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Heated Tool Bonding of Plastic Pipes

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Abstract: Heated tool joining is a popular method for joining parts made from plastics and composite materials. The method is commonly known as butt fusion in the plastic pipe industry and this paper provides a short introduction to the basics of producing a good butt fusion joint. The function of each of the essential parts of the butt fusion equipment is described followed by a presentation of the important parameters of the bonding process in reference to a well-established interfacial pressure versus time curve. The butt fusion procedure is then outlined with good practices that detail the preparation of equipment and pipes to be joined as well as the fusion joining process.

1. Introduction

Amongst many types of fusion bonding methods available for thermoplastics parts, heated tool (hot plate) bonding is a popular method, which is widely used for the assembly of injection moulded components or extruded profiles. The method utilizes having the parts to be joined in contact with a heated metal plate (heated tool) until melting occurs at the surfaces of the part to be bonded together. The fusion joint is produced by bringing the two molten surfaces together under normal force applied to the fusion interface being formed, followed by a period of cooling. The method offers a simple, reliable and economical way of making strong, leak tight joints.

Heated tool bonding of plastic pipes is commonly known as butt fusion, where it is used for creating sound and reliable joints in pipe diameters up to 2.5m. Through such efforts, high density polyethylene (HDPE) pipes are now being used in applications such as the safety class III buried piping in service water and sea water systems of nuclear power plants. In these applications, the long-term structural integrity of the fusion joint constitutes an important part of the system performance assurance.

The butt fusion process occurs in four stages [3-5]. In Stage I, heat and pressure are applied to the pipes and begin to melt the surface. In Stage II, the pressure is lowered and the heat from the hot plate continues to soak into the pipe surface, increasing the melt thickness. When a certain melt thickness is obtained the hot plate is removed (Stage III) and the molten surfaces are brought

Figure 1. Heated tool bonding of large diameter HDPE pipes. (a) Butt fusion equipment [1] and (b) butt fusion joints in HDPE pipe [2].

Figure 2. High density polyethylene pipes. (a) Before and after butt fusion, (b) butt fusion cross-section showing MFZ and fusion beads produced by the squeeze flow of molten material.

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Figure 3. Overall view of the butt fusion equipment for thermoplastic pipes (photo courtesy of +GF+, Switzerland)

together and joined/cooled under pressure (Stage IV). In Stage IV, intermolecular diffusion of polymer chains across the melt interface is promoted along with microstructure development in the melt fusion zone (MFZ), which determines the strength of the fusion joint.

In this paper, the essentials of butt fusion to create structurally sound joints in thermoplastic pipes are described, with reference to equipment, fusion parameters and procedures. In addition, some general description of current activities in research and standardization are presented.

2. Butt Fusion Equipment

Butt fusion machines for pipes vary in design depending on the manufacturer but they all have the same basic components: a chassis unit, with a facility for attaching interchangeable clamps for different pipe sizes; a mechanism for applying an axial force on the face of the pipes to be joined; a planing tool and a heater plate.

The chassis (Fig. 4) is where the interchangeable pipe clamps are fixed, up to the maximum pipe diameter the machine is designed for. Reducing inserts or shells for smaller pipe sizes can be inserted if required. The clamps have serrations to reduce slippage of the pipe during the joining cycle. The chassis is designed to ensure that the pipes remain in perfect alignment and there is minimal gap at the joint interface when the pipes are under pressure.

The joining force can be generated manually, hydraulically, pneumatically or electrically. In the case where the force is generated using fluid power rams, the force may be indicated in terms of the applied cylinder pressure. In these cases, a specific calibration table should be provided, which gives the relationship between the actual interface force and the pressure indicated by the machine pressure gauge.

Figure 4. Pipe alignment in the chassis [6].

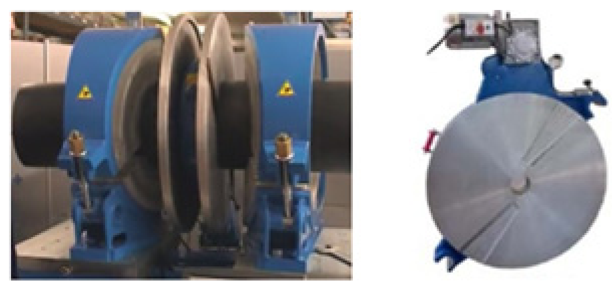

Figure 5. Planing tool shaving the pipe ends [6].

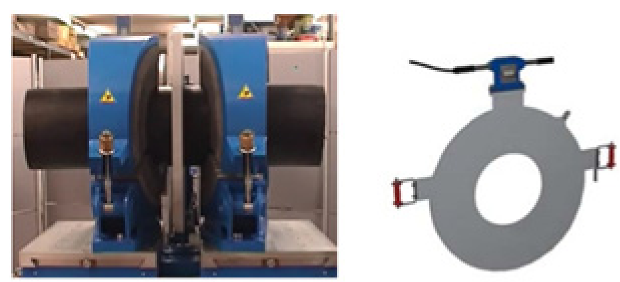

Figure 6. Melting of two pipe ends using hot plate [6].

The planing tool (Fig. 5), sometimes called the trimmer, facing tool or shaving tool is a double-sided surface planer, which can be powered by electrical, hydraulic or pneumatic power, and is used to accurately plane the pipe ends to ensure intimate contact with the heater plate. The blades should be checked for damage before use and must be kept sharp.

The heater plate (Fig. 6), usually made from aluminium, has an electronic control to accurately set the temperature for the different materials to be welded and the different standards or joining procedures being used. The surfaces of the heater plate that contact the pipes/fittings should be such that molten material does not stick to them. This can be achieved by coating the plate with coloured PTFE or the hot plate may have a removable PTFE-based fabric bolted on to both sides using a metal ring. Regular checks should be carried out to determine the quality of the surface, and the heater plates should be re-coated if necessary.

Ancillary equipment that is required includes: pipe support rollers, pipe cutters, pipe end plugs, tent (if joining outdoor) and digital thermometer with a surface probe or infra-red thermometer for calibration of the heater plate temperature.

3. Butt Fusion Parameters

The main joining parameters for the butt fusion joining process are given in Table 1. and Fig 7. These represent essential variables to be closely controlled in producing strong reliable butt fusion joints. Three different sets of parameters exist in the international standard ISO 21307, which are mainly dependent on the applied pressure. A description of the butt fusion parameters is given below.

3.1. Heater plate temperature

The temperature of the heater plate is critical to achieve a quality joint and should be set with a thermocouple surface probe before the start of the joining process. The specified heater plate temperature depends on the joining procedure used.

3.2. Initial bead-up interface pressure

This is the interface pressure applied when the pipe ends are initially in contact with the heater plate. Depending on the joining procedure used, this can be between 0.1 MPa (specified for polypropylene (PP) pipes according to DVS 2207-11) and 0.62MPa (maximum specified value for HDPE pipes according to ASTM F2620).

In all butt fusion machines a certain amount of force is required to overcome the sliding frictional drag of the moving clamp, which will vary depending on the size and length of pipe loaded into the machine and also whether pipe rollers are used. This is called drag and must be added to the required force. Since most of the machines operate under hydraulic power, the drag force (or pressure) addition is achieved by a corresponding increase in the gauge pressure of the hydraulic cylinder.

Table 1. Essential butt fusion parameters

Parameter	Units
Heater plate temperature	°C or °F
Initial bead-up interface pressure	MPa or psi
Initial bead-up size	mm or inch
Heat soak interface pressure	MPa or psi
Heat soak time	s
Minimum bead size after heating	mm or inch
Dwell time	s
Joining pressure build-up time	s
Fusion interface pressure	MPa or psi
Joining/cooling time	minutes

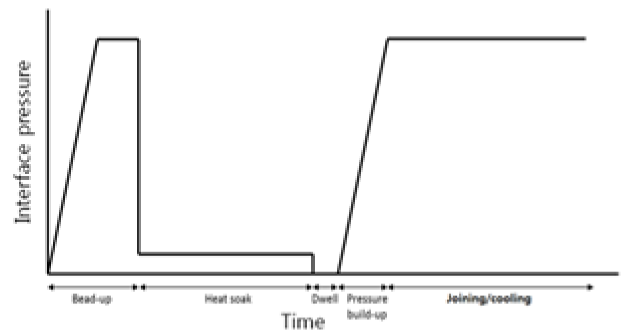

Figure 7. Interface pressure versus time curve for PE pipe butt fusion [3].

3.3. Initial bead-up size

The initial bead-up size is the minimum size of the melt bead produced during the bead-up phase of the joining cycle. This phase of the joining cycle is to ensure that the ends of the pipe are in intimate contact with the heater plate, which in turn, ensures that the material temperature at the end of the pipe is independent of the temperature of the surrounding environment. The initial bead-up size is dependent on the wall thickness and not the diameter of the pipe and, again, depends on the joining procedure used. When the required bead size is attained, the heat soak phase is started (see Fig. 7).

3.4. Heat soak interface pressure

This is the interface pressure that maintains the pipe ends in contact with the heater plate and is specified as between zero and the drag pressure.

3.5. Heat soak time

This is the time for which the pipe ends are in contact with the heater plate at the heat soak interface pressure, during which an appropriate melt thickness is developed at the pipe ends. This time increases with increasing pipe

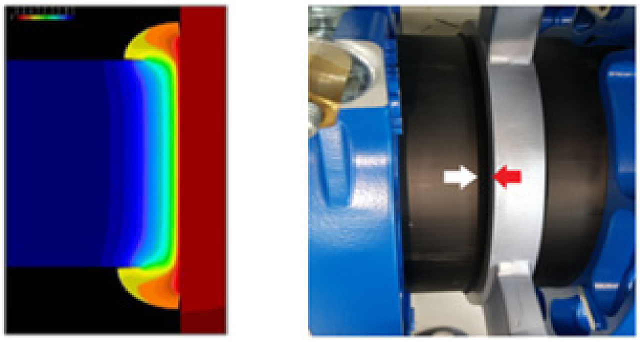

Figure 8. Bead formation during heat soaking (Stage II).

Figure 9. Butt fusion in a protective shelter (photo courtesy of +GF+, Switzerland).

wall thickness.

3.6. Minimum bead size after heating

ASTM F2620, rather than specifying a heat soak time, specifies a minimum bead size after heating, i.e. before removal of the heater plate. This value depends on the pipe diameter.

3.7. Dwell time

Dwell time, or plate removal time or changeover time, is the maximum time permitted for the separation of the pipe ends from the heater plate, removal of the plate and closure of the carriage to bring the two molten pipe ends together. This should be as short as possible.

3.8. Joining pressure build-up time

The joining pressure build-up time is the maximum time allowed to achieve the full pressure required for the joining/cooling phase. This value is not always specified in all joining procedures.

3.9. Fusion interface pressure

This is the interface pressure applied to the pipe ends during the joining/cooling stage and is normally the same value as the bead-up interface pressure.

3.10. Joining/cooling time

This is the time during which the joint remains under the fusion interface pressure whilst still clamped in the machine. This time is dependent on the wall thickness of the pipe and on the fusion procedure used and can be over an hour for pipe wall thicknesses over 50mm.

4. Butt Fusion Procedure

In order to produce reliable butt fusion joints, it is important to adhere to following practices. If the work is to take place outside, a tent should be used to provide shelter from wind or rain and covers should be fitted to the pipe ends not being joined to prevent the chimney effect, where wind can blow down the pipe, which may cause a cold joint.

4.1. Preparation

The pipe ends to be joined are cleaned inside and outside with lint free cloth and, if the dirt is excessive, water is used. Pipes with deep surface scratches or indentations greater than 10% of the wall thickness should not be used.

The heater plate is cleaned while cold using a lint-free cloth, moistened with water. If the heater plate is contaminated with grease or oil, isopropanol can be used.

The temperature of the heater plate needs to be set for the material and pipe diameter to be joined. When the heater plate has reached the required temperature, the temperature should be checked in multiple positions on both sides with a surface probe and adjusted as necessary. Differences can occur due to changes in the ambient temperature. Sufficient time should be given for the temperature to stabilize, typically 10-15 minutes for small pipe diameters and 30 minutes for large diameter machines.

4.2. Clamping and trimming the pipes

The pipes can now be loaded into the machine and clamped. If long lengths of pipe are to be welded, pipe supports should be used to achieve proper alignment and reduce drag. Good practice is to align the markings on the pipes when placing them in the machine. This will obtain the best match to correct for pipe ovality.

The pipe ends are then planed square with the trimmer by carefully bringing the pipes into contact with the rotating blades and applying pressure until a continuous strip of swarf is produced, usually equivalent to at least three full turns on the pipe. This should result in flat, parallel surfaces. The pressure should be released slowly to avoid a "step" in the surface finish. Once the planer has been removed, all loose swarf and debris should be cleared from the machine and the inside of the pipe ends. Care should be taken not to touch the planed ends as this will contaminate the suface and compromise joint quality.

4.3. Joining

The squared pipe ends are brought into contact with the heater plate under the applied bead-up pressure (Fig. 7) and maintained until a uniform bead of the required size is formed. The pressure is then released (Fig. 7) so that the pressure gauge registers between zero and the drag pressure, ensuring that the pipe ends remain in contact with the heater plate but the melt generated is not squeezed out. When the heat soak stage is completed, the pipes are removed from the heater plate, which is then removed, and the pipe ends are immediately brought together. This phase of the operation is the dwell time (Fig. 7), which needs to be as quick as possible to avoid excessive cooling of the melted pipe surface. The joining pressure is then applied in a smooth manner.

The pipes are then left under pressure for the specified cooling time to complete the joining cycle (Fig. 7). On completion of the joining cycle, the pressure is released slowly and the pipes removed from the machine. A visual inspection of the joint is then carried out to check for any abnormalities (see Fig. 2).

5. Quality Assurance

In order to ensure the quality of butt fusion joints in HDPE pipes, it is important to record all of the essential joining parameters for every joint made and compare these with the set values. This can be documented manually on paper; however, many butt fusion machines now have a facility to record and store these data. Additional data that may be required includes the complete traceability of the pipe, fittings, equipment and operators carrying out the joining. This information and the fusion data can now be transferred via wireless communication directly to the customer or uploaded to the cloud.

6. Conclusion

The use of heated tool bonding has been very successful in joining plastic pipes over a wide range of diameters for many decades. The butt fusion equipment, parameters and procedures make up an essential part of producing safe and reliable joints that will last in service for 50 to 100 years. For QA purposes, the essential parameters can be recorded by the joining machine and stored or transferred to anywhere in the world via the internet, if required. Additionally, some industries are asking for further proof that the joints are of good quality by using volumetric non-destructive testing (NDT) and, as a result, a number of international standards on NDT of butt fusion joints in HDPE pipes are being developed in ISO and ASTM, and work is also being carried out to develop flaw acceptance criteria

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