JST: Engineering and Technology for Sustainable Development
Volume 34, Issue 2, April 2024, 048-057

Research and Manufacture of Hydraulic Butt Fusion Welding Machine for Different Plastic Material Pipes

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Abstract

This paper introduces the research and manufacture of a hydraulic butt fusion welding machine that permits to weld dissimilar plastic pipes. In welding of dissimilar plastic pipes, the welding parameters at two pipe ends will be different. The butt fusion welding cycle of two dissimilar plastic pipes is established. The fabricated welding machine consists of the following basic components: machine body, two heating plates, four movable clamp rings, hydraulic movement mechanism to move the heater plate, hydraulic system to control the pressure and also to move the pipe ends during welding process. The pressed system has four movable cylinder tubes that move on four fixed pistons. At each side (left and right), a pair of two clamp rings is mounted on two movable cylinder tubes to provide forward and backward movement of a pipe during welding process. Two heater plates heat the two plastic pipe ends at different temperatures depending on the welding temperature of each plastic pipe material. The welding process is built in order to weld two dissimilar plastic pipes. The fabricated hydraulic butt fusion welding machine and the established welding process ensure accuracy and quality for the welding joint of dissimilar plastic pipes.

Keywords: Butt fusion, dissimilar plastic, pipe welding, plastic pipe, welding machine.

1. Introduction

Nowadays, plastics are increasingly used to replace metal and alloy materials because of their outstanding advantages such as durability, lightness, electrical insulation, heat insulation, sound insulation, good corrosion resistance, and low cost [1]. Plastic pipes are applied in many sectors like potable water distribution, gas transport, waste water discharge, seawater intake and discharge, chemical industry,… [2, 3]. Welding is the most effective method to join plastic pipes that require high strength and tightness. There are many different methods for welding plastic pipes, as in following.

- Extruded bead sealing (extrusion welding): a bead of very hot plastic is applied between two other plastic pipe ends. This is typically done with a welding rod and a handheld plastic extruder. After the hot plastic is applied, the plastic pipe ends are pressed together. Sometimes the two plastic pipe ends are heated to help form a bond. Extrusion welding is used for joining plastic pipes but is rarely used in joining plastic pipes for pressure applications, such as water or gas pipes.

- Hot gas welding: this method uses a specially designed heat gun to soften the two plastic pipe ends that are to be joined, along with a filler rod. The method is similar to extruded bead sealing in that it uses directly applied heat to the plastic pipe ends. This welding method is often used to join small-diameter plastic pipes [4].

- Solvent welding: this method uses a solvent, which softens the two pipe ends of plastic so the polymer chains can be merged. Rather than heat, this technique softens the plastic with solvents like dichloromethane or tetrahydrofuran to help merge the polymer chains. The solvent eventually evaporates, leaving the two plastic pipe ends to harden again, forming a weld. Solvent welding is a simple and inexpensive process that can produce durable, hermetic joints. The solvent processes also avoid the stress concentrations. The solvent welding can produce welds with very little or no weld flash, giving a better appearance. But, this welding method is not suitable for pressure plastic pipes.

- Socket fusion welding: the pipe components are welded in overlapped condition. The pipe end and fitting are heated up to welding temperature by a socket or spigot-shaped heated tool and subsequently joined together. The socket fusion welding is mainly used for pipes up to 125 mm outside diameter [4].

- Electro fusion welding: the welding is done with heating resistors inside the fusion fitting. In this method of welding, two pieces of pipe are placed in the fittings, and the ends of the welding machine are connected to the resistors of the fittings and heated.

ISSN 2734-9381
https://doi.org/10.51316/jst.173.etsd.2024.34.2.7
Received: 28 Dec 2023; revised: 6 Mar 2024;
accepted: 15 Mar 2024

Plastic pipes can be welded by resistance fusion welding up to 1200 mm in diameter.

- Butt fusion (or hot plate) welding: in this welding process, the two ends of the pipes are heated and both ends are pushed toward each other by pressure under a certain temperature. Plastic pipes up to 2500 mm in diameter can be welded using this method [5].

Each welding method has advantages and disadvantages and it is suitable for different pipe types, pipe materials, and their applications. To weld large-diameter plastic pipes, electro fusion welding method and butt fusion welding method are commonly used in practice today [1, 3]. There is not much difference in quality between the butt fusion and the electro fusion fusion welding methods. The butt fusion welding is more advantageous compared to the electro fusion welding by seeing the welding position. The electro fusion welding is more advantageous when it is necessary to weld on high ground or where a butt fusion welding machine can not fit. In the electro fusion welding method, the factors determining weld quality are higher than those of the butt welding (pipe ovality, electrical voltage and continuity, measurement tolerances,...). Therefore, butt fusion welding is more advantageous than electro fusion welding. In terms of welding cost, the butt fusion welding is more advantageous than the electro fusion welding. Butt fusion welding does not require couplings or added material while electro fusion welding requires the coupling. To weld large diameter plastic pipes, especially plastic pressure pipes, Butt fusion welding is more suitable than electro fusion welding [1, 3].

Plastic materials have three kinds: thermoplastic materials, elastomers, and thermoset resins. Almost any thermoplastic materials (for example, polyvinyl chloride - PVC, polyvinyl fluoride - PVDF, polyethylene - PE, polypropylene - PP, polystyrene - PS,…) can be welded by the butt fusion welding process, but this welding process is most often used for softer, semi-crystalline thermoplastics such as PP and PE [4]. Thermoplastic materials become pliable when heated above a specific temperature and then harden after cooling. The butt fusion welding is the process of thermoplastic pipe joining using a combination of heating, pressure, and cooling. Based on the pressure-generating mechanism, butt welding machines are divided into 3 kinds. The first kind is the hand-push butt fusion machine. In this machine, the pressure is created by hand through the lever mechanism. The second kind is the manual butt fusion machine in which the pressure is created by the mechanical mechanism (usually pinion and rack mechanism or lead screw nut mechanism). The third kind is the hydraulic butt fusion machine in which the pressure is created by hydraulic system. The hydraulic system makes the pressure accurate and the machine works smoothly.

Plastic pipes that work in different environments and conditions will be made from different plastic materials to take advantage of each plastic material and to reduce the costs. The welding of two pressure pipes of different plastic materials is a complicated problem. In order to weld the different plastic material pipes, it is necessary to research the suitable welding technology and welding parameters. In addition, to weld two pipes of different plastic materials, special welding equipment is required. Current butt fusion welding machines only allow welding two plastic pipes of similar materials [1-3, 5-7]. This paper introduces the development of automatic hydraulic butt fusion welding machine for plastic pipes of different materials. The butt fusion welding cycle for dissimilar plastic pipes will be built. In addition, the research also provides a technological process to weld plastic pipes of different materials together on this welding machine.

2. Butt Fusion Welding of Similar Plastic Material Pipes

2.1. Principle of Butt Fusion Welding of Plastic Pipes

The principle of butt fusion welding is to heat two pipe ends by means of a heater plate to a designated temperature, then fuse them together by applying pressure and cooling them under pressure for a designated time. The principle of butt fusion welding is presented in Fig. 1.

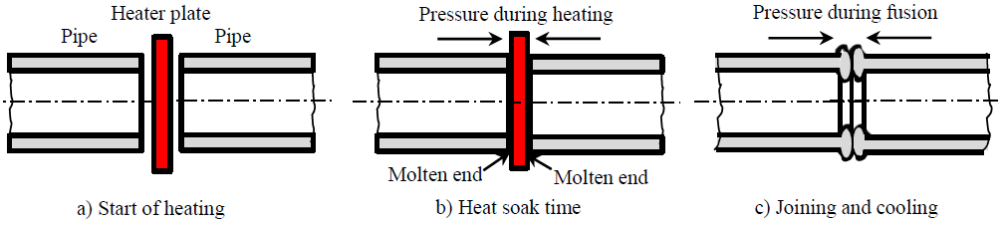

Fig. 1. Principe of butt fusion welding

Firstly, the pipe ends are cut square and flat; then they are pushed against a heater plate until they melt; after that the heater plate is removed and the pipes are pushed together under closely controlled pressures and allowed to cool, forming a weld. The butt fusion welding process consists of the following steps.

1 - The pipe ends are trimmed by a rotating cutter to remove rough ends and oxidation layers. The end faces after trimming must be square and parallel.

2 - The pipe ends are heated by contact under pressure against a heater plate. The contact is maintained until even heating is established around the pipe ends, and the contact pressure is then reduced to a lower value called the heat soak pressure. The contact is then maintained until the appropriate heat soak time elapses.

3 - The heated pipe ends are then retracted, and the heater plate is removed. The heated pipe ends are then brought together and pressurized evenly to the welding pressure value. This pressure is then maintained for a period to allow the welding process to take place, and the fused joint to cool down to ambient temperature and hence develop full joint strength. During this cooling period, the joints must remain undisturbed and under compression.

2.2. Parameters for Butt Fusion Welding of Plastic Pipes

The butt fusion welding parameters include temperature, time and pressure. If the combination of time, pressure and temperature is correct, the quality of the weld is satisfactory.

2.2.1. Temperature

Each thermoplastic has a specific temperature range for effective welding. If the temperature is too low, there will not be enough weld penetration. If the temperature is too high, it will decompose the plastic. The heating temperature is critical to the correct development of the heat affected zone and a plastic pipe melt that is sufficiently fluid that the molecules can readily mix together to produce good fusion across the weld plane.

The heater plate temperature for pipe welding depends on the pipe material and pipe wall thickness. With the same pipe material, the higher temperature is used for smaller wall thickness, the lower temperature for larger ones. Most thermoplastic pipes are welded with the heater plate temperature from 200 ºC to 240 ºC [8-12].

2.2.2. Pressure

The strength of the weld comes from the proper blending of the base material of the two pipe ends to be welded. This is not possible if the pressure is too high or too low. Excessive pressure causes the weld to protrude excessively. If the pressure is not enough, the weld penetration ability is poor. In pipe butt fusion welding, there are three basic pressure parameters (Fig. 2).

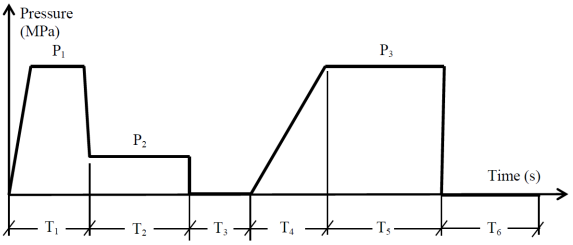

Fig. 2. Butt fusion welding cycle for two similar plastic material pipes [8, 12]

- Bead-up interface pressure (P_1): this pressure is applied during the pipe ends being in contact with the heater plate. The bead-up interface pressure is required to press the pipe ends against the heater plate with sufficient force to displace the initial melt. This pressure ensures that every part of the pipe end touches the heater plate. The bead-up interface pressure which depends on the pipe material can be from 0.1 MPa to 0.62 MPa [5, 8-12]. For example, the specified value of the bead-up interface pressure is 0.15 MPa for HDPE (high-density polyethylene) pipes [8], 0.1 MPa for PP pipes [9], 0.6 MPa for PVC-U (unplasticized polyvinyl chloride) pipes [10], 0.5 MPa for PVC-C (chlorinated polyvinyl chloride) pipes [11].

- Heat-soak interface pressure (P_2): this pressure is required to overcome frictional resistance in the welding machine and pipe string so that the pipe ends are held in contact with the heater plate. The pressure should be slightly positive but insufficient to displace molten plastic material from the heat-affected zone. This pressure is under 0.01 MPa [8-12].

- Welding interface pressure (P_3): this pressure is required to hold the melted pipe ends together so that the molten materials in each pipe end inter-diffuse. In the welding of similar plastic pipes, the welding interface pressure is at the same value as the bead-up interface pressure ($P_3 = P_1$) [5, 8-12].

In all butt fusion welding machines, drag pressure is required to overcome the sliding friction of the equipment while moving the pipes [2, 5, 12]. It is the hydraulic pressure that is required to move the pipe holding carriage (movable clamp rings). The drag pressure must be added to the applied pressure values. The drag pressure depends on the kind of butt fusion welding machine. It can vary from 0.1 MPa to 1 MPa or more [2]. The drag pressure is normally supplied by the manufacturer of the butt fusion welding machine. However, it can be determined by testing on a welding machine. In the case where the force is generated by using a hydraulic cylinder, the force is indicated in terms of the applied cylinder pressure. In this case, it is necessary to determine the relationship between the actual interface force and the pressure indicated by the

machine pressure gauge. The calculation for hydraulic gauge pressure on a butt fusion machine is as follows [12]:

$$GP = \left(IP \times \frac{A_S}{A_c} \right) + DP \quad (1)$$

in which: GP is the gauge pressure (MPa); IP is the interfacial pressure (MPa); A_c is the total effective piston area (mm^2); A_s is the interfacial surface area of two welded pipes (mm^2); DP is the drag pressure (MPa).

The interfacial surface area of two welded pipes can be calculated by the following formula:

$$A_s = \pi \text{ x } (OD - t) \text{ x } t \quad (2)$$

where: OD is the nominal outside diameter of the pipe (mm); t is the nominal wall thickness of the pipe (mm).

2.2.3. Time

The time parameters are important to the integrity of the finished weld. The pipe wall thickness has a significant influence on time parameters, and heavy walled pipes require very long heating and cooling times because of the low coefficient of thermal conduction in plastic material. The time required for a plastic pipe butt fusion weld includes the total time of the following 6 stages [8, 12] (Fig. 2):

1 - Beat-up time (T_1) is the time to generate a continuous bead around the pipe ends in contact with the heater plate under bead up pressure (P_1). The bead-up indicates the entire pipe end is in even contact with the heater plate. The beat-up time is used in order to reach the initial beat-up size (the height h) on both welding pipe edges. The height h depends on the pipe wall thickness and pipe material. This height increases with increasing pipe wall thickness. The value of this height varies from 0.5 mm to 10 mm [8-12].

2 - Heat soak time (T_2) is the time that the pipe ends are in contact with the heater plate at heat soak pressure (P_2). During the heat soak time, the heat penetrates the joint areas and the welding temperature is reached. This time depends on the pipe material and wall thickness. It can be from a few dozen to several hundred seconds [8-12].

3 - Changeover time (T_3) is the allowable maximum time to separate the pipe ends from the heater plate, remove the heater plate, and bring the two molten pipe ends together. This time should be as short as possible. The heater removal time depends on the pipe material and wall thickness. It can change from 2 seconds to 30 seconds [8-12]. The pressure in this stage is equal to zero because the pipe ends are retracted.

4 - Ramp up time (T_4) is the time to progressively increase the pressure from 0 to the welding pressure (P_3). The welding pressure must be increased in a controlled and linear fashion so that the molten plastic material is rolled out of the weld is not too great. This time depends on the pipe material and wall thickness. It changes from a few seconds to tens of seconds [8-12].

5 - Cooling time in the clamps (T_5) is the cooling time to room temperature under welding pressure (P_3). The pipe material and wall thickness influence this time range. It can be from 4 minutes to over an hour [5, 8-11].

6 - Cooling time out of the clamps (T_6) is the time cooling without pressure. After the cooling time in the clamps, the welded joint can be removed from the welding machine, without being subjected to significant stress. It is necessary to avoid pulling, installation, pressure testing, and rough handling of welded pipe for at least an additional 30 minutes. Heavier wall thickness pipes require longer cooling times.

The range of parameters for butt fusion welding of most thermoplastic pipes (PVC-U, PVC-C, PP, HDPE,…) is summarized in Table 1.

Table 1. Parameters for butt fusion welding

Parameter	Value
Heater plate temperature (°C)	200 ÷ 240
Bead-up interface pressure, P_1 (MPa)	0.1 ÷ 0.6
Heat-soak interface pressure, P_2 (MPa)	≤ 0.01
Welding interface pressure, P_3 (MPa)	0.1 ÷ 0.6
initial beat-up size, h (mm)	0.5 ÷ 10
Heat soak time, T_2 (s)	≥ 10
Changeover time, T_3 (s)	2 ÷ 30
Ramp up time, T_4 (s)	≤ 10
Cooling time in the clamps, T_5 (min)	≥ 4
Cooling time out of the clamps, T_6 (min)	≥ 30

2.3. Butt Fusion Welding Machine of Similar Plastic Material Pipes

The butt fusion welding parameters of both similar plastic material pipes (heating temperature, bead-up interface pressure, heat-soak interface pressure, welding interface pressure, beat-up time, heat soak time, changeover time, ramp-up time, cooling time in the clamps, cooling time out of the clamps) are the same. Available hydraulic butt fusion welding machines are only suitable for welding plastic

pipes of the same material together [5-7]. The general principle of these welding machines is as follows: during heating, one pipe is kept fixed while the other pipe is moved to press the two pipe ends against both sides of the heater plate; The heater plate is then pulled out and the two pipe ends are pressed together to form a welded joint. Thus, it is only necessary to use one heater plate to heat both pipe ends and a pair of hydraulic cylinders to move one pipe end. The principle diagram of available hydraulic butt fusion welding machine is presented in Fig. 3.

Based on the above principle, the current hydraulic butt fusion welding machines have the following basic components.

1 - Machine body: the machine body supports the components of the machine.

2 - Movable cylinder tube: two movable hydraulic cylinder tubes move two movable clamp rings forward and backward and supply the necessary movement for the welding process.

3 - Piston rod: two piston rods support and center the plastic pipes with two fixed and two movable clamp rings. Two pistons act as a guide for the movement of two hydraulic cylinders.

4 - Hydraulic unit: the hydraulic unit creates the movement of the pipes. It provides the pressure for the welding process.

5 - Clamp ring: the clamp rings are used to clamp the pipes. There are four clamp rings, two of which are rigidly, and two remaining clamp rings are movable. Two movable clamp rings are fastened on two movable hydraulic cylinder tubes.

6 - Heater plate: two pipe ends will be heated by the heater plate before the welding process.

3. Butt Fusion Welding of Dissimilar Plastic Material Pipes

3.1. Design of Butt Fusion Welding Cycle for Dissimilar Plastic Pipes

It is possible to weld plastic pipes with dissimilar melting temperatures (and melt flow rates) by butt fusion welding. This is done by heating the two pipe ends to different temperatures before pressing them together. In butt fusion welding of two dissimilar plastic pipes, the welding parameters at the two pipe ends will be different. Exactly, heating temperature and time, pressure and time at different stages for two plastic pipe ends are different. The pressure and the time at different stages in the welding cycle of two dissimilar plastic pipes will theoretically be within the range of pressure and time of the two respective pipe materials.

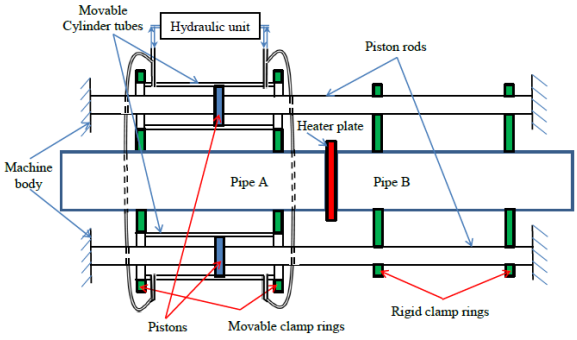

Fig. 3. Principle diagram of available hydraulic butt fusion welding machine

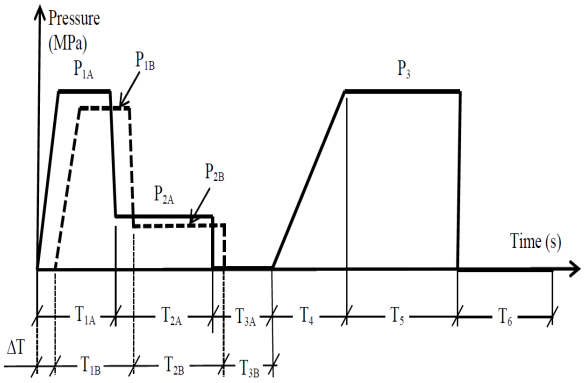

Fig. 4. Development of butt fusion welding cycle for two dissimilar plastic pipes

Based on the above analysis, the new butt fusion welding cycle for two plastic pipes of different materials is built and shown in Fig. 4, in which: T_{1A} and T_{1B} are the beat-up time for pipe A and pipe B, respectively; T_{2A} and T_{2B} are the heat soak time for the pipe A and the pipe B, respectively; T_3 , T_4 , T_5 and T_6 are changeover time, ramp up time, cooling time in the clamps and cooling time out of the clamps, respectively; P_{1A} and P_{1B} are the bead up interface pressure for the pipe A and the pipe B, respectively; P_{2A} and P_{2B} are the heat soak interface pressure for the pipe A and the pipe B, respectively; P_3 is the welding interface pressure; the pipe A and the pipe B represent two pipes in a butt welding joint.

3.2. Development of Hydraulic Butt Fusion Welding Machine for Dissimilar Plastic Pipes

In order to heat the two plastic pipe ends to two different welding temperatures, two heater plates are required. Since the heating time to the welding state and the pressing force as well as the pressing time for the two plastic pipe ends at different stages are different, the two plastic pipe ends need to be pressed independently. To do this, each pipe end will be clamped by a pair of two movable hydraulic cylinders. Thus, there will be a total of four movable hydraulic cylinders. Based on these requirements, the principle diagram of a hydraulic butt fusion welding machine for two dissimilar plastic pipes is developed and presented in Fig. 5.

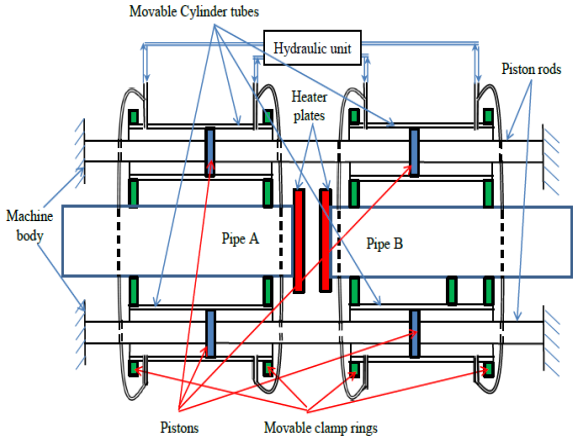

Fig. 5. Principle diagram of hydraulic butt fusion welding machine for two dissimilar plastic pipes

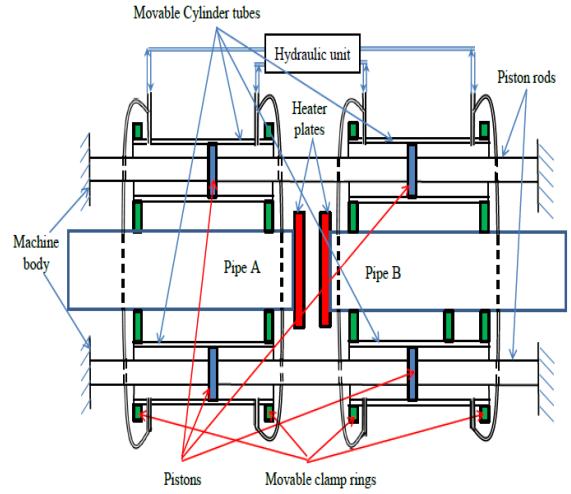

Fig. 6. Schematic illustration of a butt fusion welding machine for two dissimilar plastic pipes

The hydraulic butt fusion welding machine for two dissimilar plastic pipes is designed and presented in Fig. 6.

This welding machine consists of the following basic components.

1 - Machine body: the machine body supports the components of the machine.

2 - Movable cylinder tube: four movable hydraulic cylinder tubes move the four movable clamp rings forward and backward and supply the necessary movement for the welding process. Each side uses a pair of two movable cylinder tubes to move the two pipe ends independently and create different pressures at the two pipe ends in the heating period.

3 - Piston rod: four-piston rods support and center the plastic pipes with four movable clamp rings. These pistons act as a guide for the movement of four hydraulic cylinder tubes.

4- Heater plate movement mechanism: this mechanism brings two heater plates into the heating position and removes them after heating.

5 - Heater plate movement cylinder: this is a part of the heater plate movement mechanism. It is a hydraulic cylinder.

6 - Lower clamp ring: four lower clamp rings are fastened on four movable hydraulic cylinder tubes.

7 - Upper clamp ring: there are four upper clamp rings. Each upper clamp ring connects to one lower clamp ring to create one movable clamp ring. These clamp rings are used to clamp the pipes.

8 - Heater plate: two heater plates are used to heat two welded pipe ends at different temperatures.

9 - Clamp jaw: clamp jaws are located inside the clamp rings to clamp pipes of different diameters. The clamp jaws can be added or removed to suit different pipe diameters. Each pair of jaws has two halves that fit into each half of the upper and lower clamp rings.

In addition, the welding machine also has a hydraulic unit and a control system. The hydraulic unit creates the movements for cylinders to move pipe ends, heat plates and create appropriate pressure at different stages of the welding process. The hydraulic unit includes an oil tank, pump, hydraulic valve system,... The control system consists of programmable logic controller (PLC), control program, display screen (human machine interface - HMI), control cabinet and control panel. The built control program permits the user to select the welding parameters. This system controls the hydraulic unit to create forward and backward movement of plastic pipes, to put the heater plates into heating position and to remove the heater plates after heating. It controls the pressure during heating and welding. All these tasks of control system aim to fully automate the welding process.

3.3. Manufacturing of Hydraulic Butt Fusion Welding Machine for Dissimilar Plastic Pipes

Based on the above principles, the hydraulic butt fusion welding machine for dissimilar plastic pipes with pipe diameters from 63 mm to 200 mm is designed and fabricated (Fig. 7).

This machine has the main components with the technique specifications as follows.

- 4 movable clamp rings: these clamp rings allow clamping of a pipe diameter of 200 mm. The removable clamp jaws are installed inside the clamp rings in order to clamp smaller diameter pipes. According to plastic pipe standards [13-15], there are 9 pipe diameter sizes from 63 mm to 200 mm (63, 75, 90, 110, 125, 140, 160, 180, 200 mm). Here, 8 sets of corresponding clamping jaws are used to clamp pipe sizes below 200 mm in diameter. The pipes which have

the diameter of 200 mm are clamped directly by clamp rings without clamping jaws.

- 4 pipe movement cylinders: these hydraulic cylinders are used to move pipes and create pressure during the welding process. The movable cylinder tube has an inner diameter of 40 mm. The diameter of the piston rod is 25 mm. The stroke length of each cylinder is 100 mm. The maximum working pressure is 135 atm.

- 2 heater plates: the maximum heating temperature of each heater plate is 300ºC. This temperature allows welding of most thermoplastic pipe materials. The power of heater plate is 1.6 kw with a voltage of 220 V. The two heating plates are put into the heating position and lifted out at the same time. However, the plastic pipe with the longer heating time will be brought into contact with the corresponding heating plate first.

- 1 heater plate movement cylinder: this hydraulic cylinder has the inner diameter of cylinder tube of 40 mm. The diameter of piston rod is 20 mm. The stroke length of this cylinder is 100 mm.

- The hydraulic valve system of this welding machine includes 7 directional control valves, 6 pressure control valves and 1 flow control valve. The directional control valve is a 5/3 solenoid valve which is controlled by electric current to ensure fast and precise control.

- The control cabinet: It contains the accessories for the control system such as PLC, HMI, 24VDC source, circuit breaker (automat), contactor, terminal block,… The control system uses programmable logic controller (PLC) and the human machine interface (HMI) which is a touch screen of kind 7", 256 MB RAM, 256 MB ROM. The welding parameters are entered via the screen and saved in memory. In addition, the program also allows users to select previously entered welding programs.

- The control handle: It is used for the preparation process before welding such as mounting, aligning and beveling the pipe ends. The control handle is also used for welding process.

- Working range: the weldable plastic pipe diameter is from 63 mm to 200 mm.

The drag pressure of this machine is determined by the following procedure: the machine's hydraulic control is slowly adjusted upward to initiate the movement of a pair of movable clamp rings at one pipe end. The drag pressure is the gauge pressure at which the movable clamp ring pair starts to move on the hydraulic fusion machine. This measurement is repeated to verify the observed reading. Since the cylinders and clamping rings are the same at both ends of the welding machine, the drag pressure at both ends is the same.

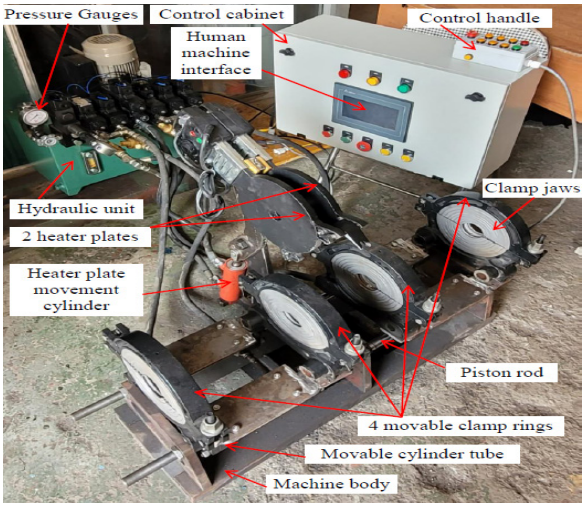

Fig. 7. Hydraulic butt fusion welding machine for two dissimilar plastic pipes

The obtained result for the drag pressure of this welding machine is 0.35 MPa. In comparison with the minimum drag pressure of 0.2 MPa in the normal hydraulic welding machines [16, 17] and the drag pressure of 1 MPa in the hydraulic welding machine for the pipe diameter of 355 mm [18], the drag pressure of this welding machine is suitable.

3.4. Butt Fusion Welding Process for Dissimilar Plastic Pipes

The process of butt fusion welding of dissimilar plastic pipes includes the following steps:

1- Installing clamps that match the diameter of welded pipes. Connect the welding machine to the mains or alternating current generator.

2 - Setting up the welding parameters: the temperature of two heater plates; the times T_{1A}, T_{1B}, T_{2A}, T_{2B}, T_3, T_4, T_5 and T_6; the pressures: P_{1A}, P_{1B} , P_{2A}, P_{2B} and P_3.

3 - Fixing two pipes into the clamp rings to ensure that the two pipes are aligned.

4 - Machining the pipe ends by planning tool. Clean the pipe surfaces to be welded.

5 - Adjusting the concentricity of the two pipes. Check the coplanarity by moving the joining areas together (conformability of maximum gap).

6 - Inserting the heater plate: when two heater plates have reached the required temperatures, they are brought simultaneously into the heating position.

7 - Heating the pipe ends: the pipe end that has larger total heating time ($T_1 + T_2 + T_3$) will be heated first. Then, after a period of time

$$\Delta T = \left|\left(T_{1A} + T_{2A} + T_{3A}\right) - \left(T_{1B} + T_{2B} + T_{3B}\right)\right|,$$

the other pipe end is started the heating process. In this period, the P_{1A} and P_{1B} pressures ensure that the A and B pipe ends, respectively, are fully contact with the heater plates. These pressures allow the formation of a bead of molten material around the pipe end. After that, the P_{1A} and P_{1B} pressures are reduced to P_{2A} and P_{2B} pressures, respectively. The P_{2A} and P_{2B} pressures are maintained until the required bead has been achieved.

8 - Removing the heater plate: after the required bead has been achieved, the pipe ends are withdrawn from the heater plates and the two heater plates are removed from the heating position in a period of time T_3.

9 - Welding two pipes: the pipes are then brought together by a pressure that increases from 0 to P_3 during the time T_4. The P_3 pressure is maintained in the period of time T_5 to ensure weld strength.

10 - Cooling the weld: the time interval T_6 without pressure is required to ensure a stable weld.

11 - Inspecting the weld : the finished weld can be inspected for uniformity and alignment.

4. Test Welding and Result

In order to test the manufactured welding machine, two pipes of HDPE and PP-R (polypropylene random copolymer) are joined by the machine and cycle of butt fusion welding for dissimilar plastic pipes which are constructed above. The outer diameter of these pipes is 75 mm. The wall thickness of HDPE pipe and of PP-R pipe is 3.6 mm and 6.8 mm, respectively. The physical and mechanical properties of these two pipe materials are presented in Table 2 [19].

The parameters for butt fusion welding of these two pipes are shown in Table 3. The butt fusion welding cycle for these two pipes is presented in Fig. 8.

Table 2. Properties of HPDE and PP-R

Property	HDPE	PP-R
Density (g/cm^3)	0.95÷0.96	0.90÷0.91
Thermal expansion coefficient (mm/m^{0}C)	0.2	0.15
Temperature range (^{0}C)	≤ 50	0 ÷ 95
Heat conductivity coefficient (W/mK)	0.4	0.24
Tensile strength (MPa)	20	23
Elastic modules (MPa)	800-1100	800

Table 3. Parameters for butt fusion welding of HDPE pipe and PP-R pipe

Parameter	HDPE	PP-R
Heater plate temperature (^{o}C)	220	210
Bead-up interface pressure, P_1 (MPa)	0.15	0.1
Heat-soak interface pressure, P_2 (MPa)	0.05	0.05
Welding interface pressure, P_3 (MPa)	0.1	0.1
Beat-up time, T_1 (s)	2	3
Heat soak time, T_2 (s)	13	17
Changeover time, T_3 (s)	1.5	2
Ramp up time, T_4 (s)	5	
Cooling time in the clamps, T_5 (min)	6	
Cooling time out of the clamps, T_6 (min)	30	

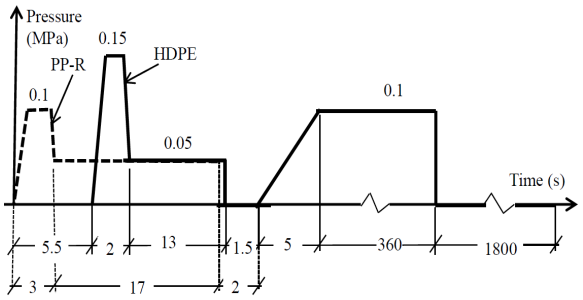

Fig. 8. Butt fusion welding cycle for two pipes of HDPE and PP-R

The welded specimen of butt joint between the HDPE pipe and PP-R pipe which is realized by the manufactured machine is presented in Fig. 9. The shape and size of this weld meet the requirements according to DVS 2202-1 [20]. The tensile test specimens of pipe butt welded joints of HDPE and PP-R are prepared in accordance with DVS 2203-2 [21]. The specimen of pipe welded joints of HDPE and PP-R after the tensile test is given in Fig. 10. The tensile strength of this pipe welded joint is 18.9 MPa. Thus, the tensile strength of this pipe welded joint reaches 94.5% of that of the base material (HDPE). This value is higher than the minimum required tensile welding factor for HDPE and PP-R pipes which is 90% [22]. So the joint of HDPE and PP-R pipes which is welded by the manufactured machine meets the requirements. This proves that this machine can weld two pipes of different materials.

Fig. 9. Pipe welded specimen of HDPE and PP-R

Fig. 10. Specimen after the tensile test

5. Conclusion

Based on the butt fusion welding cycle for two similar plastic material pipes and the existing butt fusion welding machine which is used to weld two plastic pipes of the same material, this study has built the butt fusion welding cycle and developed the welding machine for two plastic pipes of different materials. The butt fusion welding machine for dissimilar plastic pipes is developed with four movable hydraulic cylinder tubes that are divided into two pairs to move two plastic pipes. These cylinder tubes allow the two pipes to move independently and to be pressed with different pressure values and pressing times. This welding machine has two heater plates that allow the two pipe ends to be heated at different temperatures and heating times. The movement of heater plates is carried out by the hydraulic movement mechanism. This welding machine also includes a control system that allows to change of the welding parameters and to fully automate the welding process according to the desired welding cycle.

The butt fusion welding machine for dissimilar plastic pipes is designed and fabricated with a simple structure to reduce costs, but it is integrated with modern mechanisms and control systems to improve the weld quality and the accuracy of the welded joint.

The constructed welding machine has been tested and completely satisfies exactly the requirements of welding parameters such as the desired welding cycle. This proves that this welding machine is completely suitable for welding two dissimilar plastic pipes. This study also conducted tests on the fabricated welding machine to determine the drag pressure. The drag pressure of this welding machine is 0.35 MPa.

This welding machine is not only used to weld two plastic pipes of different materials but it can also be used to weld pipes of the same material. The fabricated welding machine allows for welding plastic pipes with different diameters and wall thicknesses. The outstanding novelty of this study is the butt fusion welding cycle for two plastic pipes of two different materials has been built, and; the butt fusion welding machine in order to weld two pipes of two different materials has been designed and manufactured.

Acknowledgments

This work was supported by the Ministry of Education and Training of Vietnam under the Project "B2023-BKA-12".

The author would like to thank the Ministry of Education and Training of Vietnam and the Hanoi University of Science and Technology.

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