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ADVANCES IN FIELD JOINT COATING FOR UNDERGROUND PIPELINES

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ABSTRACT

The increase in use of high quality and expensive pipeline coatings has heightened the need for field joint coating systems to match the quality of the factory coating. Recent developments in field joint coating technology have gone a long way to address this need.

This paper describes one major Middle Eastern oil and gas company's experience with a number of field joint coating systems for three layer polyethylene and polypropylene coated pipes. This experience includes coating well over a 100,000 field joints in some of the toughest conditions (extreme heat and humidity, coupled with sand storms) existing in any oil & gas field.

A comparison is made between the different field joint coating systems in terms of technical characteristics, cost and ease of application in the field. The relative scarcity of international standards, and hence the importance of pre-qualification trials & production testing in the field is also highlighted.

Keywords: coating, pipeline, underground, field joint, polyethylene, polypropylene, polyurethane, FBE, heat shrink sleeve, tape wrap, flame spray

INTRODUCTION

Underground steel pipelines in the Middle East, carrying oil and gas, have traditionally been coated and often supplemented by cathodic protection. One of the most common types of coating for these pipelines has been coal tar epoxy. Environmental concerns with coal tar have led to limiting, and in most European and North American countries, total banning of the use of coal tar based coatings. An attractive alternative appeared to be cold wrapped tapes. These offer the advantage of easy field application and negate the requirement for speciality field joint coatings. The experience with these coatings has, at best, been mixed in the Gulf desert environment[1]. A major reason for this is the existence of Sabkha areas in the Arabian deserts. These are highly saline marshy soils which are both highly corrosive and subject to much movement. The coatings in these areas are therefore subjected to saline water, stress and high temperatures. Cold wrapped tapes[1], and even in some instances fusion bonded epoxy (FBE)[2], have been found to undergo rapid deterioration in these Sabkha areas. This can cause accelerated corrosion of the pipeline leading to leaks. Normally it should be possible to avoid leaks, at least in the short term, by adjusting the level of cathodic protection. However, if the coating deterioration is on a large scale, or if the CP levels are not continuously monitored, leaks can still occur. These factors, and the need for coatings with higher temperature resistance, has led to the increasing use of three layer polyethylene (PE) and three layer polypropylene (PP) coating systems in the Gulf countries. In Abu Dhabi Company for Onshore Oil Operations (ADCO) the majority of new steel underground pipelines are coated with these three layer coatings.

Coatings can degrade due to a number of reasons. These include:

- Pipe movement and soil stress
- High temperatures
- Ultra Violet radiation
- Bacterial attack
- Saline moisture in the soil
- Chemicals

The damage can also be done before pipeline installation during transportation from factory to site. Perhaps the greatest contributor to coating failures is poor coating application.

The main factors that determine the selection of a suitable pipeline coating system are:

- Soil resistivity
- Design life
- Pipeline design temperature
- Cost
- Climatic conditions
- Ease of application & repair
- Pipeline laying method
- Availability of skilled applicators
- Equipment requirements
- Coating of field Joints
- Track record
- Health, safety & environmental regulations

In soils with very high resistivity it may be possible to bury a pipeline without any coating, particularly if it is being cathodically protected. However, in low resistivity soil, such as the Sabkha areas, corrosivity levels are high and a good, impermeable coating is required in addition to cathodic protection. Such a coating not only should have good resistance to corrosion and water permeation but also be able to withstand extensive soil movement and high external temperatures.

Temperature is a major factor in selecting a coating. For example, the choice between the three layer polyethylene and three layer polypropylene coating systems is usually based on the maximum operating temperature. Table 1 provides a general guideline for maximum operating temperature of a number of different coatings[3].

The welded joint is the weakest structural area in a pipeline. Unless it has been stress relieved, it can have a much higher stress concentration than the surrounding metal and thus be more susceptible to cracking. Its corrosion resistance, measurable by its critical pitting temperature (CPT), is also usually less than the parent metal. It therefore requires excellent protection. For this reason, the quality of the field joint coating should be at least as good as the rest of the pipeline's factory coating. Otherwise the combination of the weld and inferior field joint coating can present a double weak spot in the pipeline.

The desert environment, with high temperatures, humidity and frequent sand storms make successful field coating application very difficult. It is a universal belief that surface preparation is critical to the success of any coating, particularly in severe environments[4,5]. The performance of field joint coatings has been directly related to surface cleanliness[6].

The three layer coating systems have become increasingly popular for coating of oil and gas pipelines, both in the Middle East and the North Sea. These coatings consist of a FBE primer, a modified adhesive layer and a top layer of either polypropylene or polyethylene. They are applied in the factory in an automated, assembly line manner. Polyethylene and polypropylene have no adherence to steel and therefore must have a primer (usually FBE). Prior to coating the pipeline surface is blast cleaned, heated, spray washed (sometimes with phosphoric acid), spray rinsed with hot water and dried. If required, it can also be chemically treated with chromate solution.

Once the candidate coating systems pass the procedure qualification tests, the final choice is often made by the contractors. Cost, ease and speed of application and equipment requirements are then likely to become the major selection criteria. Table 2 gives some indications of relative costs of a few coatings[3,7] and Table 3 offers a cost comparison between field joint coating systems for polypropylene.

Field joint coating systems for pipelines coated with FBE and 3 layer PE/PP systems are described.

FUSION BONDED EPOXY (FBE) FIELD JOINT COATING

FBE is a very popular coating for pipelines in Europe and North America. It is also used frequently in the Middle East. One of its great advantages is that it can be applied to the entire line. It permits the formation of a protective magnetite layer and does not suffer adversely from cathodic protection[4]. However,ADCO's experience has shown that in the very aggressive Sabkha soil and under the extreme heat and humidity of the desert, the combination of high soil stresses, coupled with continuous wetting and drying, can cause embrittlement and disbonding of FBE coating[2]. This can happen quicker than expected if the coating application has been less than ideal. FBE is also more prone to mechanical damage during transport than the three layer coatings.

As mentioned above, the coating for the field joints of FBE coated pipeline is also FBE. The field joints are abrasively blasted and induction heated up to 240°C. Fluidised epoxy powder is then applied to the pre-heated surface by a semi-automated electrostatic spray machine. This is not a complex piece of equipment and can easily be transported from one location to the other in the field.

If FBE was selected for field joint coating, then it may be sensible to consider dual FBE coating due to its improved mechanical properties over standard FBE coating[8].

FIELD JOINT COATINGS FOR 3 LAYER POLYETHYLENE COATED PIPE

For the three layer polyethylene coatings the most common field joint coating systems are heat shrink sleeves and polyurethane. We use heat shrink sleeves for the field joints and polyurethane for bends and fittings. Flame sprayed polyethylene has also recently been used on some projects in the Gulf.

a) Heat Shrink Sleeves

This is typically a cross linked polyethylene sheet, coated on one side with a hot melt adhesive. Sometimes, as an added protection measure, an extra FBE primer is applied to the steel joint area prior to sleeve application.

The sleeves are generally approved for use for design temperatures up to 100°C. The field joint is again blast cleaned and pre-heated, to a temperature up to 100°C for FBE primer application. In the desert environment, wind shield screens are often set up to prevent sand being blown on to the coating (Figure 1). The pipe is then re-heated to about 90°C, whilst ensuring that the epoxy is substantially cured and dried. The sleeve is then carefully wrapped around the field joint and heated by a flame torch until full adhesion to the pipeline has been achieved (Figure 2). This whole process is relatively fast. The main difficulties with this system are ensuring an even supply of heating to all parts of the sleeve and prevention of overheating at any point. Sometimes, in order to achieve a more even distribution of heat, or due to space constraints, a magnetic induction heating unit is used (Figure 3).

We have used this system on our latest main oil pipeline and in the three years since installation no significant problems have been encountered. Random excavations of the coated pipeline have verified this point. It is one of the easier field joint coatings to apply on site and the training of its applicators is fairly simple.

b) Polyurethane Coating

The polyurethane system offers the advantages of being a one layer coating, equally applicable to field joints, bends and fittings. It is normally applied by spray. Although expensive, it offers the advantages of simple coating procedure, durability, strength and corrosion resistance. However, due to lack of factory application, its use on pipelines in the Gulf has been mainly limited to bends, tees and some field joints. A study on performance of various coating systems in the Gulf showed that polyurethane exhibited a life expectancy of 3-4 years under severe conditions. The same study showed that a coating system comprising of an inorganic zinc silicate primer, epoxy second coat and polyurethane top coat had a life expectancy of 10-12 years under severe conditions[9].

c) Flame Sprayed Polyethylene

This system is very similar to flame sprayed polypropylene (see below) and uses a special gun to spray the polyethylene and its adhesive on an FBE primer. We have not used this system yet but are aware of its recent use on field joints, bends and tees on an oil & gas pipeline project in the UAE. Its advantages are its ease of use, compatibility of field joint coating with the pipeline coating and its applicability to weld joints, bends and tees.

FIELD JOINT COATINGS FOR 3 LAYER POLYPROPYLENE COATED PIPE

Currently, there are five main systems for coating the field joints of pipelines coated with the three layer polypropylene. These are:

a) Two Layer Fusion Bonded Epoxy (FBE) / Sintered Polypropylene Coating
b) Three Layer FBE / Adhesive / Co-extruded Polypropylene Sheet Coating
c) Two Layer FBE / Combined Adhesive and Polypropylene Applied by Flame Spray Gun
d) Polyurethane Coating
e) Heat shrink sleeves

a) Two Layer Fusion Bonded Epoxy (FBE) / Sintered Polypropylene Coating

This system is composed of an FBE primer plus a polypropylene topcoat. After blast cleaning and surface preparation, the pipe is induction heated up to 230°C. Then the joint is coated with FBE using a semiautomatic flock spray equipment. Finally, the polypropylene topcoat is applied, again using a flock spray equipment. Since the adhesion of the polypropylene to the FBE is dependent on the pipe temperature, the total thickness of the polypropylene layer is limited by the pipe surface temperature. It is not usually possible to achieve more than 1.5 mm coating thickness.

A problem, common to systems (a), (b) and (c) above, is the potential damage caused by the high pre-heat temperatures to the bond between factory and field applied polypropylene coatings[3].

When direct methods of heating the coating, such as flame torch guns, are used there will be some concern about possible loss in some of the coating properties. For this reason, sintered coatings are not as highly recommended as flame sprayed or co-extruded sheet coating systems. If used, careful procedure qualification trials and production testing should be carried out.

b) Three Layer FBE / Adhesive / Co-extruded Polypropylene Sheet Coating

This field joint coating was developed during an earlier project for three layer polypropylene coated pipelines being routed underground through Sabkha areas in the Abu Dhabi desert environment[2]. Earlier, FBE had failed as a coating system on these pipelines.

The 3.5 mm thick "smart sheet" or "co-extruded sheet" system used consists of a FBE primer (~300 μm), a chemically modified polypropylene adhesive (~200 μm) and a co-extruded polypropylene sheet (~3000 μm).

The initial stages of this coating, i.e., surface preparation, induction heating and application of FBE by electrostatic flock spraying, are identical to those of the sintered joint. After the FBE application, a modified polypropylene adhesive layer is also applied by the flock spray equipment. This adhesive layer forms an intimate cross link with the FBE layer. Finally, a pre-fabricated polypropylene sheet is clamped on around the field joint and, after the sheet has fully cured, it is welded manually longitudinally and circumferentially using weld guns and a semi-automatic rotating welding machine.

Typically, it would take 45 minutes to complete one such field joint. However, the coating can be significantly speeded up using multiple crews as follows:

CREW 1: Surface preparation and induction heating of the field joint (2 minutes), FBE and adhesive application (3 minutes), followed by clamping and curing the co-extruded sheet (25 minutes).

CREW 2: Longitudinal and circumferential welding of the co-extruded sheet after curing (15 minutes).

The great advantage of this coating is the fact that the co-extruded Polypropylene sheet is pre-fabricated in the factory and one therefore obtains a uniformity in the quality and properties of the coating. The chances of deterioration in coating properties as a result of poor coating application in the field and insufficient quality control is therefore considerably reduced. The main disadvantage of this system is that it can not be applied to bends and tees, thus necessitating the use of another coating system for these applications. Also it is a relatively slow process, particularly if carried out by a single crew, and requires a degree of skill in its applicators.

We have had around 50,000 pipeline joints in the desert coated with this system and it the 5 years since the job completion have not encountered any significant problems. Limited excavations have not shown anything to indicate otherwise.

c) Two Layer FBE / Combined Adhesive and Polypropylene Applied by Flame Spray Gun

This is one of the most recently developed systems for coating of the field joints. The surface preparation for this coating is identical to the other two field joint coating systems described above. The joint surface is blast cleaned to achieve the required standard (Figure 4). During the induction heating (up to 230°C), the factory applied polypropylene coating around the field joint is isolated from the heat by temporary aluminium or fibreglass shields. FBE and chemically modified polypropylene powders are then applied by flock spraying (Figure 5). After this stage another layer of chemically modified polypropylene is applied by a flame spray gun on to the joint until the required thickness is achieved (Figure 6). The polypropylene is transported through a mixture of gases (propane, nitrogen and oxygen or propane & nitrogen only) and melts in the gun *before* reaching the pipe surface. The thickness of the finished joint coating may be equal or less than that of the factory applied coating.

When using a single crew, flame spray coating would require a shorter time to reach a coating thickness equal to the co-extruded sheet. This advantage is particularly important for offshore pipelines where time spent on site by the coating crew can be very costly. Another advantage is that this system can be also applied to bends and tees. Its equipment is relatively easy to mobilise in the field and its application requires a lesser degree of skill than the co-extruded sheet.

We have used this coating system on some 40,000 field joints recently after extensive procedure qualification testing. It is therefore early days to judge its success in the climatic conditions existing in the Gulf. As can be seen in Table 4, mechanical and other associated properties of flame sprayed field joint coatings are inferior to those of the co-extruded sheet coatings. However, due to its easier application and its applicability to the bends, tees and welded joints, flame sprayed polypropylene appears to be favoured by coating contractors.

d) Polyurethane Coating

Most of the track record with polyurethane field joint coatings is with polyethylene coated pipes. There have recently been some applications of this coating to polypropylene coated pipes in the North Sea. Our procedure qualification testing has shown that polyurethane's weak points are its adhesion to the factory applied polypropylene and its resistance to high temperatures.

e) Heat shrink sleeves

Heat shrink sleeves have been tried for field joint coating of polypropylene coated pipelines. It has been found that at temperatures above 40°C they showed very low resistance to mechanical damage and soil stressing and also poor adhesion to both the steel substrate and the polypropylene at the overlap[3]. However, indications from the coating industry are that the new generation of heat shrink sleeves for polypropylene coated pipelines will offer significant improvements in all the above weakness areas.

COLD WRAPPED TAPE COATING

Another coating system that, like FBE, can be used for coating the entire line is cold wrapped tapes. This feature, together with their relative low cost and ease of installation, has made them fairly popular. Our experience with tapes has not been very satisfactory. We have observed a number of failures, especially in Sabkha areas, where the tape has disbonded and salty water has caused rapid corrosion of the pipeline. Another oil and gas company in the UAE has reported a large number of failures of cold wrapped tape coatings[1]. The reasons for the failures included:

- Low resistance to soil stress and pipe movement
- Insufficient and non-uniform tension during application
- Thermal degradation
- Poor adhesion to metal surface

Another study has reported very poor adhesion of tapes to polypropylene coated pipelines and extremely low resistance to soil stressing at high temperatures (~105°C)[3]. A comparison of tapes with other field joint coating systems, including FBE and heat shrink sleeves, has found them to be much inferior to the rest[10].

PRE-QUALIFICATION TRIALS AND PRODUCTION TESTING

Field joint coating selection and qualification is handicapped by the relative scarcity of international standards on this subject. For example, the standards for polypropylene coatings have been written for extruded coatings and many of their qualification tests can not be applied to sintered or flame sprayed polypropylene coatings. The Shell Design and Engineering Practice (DEP) on polyethylene and polypropylene coating for line pipe[11] does not cover the field joints. The main standards used by us for the procedure qualification and production testing of field joint coatings of pipelines are the German (DIN)[12-14] and French (NFA)[15] coating standards.

Like most oil and gas companies, We have our own coating specifications. These include stand alone specifications for field joint coatings. Many of the tests included in our specifications have been developed by trial and error or improvisation on standard tests.

Extensive procedure qualification trials (PQT) and production tests should be carried out on any proposed field joints. Table 4 shows some of the tests used in PQT. For hostile field environments, such as the Arabian deserts, the PQT should not be confined to the coating yards but include the actual desert environment. Often procedures that look easy in the yard may prove difficult, and even sometimes impractical in the field. Even if the PQT is confined to the yards, one should always try to imagine the procedure taking place in the field and then try to judge its ease of application and practicality. Magnetic induction heating and coating of a field joint under desert conditions are shown in Figure 7 and Figure 8 respectively. The heat, humidity and sand storms make field joint coating a very arduous venture in the desert. When considering a number of different field joint coating systems for a hostile environment, the ease of application should be given a high priority in the selection criteria. As mentioned earlier, most coating failures are due to poor application. It is much harder to attain ideal application procedures in tough field conditions (e.g., in the desert) than in the yard.

CONCLUSIONS

Three layer polypropylene and three layer Polyethylene are advanced, environmentally friendly coating systems for pipelines buried in hostile environments, such as wet and saline soil, subject to soil movement and operating at elevated (65°C - 110°C) temperatures. They are less prone to mechanical damage than FBE. Many different types of field joint coatings exist for the three layer coatings. The preferred systems for coating three layer polyethylene coated pipes are sprayed polyurethane and polyethylene heat shrink sleeve. The most mechanically sound system for field joint coating of three layer polypropylene coated pipes is the co-extruded polypropylene sheet. Flame sprayed polypropylene, however, is often preferred for its greater flexibility and easier applicability. An overall ranking of the coating systems used for polypropylene coated pipe field joints is presented in Table 5. This indicates that, should polyurethane system manufacturers succeed in improving its technical characteristics, it could become much more popular for polypropylene field joint coatings. Another serious contender is polypropylene heat shrink sleeves. This has not as yet, at least in the Gulf region, become popular for polypropylene field joint coating. Cold tape wrap has been found to be less than ideal for climates such as those in the wet, saline and hot soils found in some parts of the Arabian deserts.

There are, as yet, no international standards dedicated to field joint coatings for polyethylene or polypropylene coated line pipes. There is a real need for such standards to ease the process of selection, testing and inspection of field joint coatings. Meanwhile, it is recommended that thorough procedure qualification trials both at the coating yards and in the field be carried out before the final selection is made.

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TABLE 1
PROJECTED MAXIMUM OPERATING TEMPERATURES[3,7]

Coating	Temperature °C (F)
Coal Tar Enamel	70 (158)
Coal Tar Enamel + Concrete	90 (194)
Three Layer Polyethylene	85 (185)
Fusion Bonded Epoxy	90 (194)
Three Layer Polypropylene	140 (284)

TABLE 2
COST COMPARISON BETWEEN DIFFERENT COATING SYSTEMS[3,7]

Coating System	Order of Cost	Cost as % of total pipeline cost (onshore)	Cost as % of total pipeline cost (offshore)
Coal Tar Enamel	1	8%	11%
FBE	1.4		
3 layer polyethylene	2.0	11%	15%
3 layer polypropylene	2.0-2.3	11%	15%

TABLE 3
COST COMPARISON BETWEEN FIELD JOINT COATING SYSTEMS FOR POLYPROPYLENE COATED PIPELINES*

Coating System	Order of Cost (includes material & installation)
Co-extruded sheet	1
Flame sprayed	0.9
Polyurethane	0.4

*Data obtained from one pipeline coating contractor in the UAE.

TABLE 4

COMPARISON OF PROCEDURE QUALIFICATION TESTS DATA BETWEEN FIELD JOINT COATING SYSTEMS FOR POLYPROPYLENE COATED PIPELINES[7]

Test	Co-extruded sheet	Flame spray
Bending Test result	No crack	No crack
Penetration at ambient temp	0.06 mm	0.03 mm
Penetration at 110°C	0.13 mm	0.9 mm
Impact resistance	23 J/mm	16 J/mm
Peel adhesion at ambient	1550 N	510 N
Peel adhesion at 110°C	510 N	400 N
Cathodic Disbondment @ 65°C/ 48hours	0 mm	0 mm
Cathodic Disbondment @ 110°C/ 48 hours	0 mm	0 mm
Cathodic Disbondment @ 20°C/ 28 days	1.0 mm	1.0 mm
Impact strength	> 16 Mpa	> 15 Mpa
Oxygen induction time	50-75 minutes	15-20 minutes
Typical time for field joint coating (3mm thick)	45 minutes (applying a 3.4 mm sheet)	18-20 minutes

TABLE 5

RANKING OF THREE SYSTEMS FOR FIELD JOINT COATING OF POLYPROPYLENE COATED PIPELINES (IN DESCENDING ORDER, 1 BEING THE BEST)

Coating System	Technical Characteristics	Ease of Field Application	Equipment Required for Field Joint Coating	Cost
Co-extruded Sheet	1	3	3	3
Flame Sprayed	2	2	2	2
Polyurethane	3	1	1	1

FIGURE 1. Application of epoxy primer on a pipeline field joint in the desert prior to installation of a polyethylene heat shrink sleeve (photo courtesy of Shaw Industries).

FIGURE 2. Installation of a polyethylene heat shrink sleeve on a pipeline field joint by application of gas torch flame heating (photo courtesy of Shaw Industries).

FIGURE 3. A polyethylene heat shrink sleeve being heated into shape by magnetic induction heating (photo courtesy of Shaw Industries).

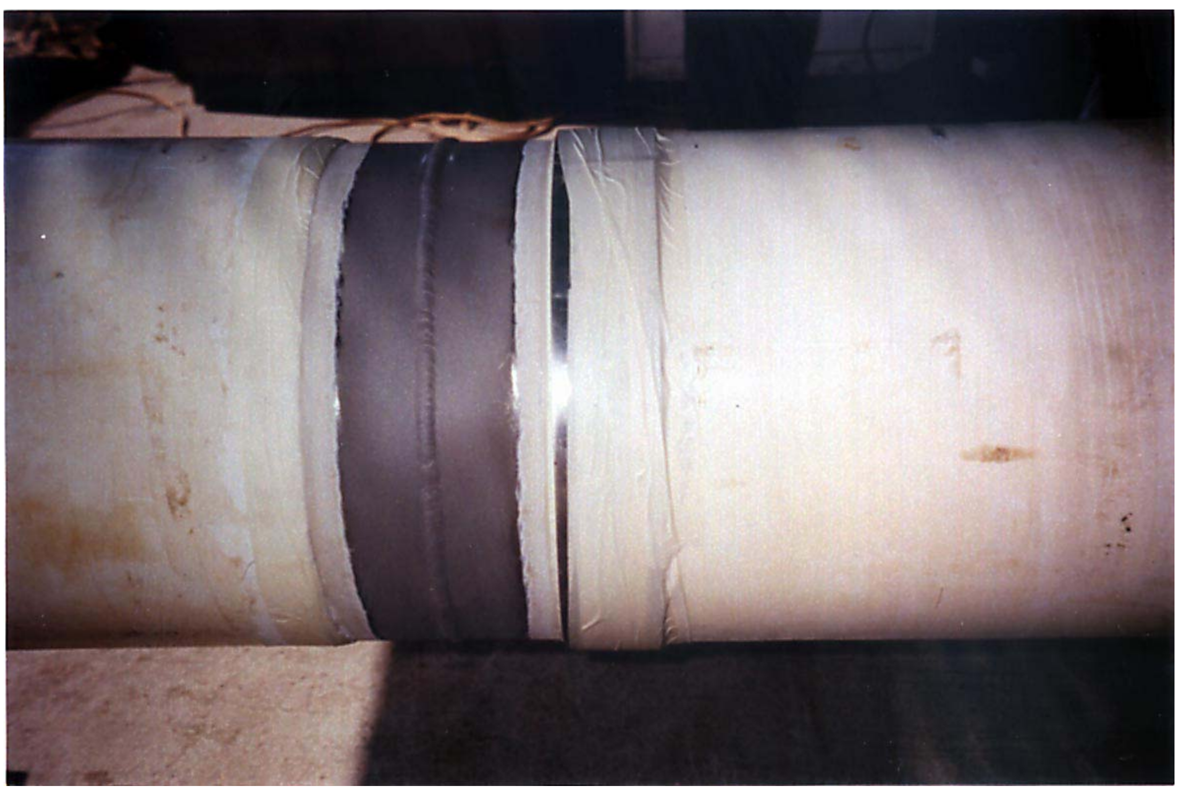

FIGURE 4. A welded pipeline joint surface after surface preparation and in readiness for coating.

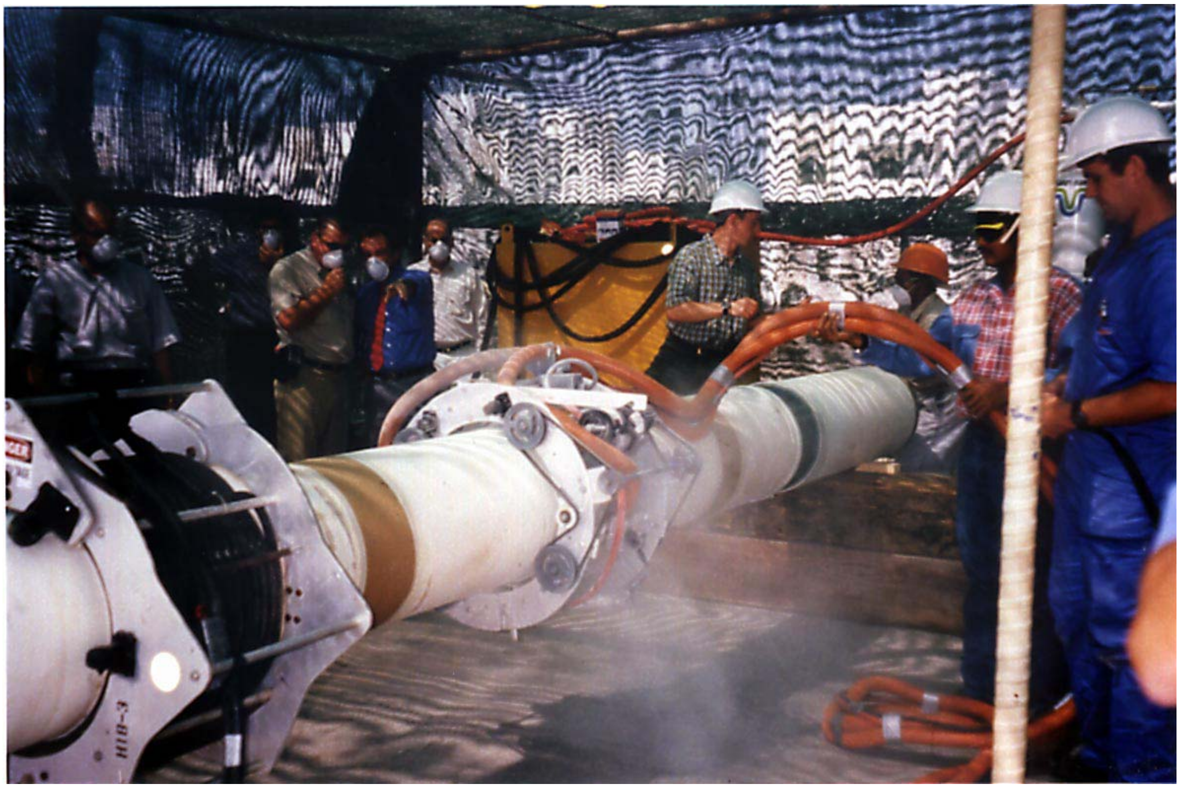

FIGURE 5. Application of FBE primer and modified polypropylene adhesive by flock spraying.

FIGURE 6. Application of polypropylene coating to a pipeline joint by flame spray gun.

FIGURE 7. Application of magnetic induction heat to a pipeline joint in the desert.

FIGURE 8. Application of polypropylene coating by the sintering method in the desert.