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Influence of Butt Fusion Welding Parameters on Tensile Strength of Unplasticized Polyvinyl Chloride Pipe Welding Joints

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Abstract

Unplasticized polyvinyl chloride (PVC-U) plastic pipes are used in many fields such as water distribution, wastewater discharge, electric cable protection systems, gas distribution, etc. The butt fusion welding is often used for large diameter plastic pipes. The welding process is used to weld the pipes which are subjected high pressure. The butt fusion welding process produces durable, high-quality welds at low cost. The paper studies the influence of butt fusion welding parameters such as heating temperature, heating time, heat soak pressure, and fusion joining pressure on the tensile strength of PVC-U pipe welding joints. The studied results showed that the reasonable tensile strength of welded joints of PVC-U pipe will be reached in a narrow range of butt fusion welding parameters. The research also indicated that some welding parameters of PVC-U pipe such as heating temperature, changeover time, bead-up pressure, heat soak pressure, and fusion joining pressure can be fixed. These parameters do not depend on the diameter or wall thickness of the PVC-U pipe. Other welding parameters such as heating time and joining time will depend on the diameter and thickness of the PVC-U pipe. With reasonable welding parameters, the tensile strength of PVC-U pipe welding joint can reach more than 90% of the tensile strength of base material which meets the minimum requirement of standard. The highest tensile strength of PVC-U pipe welding joint in this study can obtain to 97.6% of the tensile strength of base material.

Keywords: Butt fusion welding, plastic pipe welding, PVC-U pipe, tensile strength, unplasticized polyvinyl chloride.

1. Introduction

Polyvinyl chloride (PVC) is one kind of thermoplastics which soften and melt during heating and harden after cooling. Therefore, it can be joined by welding. PVC has amorphous structure [1]. Its basic properties are high strength to weight ratio, chemical inertness, corrosion weather resistance, electrical, and thermal insulators. PVC pipe is commonly used for drainage, water supply, gas distribution, electrical insulations, chemical processing, and industrial piping systems due to its low cost, moderate toughness, strength, chemical inertness, and light weight [1–6]. The research results of Emmanuel K. Arthur *et al.* [2] showed that PVC is the most suitable material for water pipe application in tropical environment. Pipes made of PVC material has a maximum operating temperature of 82 °C. So, it is not good for hot water transportation. There are two commonly used types of PVC pipes: unplasticized polyvinyl chloride (PVC-U) and chlorinated polyvinyl chloride (PVC-C). PVC-U pipe is less expensive than PVC-C pipe. Therefore, PVC-U pipe is used more commonly than PVC-C pipe.

PVC plastics can be welded by adhesive bonding [7], hot air welding [8-11], high frequency welding [12], ultrasonic welding [13], friction welding [4], socket welding [14], butt fusion welding [3], etc. There are many studies on welding of PVC plates or foils. Md Shakibul Haque *et al.* [8] have studied and fabricated hot air welding equipment with low cost for welding of PVC plates. This hot air welding equipment gives high quality weld with the tensile strength of 11.25 MPa. Ion Mitelea *et al.* [12] are researched on quality of welding joints from PVC foils at high frequency (HF) welding. This study indicated that the welding joint strength obtained by HF symmetric welding is better than other welding processes (pressure welding, ultrasonic welding, etc). Mahmood Alam and M. I. Khan [10] are studied the effect of variables in welding PVC plates by hot air welding process on the weld bead shape. In the research of Shakeel Ahmad Dar *et al.* [11], the relation between process parameter in hot air welding process and quality of welded structure of hard PVC plates is considered. This study showed that the joint made is still weaker than the parent material.

To weld PVC pipes, the following welding processes are often used: adhesive bonding [7], hot air welding [9], ultrasonic welding [13], friction welding [4], socket welding [14], butt fusion welding [3], etc. Among them, butt fusion welding is most commonly used to weld large diameter pipes with high pressure [3]. There are some studies on welding of PVC pipes in general and of PVC-U pipes in particular. S. C. Petriceanu *et al.* [13] are determined ultrasonic parameters and measured the relevant ultrasonic parameters in the detection of defects for welded PVC pipe. Kamran Ali and Shara Khursheed [9] are studied the influence of welding parameters in hot air welding on the microstructure of

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Heat Affected Zone (HAZ). Hanan Kouta *et al.* [4] are considered the influence of welding parameters of the inertia friction welding on residual stress and temperature distribution in welding joints of PVC pipes.

Considering the reviewed literature, one can conclude that although there have been several studies on welding of PVC pipes in general and of PVC-U pipes in particular, there is a shortage of butt fusion welding of PVC-U pipes, particularly a comprehensive study of the tensile strength of PVC-U pipe welds. Thus, the main purpose of this study is to determine the influence of butt fusion welding parameters such as heating temperature, heating time, pressure during heating, and joining pressure on the tensile strength of PVC-U pipe welding joints.

2. Butt Fusion Welding Parameters of Unplasticized Polyvinyl Chloride Pipes

In butt fusion welding, the plastic pipe surfaces to be welded are pressed into full contact with the heater plate under a pressure. When the pipe surfaces are sufficiently molten, they must be detached from the heater plate, the heater plate is removed. Then, two pipe surfaces are pressed together under a pressure (Fig. 1). The butt fusion welding cycle of plastic pipes includes six phases: bead-up time (t_1) under bead-up pressure (p_1), heat soak time (t_2) with heat soak pressure (p_2), changeover time (t_3) without pressure, ramp-up time (t_4) with pressure increasing linearly from zero to fusion joining pressure (p_3), cooling time in the machine (t_5) under fusion joining pressure, and cooling time out of the machine (t_6) without pressure (Fig. 1) [15, 16].

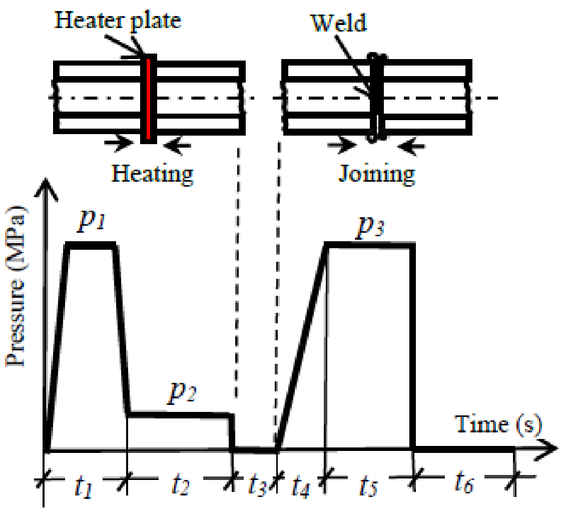

Fig. 1. Butt fusion welding principle and cycle

Butt fusion welding principle and cycle show that temperature, pressure, and time are significant parameters in butt fusion welding process.

The welding temperature is the temperature required for the plastic pipe material to reach the molten state. This temperature depends on the melting point of welded pipe material. The melting point of PVC material is 212 °C [17]. If welding temperature is too low then insufficient heat will be taken up by the plastic pipes, if it is too high then the degradation of the pipe material can occur. In butt fusion welding, the welding temperature is the temperature of heater plate. The heater plate temperature for butt fusion welding of PVC-U pipes is situated usually in the range of 220 °C to 240 °C [15]. The heater plate temperature is set on the heater plate. When the heater plate temperature reaches the preset temperature, the relay will automatically cut off the current. When the heating plate temperature drops to a certain temperature, the relay will switch on again to reheat the heater plate.

The pressure includes bead-up pressure, heat soak pressure, and fusion joining pressure:

- The bead-up pressure (p_1) is high enough to ensures that complete pipe to heater plate contact is achieved. The initial contact pressure should be held very short and reduced without breaking contact. The bead-up pressure for welding PVC-U pipes is about 0.6 MPa [15].

- The heat soak pressure (p_2) is very low, near zero ($p_2 \leq 0.01$ MPa [15]). It is just enough to maintain the continuous contact between the pipe surfaces and the heater plate. Therefore, this pressure only needs to overcome the friction force of the movable clamp rings in the welding machine. The high pressure during this phase will cause the molten plastic to be squeezed out.

- The fusion joining pressure (p_3) is used to ensure the molten pipe surfaces are fully squeezed together to form an intimate joint. The pressure applied during this stage is strictly controlled to create a high strength joint, to minimise the burr and the deformation of the welded pipes. In this phase, the strength of the welded joint depends on the proper mixing of the base material at both ends of the pipe to be welded. This is impossible if the pressure is too high or too low. An insufficient pressure results in poor penetration of the weld. Furthermore, too little pressure may be insufficient to move melt to cause de-fusion bonding and achievement of full strength. An excessive pressure causes the protruded excessively weld. Moreover, too much pressure may simply squeeze all the melt out of the joint causing voids and cold lap weld conditions. In general, the fusion joining pressure is equal to the bead-up pressure ($p_3 = p_1$) [15, 16].

The pressure which is created by the hydraulic cylinders is calculated by the following formula [16]:

$$p = \frac{(p_c - p_d).A_c}{A_s} \quad (1)$$

in which: p is the interfacial pressure between two pipe surfaces or between the pipe surface with heater plate (MPa); p_c is the gauge pressure at the inlet gate of cylinder (MPa); p_d is the drag pressure at which the pipe clamp rings begin to move (MPa); A_c is the total effective hydraulic cylinder area (mm^2); A_s is the interfacial surface area of two welded pipes or the contact surface area between the pipe and the heater plate (mm^2).

Each time period has an individual goal as following:

- The bead-up time (t_1) is required to create a continuous bead around the plastic pipe surfaces in contact with the heater plate. The bead-up time is finished when the bead heights around the entire pipe end have reached the values specified. The bead height is about 0.5 mm to 1 mm for the pipe wall thickness in a range of 3 mm to 6 mm [15].

- The heat soak time (t_2) is necessary to have adequate melt thickness at the pipe surfaces. In this time, the heat will penetrate into the pipe surfaces to be welded and heats these up to the welding temperature.

- The changeover time (t_3) includes detaching the pipe ends from the heater plate, removing the heater plate, and carrying the two molten pipe ends together. The changeover time should be kept as short as possible. If this time is long, the melted pipe ends can be cooled down. This will affect the weld quality.

- The ramp-up time (t_4) is the time to get the fusion joining pressure.

- The cooling time in the machine (t_5) is necessary for the achievement of the weld strength. This is the time duration for the cooling of the weld to ambient temperature.

- The cooling time out of the machine (t_6) is needed to stabilize the welding joint before loading.

The welding time for one pipe welding joint of butt fusion welding process can be calculated as the time from the start of welding (from beginning of t_1) until the end of the cooling time in the machine (finishing of t_5). During the remaining cooling time out of the machine (time t_6), the next weld can be started. The welding process has two principal stages: heating time and joining time. The heating time includes the bead-up time (t_1) and the heat soak time (t_2). The joining time includes the ramp-up time (t_4) and the cooling time in the machine (t_5).

Temperature, pressure, and time parameters must be coordinated during the heating stage to achieve the appropriate melting depth around the pipe ends. Similarly, the coordination of pressure and time parameters during the joining stage is essential to obtain a good appearance and high-quality weld.

3. Pipe Material and Study Methods

Two diameter groups of PVC-U pipe are studied. The first group is the PN 10 pipe of 10 bar nominal pressure, outer diameter of 75 mm and wall thickness of 3.6 mm. This pipe is called 75 mm pipe. The second group is the PN 12.5 pipe of 12.5 bar nominal pressure, outer diameter of 110 mm and wall thickness of 5.3 mm. This pipe is named 110 mm pipe. The physical and mechanical properties of PVC-U pipe material are given in Table 1 [18].

In these cases, the pipe wall thickness is situated in a range of 3 mm to 6 mm. Therefore, the bead-up time (t_1) is determined when the bead height reaches the required value of 0.5 mm to 1 mm [15]. Other time parameters can be preliminarily determined based on reference to the time calculation formulas for butt fusion welding of high-density polyethylene (HDPE) pipes as presented below.

- The heat soak time (t_2) is determined by the following equation [16]:

$$t_2 = (13.5 \pm 1.5) \text{ x } t_p \quad (2)$$

where: t_p is the pipe wall thickness (mm); t_2 is the bead-up time (s).

- The ramp-up time (t_4) is calculated by the following expression [16]:

$$t_4 = 3 + 0.03 \text{ x } d_o \quad (3)$$

where: d_o is the outside diameter of the pipe (mm); t_4 is the ramp-up time (s).

- The cooling time in the machine (t_5) is given by the following equation [16]:

$$t_5 = t_p + 3 \quad (4)$$

in which: t_p is the pipe wall thickness (mm); t_5 is the cooling time in the machine (min).

Table 1. Properties of PVC-U pipe material

Property	Value
Density (g/cm^3)	1.4–1.45
Thermal expansion coefficient (mm/m°C)	0.08
Minimum tensile strength (MPa)	45
Elastic module (MPa)	3000–3200

The welding time durations for the pipe of 75 mm in outer diameter and of 3.6 mm in wall thickness are: t_2 = 43-54 (s); t_4 = 5 (s); t_5 = 6.5 (min). The welding time durations for the pipe of 110 mm in outer diameter and of 5.3 mm in wall thickness are: t_2 = 64-80 (s); t_4 = 6 (s); t_5 = 8 (min). These are reference values for butt fusion welding of HDPE pipes. Then, in combination with the requirements as presentation in previous section for butt fusion welding of PVC-U pipes, these values are adjusted and experimentally welded to the PVC-U pipe. Finally, the survey parameters for butt fusion welding of PVC-U pipes in this paper are presented in Table 2.

Table 1. Parameters for butt fusion welding of PVC-U pipes

Parameter	Unit	75 mm pipe			110 mm pipe	
		Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**
Heater plate temperature (T)	ºC	200–250	230	230	230	230
Bead-up pressure (p_1)	MPa	0.5	0.5	0.1–0.8	0.5	0.2–0.8
Heat soak pressure (p_2)	MPa	0.01	0.01	0.01	0.01	0.01
Fusion joining pressure (p_3)	MPa	0.5	0.5	0.1–0.8	0.5	0.2–0.8
Bead-up time (t_1)	s	3	3	3	5	5
Heat soak time (t_2)	s	22	7–37	22	15–55	35
Changeover time (t_3)	s	3	3	3	3	3
Ramp-up time (t_4)	s	3	3	3	4	4
Cooling time in the machine (t_5)	s	240	240	240	360	360
Cooling time out of the machine (t_6)	min	30	30	30	30	30

The welding time durations for the pipe of 75 mm in outer diameter and of 3.6 mm in wall thickness are: t_2 = 43-54 (s); t_4 = 5 (s); t_5 = 6.5 (min). The welding time durations for the pipe of 110 mm in outer diameter and of 5.3 mm in wall thickness are: t_2 = 64-80 (s); t_4 = 6 (s); t_5 = 8 (min). These are reference values for butt fusion welding of HDPE pipes. Then, in combination with the requirements as presentation in previous section for butt fusion welding of PVC-U pipes, these values are adjusted and experimentally welded to the PVC-U pipe. Finally, the survey parameters for butt fusion welding of PVC-U pipes in this paper are presented in Table 2.

The welded joints of PVC-U pipes in this study are realized on the automatic butt fusion welding machine for dissimilar plastic pipes which is developed to weld two plastic pipes of different materials [19]. The image of this welding machine is showed in Fig. 2.

Fig. 2. Automatic butt fusion welding machine

This welding machine has two heater plates and two pairs of hydraulic cylinders. Each pair of hydraulic cylinders holds and move one pipe end. Therefore, the welding machine can heat two pipe surfaces with different heating temperatures and press the two pipe ends with different pressing times, and different pressing forces. So, it is suitable for welding two plastic pipes of different materials together.

The welding machine has a clamp system for holding the two pipes. The clamp system consists of four movable clamp rings and clamp inserts. Each pipe end is fixed by a pair of movable clamping rings. The clamp inserts are installed inside the clamp rings. The clamp inserts can be added or removed to fit different pipe diameters. The pipe clamp system not only securely holds the two pipes but also ensures the alignment and concentricity of these pipes. Additionally, it moves the pipe during bevelling and welding.

In addition, this welding machine has the automation control system by the programmable logic controller (PLC) and control program. In that way, the welding process is completely automated, and the welding parameters are precisely controlled. This butt fusion welding machine not only permits welding dissimilar plastic pipes together, but it also allows welding similar plastic pipes together [19]. In the case of welding two pipes of different materials, the welding parameters at the two pipe ends are selected differently to suit the welding parameters for each type of pipe material. In the case of welding two pipes of the same material, the welding parameters at the two pipe ends are chosen the same.

After welding, the welded specimens will be cut with the length of 200 mm (100 mm on each side of the weld seam) (Fig. 3 and Fig. 4). These welding specimens are inspected by the visual test according to DVS 2202-1 [20]. When the welding specimens meet the requirements of the visual test, they are cut along the length of the pipe to take 3 tensile test samples.

A tensile test on an electronic universal testing machine (WDW-10D, SUNPOC, China) is used to determine the tensile strength of both base material sample and welding sample of PVC-U pipes using standard sized specimens with dimensions as prescribed in DVS 2203-2 [21]. The length and width of the tensile test sample are 200 mm × 15 mm, respectively (Fig. 4). The thickness of this sample is the wall thickness of the welding specimen. The tests are performed at room temperature, with the length of the sample behind the jaws (gauge length) 120 mm. The test speed is 10 mm/min [21]. According to DVS 2203-1 standard [22], the tensile strength of PVC-U pipe welding joint is required to be at least 90% of the tensile strength of the base material.

When studying the influence of certain welding parameter on the tensile strength of the PVC-U pipe welding joint, the remaining welding parameters are fixed. Each of these fixed parameters is determined based on performing many experiments.

Fig. 3. Welding specimen of PVC-U 75 mm pipe

Fig. 4. Welding specimen of PVC-U 110 mm pipe

4. Results and Discussion

The welding specimens of PVC-U pipes are showed in Fig. 3 and Fig. 4. The tensile test sample of PVC-U pipe welding joint is presented in Fig. 5.

Fig. 5. Tensile test sample of PVC-U 110 mm pipe

The tensile strength of base material of PVC-U pipes which obtained by the tensile test is 44.9 MPa for 75 mm pipe and 44.7 MPa for 110 mm pipe. The tensile strength of PVC-U pipe welding joints will be compared with these values of tensile strength of the base material.

4.1. Welding Joints of 75 mm Diameter Pipe

In the first case, the heating temperature is increased from 200 ºC to 250 ºC with the step of 5 ºC. The other welding parameters are unchanged and presented in Table 2. The effect of the heating temperature on the tensile strength of PVC-U pipe welding joint is given in Fig. 6. The tensile strength of the pipe welding joint increases from 31.8 MPa to 43.8 MPa and then decreases from 43.8 MPa to 34.3 MPa. This is explained that if the heating temperature is too low, the PVC-U pipe will not absorb enough the heat. If the heating temperature is too high, a risk of thermal degradation of the PVC-U pipe material might occur. Both of these cases lead to a reduction in the tensile strength of welding joint. The tensile strength of the welding joint is higher than 90% of the tensile strength of the base material in a range of the heating temperature from 220 ºC to 240 ºC. It means that the reasonable heating temperature for PVC-U pipe situates in a range from 220 ºC to 240 ºC. The maximum tensile strength is 43.8 MPa at the heating temperature of 230 ºC. This value is equal 97.6% of the tensile strength of the base material. This temperature will be fixed in the following cases.

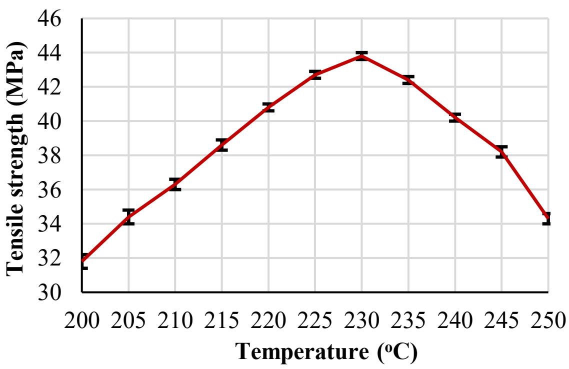

Fig. 6. Tensile strength of 75 mm pipe joint with different heating temperatures

The influence of heating time on the tensile strength of welding joints will be considered in case 2. The heating time includes the bead-up time and the heat soak time. The bead-up time of 3 seconds is selected for welding of PVC-U 75 mm pipes. The dependence of tensile strength of welded joint on the heat soak time is given in Fig. 7.

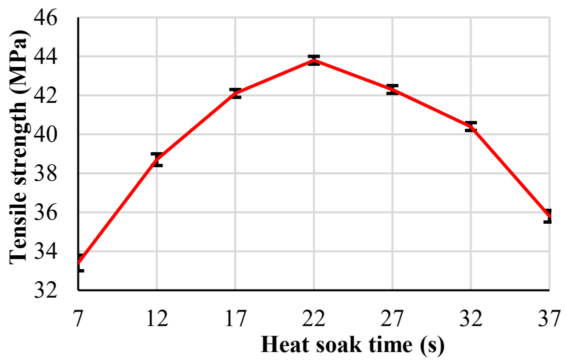

Fig. 7. Influence of the heat soak time on the tensile strength of 75 mm pipe welding joint

The tensile strength of welded joint is larger than 90% of that of the base material when the heat soak time is between 17 seconds and 32 seconds. The tensile strength reaches the maximum value of 43.8 MPa when the heat soak time is 22 seconds. The tensile strength of welded joint has a declining trend when the heat soak time increases above 22 seconds or decreases below 22 seconds. This can be explained that when the heating time is low, the required melt thickness is not enough. When the heating time is high, there may be a risk of degradation of pipe material at the joint surfaces. All of these reduce the strength of the welded joint.

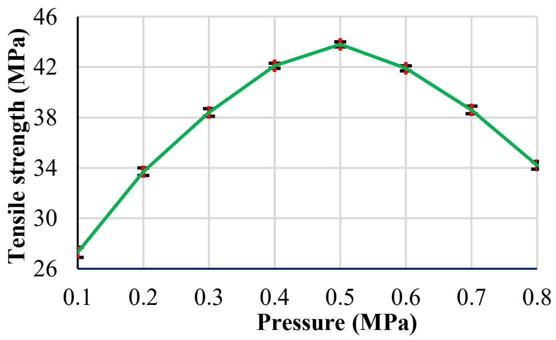

Fig. 8. Effect of the fusion jointing pressure on the tensile strength of 75 mm pipe welding joint

In the next case, the influence of the pressure on the tensile strength of PVC-U pipe welding joint is investigated. The heat soak pressure (p_2) is chosen at the minimum value of 0.01 MPa with the aim of maintaining the continuous contact of the pipe surfaces with the heater plate. As usually, the bead-up pressure is selected equal to the fusion joining pressure ($p_1 = p_3$) [15, 16]. Therefore, in this case only the fusion joining pressure is considered. The fusion joining pressure is increased from 0.1 MPa to 0.8 MPa with a step of 0.1 MPa. When the fusion joining pressure increases, the tensile strength of the welded joint gradually increases and gets the maximum value of 43.8 MPa at the fusion joining pressure of 0.5 MPa (Fig. 8). When the fusion joining pressure is higher than this value, the molten plastic is pushed out, the tensile strength of welded joints is decreased. When the pressure is less than this value, it is not enough to create the bonding between the molten pipe surfaces, it leads to low tensile strength of welded joint. The tensile strength of welded joints meets minimum requirements of 90% of the tensile strength of base material in a range of the fusion joining pressure from 0.4 MPa to 0.6 MPa.

The above surveys shown that the reasonable welding parameters for PVC-U 75 pipe with the wall thickness of 3.6 mm are heating temperature of 230 ºC, bead-up pressure of 0.5 MPa, heat soak pressure of 0.01 MPa, fusion joining pressure of 0.5 MPa, heating time of 25 seconds, changeover time of 3 seconds, and joining time of 243 seconds. In this case, the tensile strength of welded joint is highest (43.8 MPa). This tensile strength reaches 97.6% of the tensile strength of PVC-U pipe base material.

4.2. Welding Joints of 110 mm Diameter Pipe

In the first case of 110 mm diameter pipe (case 4), the heat soak time is changed from 15 seconds to 55 seconds, other welding parameters are fixed as in Table 2. Fig. 9 indicates that the tensile strength of welded joints increases from 35.9 MPa to the highest value of 43.4 MPa at the heat soak time of 35 seconds and then decreases from this highest value to 37.4 MPa. The tensile strength of the welded joint is larger than 90% of the tensile strength of base material when the heat soak time is situated in a range from 25 seconds to 45 seconds.

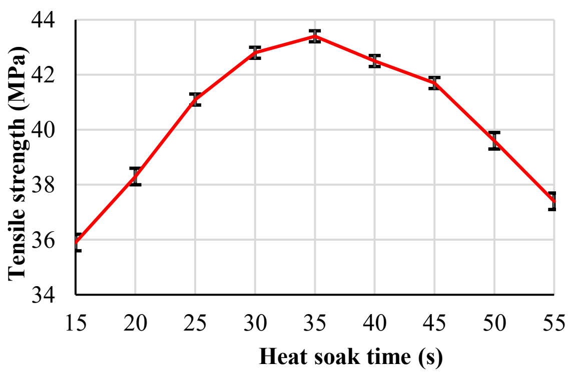

Fig. 9. Influence of the heat soak time on the tensile strength of 110 mm pipe welding joint

The variation of the tensile strength of the welded joint of PVC-U 110 mm pipe via the fusion joining pressure is showed in Fig. 10. This figure indicates that the low fusion joining pressure creates a weak bond. The maximum tensile strength obtains 43.4 MPa when the fusion joining pressure is 0.5 MPa. When the pressure is in a range from 0.4 MPa to 0.6 MPa, the tensile strength of welded joints is greater than 90% of the tensile strength of the base material.

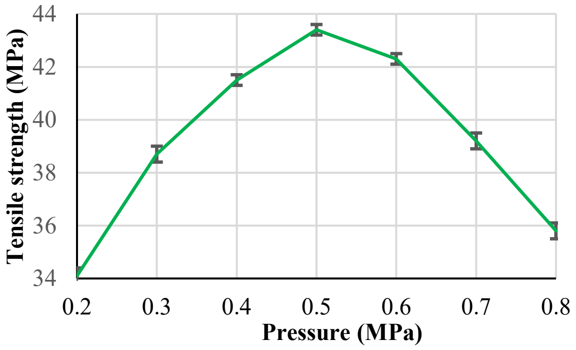

Fig. 10. Effect of the fusion jointing pressure on the tensile strength of 110 mm pipe welding joint

The above studies indicated that the reasonable welding parameters for PVC-U 110 mm pipe with the wall thickness of 5.3 mm are heating temperature of 230 ºC, bead-up pressure of 0.5 MPa, heat soak pressure of 0.01 MPa, fusion joining pressure of 0.5 MPa, heating time of 40 seconds, changeover time of 3 seconds, and joining time of 364 seconds. In this case, the tensile strength of welded joint gets the maximum value of 43.4 MPa which is 97.1% of the tensile strength of PVC-U pipe base material.

The above results show that, for ensuring the welding quality requirement, the welding parameters of butt fusion welding for PVC-U plastic pipes need to be controlled within a very narrow range. Specifically, the tensile strength of PVC-U pipe welding joint wants to reach 90% of the tensile strength of the base material as requirement of the standard, then the heating temperature must be between 220 ºC and 240 ºC, the bead-up pressure and fusion joining pressure have to situate in a range from 0.4 MPa to 0.6 MPa, and the heat soak pressure is maintained at the value of 0.01 MPa.

Some welding parameters in butt fusion welding of PVC-U pipe such as heating temperature, changeover time, bead-up pressure, heat soak pressure, and fusion joining pressure do not depend on the diameter or wall thickness of the pipe. The values of these parameters can be fixed as 230 ºC, 3 seconds, 0.5 MPa, 0.01 MPa, and 0.5 MPa, respectively. The remaining welding parameters such as heating time and joining time depend on the diameter and thickness of the PVC-U pipe. In general, these parameters depend on the cross section of the pipes to be welded. When the pipe cross section increases, it is necessary to increase the heating time and joining time and vice versa.

5. Conclusion

This study shown that the tensile strength of the welded joint of PVC-U pipes depends greatly on the butt fusion welding parameters such as heating temperature, heating time, bead-up pressure, fusion joining pressure, and joining time. The welding parameters such as heating temperature, bead-up pressure, heat soak pressure, fusion joining pressure, and changeover time are independent of the welded pipe cross section. The unchanged parameters of butt fusion welding for PVC-U pipes with any pipe diameter and any pipe wall thickness will be heating plate temperature of 230 ºC, heat soak pressure of 0.01 MPa, bead-up pressure of 0.5 MPa, fusion jointing pressure of 0.5 MPa, and changeover time of 3 seconds. While other welding parameters such as the heating time and joining time depend on the welded pipe cross section.

The tensile strength of PVC-U pipe welding joint can reach the requirement of standard (greater or equal 90% of the tensile strength of base material) in a narrow range of parameters of butt fusion welding. With proper welding parameters, tensile strength of PVC-U pipe welding joint can reach 97% of the tensile strength of PVC-U pipe base material.

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