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Research Paper

Accelerated electrofusion welding of polyethylene pipes employing a novel xylene-based conductive polymer intermediary for optimized pulse application

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Abstract

The natural gas is an important energy source that is increasingly being utilized due to its convenience and clean energy provision. Natural gas is safely supplied to consumers through an underground gas pipeline network made of polyethylene materials. In electrofusion, which is one of the joining methods, copper wire is used as the heating wire. However, it takes a long time for the fusion to occur because of the low electrical resistance of copper. Therefore, in this study, electrofusion with the replacement of the copper heating wire with an intermediate material containing an electrically conductive and thermally conductive polymer was performed to reduce the fusion time and improve the production during the connection of large

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pipes. After the fabrication of the electrofusion joint in the polyethylene pipe using the intermediate material, fusion, thermal and tensile tests were conducted. The results showed that the fusion time is shorter, and the temperature inside the pipe is higher with the increase in the current amount. The optimal welding voltage value was the one in which the melt time was short, and no deformation was observed in the pipe. Therefore, it was demonstrated that the conductive interface can be used to replace the copper heating wire.

1. INTRODUCTION

Thermoplastics are a class of polymers that exhibit a unique characteristic, they soften and become moldable upon heating and solidify upon cooling. This process is entirely reversible, meaning the material can be repeatedly heated and reshaped without significant degradation. This property sets them apart from thermosets, which undergo irreversible chemical changes upon heating, hardening permanently. The ability of thermoplastics to soften upon heating stems from the weak intermolecular forces holding their polymer chains together [1, 2]. These forces, such as van der Waals forces and hydrogen bonds, are easily overcome by thermal energy, allowing the chains to move past each other. Upon cooling, these forces re-establish, solidifying the material. This reversible behavior makes thermoplastics highly adaptable for various applications [3, 4].

The versatility of thermoplastics extends beyond their processing methods. Their properties can be tailored by varying the chemical composition, molecular weight, and additives. For example, increasing the molecular weight generally leads to higher strength and rigidity, while adding plasticizers can improve flexibility. This tunability makes thermoplastics suitable for a wide range of applications, from everyday items like food packaging and clothing to specialized applications in aerospace and electronics [5-7].

Polyethylene, a widely used thermoplastic, is a linear polymer consisting of repeating ethylene monomers ($-CH_2-CH_2-$). Its structure, specifically the length of the polymer chains and the degree of branching, determines its properties. Polyethylene's properties make it suitable for a wide range of applications [8, 9]. Low-density polyethylene (LDPE), with its branched structure, is flexible and used in packaging films, bags, and containers. High-density polyethylene (HDPE), with its linear structure, is more rigid and finds use in bottles, pipes, and other structural components. The versatility of polyethylene, combined with its low cost, makes it one of the most widely produced and consumed plastics globally [10-12].

The surface of plastics typically has microscopic roughness, which increases the contact area and adhesion between two plastic parts. When these two plastic parts are exposed to heat, the polymer chains on their surfaces start to move and intermingle with each other [13]. This process creates strong physical and chemical bonds between the two surfaces, resulting in their adhesion to one another. This principle is applied in the connection of polyethylene gas pipes to create secure and safe joints [14, 15].

Several methods and technologies are employed to achieve this, each with its own advantages and considerations. Butt-fusion is one of the most common methods for joining PE pipes. This technique involves heating the ends of the pipes and then pressing them together to form a joint [16]. The process requires precise control of temperature, pressure, and alignment to ensure a strong bond. Research has shown that machine learning (ML) can be used to automate the ultrasonic inspection of these joints, improving the detection of flaws and ensuring the quality of the connections [17]. Convolutional neural networks, in particular, have been effective in classifying signals from ultrasonic inspections, achieving high accuracy in identifying defects. Electrofusion involves using special fittings with built-in electrical heating elements. When an electric current is applied, the heating elements melt the PE material, creating a strong bond between the pipe and the fitting. This method is particularly useful for making connections in confined spaces or for repairs [18]. Finite element analysis has been used to study the stress distribution in electrofusion joints, showing that stress concentrations can occur due to the presence of the socket or repair patch, which must be carefully managed to ensure joint integrity. Other types include Friction Stir Welding (FSW), Hot Tool Welding and Saddle-Heat-Fusion [19-21]. Ensuring the quality and safety of PE pipe joints involves rigorous inspection and testing. Ultrasonic inspection, often supported by machine learning algorithms, is a key technique for detecting flaws in butt-fused joints. Additionally, the performance of joints under various environmental conditions, such as temperature changes and soil movements, is studied to predict their long-term behavior and ensure their reliability in service [22].

In tropical regions, partial and weak welds often occur during the execution of projects that include electrofusion welding. An underlying factor contributing to incomplete welding is the presence of looseness in polyethylene pipes and joints, where the actual diameter of the junction is near the upper limit specified in the standard. The presence of a significant gap between the pipe and the connection during welding results in reduced heat transfer from the heating coil to the pipe. As a result, only a small portion of the pipe is melted, leading to inadequate fusion and weak welding, which can result in brittleness.

The incorporation of an adhesive-like material, known as the third polymeric portion, in the electrofusion welding of polyethylene (PE) pipes provides several benefits that improve the dependability and excellence of the welding procedure [23-25]. They enhance the fusion between the polyethylene components and the pipe wall when heated. Their presence enhances the ability of the molten polyethylene to deeply penetrate the surfaces of the pipe and fittings, resulting in a more consistent and strong union. Utilizing these auxiliary materials may enhance the overall dependability of the electrofusion welding procedure, hence diminishing the probability of joint malfunctions and leaks, which are vital for maintaining the integrity of gas, water, and other utility distribution systems. This study explores the use of a uniform polymer material to eliminate the thermal resistance caused by the empty space between the pipe and the joint. The heat transfer process is thoroughly examined and simulated using precise calculations to ensure optimal fusion of the two pieces.

2. EXPERIMENTAL

A. Materials and methods

1) Preparation of the third polymeric part (Adhesive-like substance Xylene-Polyethylene)

To prepare the adhesive compound for application at pipe connection joints, we first crushed the 5 mm-sized polyethylene granules (with pipe production grade (HDPE Masterbatch)) into a fine, soft powder. In the next step, we added a very small amount of xylene solvent to convert the powdered material into a dense, paste-like consistency. This process was continued until the mixture transformed into a non-greasy, non-runny paste-like substance with the right viscosity, without becoming too stiff or dry. The purpose of this two-step procedure is to create a specialized adhesive compound that can be easily applied between pipe sections to form a secure, leak-proof seal at the connection points. The powdered polyethylene provides the primary bonding agent, while the xylene solvent helps to adjust the compound's rheological properties for optimal workability and adhesion during the pipe installation process by electrofusion welding. It is important to mention that all of these stages were carried out at room temperature without the use of any specific conditions.

2) Apply of the adhesive Xylene-Polyethylene grease on the polyethylene pipes

The Xylene-Polyethylene grease adhesive was applied to the surface of the pipes where the coupler was to be placed, and then the pipe and coupler were fitted together. Any excess synthesized grease was removed. This adhesive was chosen because it is made from the same polyethylene material as the pipes, so it would be compatible and integrate seamlessly into the system as part of the pipes themselves. It was noted that all necessary safety precautions were taken. Since xylene is a toxic solvent, only a very small amount was used. When the adhesive is applied in a paste-like consistency, its harmful properties like flammability are lost, and other beneficial characteristics are exhibited instead. The grease-like consistency allows adhesive component to be easily applied and distributed across the pipe connection points. This adhesive application helps ensure the overall integrity and reliability of the final polyethylene pipe network after electrofusion welding.

3) Field visit to the implementation process of gas supply

An inspection was conducted of the gas distribution development project, as coordinated with the research department and technical inspection unit of the gas company. During this site visit, the method of preparing the pipeline bedding and the welding process performed by the approved welders of the gas company were examined.

Some of the key points discussed are as follows:

Before starting the welding operations, a "preliminary coating" is applied at the designated location for gas distribution. This preliminary coating is essential prior to the welding work. After preparing the preliminary coating, the site requires excavation. Using a mechanical shovel, a trench is dug to a depth of 110 cm plus the pipe diameter and a width of 40 cm plus the pipe diameter. These dimensions are specific to the urban gas distribution network. Based on the soil tests conducted, the optimal excavation depth is between 1 to 1.5 m, as it results in the least amount of stress. However, if there is an obstacle (such as a water pipe) in the path, an additional 40 cm of depth should be considered between the water pipe and the gas pipe. Provisions must also be made for the potential expansion and contraction of the pipe during different seasons. Approximately 15 cm of screened soil is placed under the pipes, which is referred to as the "cushion." These cushions are constructed approximately every 1 to 1.5 m along the trench (Fig. 1A). Once the initial conditions for pipe laying are prepared, the pipe segments are placed within the trench, with the polyethylene pipes resting on the cushions (Fig. 1B). Subsequently, an additional 30 cm of soil is placed on top of the pipe sections resting on the cushions (Fig. 1C). As a result, the installation depth of the 63 mm pipes is approximately 95 cm from the ground surface.

Eq. 1:

$$(110 + 6)cm - \frac{30}{2}cm - 6cm = 95cm$$

During the site visit, the process of electrofusion welding was also explained, and a sample field joint was prepared outside the trench (Fig. 1D). Additionally, the research team discussed and reviewed the experiences of the welder, contractor, and technical inspectors regarding the selection of different coupling brands, common defects, and related considerations.

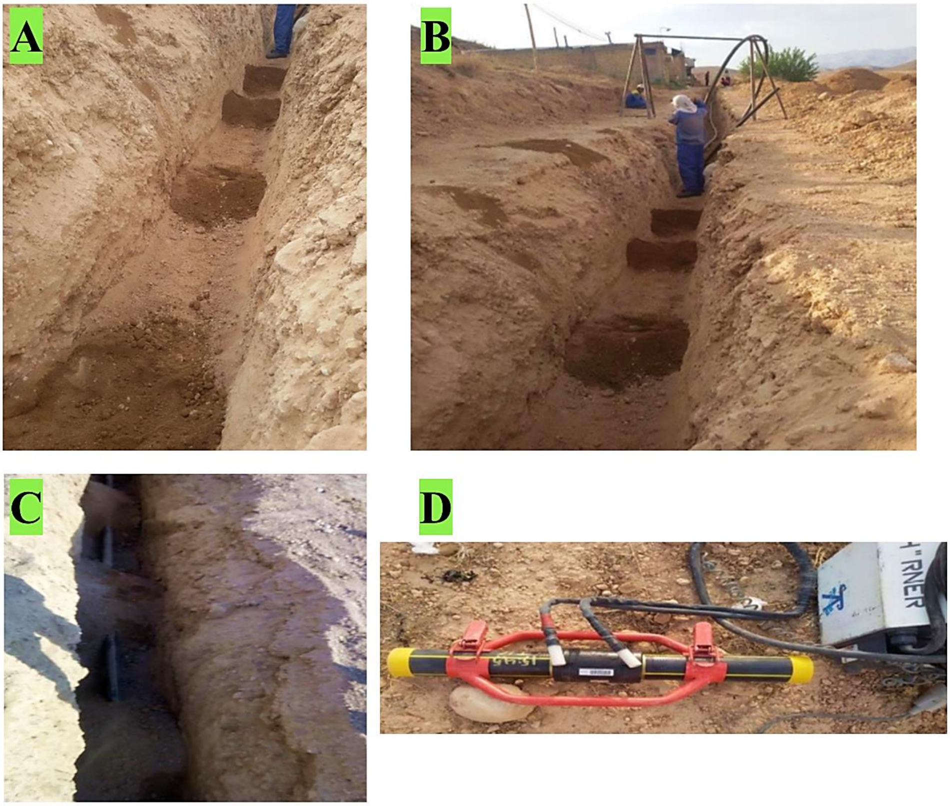

Fig. 1. Cushions created in the channel (A), how to place the pipe in the channel (B), covering the tube on the Cushions after tube placement (C), electrofusion welding in open space - gas delivery (D)

4) Select the target coupler

In this study, the focus is on 63mm domestic couplers. Due to differences in the soldering process, two brands (a) and (b) were initially investigated. For this purpose, two separate field joint samples and two cut-off coupler samples of each brand were used. Their dimensional and physical information is presented in the table 1.

TABLE 1
Some Information About Two Types Of 63 mm Size Coupler

Sample / Information	Coupler (a)	Coupler (b)
Electrofusion voltage (volt)	38	38
Electrofusion time (s)	35	35
Cooling time (min)	93	93
Approximate thickness of coil (mm)	130	130
The number of rounds of coil	12	12
Weight (g)	10	10
Stopper location (mm)	53.0	53.0

Since the geometry of the windings is one of the most important factors in the thermal study of the field joint, special attention was paid to it. In the Fig. 2A, the arrangement of the windings in both types is compared. As shown in Fig. 2B, unlike sample (a), the path of the winding in sample (b) is almost straight. In the design of this coupler, unlike other types of couplers, the soldering is done after the injection of polyethylene. Also, in sample (a), the connecting ring on both sides of the coupler moves further away from the center. The points of this ring are shown by the arrows in the figure. The field experience of the technical inspectors has been indicating that the samples (b) have been having a greater history of operational problems (unfortunately, at this juncture, the possibility of preparing statistics has not been available.) Therefore, by selecting this sample, the possibility of examining and addressing more defects has been made available. Another advantage of this selection has also been the approximate constancy of the winding path (due to the winding marking method during the coupler production). This matter has been finalized after consultation with the final technical inspection and the studies have been focused on sample (b). Note: Based on the documentation provided in Fig. 2A and Fig. 2B, it had been expected that the performance of samples (b) would be better than sample (a), which the experience of the experts at the gas company has been rejecting this possibility. This research group has been showing in the present project that by conducting a careful scientific study, significant improvements can be made to the quality of this product. To gather more information about the path of the windings, X-ray radiography was performed on the destroyed samples. The results are shown in Fig. 2B. In this image, the passage of both the upward and downward movement of the middle winding, and the change in radius in sample (a) are clearly visible. Another notable point is the different winding pitch. The distance between the two sides of the winding is indicated by the red arrows. It is clear that the pitch generated in sample (b) is greater.

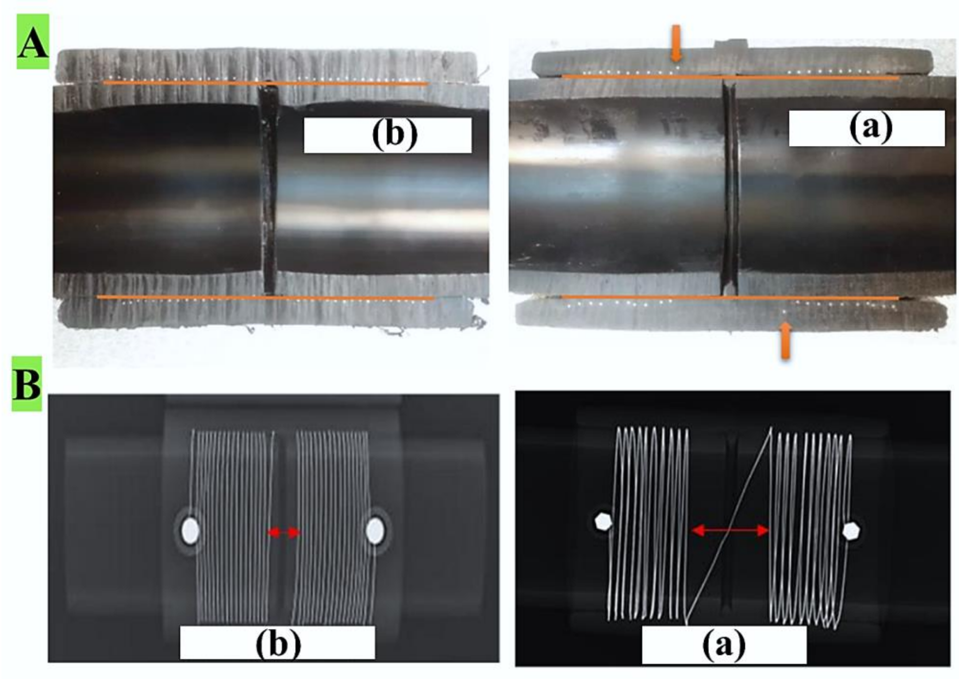

Fig. 2. Comparison of coils of two brands of field joint (A) and radiographic image of two brands of field joint (B)

5) Principles of the Thermal Pulse Method

Every thermal non-destructive testing (NDT) method comprises a source to induce temperature variations and a receiver/recorder to monitor the resulting thermal changes. The proposed approach in this study aims to utilize the existing resources in the gas pipeline network, rather than introducing new sources, to perform thermal measurements with minimal modifications. It is important to note that the coils embedded within the couplers are only used during the welding operation to facilitate the bonding between the coupler and the pipe, and they become redundant after the welding is completed. In fact, this valuable resource remains buried within the extensive polyethylene pipeline network in countries and is left unused after the welding process. This project investigates the feasibility of reusing and optimizing the application of these existing couplers. The novel and creative idea presented here is the reuse of these coils as the primary tool for inducing thermal excitation. This eliminates the need for separate conventional thermal sources, such as heat guns or UV lamps, to generate the required heating. Further, the effect of the intermediate material was experimentally investigated to improve the coupler's performance, and the results are reported experimentally [26, 27]. Each thermal NDT method involves a source of change. For this purpose, two-stage radiographic and infrared thermographic tests, as well as complementary non-destructive testing methods such as TGA, DSC, and MFI polymer tests, were used as indicators. The preparation of the mentioned intermediary was also carried out by the research group. The final results of the above tests showed that the defined main objective has been achieved. Alongside these cases, potential sources of error were identified, and decisions were made to control and address some of them. Finally, by performing a sensitivity analysis, the initial range of use of the aforementioned method was examined, and its performance was ultimately evaluated. The results of this project ultimately gave the research group greater confidence that the possibility of using the intermediate material to a high degree can help address the challenge of using excess connections and improve the performance of the coupler.

6) Correction of the Geometry of the Coils

In the simulation review stage, the following changes were made to the joint geometry:

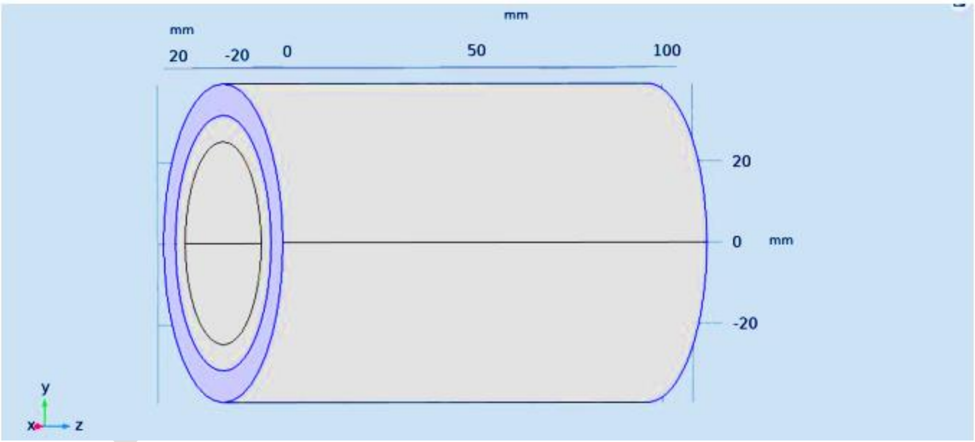

Fig. 3. The Region with Updated Boundary Conditions

- Addition of a stopper in the space between the two tubes
- Modification of the boundary conditions for the two radial bands of the coupler, introducing a heat convection flux condition (Fig. 3)

- Correction of the coil radius
- Division of the coil winding into 5 helix sections
- Alterations to the coil winding paths, based on observations of the geometry of the intact coupler

These adjustments to the coil geometry were implemented in the simulation model to better reflect the actual physical configuration of the device. The purpose of these changes was to enhance the accuracy and fidelity of the simulation, allowing for a more reliable evaluation of the device's performance and the effects of the design modifications. This improved simulation accuracy is a crucial step in the overall design optimization and validation process.

7) Thermal Data Testing (αcp)

The three thermal parameters are density (ρ), thermal conductivity (k), and specific heat capacity (cp).
Eq. 2:

$$\alpha = \frac{k}{\rho \cdot Cp}$$

These three parameters are related to the thermal diffusivity (α) through the following relationship:
With the availability of these parameters, it becomes possible to calculate k using cp and ρ.
According to the technical laboratory's instructions, to obtain the specific heat capacity, samples with dimensions of 2×20×20 and 2×15×15 cm^3 were required. Similarly, to determine the thermal diffusivity, samples with dimensions of 2× 20×10 cm^3 were needed. Appropriate molds had to be fabricated to produce these sample sizes. This testing approach allowed for the accurate measurement of the key thermal properties, which are essential for the comprehensive characterization of the material's thermal behavior. The specific sample dimensions were specified by the technical laboratory to ensure the validity and reliability of the thermal data obtained through the testing procedures.

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Fig. 4. Pipe cutter and coupler (A), using radiography to ensure that there is no remaining copper wire in the cut parts of the coupler (B), preparing the sample for pressing in the hot press machine (C), pressed samples of coupler and polyethylene pipe (D)

3. RESULTS AND DISCUSSION

A. Non-destructive testing

1) Pulse time correction

Initially, the proposed pulse duration was estimated to be approximately 40 seconds. Therefore, in the initial phase steps, the power profile was measured by applying a 40-second electrical current, and the results are shown in Fig. 5A. After this measurement, it appeared that the pulse duration required revision. Evidence of this was the observation of the polyethylene temperature between two consecutive windings, which exhibited the highest temperature due to the cumulative heating effect. The location of interest is indicated by the red point in Fig. 5B, and its thermal profile is shown in Fig. 5D. As clearly evident, the temperature in this case rose up to 152 ℃, which corresponds to the melting point of polyethylene. Therefore, the decision was made to reduce the pulse duration. The new duration of 5 seconds was considered, and the corresponding experimental power data was subsequently collected using a clamp meter, as shown in Fig. 5C. Again, for verification, the temperature of the same point in Fig. 5B was examined, and the results of the temporal temperature profile at this point are shown in Fig. 5E. According to this figure, the maximum temperature at this point will be less than 80 ℃, which is far from the melting point. It should be noted, in the analysis of polymer test results, the maximum temperature in the fusion region during the pulse operation should be frequently referenced. As per the above explanation, this maximum in the 5-second pulse is approximately 80 ℃.

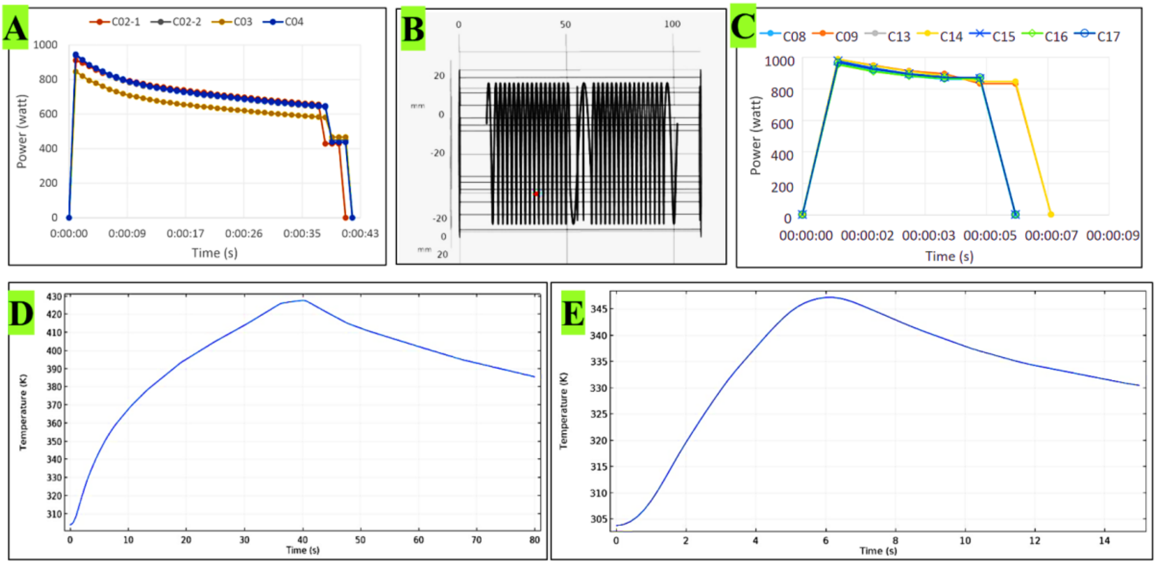

Fig. 5. Pulse profile of 40 seconds (A), Location of the point under temperature investigation in the left winding wire (B), 5 second pulse profile (C), The effect of 40-second pulse on the temperature profile of point between two coils of coiled wire (D), Temperature profile at a point between two coils of wire (E)

B. Polymer supplement test results

1) Thermogravimetric (TGA) and Differential Scanning Calorimetry (DSC) analysis

The Fig. 6A shows the results of the TGA (Thermogravimetric Analysis) test for the pipe and coupler samples. As can be observed in these figures, both samples exhibit similar thermal stability behavior and show only a single stage of thermal degradation corresponding to the breakdown of the polyethylene chain, which occurs at around 477 ℃ for both samples. As seen in the figure, the onset of degradation for the coupler is around 250 ℃, with a relatively gentle weight loss until the temperature range of 400 ℃. The main degradation, which is related to the rupture of the polyethylene chains, occurs at 477 ℃, which is the same as the degradation temperature of the pipe. Therefore, considering the explanations related to the maximum temperature during the pulse (Fig. 5E), it can be concluded that the pulse temperature (below 80 ℃) will not have any effect on the degradation of either the coupler or the pipe. It is evident that at this temperature, no weight loss is observed in these materials. Therefore, there is no need to repeat the TGA test for the bonding region after the pulse, and the examination of the DSC graphs will be sufficient. The results of the DSC test for the tube, coupler, pulse-free field joint (with code C19 from two field joint regions) and also the weldment after two 5-second pulse stages (with code C11) are shown in Fig. 6B.

Initially, the samples of tube, coupler, pulsed weldment, and non-pulsed field joint were examined. The results are as follows:

As observed in Fig. 6B, the melting and crystallization temperatures for the tube, coupler, and field joint C11 after pulsing are almost identical, indicating that the thermal behavior due to pulsing has not changed in the joint region compared to the tube. The crystallinity% is directly related to the melting heat at the melting temperature, which is actually the area under the curve in the melting range. As observed in Fig. 6B, the intensity of the melting peak for the coupler at a melting temperature of 132 °C is higher than that of the tube (with a melting temperature of 131 °C) and the weldment C11 after pulsing (with a melting temperature of 132.5 °C). According to this figure, the intensity of the melting peak for the sample after pulse application (C11) is similar to that of the tube and coupler. In other words:

Crystallinity in coupler % > Crystallinity after pulse application % > Crystallinity in tube %

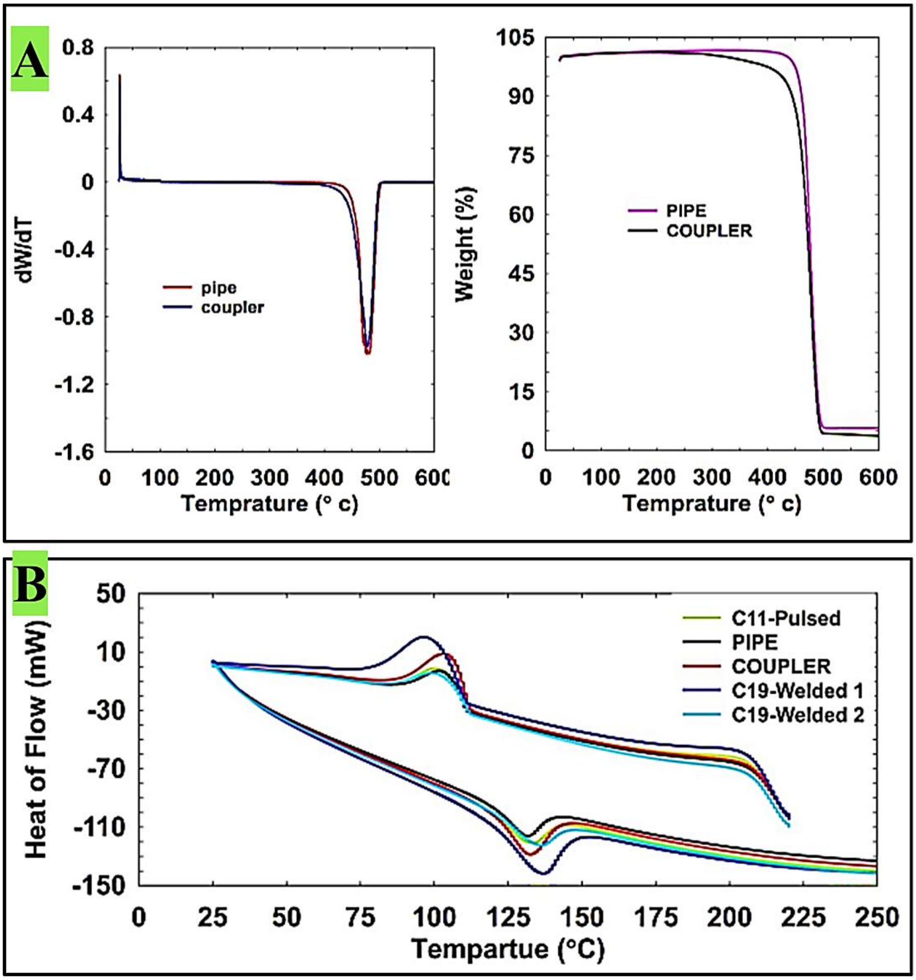

Fig. 6. The curve of differential thermal gravimetric (A) and differential scanning calorimetry (B) analysis

As explained earlier, the application of a 5-second pulse, at its most intense in the vicinity of the coil (the melt region), only increases the temperature by up to around 80 ℃. As observed in Fig. 6B, this temperature is lower than the crystallization temperature of all the samples (around 103 ℃ for the tube and coupler, and around 98 ℃ for the field joint C19 region 1). Therefore, due to the application of the pulse, no crystals will melt or form, and the operational conditions will not have any effect on the degree of crystallinity. According to the DSC test results, the melting temperature and crystallization temperature for the C19 field joint without the application of a pulse can be observed. The results indicate that the melting temperature for the first region of the C19 field joint is higher than all other samples, and the melting range is also broader compared to the other samples. To interpret this phenomenon, it should be noted that polyethylene is a semi-crystalline polymer, and the degree of crystallinity is highly dependent on the cooling conditions. This event can be attributed to the interpenetration of the polymeric chains present in the coupler and pipe during the welding process, leading to the formation of crystalline structures with significantly different dimensions and shapes. This, in turn, has resulted in a broader melting temperature range in the region 1 of the C19 field joint. A similar trend is observed in the crystallization temperature range. However, when a 5-second pulse with a maximum temperature of around 80°C is applied to the C11 field joint sample, the melting and crystallization temperature ranges become narrower. The application of the pulse can potentially lead to the elimination of imperfect crystals and the formation of more uniform crystalline structures, consequently narrowing the melting temperature range. As a result, the application of a pulse not only does not have a detrimental effect on the weld region but can also lead to the creation of a more uniform and less defective structure, potentially resulting in improved properties in the weld region.

C. Investigating the effect of the intermediate material on increasing the temperature by thermography

In order to examine the modified samples with the intermediate material, the following cases have been investigated:

a) Comparison of the field joint coil status with the reference state

b) Mapping of the location

c) Temperature profiles or their corresponding errors

d) Comparison of the temperature profiles of the modified field joint and the original field joint

These examinations provide insight into the effects of the intermediate material on the field joint and allow for a comprehensive evaluation of the modifications made to the samples.

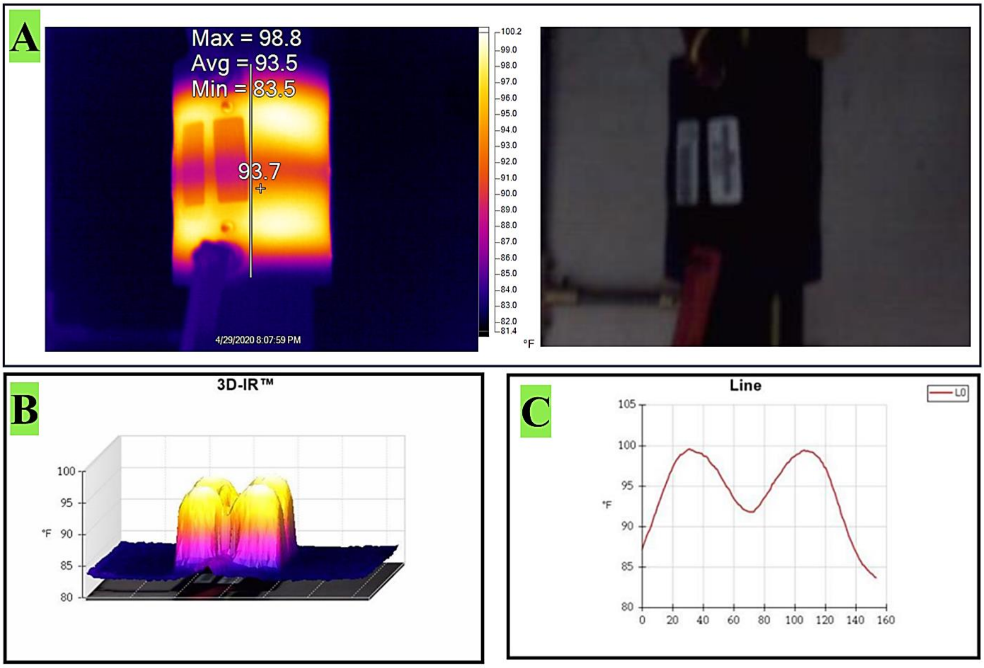

Fig. 6. (A) field joint C13 data collection line, (B) and (C) linear and three-dimensional temperature-location profiles at the same time.

D. Comparison of the Temperature Profile Differences between Modified Field Joints and Reference Field Joints, and Reproducibility

The modified samples were prepared under the same conditions and with the same dimensions, as described in the previous sections. The modifying polymer was synthesized by the research group in the laboratory. A combination of xylene and modifying oils was used for the synthesis. In the modified sample, the modified material was applied as a paste on the surface of the original sample. Measurements were carried out for both the reference sample and the modified sample under the same conditions in terms of the applied voltage, pulse time, and sampling time. The results are shown in Fig. 7A. This comparative analysis of the temperature profiles between the modified field joints and the reference field joints provides insights into the effects of the introduced modifications on the welding process and thermal behavior of the field joints. The state of the windings due to the pulse, as well as the thermographic thermal profile during two consecutive pulses, were investigated to examine the repeatability of the tests. The results are shown in Fig. 7B. According to these results and the complementary polymer tests, it is evident that due to the lack of re-melting, the location of the windings did not change upon the application of the pulse. Additionally, the overall consistency of the thermal profile formats during the two pulses confirms the repeatability of the proposed method. It should be noted that this has been verified through validation tests conducted for both pulses, and here only the general shape of the experimental graphs is presented. This analysis of the repeatability of the test results, including the winding behavior under the pulse and the consistency of the thermographic thermal profiles, provides confidence in the reliability and robustness of the experimental approach.

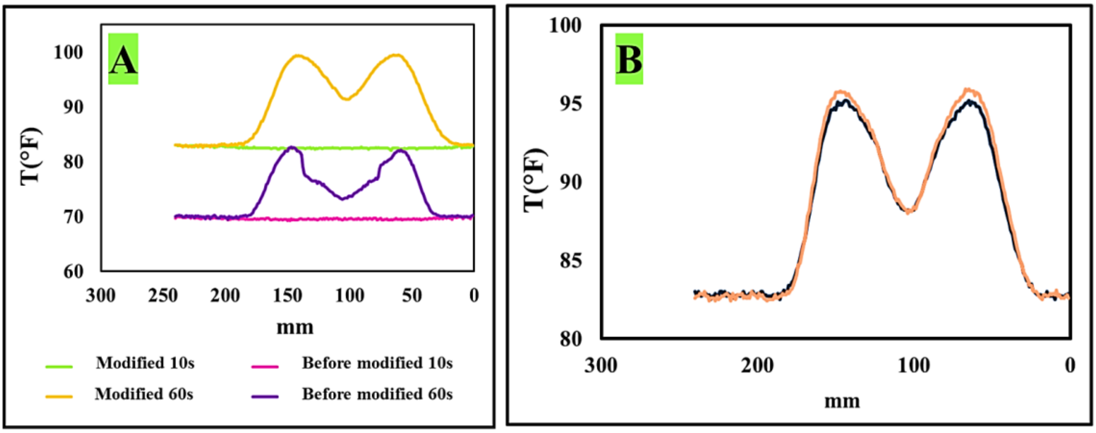

Fig. 7. Comparing the difference in temperature profiles of modified field joints and control field joints (A), temperature profile in two different pulses (B)

E. Sensitivity analysis

1) Effect of pulse duration

In this section, the sensitivity of the surface temperature to the variable of pulse duration was investigated. For the analysis of these results, the reference time of 5 seconds should be considered. According to the Fig. 8, a delay or acceleration in the pulse cutoff by up to one second can result in a maximum error of approximately one and a half degrees. However, if the time error range can be reduced to below one second, the maximum error will be less than one degree. This assessment of the sensitivity of the surface temperature to the pulse duration variable provides insight into the critical importance of precise control and timing of the pulse application to ensure accurate and reliable thermal measurements.

Minimizing the temporal error in the pulse parameters is essential for obtaining high-quality, low-uncertainty thermal data from the experiments.

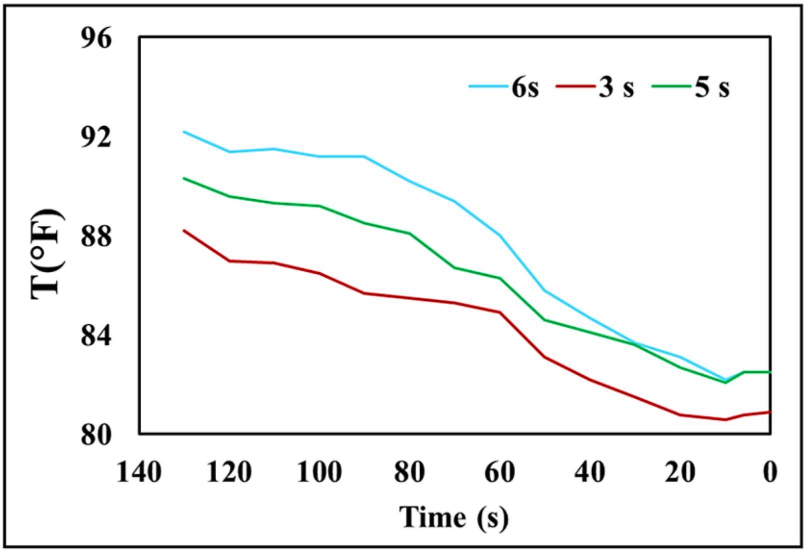

Fig. 8. The effect of pulse duration for the average temperature profile at different times

F. Comparison of the qualities and performance of xylene-polyethylene grease in reference to other suitable intermediate materials

This comparison table outlines various intermediate materials used in electrofusion welding, highlighting their composition, thermal conductivity, adhesion properties, bond strength, and application limitations (Table 2). Xylene-polyethylene grease stands out for its excellent adhesion and bond strength, making it a preferred choice in many applications.

TABLE 2

Comparison table the properties and performance of xylene-polyethylene grease in relation to other potential intermediate materials

Intermediate Material	Composition	Thermal Conductivity	Adhesion Properties	Bond Strength	Application Limitations	Ref.
Xylene-Polyethylene Grease	Xylene and polyethylene blend	Moderate	Good adhesion to polyethylene	High bond strength	Limited to specific temperature ranges	This work
Polypropylene (PP)	Polypropylene polymer	Moderate	Good adhesion	High bond strength	Lower chemical resistance compared to HDPE	[28]
Polyvinylidene Fluoride (PVDF)	Fluoropolymer	High	Excellent adhesion	Very high bond strength	More expensive, limited availability	[29]
Polyethylene Terephthalate (PET)	Polyester polymer	Moderate	Moderate adhesion	Moderate bond strength	Limited thermal stability compared to PE and PP	[30]

4. Conclusion

This study investigated the impact of pulse application on the performance of electrofusion welding using thermographic analysis. The results demonstrate that the pulse application, even with a duration of 5 seconds, does not cause any significant degradation to the materials involved, including the coupler and pipe. TGA revealed that both the coupler and pipe exhibit similar thermal stability, with a single degradation stage attributed to polyethylene chain breakage occurring at approximately 477°C. This suggests that the pulse temperature (below 80°C) does not induce any detrimental effects on the materials. DSC analysis indicated that the pulse application does not alter the thermal behavior of the connection zone compared to the pipe. The crystallinity of the coupler was found to be higher than that of the post-pulse region, which in turn was higher than the pipe. Notably, no crystal melting or formation was observed during the pulse application, indicating that the operational conditions do not affect the overall crystallinity. Furthermore, the pulse application may even enhance the crystallinity by eliminating imperfect crystals and creating a more uniform and less defective structure, leading to improved properties in the weld zone. DSC results also suggest that regions closer to the melt formation zone cool down at a slower rate, resulting in higher crystallinity, while regions further away from the melt zone cool down faster, leading to lower crystallinity. The pulse application can potentially improve the crystallinity by eliminating imperfect crystals and creating a more uniform crystalline structure. The reduction of the pulse duration from 40 seconds to 5 seconds, while increasing the test speed, also decreased the maximum temperature of the polymer region between the two consecutive coils from 152°C to 80°C. In the former case, polyethylene melting occurred, but not in the latter. To ensure the non-destructive nature and reproducibility of the tests, the pulse duration was adjusted to 5 seconds. The presented data confirms the repeatability of the method. Sensitivity analysis revealed that a delay or advancement in pulse termination by up to one second results in a maximum error of approximately 1.5°C. However, if this time error range can be reduced to less than one second, the maximum error will be less than 1°C. Overall, the thermographic method proves to be an effective tool for easily assessing the impact of various materials on the performance of electrical welding. This project successfully demonstrates the positive influence of an intermediary material on the performance of electrofusion welding.

Competing interests

We confirm that there are no competing interests to declare.

Data availability

No data was used for the research described in the article

Acknowledgement

Reference

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