

# Forming Completely Penetrated Welded T-joints when Pulsed Arc Welding

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**Abstract.** The paper is focused on revealing the influence of welding parameters on weld formation when pulsed arc welding. As an experimental sample a T-joint over 10 mm was selected. Welding was carried out in flat position, which required no edge preparation but provided mono-directional guaranteed root penetration. The following parameters of welding were subjected to investigation: gap in the joint, wire feed rate and incline angles of the torch along and across the weld axis. Technological recommendations have been made with respect to pulsed arc welding; the cost price of product manufacturing can be reduced on their basis due to reduction of labor input required by machining, lowering consumption of welding materials and electric power.

## 1. Introduction

At present welding is one of key procedures to manufacture permanent joints in mechanical engineering and in other branches of industry. Thicknesses to be welded are diverse, varying from millimeter shares to dozens centimeters. It is not difficult to weld 2 to 4 mm thicknesses. Thinner metal is welded if heat input is reduced [1-5]. To achieve guaranteed root penetration constructions containing metal sheets over 4 mm are welded with edge preparation. As the consequence, manufacturing process gets more labor-intensive, and more welding materials and electric energy are consumed. Hence, the cost price of a product increases.

The key difficulty of arc welding steel plates and components without prepared edges is to form a correct back of a weld. Incomplete fusion of the section can be caused by insufficient heat supply to the place of welding. Excessive heat supply leads to complete penetration, molten metal flows out of the weld creating holes (burn-through) or sinters on the back. It is quite hard to have complete penetration of the total section thickness free of sinters or burn-through. The back can't be seen when welding, and a welder works in conditions leading to incomplete fusion. The gap being the result of incomplete fusion is the center of concentrating stresses; i.a. a weld destroys fast, especially under permanent or constant loads. Incomplete fusion can be eliminated if a joint is welded from the back for a long time. However, additional welding is difficult because of partial (overhead position) or complete inaccessibility (pipe welding in a butt joint etc.) of the back. Additional welding also causes growing labor intensity (by 30 – 40%) [6].

The paper outlines investigations into weld formation when T-joint welding in flat position without edge preparation, mono-directional guaranteed root penetration over 10 mm is provided.



At present there are a few recommendations available concerning welding this kind of joints in literature, moreover, the most of them are for advertising purposes and can hardly be used in manufacturing process because include no certain data. A great number of parameters affecting weld formation and its geometry [7] do not support the search for efficient conditions [8]. Assessment of arc pressure on the weld pool, gas-dynamic impact on the electrode metal bead [9], and thermal cycle of welding is required [10]. Such parameters as joint gap, incline angle of the torch, circuit inductance etc. were determined experimentally in this paper.

As a welding process we selected gas-shielded welding distinguished by better technological characteristics and lower expenditures on equipment and materials in comparison with submerged-arc, laser, electron-beam, and hybrid types of welding. When gas metal arc welding it is necessary to submerge the arc in the gap and support its stable burning between two edges. The authors of paper [11] dealt with various procedures of pulsed arc welding. We concentrate on short focused pulsed arc welding for research purposes. Complete penetration is possible provided that breadth of the gap, wire feed rate, arc voltage, as well as incline angles of the torch along the weld and towards the upright edge are selected correctly, therefore, results of experimental studying these parameters are given below.

## 2. Methods of experiments

We used samples made of 300x50 mm plates for carrying out experiments. The surface of plates was pre-polished so it has metallic luster. Pulsed arc welding was with short circuits. Recommended voltage for this thickness was 33.6 V (33 V). Welded samples were band-sawed and polished. Samples without visible defects were subjected to etching.

The experiment included several phases.

The gap in the joint was specified during the first phase. The plates were assembled so the gap changed 0 to 8 mm. The assembled sample was undergone pulsed arc welding with short circuits. We selected a zone with good penetration but without burn-through. Then, the gap was varied with small deviation in this zone.

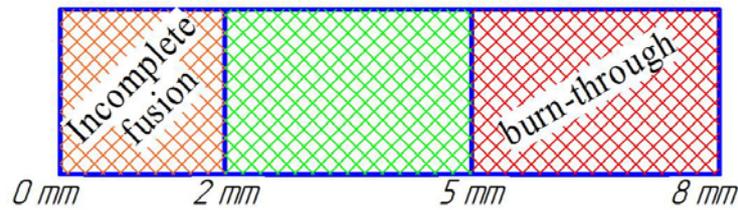
The second phase was focused on influence assessment of incline angle of the torch along the weld axis. The gap was selected according to the data determined in the first experiment. Short beads (50 mm) were welded on the sample via pulsed arc welding with short circuits. Incline angle of the torch was varied within the range  $\pm 60^\circ$  from the weld axis, with  $10^\circ$  step.

The third phase involved influence assessment of the incline angle of the torch across the weld axis. The gap was selected according to the first experiment. Short beads (50 mm) were welded on the sample via pulsed arc welding with short circuits. Incline angle of the torch was varied within the range  $40-90^\circ$  from the weld axis, with  $10^\circ$  step.

We specified the wire feed rate in the fourth phase. As voltage and wire feed rate are interdependent in up-to-date welding power sources, the change in wire feed rate was evaluated in view of the recommended value. Decreasing the electrode wire feed rate below the recommended value gave rise to growing voltage, whereas its increasing led to falling voltage and current strength. The wire feed rate was selected so the arc column could cover both edges to be welded.

## 3. Results of experiment

Specifying gap in the joint. When welding without a gap, even under high current strength guaranteed penetration was not provided (Figure 1, 2 a). Welding with big gap under low current strength did not support complete penetration too (Figure 1, 2 b). Complete penetration is possible in a very narrow area of the gap. Slight deviations from any parameters or uneven movement of the electrode caused incomplete fusion or burn-through.

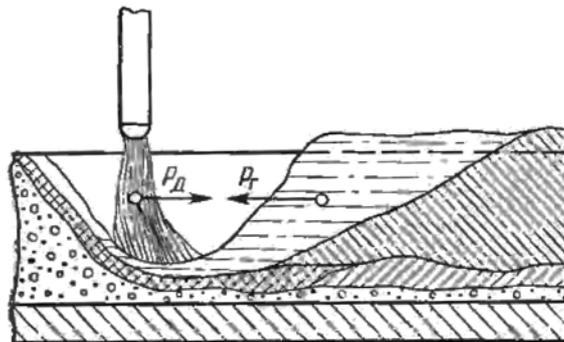


**Figure 1** Influence of clearance on penetration



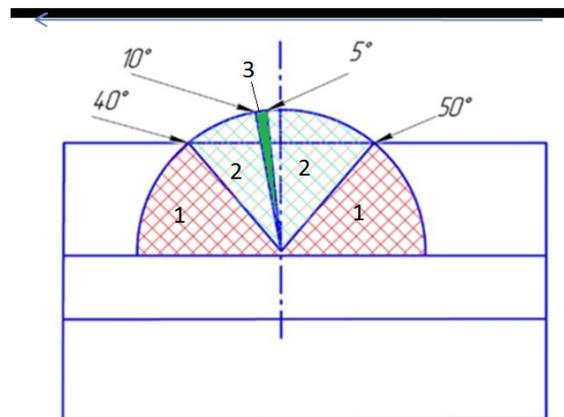
**Figure 2** Incomplete fusion without the gap (a), with big gap but insufficient current strength (b)

Determination of the incline angle along the weld axis. Metal is on different levels in head and tail ends of the weld pool because of its displacement from under the arc root in the direction opposite welding wire movement [12]. Molten metal is displaced as long as the horizontal component of the arc column force  $P_a$ , directed towards displaced molten metal is balanced by the counterforce of hydrostatic pressure  $P_h$  of molten metal and weld dross (Figure 3). Welding process is stable if these two forces are counterbalanced. Displacement of equilibrium in any direction can cause either further arc deepening into base metal or molten metal dribbling under the arc root, as the consequence, the depth of penetration is incomplete due to worsening conditions of heat transfer through the liquid layer of metal [13].



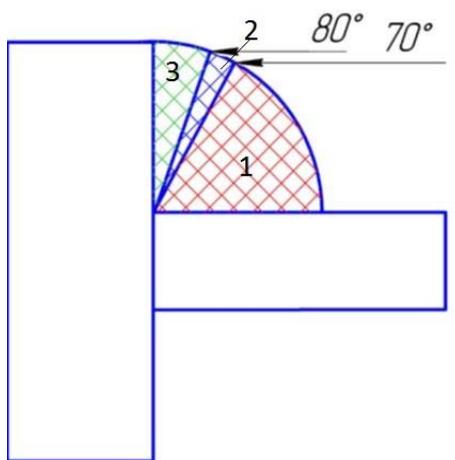
**Figure 3** Forces affecting the weld pool

The experiment has determined the most efficient angle in conditions of welding with electrode inclined under obtuse angle is one of 5-10° (Figure 4).



**Figure 4** Defectless formation zones according to incline angle of the torch along the weld axis (zone 1 – zone of incline angle of the torch providing no complete penetration; zone 2 – zone of higher splattering; zone 3 – zone with recommended incline angle of the torch)

*Specifying the incline angle across the weld axis.* The experiment has determined the incline angle of the torch 80-90° from the horizontal plate is the most efficient one. As one can see in Figure 5 there is no edge undercut and incomplete fusion in zone 3.

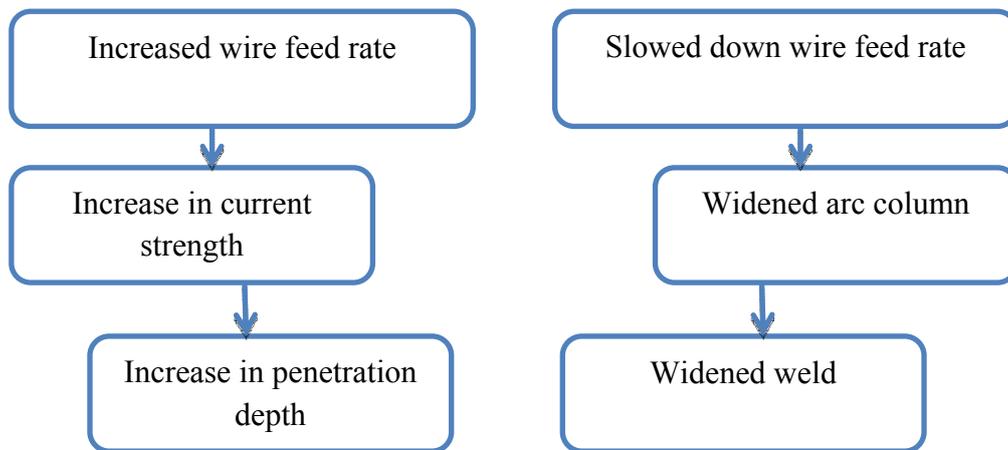


a

b

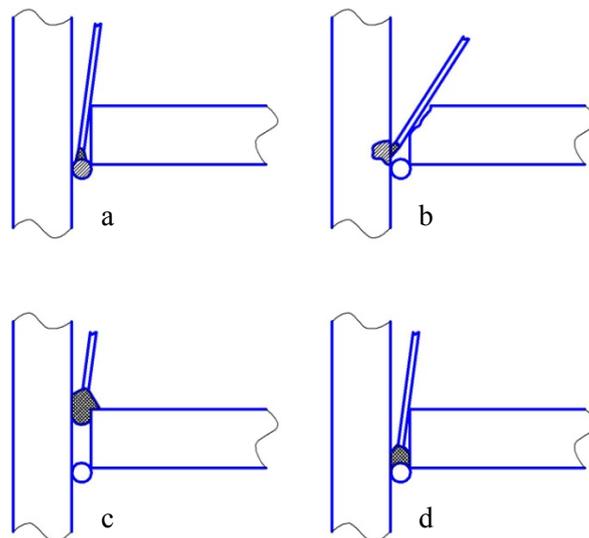
**Figure 5** The importance of incline angle of the torch across the weld axis for penetration depth (a) (zone 1 – incomplete penetration; zone 2 – undercutting; zone 3 – efficient angle) and wall undercutting (b)

*Specifying the rate of electrode wire feed.* For slowed down rate of wire feed we selected such a long arc that was burning between two edges (Figure 6) when welding wire and arc were submerged in the gap. The efficient wire feed rate was in the range 9.5-10.5 m/min. The mean current strength was 325-340 A.



**Figure 6** The dependence of weld parameters on wire feed rate

Welding was unstable even though all the afore-mentioned requirements and recommendations were met. That is why we decided to use the permanent backing of wire with diameter similar to the gap size. The permanent backing was mounted when assembling so the gap size was checked. A burn-through and molten metal outflow occurred in conditions of a short arc and wire support (Figure 7, a). One edge was cut off and there was an undercut on the other one with inclined torch and short arc (Figure 7, b). In conditions of increased voltage and slowed down wire feed rate there was arcing between two edges without penetration into the joint though (Figure 7, c). To provide simultaneous heat input into both edges and permanent backing we specified needed voltage and arc column diameter similar to the gap size (Figure 7, d). So weld root formation and fusion with edges were provided.



**Figure 7** Welding with permanent backing in the weld root (a – wire burn-through, b – edge undercut, c – incomplete fusion, d – perfect process)

Figure 8 outlines etched metallographic section of a root weld. As one can see, a back weld bead was formed, and edges were fused along the whole gap thickness. These welding parameters facilitated complete filling the gap. If required a facing bead can be made.



**Figure 8.** A metallographic section of a root weld of 12 mm T-joint

Had analyzed the experimental data the following conditions and operating recommendations were offered: voltage 33.6 V, wire feed rate 9.5-10.5 m/min, mean current strength 325-340A, gap in the joint  $4\pm 0.5$  mm, incline angle of the torch along the weld axis  $5-10^\circ$  when welding with electrode inclined under obtuse angle, and incline angle across the weld axis  $80-90^\circ$ .

Therefore, on the basis of carried out investigations the interdependence of pulsed arc welding and formation of a T-joint over 10 mm has been revealed. Technological recommendations have been made with respect to pulsed arc welding with short circuits; the cost price of product manufacturing can be reduced on their basis due to reduction of labor input required by machining, lowering consumption of welding materials and electric power.

#### 4. Conclusions

1. Complete penetration is possible provided that gap breadth is  $4\pm 0.5$  mm, wire feed rate is 9.5-10.5 m/min, mean current strength 325-340A, and incline angle of the torch along the weld axis  $5-10^\circ$  and incline angle of the torch towards the vertical edge  $80-90^\circ$ .

2. The efficient welding conditions are those when welding arc melts both edges and backing simultaneously. These conditions are provided at arc voltage 33 V and gap breadth  $4\pm 0.5$  mm.

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