

Features of friction stir girth welding of small-dimension parts

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Abstract. Friction stir welding is a competitive method to other welding methods when manufacturing tanks made of aluminum alloys. Nonetheless, a lot of articles on FSW are carried out when manufacturing linear butt welds. In this article, features of manufacturing friction stir girth welds are considered. The aim of the study is to develop a list of recommendations for welding small-dimension girth joints. The experiments was carried out using pipes made of AlMg6 with 112 mm outer diameter and 6 mm wall thickness, and solid blanks with 118 mm outer diameter. The results that have been obtained allow us to conclude that the quality of the weld is stand on the contact area of the tool with the workpiece and the tool tilt angle. A scheme of welding with tool offset is proposed. Defects that are characteristic only for the small-dimension girth joints are identified. Results can be used in the process engineering of welding small-dimension tanks and pipes made of aluminum alloys.

1. Introduction

Girth welding joints are using when manufacturing tanks, pipes and bodies of products of various industries. These joints in mass production are usually welded using special machines in a semiautomatic mode. Welding machines usually include equipment for fixing the parts to be welded, their rotation device and a welding blowpipe. In industry, the method of flux girth welding of steel gas tanks is often used. The disadvantages of this method are use of welding consumables: rods, flux, and also the need for edge preparation. A method of electron-beam welding, which is devoid of these disadvantages, is also used. However, this method also has disadvantages caused by the features of the method itself, namely: the need to create a vacuum chamber in the welding zone and also the need to use special machines. The friction stir welding (FSW) is devoid of these disadvantages. In modern engineering, the FSW is considered promising for solving many technological problems, including welding tanks and products of complex geometric shapes from aluminum alloys. Advantages (as well as some disadvantages, including removable ones) of FSW in relation to arc welding have been repeatedly mentioned in many articles [1-4].

Among a number of researches of FSW and its applicability to solving various technological problems, only some is directed to the produce of girth and complex geometric joints. Among all articles it is possible to single out the work that was made by the Russian specialists of Company "Experimental Engineering Plant" and RSC Energia for the manufacture of parts close to the tanks of rocket and space technology [5]. It is also worth noting a study on welding aluminum pipes from 6082-T6 alloy with an outer diameter of 38 mm with a thickness of 3.5 mm using a tool with a movable pin [6]. The research [7] on friction stir welding of small-dimension Al30003 and pure Cu pipes is closest to the current article. In the above researches, sound welds were obtained; however, experiments were carried out on specialized FSW machines from I-STIR and PowerStir. One of the advantages of FSW is that welding can be carried out using universal machines, such as industrial robots or milling machines. Of course, the machines must withstand high strength acting on the spindle during the welding process (when welding aluminum parts, the load can reach 15 kN [8] or

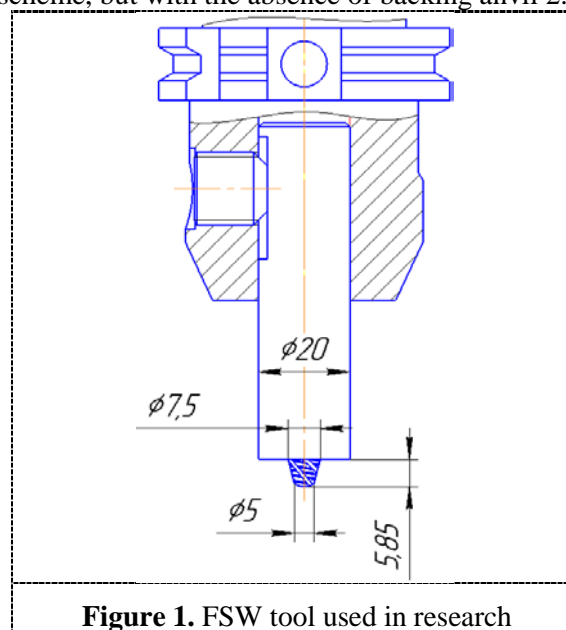


more). An important feature of specialized machines for FSW is that the spindle head has the ability to rotate in a small range of angles. The need for a rotary spindle head is due to the fact that for the formation of a sound welds, it is necessary to provide tool tilt angle. The tool tilt angle can range from 2 to 5 ° depending on alloy and tool geometry. For example, in the above research [6], the welds were made with a tool tilt angle of 2 and 2.5 ° with a workpiece diameter of 38 mm; in a research conducted by Russian scientists at SUSU [9], the tool tilt angle was also set at 2 ° with a larger diameter of the workpieces. The availability of a rotary spindle head is not always justified, since a non-rotary spindle head has greater stiffness and lower cost. In the case of welding girth joints of small-dimension workpieces (up to 1 m), the necessary tool tilt angle can be “artificially” created, which will allow welding on three-axis CNC vertical milling machines, that are not equipped with a rotary spindle head.

2. Formulation of the problem

The aim of this study is to obtain friction stir welded aluminum alloy AMg6 pipes with 112 mm outer diameter and 6 mm wall thickness, and also solid blanks with 118 mm outer diameter using a three-axis vertical milling machine, then check their quality and develop a list of recommendations for welding small-dimension girth joints using machine with no rotary spindle head.

The experiments will be carried out using vertical milling machine. A drawing of a tool installed in a Weldon Ø20 holder with a DIN 40 cone is shown in Fig. 1. The tool used in the current article is made of 45CrMoWSi (~0.45% C, ~1% Cr, ~1% Mo, ~1% W, ~1% Si and others) heat treated steel with the design geometry of VNIIMALMAZ JSC for FSW aluminum alloys with a thickness of 6 mm. The scheme for welding pipe workpieces is shown in Fig. 2. Welding of solid workpieces will be carried out according to a similar scheme, but with the absence of backing anvil 2.



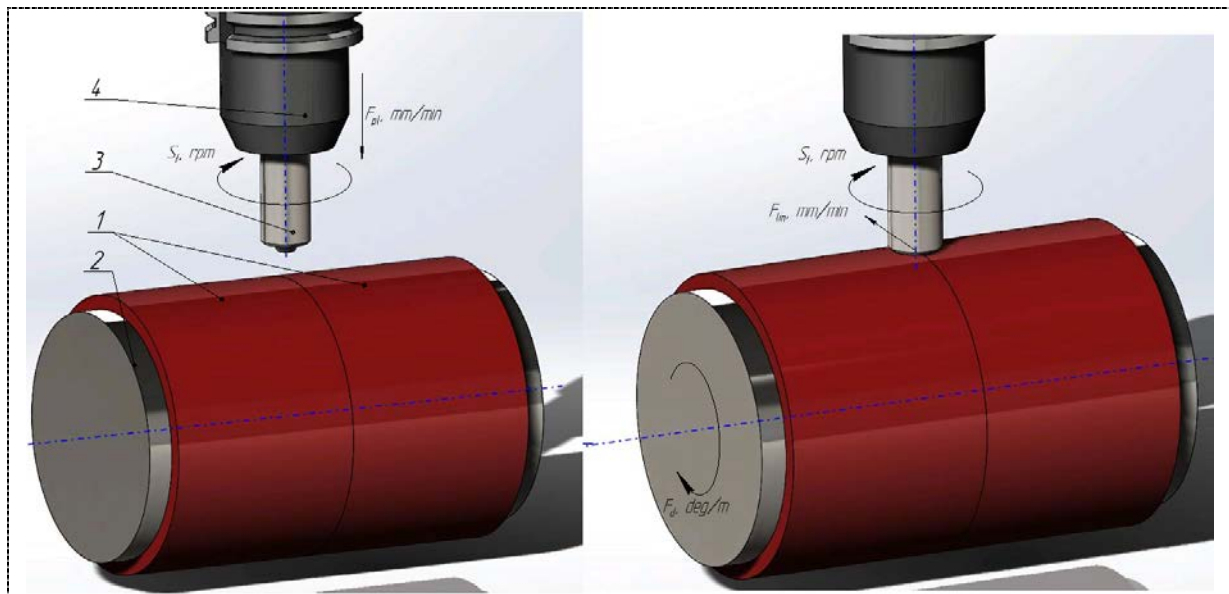


Figure 2. Scheme for welding pipe workpieces: a) position before welding; b) position during welding. 1 – Pipes to be welded, 2 – backing anvil, 3 – FSW tool, 4 - holder.

According to the welding scheme, when the tool tilt angle is zero (Fig. 2), the parts 1 are nonmovable mounted on a rotating backing anvil 2. The FSW tool 3 is mounted in the holder 4. The axis of the tool, rotating with a speed S_i (rpm), coincides with the junction plane (for example, pipes). At the beginning of welding, a rotating tool plunging at a speed of F_{pl} (mm/min) into the parts to a depth equal to 80-95% of the length of the pin. After the tool has plunged to the required depth, the parts are rotated at a speed of F_d (deg/min) or F_{lin} (mm/min) in any direction.

3. Theory

Since the overwhelming majority of milling machines the feed rate of rotatory table is set in deg/min, it is necessary to transform the linear welding speed into angular. For this, the following equation can be used:

$$F_d = \frac{F_{lin}}{3.14 \cdot D} \cdot 360^\circ, \text{ deg/min} \quad (1)$$

where F_{lin} is linear welding speed, mm/min; D is the outer diameter of the workpiece.

According to the scheme described above, direct provision of the tool tilt angle is impossible; therefore, an alternative welding scheme can be used – welding with tool offset in the junction plane (Fig. 3).

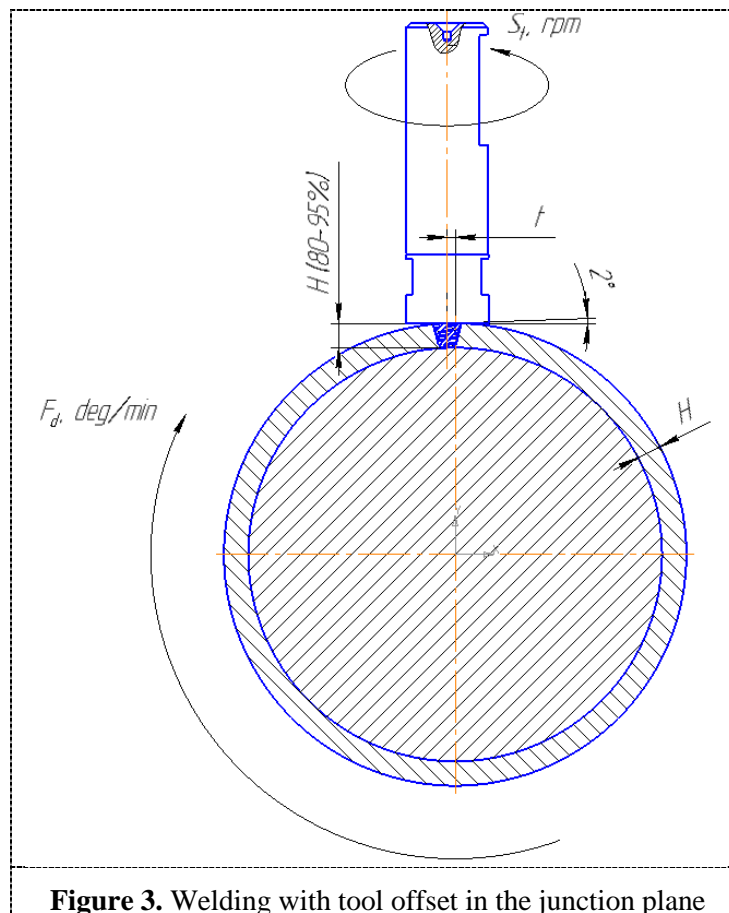


Figure 3. Welding with tool offset in the junction plane

According to this scheme, the tool has offset by a value that will provide an inclination of the tool axis to the plane tangent to the parts to be welded, equal to 1–5 °. The offset depends on the radius of the parts to be welded and the tool tilt angle that must be ensured. The side of offset is depends on the direction of rotation of the parts. The offset value calculation scheme showed in Fig. 4. In the scheme, the offset t (OA_x) will be equal to the projection of the vector OA onto the abscissa. The length of the vector (offset t) is calculated by the equation:

$$OA_x = OA \cos(90^\circ - \alpha) \quad (2)$$

where OA_x is the offset value (t); OA is the outer diameter of workpieces; α is the tool tilt angle.

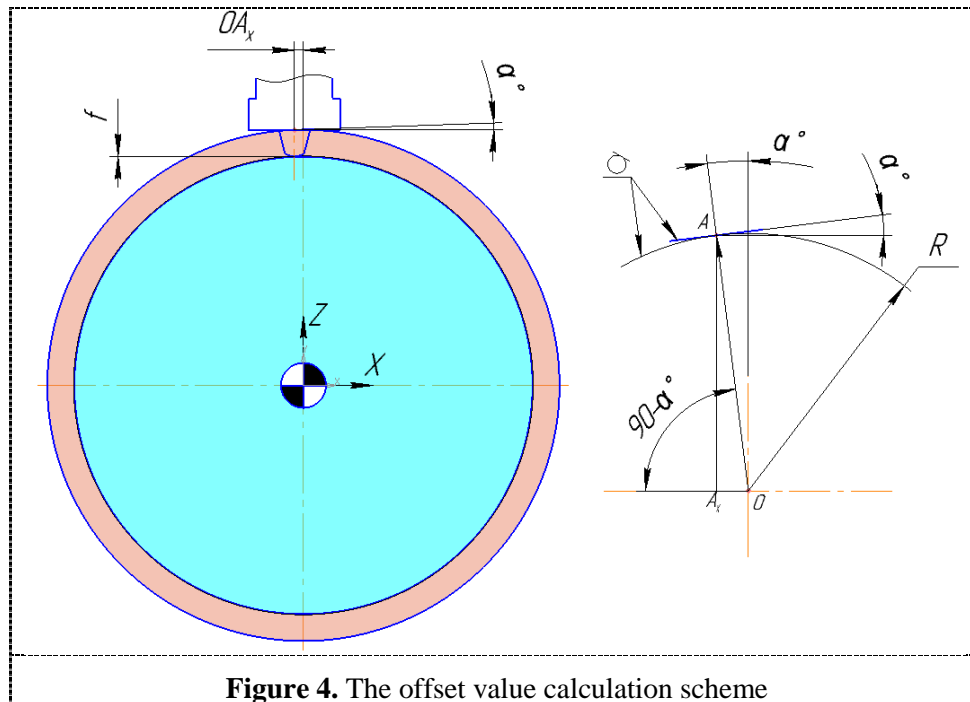


Figure 4. The offset value calculation scheme

The significant problem of girth welding of small dimension parts is the small contact area between shoulder and parts to be welded (Fig. 5), which, as known, has a direct impact on the weld quality.

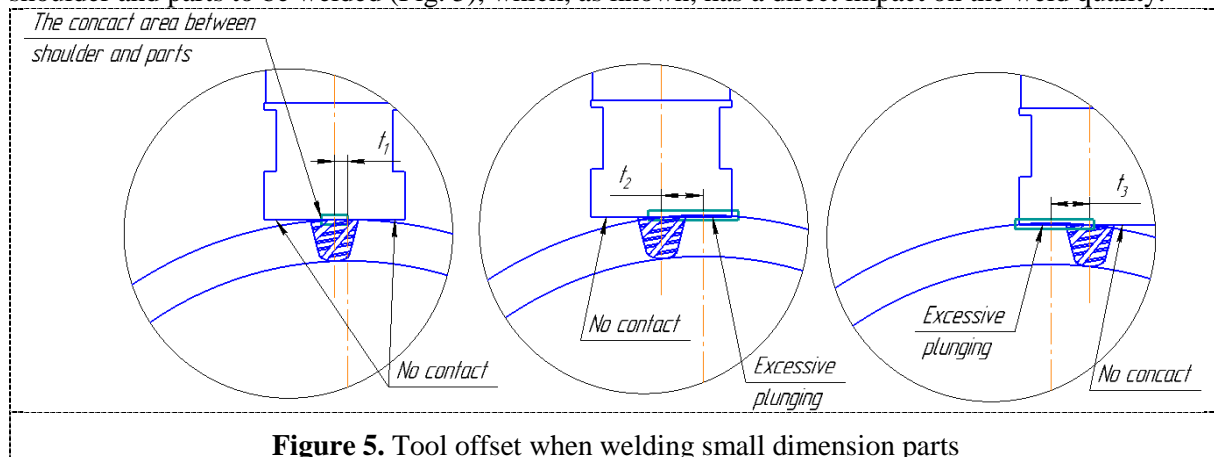


Figure 5. Tool offset when welding small dimension parts

The contact area of the between shoulder and parts (Fig. 5) will depend on the offset value (and thereafter on the tool tilt angle). To ensure the optimal contact area, it is necessary to find the optimal tool offset value experimentally, or to change the shape and dimension of the shoulder until the required quality is achieved.

4. Experimental results

The welds manufactured using the above scheme are shown in Fig. 6, 7. Welding was carried out at a tool rotation speed of 600 ... 710 rpm and a travel speed of 40 ... 60 mm / min on various samples.

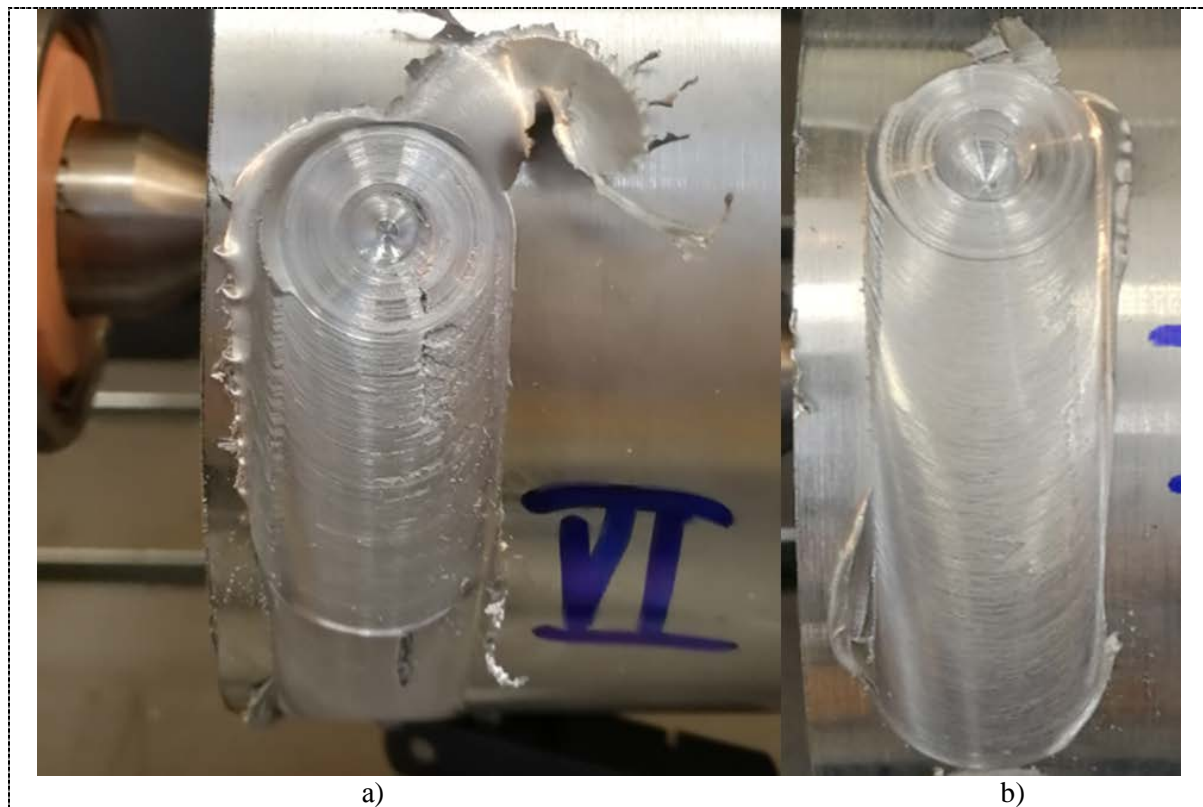


Figure 6. FSW of the solid blank: a) – with zero offset (the tool tilt angle 0°); b) – with offset value in proportion to the tool tilt angle 2°



Figure 7. FSW of the pipes with tool tilt angle 2° after scraping bright: a) face; b) backside

5. Discussion

When welding girth joints of small dimension parts, two defects are observed that are not observed in linear welding. One of them is a barrel form section of the weld (Fig. 8, a). This defect is characterized by a lower weld edges according to the outer diameter level of the workpiece in cross section, while the central part is located at or above the outer diameter level. The occurrence of a barrel form defect can be explained by the uneven tool and shoulder plunging due to the small outer diameter of parts. In this case, plunging can be optimized only by tool size adjusting to the optimum value, which will allow obtaining a high-quality weld. It is impossible to completely eliminate the barrel form defect when welding small dimension parts, but it can be minimized. In the process engineering of welding

small-dimension parts it is necessary to taken this defect into account – it creates a local thinning in the cross section, which reduces the part strength.

The second defect, characteristic of FSW of small dimension parts, is the occurrence of local overlap at the end of the weld (Fig. 8, b). When welding small dimension parts, the back side of the shoulder is in contact with the workpiece, and on the front side there is a gap between the shoulder and the workpiece. During welding, the plasticized material is pushed out by the pin, fills the gap and solidifies at the end of the weld when the tool lifts. This defect can also be eliminated by tool size adjusting, but this is also not always advisable. During tool travel, this gap is also the field in which the flash may lift and then formed along the weld edges.

The occurrence of these defects is also observed at the specimens in the research [8].

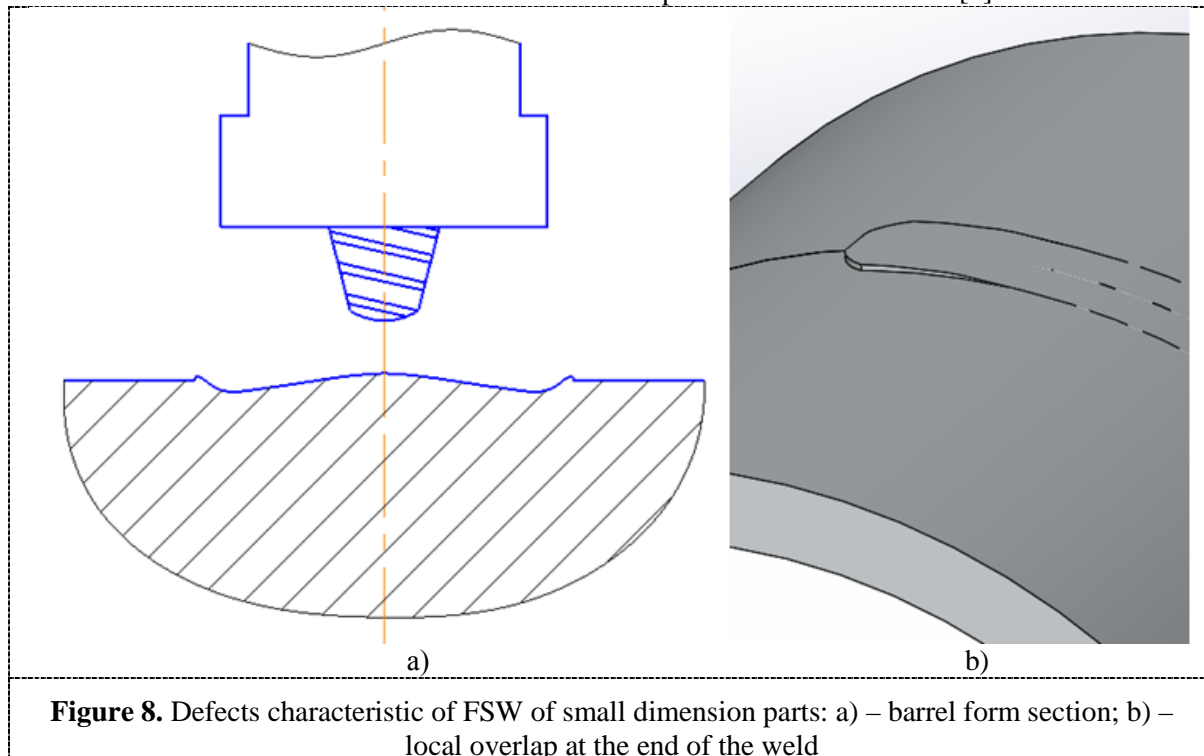


Figure 8. Defects characteristic of FSW of small dimension parts: a) – barrel form section; b) – local overlap at the end of the weld

Welding modes (tool rotation and travel speed) for friction stir girth welding can be setting as for linear welding. Much attention needs to be paid to rigidity of equipment for fixing parts. In the case of linear welding, the parts are rigidly set on the backing anvil, and when welding pipes, special equipment must be used as the backing anvil. It is also necessary to use steadyrests or other devices to prevent deformation of parts. The pipes or solid blanks, the outer diameter of which will coincide with the inner diameter of the parts, or special adjustable equipment can be used as backing anvil, and the second is preferable, since the pipes may deform during welding. Due to the axial force of the tool on the pipes, inner diameter of last one decreases caused of deformation, and it leads to the formation of a fixed joint between equipment and workpieces, comparable to an interference fit.

6. Conclusion

The results shows that the friction stir girth welding using vertical milling machine with non-rotary spindle head is possible with a tool offset. The offset value is set depending on the required tool tilt angle (similar to linear seams). The experimental results showed that for the manufacture of sound joints of the aluminum alloy AMg6 with a diameter of 100–120 mm, the optimal tool tilt angle is 2 ... 4 °. Further, in-depth study of the welding process will be carried out using the scheme (Fig. 3), as well as the occurrence of defects (Fig. 8) and their elimination methods.

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