
   While constraining plate separation produced by thermal expansion, workpiece plates can sometimes buckle upward into a convex profile, rising around the welding tooland making the tool appear to be diving into the workpiece when actually the surrounding plate is lifting off the backing plate. This result in a weld with "dropout", a term borrowed from fusion welding, where the weld zone protrudes from the back of the welded panel. The effect is often worse with thin plates, in the 3mm to 10mm range, since these plates are less able to resist the in-plane moment without buckling. To counteract this, clamping is required to apply out-of-plane forces that prevent buckling. This is best applied as close as is practical to the weld zone, usually about 50mm on either side of the joint. This clamping also serves the purpose of deflecting plates that may not be perfectly flat so that the plates are in contact with the backingplate at all points along the joint
4. *Preventing the longitudinal sliding of workpieces*
   Preventing workpiece plates from sliding longitudinally is not usually important for flat butt welds, since the large axial load applied by the welding tool tends to pin the workpiece to the backingplate. However, in making corner welds it is necessary to pin one of the two plates being welded to prevent sliding in the

direction of the weld. Restraining only one plate is adequate to prevent sliding of the pair, since the pair of plates are sufficiently welded at completion of the initial plunge of the workpiece to prevent the unrestrained plate from sliding on its own

Subsequently, clamps were manufactured for holding both backing plate and plates to be welded, five clamps were needed for proper holding of plates. Figure 1.3 shows the drawing and dimensions of clamps.

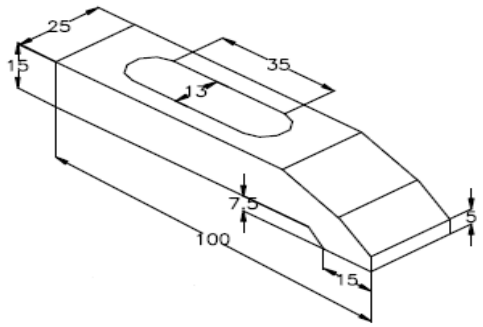

Figure 1.3- Dimensional drawing of clamp

Manufacturing of clamps was done using milling operation on vertical milling machine. Climb milling process was used for milling. The tool used was high speed steel cutter. Figure 1.4 shows the complete manufactured clamp

Figure 1.4 - Final developed clamp

1.3 Key Requirement

One key was also needed for proper fixing of the plate so that it does not move from their initial position during FSW operation. Manufacturing of key was done using shaper machine. The key was manufactured using the shaper machine. The high speed steel is the tool used during operation. After shaping operation, surface grinder was used to provide smooth surface finish as desired tolerance level. Figure 1.5 shows the dimensions of the key.

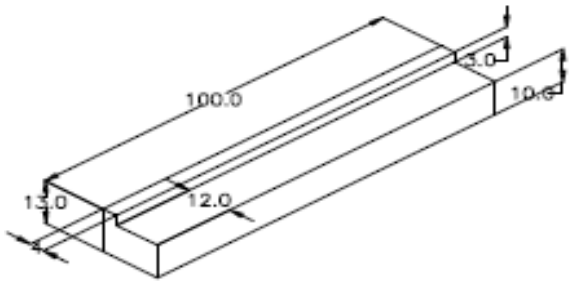

Figure 1.5-Dimensional drawing of key

After performing shaping operation on shaper machine, key was developed as, shown in Figure 1.6

Figure 1.6 - Final developed key

2. Conclusion

The innovative designed fixture is best suited for robust vertical milling machine (VF- 3.5 of BFW with spindle motor . This fixture has the flexibility to weld Stainless Steel 304 plates of various thickness. Fixturing and material clamping techniques had been designed and manufactured. The clamping of the workpieces plays an important role during the welding process since it must prevent any deflection or movement of the base material. Apart from this clamps has been designed such that it is easy to disassemble and also easy to manufacture.

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