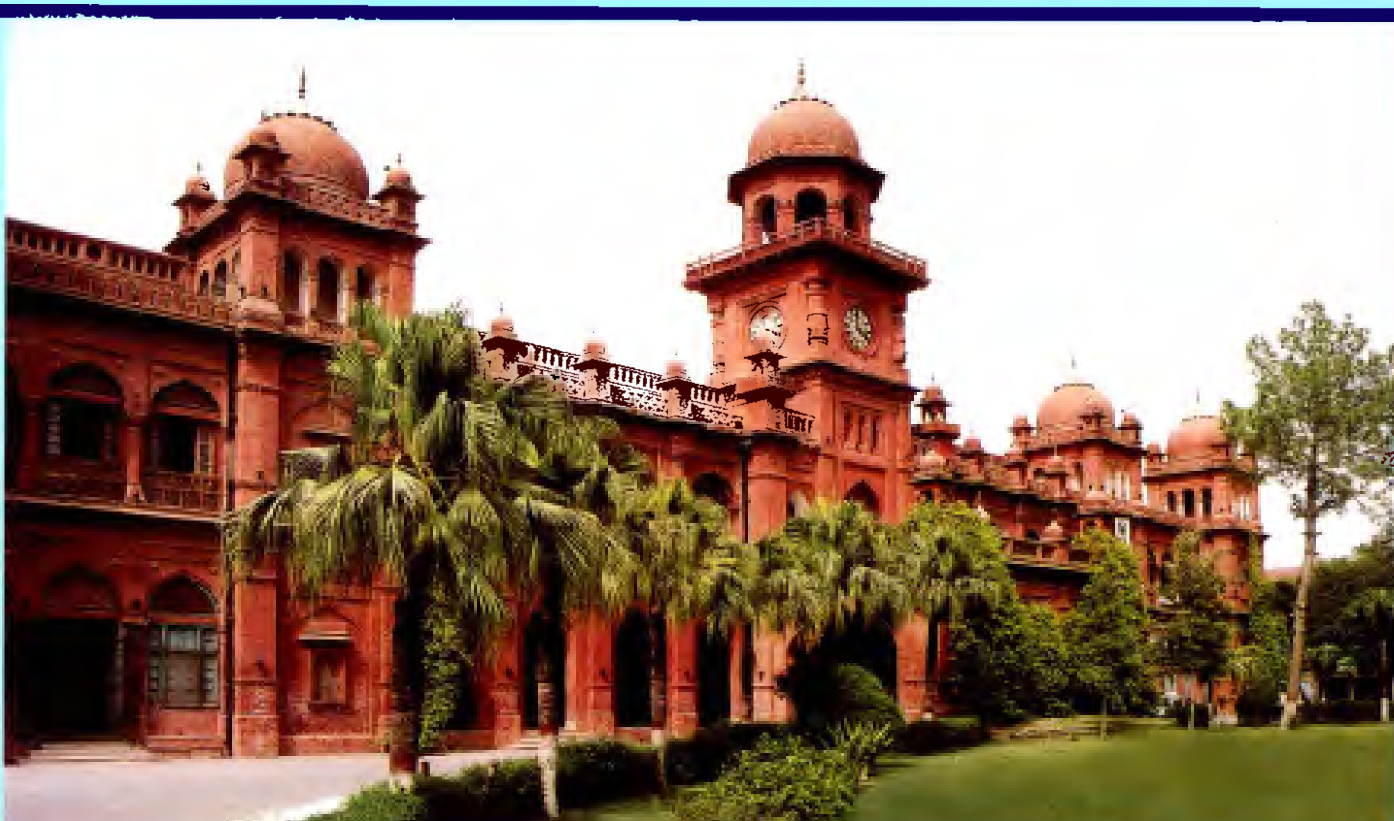
RECOMMENDED STANDARD OPERATING PROCEDURES FOR SSGC FUTURE GAS PIPELINE PROJECTS



CORROSION CONTROL RESEARCH CELL (ICET)
ENGINEERING RESEARCH CENTRE
FACULTY OF ENGINEERING & TECHNOLOGY

UNIVERSITY OF THE PUNJAB, NEW CAMPUS, LAHORE
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SOCIETY OF CORROSION ENGINEERS PAKISTAN

2007

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FOR
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PREFACE

Underground pipelines are designed and constructed with corrosion resistant coating and protected simultaneously with Cathodic Protection. A wide variety of organic coatings have been developed and used, ranging from factory applied systems to over the ditch applied tapes, original coal tars, asphalt enamels and vinyl tapes have given way to more dependable and better performing extruded polyethylene, Fusion Bonded Epoxy (FBE) coatings. The uses of two or more layers of FBE coatings provide much greater versatility to coating-protection-system capability. Corrosion coatings on most cross-country pipelines are done in mechanized coating plants with FBE or multilayer polyolefin. Specific FBE formulations are designed to meet the different nature of the application process while maintaining performance characteristics. The coating costs represent only a small part of the overall project cost. However it protects a pipeline, which has high replacement cost and this in turn protects the viability of much larger assets. The cost of lost production or environmental damage claims from a failed pipeline or one shut down for repairs or maintenance can far exceed the cost of the coating. These recommendations discuss the major factors for the reliability of the 3L Epoxy/PE Coating. The coating needs to provide high electrical resistance and have the capability of maintaining electrical resistance over the lifetime of the pipeline (50 to 60 years). The coating must not allow the development of an environment that leads to Stress Corrosion Cracking (SCC) of the steel. The specifications writer must ensure that comprehensive specifications are written and enforced. Moreover the application process must be well understood and practiced with an effective quality control system. The chemistry of majority of epoxy resins used commercially has been briefly discussed elsewhere. The polar groups, such as epoxy and hydroxyl, give epoxy resins their well-known adhesion characteristics. The aliphatic sequences between either linkages confer flexibility. Both the epoxy and hydroxyl groups can participate in further chemical reactions, essential for cure. In addition to the different end groups, varying amount of inorganic material, such as sodium chloride (formed by the reaction of sodium hydroxide with epichlorohydrin residues) can remain in the epoxy resin. This is important for some applications, particularly electrical ones, and some manufacturers of epoxy resins offer special ultra pure electrical grades or low chloride grades.

All FBE products for pipeline coating are not the same (D.G. Temple, K.E.W. Coulson, "Pipeline Coatings, Is It Really a Cover-up Story? Part 1," CORROSION 84, paper no.355 (Houston, TX: NACE, 1984), (D.G. Temple, K.E.W. Coulson, "Pipeline Coatings, Is It Really a Cover-up Story? Part 2," CORROSION 84, paper no.356 (Houston, TX: NACE, 1984). Following are the main points for consideration:-

- Performance characteristics of these coatings result from a calculated process of balancing components and chemical reactions to provide certain properties.
- Trade-offs in formulation development are required to achieve specific target test results.
- Pipeline owners or their representatives must be aware of these product differences and the way in which they impact performance. This implies a thorough understanding of test protocols and significance of results. They must also possess the ability to apply the knowledge skillfully in the coating selection process to satisfy specific pipeline needs.
- Similar trade-offs are made for the polyolefin systems, primers, and MCL systems.
- While a deep understanding of the underlying chemistry is not required, a general understanding provides a better basis for the coating decision making process.

Most coatings are the result of the combination of two different materials - an organic or an inorganic substrate and a polymeric resin - which form adhesive bonds with each other. The quality and durability of a coating is directly related to the nature of adhesion. Chemists tend to associate adhesion with the energy liberated when two surfaces meet to form an intimate contact termed as an interface. In other words, adhesion may be defined as the energy required dismantling the interface between two materials. Physicists and engineers usually describe adhesion in terms of forces, with the force of adhesion being the maximum force exerted when two adhered materials are separated. There are many theories regarding the mechanism of adhesion - such as adsorption (Van der Waals forces) electrostatic, diffusion (entanglement of polymers with a substrate), chemical bonding, mechanical interlocking etc. - all of which may play a significant role in interfacial bonding. The energy required to separate the adhesive (coating) and the substrate is a function of the adhesion level i.e. interactions at the interface, but it also depends on the mechanical and viscoelastic properties of the materials.

When a polymeric coating is applied on a substrate, a chemical reaction takes place when each surface contains functional groups. It is often desirable to modify the substrate to ensure the reactivity at the interface by removing contamination and/or introducing functional groups. This simplified view of the interfacial or interface bonding neglects physical forces between two materials which are influenced by e.g. surface roughness. For a comprehensive characterization of coatings, surface analysis of the substrate (chemical as well as topographic) and thermal analysis of cured polymeric coating materials is of great importance.

The purpose of this work is to underline the importance of the substrate surface and the polymer (coating) viscoelastic/thermal properties for a durable adhesive behavior of the polymer/substrate assemblies.

Standard Operating Procedures are just the procedures and processes that you use to ensure that you do them the same way each time. An SOP is nothing more than a clearly written description of how a particular task is to be performed. SOPs are critical tools in all successful industrial operations. They are essential for:-

(i) Standardizing processes
(ii) For ensuring that regulatory and organizational policy requirements are met, and
(iii) For training new professional.

This recommended set of SOPs has several other purposes as well. It will ensure that all those involved with coating systems are aware of the international standards and that all employees are familiar with the processes. Adherence to this SOP will also ensure that processes are reviewed and updated on a regular basis. Adhering to the following SOP will ensure that the coating systems being produced under the domain of SSGC will have enough integrity to cover the span of its industrial life.

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This is submitted with best of our capability, without any bias, prejudice or greed.

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Introduction

Standard Operating Procedures are the procedures and processes that are used to ensure that all the procedures and processes are done the same way each time. An SOP is nothing more than a clearly written description of how a particular task is to be performed.

SOPs are critical tools in all successful industrial operations. They are essential for:-

(i) Standardizing the process
(ii) Ensuring that regulatory and organizational policy requirements are met, and
(iii) Training new professionals.

Before writing down a set of recommended SOPs for SSGC use, it is important to review history of FBE/PE coating, usage and its technical/scientific requirements. A brief introduction is as follows:-

Fusion bonded epoxy (FBE) was introduced in Europe in 1953 for the coating of electrical equipment by the fluidized bed dipping method. In the early '60s it was introduced to the pipeline industry for the protection of small diameter water and oil field production piping. The first FBE for large diameter pipe was supplied in the mid '60s. By the late '70s FBE became the most widely used pipeline coating in the U.S., Canada, Saudi Arabia and the U.K. Presently, FBE is used on every continent for the protection of line pipe, production tubing and drill pipe for the oil and gas industries. It has also gained acceptance for the protection of reinforcing steel (rebar) in the U.S., Canada, the U.K. and the Middle East.

Although FBE is extremely successful as a corrosion protection system for underground pipelines, there are some inherent limitations, which make it difficult to achieve total corrosion protection with coatings alone. Some of these limitations are due to the chemical nature of organic materials in the coating and some are related to coating application procedures. To overcome the deficiencies and achieve total corrosion protection, another alternative method, cathodic protection (CP), is used in conjunction with the coating. Presently, FBE with the CP system is the most effective and economical corrosion control system for underground pipelines, but the success depends on the coatings ability to become an integral part of the "CP coating" combination system.

FBE/PE was introduced in Pakistan in 1991. Asphalt and bitumen coating were using before this new technology. Economic and technological conditions of the country were not so to implement the advance specifications/standard of the pre-coating and post-coating evaluations with full laboratory and certified inspector/specialist. Furthermore shift to advance technology was not easy and execution of standards/specifications lagged behind. If these technological aspects and standard/specification for the applicator and all other surrounding elements were considered, there were fewer chances of disbondment and other problem we are facing at the moment. Following elements had to be considered while executing the process.

1. Applicator staff certification and qualification for specific job.
2. Third party inspectors' certification and authorization to conduct inspection test and prepare report in highly scientific spirit of testing.
3. Customer certification of the staff to check the execution of specification and procedures.(i.e. raw material, surface preparation coating etc)

In early '90 as FBE/PE coating was a new technology, conducting FBE powder tests, coating test during applications, after application, curing and regular monitoring was not possible due to lack of technical facilities and expertise in the country. Under recent time availability of the evaluating equipment and experiment conducting apparatus, it is feasible to verify most of the parameters. This can be either done in house facilities or nationally available apparatus. Apparatus like DSC, TGA, FTIR, surface profile-meter; surface contamination characterizing, etc. can be either carried out by establishing in house facility if possible or can be executed through external source facility in the country.

Theoretically the specification/application procedures and quality control tests are described in black and white, but problem exists during coating application and scientific execution due to lack of adequate knowledge and skills at various levels. Engineers, technicians and inspection staff at all levels are not duly certified (i.e. qualified for the specific job at all levels). In order to execute any job (i.e. material inspection, surface preparation, coating application, quality control and assurance) one has to be certified and qualified for that particular job.

Purpose of SOPs

The purpose of these SOPs is to cover the various aspects relating to safe upkeep of all future pipeline projects of Sui Southern Gas Company Pakistan. It will present an approach as to ensure that international preparatory and safety standards are met while preparing pipes for coatings, application of coatings and their safety till the time they are laid at their requisite field sites.

This SOP has several other purposes as well. It will ensure that all those involved with coating systems are aware of the international standards and that all employees are familiar with the processes. Adherence to this SOP will also ensure that processes are reviewed and updated on a regular basis. Adhering to the following SOP will ensure that the coating systems being produced under the domain of SSGC will have enough integrity to cover the span of its industrial life.

Certification

Certification serves following purposes:-

(a) Proper scientific and technological understanding of a test, procedure.
(b) Interpretation of the results, product specification or standards.
(c) Scientific and engineering implementation of the specifications and standards being followed.
(d) Properly implementation of standards in scientific terms & thus accurate interpretation is obtained.
(e) Highly experienced professional lays down standards and specification and specialists with best state of the art and to be executed and followed by trained certified by engineers and technologist.

Coating System Triangle

If we represent coating system as a triangle, on two base points we need specifications and standards in order to execute a job with precise scientific approach. But on the top of it we need a certified professional, who can understand, implement, translate and interpret result and findings in scientific way. Standards and specification can be secured through different sources but for their productive use basic need is a certified professional.

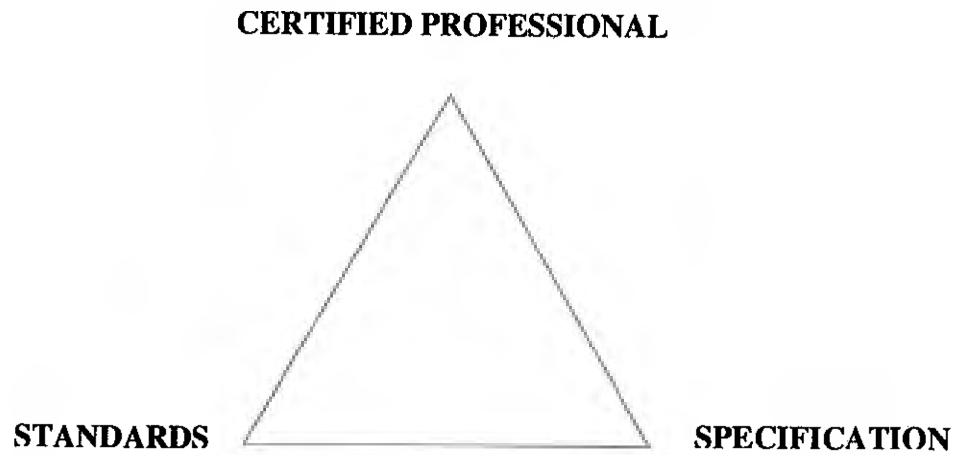

Figure 1: Coating System Triangle

In addition to the requirement of qualification and experience for an engineering/scientific job, there is requirement of registration and certification at all level of work. 3-layer epoxy/PE coating technology is most advance and recent development in the field of coating and their application method. Chemistry of these coatings is more advanced and sophisticated. With rigid specification of formation, testing, surface preparation, application method and monitoring it should consider as a specialized work. Each level of job is specialized activity; if one step is not executed properly the proceeding steps will not lead to a defect free long life coating.

Coating will not properly function in service if surface preparation is not properly and adequately carried out in accordance with standards/specifications. Scientifically tested anchor pattern, freedom from contamination and required specification/standards are basic parameters for getting accurate and reproducible results. These interfacial characteristics necessitate the qualified, experience and properly certified technicians, technologist and inspection engineer to authenticate in his job.

Research related Activity at ICET Punjab University

3-layer FBE/PE coating was new technology for Pakistan in 1991. Internationally its usage reaches more then 35 years. A lot of research activities are going on around the world to over-come the existing problems (disbondment, curing etc), modification and improvement in service life of the 3-layer FBE/PE coating. To go along the world and absorb the new technology we should prepare ourselves scientifically and technologically.

Internationally it has been proven coating with silane coupling on the steel surface gives good chemical bonding between steel surface and epoxy coating. It is not yet introduced in Pakistan, with technological/scientific advancement this should be considered as future technology. To consider the technology requirement and to absorb the future development, University of Punjab has a plan to conduct PhD program on affect of silane coupling on steel substrate for disbondment, which is beyond the project with SSGC. To execute and validate this affect same type of steel pipe coated without silane couple agent and with coupling agent will be part of future research studies.

Coating Rating According to their Corrosion Performance in Service:

Companies and services define corrosion performance of underground pipe line according to their experience, knowledge and expertise. Richard Norsworthy, "Lone Star Corrosion Services" USA, having more than 20 years of pipeline coating and corrosion control experience This experience involves numerous tests, specification writing and reviews, coating inspections, field applications and evaluations, literature reviews and plant applications. He selected the index of 10 for rating a particular parameter. It can be seen from table; in FBE/PE coating surface preparation and application are two crucial parameters to be considered during execution of FBE/PE coating.[1] The failure of integrity of the coating could lead to initiation of corrosion underneath the coating which could lead to hazardous consequences. Over the recent years 70% of the coating failure is attributed to poor surface preparation.

FBE Ratings

The FBE Ratings are given below:-

Characteristics	Comments	Rating
SS	Because of its excellent bond to steel and its smooth exterior, FBE is not affected by soil stress.	10
AD	FBE has the strongest adhesion to steel of any coating on the market today. This is one reason it is used as a primer coating on some multilayer systems.	10
SP	FBE has one of the most stringent surface preparation requirements of plant-applied pipeline coatings. Water absorption can cause blistering/disbondment if underfilm contaminants are present on pipe surface.	3
CPS	FBE allows enough current through the film to protect the steel under blisters or disbonded areas.	10
CPR	Even though some cathodic protection current passes through FBE, it has one of the lowest initial and long-term CP requirements of any coating.	8
H&C	FBE coated pipe handles very well during transportation, storage and construction. Even when damaged, the damage can be easily found and repaired. Ultraviolet rays will deteriorate FBE if it is left in storage too long.	8
RP	A variety of repair materials are used for FBE coatings. These may include, but are not limited to patch sticks, tapes, shrink sleeves & two part epoxies.	8 (for two-part epoxies) 6 (for others)
FJ	Field joints of FBE are expensive but offer the same coating as the base pipe coating. Tapes, shrink sleeves and two-part epoxies are also used for field joint coatings on FBE pipelines.	10 (FBE joints) 8 (for two-part epoxies) 16 (for others)
B&C	Bends and most other components can be coated with FBE. Brush-able epoxies are also acceptable coatings for these components.	10 (for FBE) 8 (for two-part epoxies)
AP	As discussed above, FBE application must follow a very stringent process to be successful	3
OA	FBE has been the most popular pipeline coating (especially in the United States) over the last few years, because of the reasons mentioned above.	8

Table 1: FBE Ratings.

[1] [Richard Norsworthy, Lone Star Corrosion Services U.S.A. (Hart's Pipeline Digest Focus Series 13 Spring 1998)]

Conclusive points in Coating Chemistry and their Implementation[2]

- Performance characteristics of these coatings result from a calculated process of balancing components and chemical reactions to provide certain properties.
- Trade-offs in formulation development are required to achieve specific target test results.
- Pipeline owners or their representatives must be aware of these product differences and the way in which they impact performance. This implies a thorough understanding of test protocols and significance of results. They must also possess the ability to apply the knowledge skillfully in the coating selection process to satisfy specific pipeline needs.
- Similar trade-offs are made for the polyolefin systems, primers, and MCL systems.
- While a deep understanding of the underlying chemistry is not required, a general understanding for applicator and owner provides a better basis for the coating decision making process.
- Penetration of Cl^- ions in coating also play important role in disbondment. Cl^- contribution in disbondment should be considered before burring pipe line or if any disbondment happened.

Cathodic Disbondment Resistance

The big advantages of three-layer systems are thickness and low-moisture permeation of the polyolefin. These factors significantly slow the rate of cathodic disbondment. On the other hand. residual stress in the polyolefin from the application process can increase the rate of cathodic disbondment. Beyond these aspects, the same factors that affect FBE play a part in three-layer coating disbondment.

- Intrinsic cathodic-disbondment resistance of the FBE formulation
- Cleanliness, anchor pattern, and peak density of the substrate
- Inorganic or organic contaminants on the substrate
- Steel temperature at the time of FBE application
- Level of FBE cure
- Thickness of FBE
- Soil stresses
- Indentation[3]

Prerequisites

It must be verified that all instruments and test equipment have been calibrated and are in good operating condition as verified by periodic tests.

Methodology

The methodology described in this SOP is outlined as below:-

Step No 1	Choice of the pipe and the coating system
Step No 2.	Surface preparation
Step No 3.	Procedures before blast cleaning
Step No 4.	Blast cleaning methods
Step No 5.	Blast cleaning abrasives

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[2] [All FBE products for pipeline coating are not the same (D.G. Temple, K.E.W. Coulson, "Pipeline Coatings, Is It Really a Cover-up Story? Part 1," CORROSION 84, paper no.355 (Houston, TX: NACE, 1984), (D.G. Temple, K.E.W. Coulson, "Pipeline Coatings, Is It Really a Cover-up Story? Part 2," CORROSION 84, paper no.356 (Houston, TX: NACE, 1984).]

[3] [(NF A 49-711, "Steel Tubes Three Layer External Coating Based on Polypropylene application by Extrusion," November 1992, ASTM G17-88 (1998) "Standard Test Method for Penetration Resistance of Pipeline Coatings Blunt Rod," West Conshohocken, PA: ASTM, 1998, J. Cox, DuPont, fax to author, Mar. 17, 2002).]

Step No 6	Acid Wash
Step No 7.	Procedures following blast cleaning and immediately prior to coating (Precautionary Measures after Surface Preparation)
Step No 8.	Verification of the cleanliness and surface roughness
Step No 9.	Application of the coating
Step No 10.	Storage/transportation conditions
Step No 11.	Coating Repairs

In order to formulate a well defined and comprehensive SOP for use at all future SSGC gas pipeline projects, we shall begin with Step No 1.

Step No 1. Choice of the pipe and the coating system

The choice of the pipe and the coating system is very important. A majority of coating system integrity related parameters are dependent on the type of the steel pipe and coating used. Standard API grade pipe is to be used. As regards the coating system, it is very important that few qualification parameters must be kept in mind while finalizing as to which coating is to be used:-

(i) Permeability:

It has been calculated that an extremely small concentration of oxygen and water ($10^{28.4}$ M) can start the corrosion process. Therefore, to minimize corrosion, materials those have extremely low permeability have to be used in the formulation.

(ii) Cohesive strength:

Although coatings with higher cohesive strengths are preferable, the ability to preserve their initial cohesive strength is perhaps more important, especially for pipelines designed for long service life (60 years).

(iii) Wetting property:

A powder coating's ability to be in intimate contact with the metal surface is known as the wetting property. This is one of the most important factors which related with mechanical bonding of the coating with substrate. If FBE primer got good wet-ability, it will go into valleys of anchor pattern giving good mechanical bond between the substrate and primer. When the substrate is grit blasted prior to application, this expands the available surface to be wetted thereby increasing the adhesion. The expansion of available surface for wetting is therefore only marginal. Additionally, the polyethylene has very low surface energy and the problem of obtaining adhesion, particularly by high energy paints, to polyethylene is well known.in the paint and plastics industries.

(iv) Contact Angle

Solid liquid gas boundaries are characterized by the contact angle measured through the liquid phase. The contact angle specifies the degree of affinity the fluid has for the substrate. If the substrate has a surface energy greater than the liquid, the adhesive forces of the liquid will overcome the cohesive forces. And the liquid will "wet out" or spread over the substrate. This situation gives a low contact angle (less than 90 degrees), for something such as water on glass. A non-wetting situation would be water on certain plastics or mercury on glass. The glass surface has lower surface energy than mercury or one can say the cohesive forces of mercury are greater than the adhesive forces between mercury and glass and the contact angle will be greater than 90 degrees.

(v) **Viscosity:**
Powder coatings essentially control corrosion by separating the cathode and anode. This can only be achieved if the coating can wet out the surface completely on the micro level. To have excellent wetting properties, the powder coating should have low viscosity.

(vi) **Flexibility:**
It is one of the most important mechanical properties of a pipeline coating. It affects the construction activities in terms of expense, time and installed coating integrity. Flexibility is a measure of the powder coating's ability to resist mechanical damage when stretched. This property is critical in pipeline construction because it will decide the field bending limits of the coated pipe.

Step No 2. Surface preparation

As far as surface preparation standards are concerned, it is to be kept in mind that, for FBE, any of the following standards could be used effectively to achieve an optimum level of surface roughness for the pipe to be coated with:-

(i) Sa 2.5 per ISO 8501-1/SIF
(ii) NACE level2, or
(iii) SSPC-SP 10.

In order to have a truly cleaned surface it is very important to strictly abide by any of the above standards [Table-4 & 5]. These standards specify a near-white metal blast cleaning which means that a near-white metal blast surface, when viewed without magnification, shall be free of all visible oil, grease, dust, dirt, mill scale, rust, coating, oxides, corrosion products, and other foreign matter, except for staining which should be not more than five percent of each unit area of surface. This unit area should be $58cm^2$ ($9.0 in^2$). (Ref SSPC-SP10).

The acceptable variations in appearance that do not affect surface cleanliness as defined earlier include variations caused by the type of steel, original surface condition, thickness of the steel, wells-metal, mill or fabrication marks, heat treating, heat-affected zones, blasting abrasives, and differences in the blast pattern.

An improperly cleaned surface can limit the number of hydroxyls available for bonding. The two important components of adhesion, polar-polar and chemical, are directly linked to the bonding hydroxyls of the substrate surface. The absence of these hydroxyl groups can adversely affect the overall adhesive strength of the coating.

Furthermore it is important that for the application of FBE coatings, the blast cleaned surface must have deep profiles of 2.5 to 4.5 mils. (60-110 microns).

The surface roughness generated as a result of grit blasting must be measured by use of any of the following techniques:-

Step No 3. Procedures before blast cleaning

All visible deposits of oil, grease, or other contaminants must be removed in accordance with SSPC-SP 1. (Solvent Cleaning). It is highly desirable that a visual standard or a comparator be specified to supplement the procedures before blast cleaning. This should be done in accordance with SSPC-VIS 1 which provides colour photographs for various grades of surface preparation as a function of the initial condition of the pipe. These photographs include the series A-SP 10, B-SP 10, C-SP 10, and D-SP 10 which depict surfaces cleaned to a near-white metal blast grade.

Step No 4. Blast cleaning methods

Clean, dry compressed air must be used for nozzle blasting. The engineer in-charge of the blasting operation must ensure that moisture separators, oil separators, traps, or other equipment must be available for this purpose.

Step No 5. Blast cleaning abrasives

The selection of abrasive size and type should be based on the type, grade, and surface condition of the pipe to be cleaned, the type of blast cleaning equipment employed, the finished surface to be produced (cleanliness and roughness), and whether the abrasive will be recycled. The abrasive should be dry and free of oil, grease, or other contaminants as determined by test methods found in either of the following standards:-

(i) SSPC-AB 1 (Mineral and Slag Abrasives)
(ii) SSPC-AB 2 (Specification for Cleanliness of Recycled Ferrous Metallic Abrasives),
(iii) SSPC-AB 3 (Newly Manufactured or Re-Manufactured Steel Abrasives).

Following qualification characteristics of the abrasive blast media should be considered before making any scientific selection.

(i) Shape of abrasive grains could range from extremely angular to spherical or rounded. Specific shape of the blast media should be selected as per requisite of the standard and degree of roughness required.
(ii) Hardness of abrasive media is a relative measure of the abrasive's resistance to abrasion by other materials. Hardness of the metallic abrasives is usually measured on Rockwell system, and steel grit normally has Rockwell values from 45 to 60. This value is roughly equal to 6.0 to 6.5 on the Mohs scale.
(iii) Mesh size of abrasives is numerical expression that defines the average abrasive mix. Normally G24 to G50 grit provide the specified anchor pattern.

Step No 6. Acid Wash

Phosphoric acid wash shall be applied to the pipe, item, or piece of equipment after sand blasting. The average temperature, measured in three different locations, shall be 80°F to 130°F during the acid wash procedure. The acid wash shall be 5% by weight phosphoric acid solution.

The duration in which the acid is in contact with the surface shall be determined by using the average temperature as tabulated below:

PIPE TEMPERATURE (°F)	CONTACT TIME (SECONDS)
80	52
85	45
90	36
95	33
100	28
105	24
110	21
130	10

Table 2: Pipe temperature versus contact time

After the acid wash has been completed, the acid shall be removed with de-mineralized water having a maximum conductivity of 5 micro-mhos/cm at a minimum nozzle pressure of 2,500 psi.

Step No 7. Procedures following blast cleaning & immediately prior to coating. (Precautionary Measures after Surface Preparation)

All visible deposits of oil, grease, or other contaminants must be removed in accordance with SSPC-SP 1 (Solvent cleaning). Dust and loose residues must be removed from prepared surface by brushing, blowing-off with clean, dry air, or vacuum cleaning. In order to have clean, dry air, the availability of moisture separators, oil separators or traps must also be ensured.

In no way the removal of surface imperfections should result in damage to the surface profile. If such a thing happens, these should be corrected to the degree suitable for the specified coating system.

Any visible rust that forms on the surface of the steel after blast cleaning must be removed by re-cleaning the rusted areas to meet the requirement of SSPC SP 10 before coating. The rust-back can also be minimized by removing soluble salts (e.g. chlorides and sulfates) from the pipe surface, and eliminating sources of contamination during and after blast cleaning.

For further information on removal of chemical contamination, please refer to SSPC-SP 12 (Surface Preparation of Steel and Other Hard Materials by High and Ultrahigh-Pressure Water Jetting Prior to Recoating).

Identification of the contaminants along with their concentrations may be obtained from laboratory and field tests as described in SSPC-TU 4 (Technology Update on Field Methods for Retrieval and Analysis of Soluble salts on Substrates).

In case the chemical contamination is not present, it must be ensured to blast clean and coat the pipe on the same day. It is also recommended that temperature of the pipe steel surface must be at least 3°C (5°F) above the dew point during dry blast cleaning operations. The engineer in charge must also ensure that pipe surface is visually inspected for moisture, pipe surface temperature and dew point during blast cleaning operations. It is very important to ensure that coating is not being applied over a damp surface.

Step No 8. Verification of the cleanliness and surface roughness

The blast cleaned surface shall not be contaminated with dirt, dust, metal particles, hydrocarbons, water, chloride, sulphate or any other foreign matter which would be detrimental to the coating. Pipe shall be checked with magnifying glass (X30) to confirm no residues of foreign materials remain in the anchor pattern valleys. The anchor pattern profile should not be less than 0.05 mm and not greater then 0.100 mm.

Prior to coating application, the exterior surface shall be thoroughly inspected, under adequate lighting all surface imperfections such as scabs, burrs, gouges and sharp edges defects etc shall be completely removed by grinding. If grinded area is more then 25mm it should be re-blasted.

In order to have a full evaluation of the effect of roughness it must be measured objectively and quantitatively. Parameters like R_{max}, R_t, P_c and R_z are used to describe a profile and these can be measured with the help of a portable stylus which operates by drawing a stylus at constant speed across a small length (5-6mm) of the surface.

A brief description of these parameters is as follows:

R_{max}	Largest peak-to-valley measurement in the evaluation length
R_t	Maximum peak to lowest valley measurement in the evaluation length.
P_c	Number of peak/valley pairs per unit distance extending outside a dead-band centered on the mean line. Dead-band is the distance above and below the mean line that a continuous trace line must cross in both (up and down) directions to count as a single peak.
R_Z	Maximum peak-to-valley height averaged over a specified number of evaluation length.

Table 3: Surface roughness parameters

Step No 9. Application of the coating

After carrying out all inspection/testing when all specification and standard criterion have been met, the final and most crucial step is application of coating.

Before applying fusion bonded epoxy powder the pipe surface should be uniformly preheated to a minimum and maximum temperature recommended by the powder manufacturer for optimum application conditions. Temperature should be checked with accurately calibrated pyrometer and should be regularly monitored with every four hours.

Prior to application of FBE powder, the application system should be thoroughly clean to remove any powder other than that in use. FBE/PE coating is applied by electrostatic spray with a uniform coating. Dry film thickness should be from 300 to 400 micron. [Table-1].

Care should be taken that all compressed air used for delivery of FBE coating should be free from moisture, oil and other contaminants. Failure to fulfill this requirement can lead to future problem.[4]

Immediately after application of FBE layer, copolymer adhesive and HDPE will be co-extruded within the gel time of FBE as per manufacturer requirement. Adhesive polymer layer can be done either crosshead or lateral extrusion technique. The applicator should state the proposed interval time between the FBE and adhesive coating, temperature range and extent of overlap. These factors lead toward the proper curing of the FBE, adhesive and polyethylene backing.[5]

The adhesive layer shall be applied to a thickness of between 250 to 350 microns as agreed by the applicator and owner. [Table-2]. During application of adhesive layer it should be ensured that roller push the adhesive into base of the weld to eliminate presence of any air entrapped coinciding to longitudinal weld.

Top coat polyethylene coating should be either applied by cross-head or annular technique or by the procedure agreed between the applicator and owner. PE layer should be applied over the adhesive layer with the time limits established during production time. FBE combined with adhesive and top polyethylene layer should be capable of withstanding external hydrostatic pressure of water depth up to

[4] [Moisture is present at all interface; steel-epoxy interface is damaged by the presence of diffused moisture]

[5] [Epoxy resins on all coatings are not completely cross-linked as we can show by simulation of post-cure reaction that some reactive groups are still there in epoxy coating]

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20m. Recommended thickness of top polyethylene coating should not be less then 2500 micron. [Table-3]

Each layer of FBE/PE coating consists of different ingredients. These ingredients control their physical, chemical and mechanical properties. Their colors are not very well distinguished from each other. It should be considered as a future recommendation to give different color to FBE, adhesive and outer polyethylene layer. This will provide benefit in visual inspection i.e. ease in recognizing thickness, its regularity and distinguishing disbondment, where it is actually happening.

Application of a silane coupling agent on the steel surface is strongly recommended for a good chemical bonding between the steel surface and the epoxy coating.[6]

Step No 10. Storage and Handling

Coating pipe should be handled, stored and transported in a way to minimize damage to the coatings. Stressing on the coating needed and direct contact with the coating should be avoided as much as possible. Damaged or pipe length for repair should be separated from the good ones. Pipe should not be stored in stacks of more then six.

Following standards should be considered for further help in handling, storage and transportation of the coated line:-

(i)	ANSI B31.4	Liquid Petroleum Transportation Piping system
(ii)	ISO 9000/9001/9002	Quality System
(iii)	API RP 5L1	Recommended Practice for Railroad Transportation.
(iv)	API RL 5L5	Recommended Practice for Marine Transportation.

Step No 11. Coating Repairs

Before starting coatings at production level, repair procedure should be submitted by the contractor to the purchaser. The methodology of the contractor for repair should be evaluated with scientific and realistic approach.

Repair of Bare Pipe

Scratches grooves, gouges etc. can be removed either by filing or grinding according to the procedure approved by the purchaser. Repair of the bare pipe line should be carried out with the pipe repair section of the line pipe specification 489-PA-2002.

Repair of Polyethylene Coating

Small damaged line coating if it is not more then 1.0 cm^2 should be repaired using PE melt sticks; with epoxy primer if bare metal is visible.

If damages exceeding up to 100 cm^2 polyethylene repair patches pre-coated with hotmelt adhesive, should be used in conjunction with a hotmelt filler adhesive and epoxy primer as per manufacture's recommendation. Repair patches should overlap the damaged area by minimum 50 mm all round. Surface should be mechanically cleaned before FBE primer.

[6] [COMTECH has demonstrated the positive effect of a silane coupling agent to many customers in USA/Europe with similar interface problems].

If damages extending over 100 cm^2 full enrichment heat shrink sleeves with epoxy primer in accordance with specification No. 4897-PA-2004. Surface should also be cleaned before the application of FBE primer.

Quantitative view of SOPs and their respective standards and specifications

Following tables express elucidate standards to be followed for primer, co-polymer adhesive layer and outer polyethylene coating. Although these standards are basically prescribed for vendor/applicator for evaluation of coating properties, yet they are required to randomly conduct different tests to verify that what we are getting is actually what we had asked for. Keeping a check on the vendor and maintaining quality and standard of our process through regular/periodic random testing should be a part of our SOPs so as to maintain and improve quality & reduce any future hassle.

The properties/standards and specified values for Fusion Bonded Epoxy (FBE) are produced as below:-

PROPERTY	STANDARD	VALUE
Coating Thickness		300 to 400 micron
Powder Density		1450 ± 50 kg/m^3
Elongation	ASTM 2370	6%
Hardness 1/8"Ball 100 kg Load		48 to 50 Rockwell
Water Absorption at 65° C	ASTM D570	3% Weight basis
Impact Resistance	ASTM G-14-72	18 J @ 25° C
Abrasion Resistance	ASTM D-1044	0.198/1000 gm weight loss for 5000 cycles
Shear Adhesion	ASTM D-1002	185 kg/cm^2
Tensile Strength	ASTM D-2370	40 M Pa @ 45° C
Dielectric Strength	ASTM E-149	48 ± 8 Volts/micron

Table 4: Properties/standards and specified values for Fusion Bonded Epoxy (FBE)

The properties/standards and specified values for Intermediate co-polymer adhesive layer are produced as below:-

PROPERTY	STANDARD	VALUE
Coating thickness		250 to 350 microns
Melt Index	ASTM D1238 19°/2.16 kg	1.0 to 2.0 g/10min
Density	ASTM D1505	0.92-0.93 g/cm^3
Vicat Softening Point	ASTM 1525	90° C (min)
Melting Point	DSC	110° C (min)
Ultimate Tensile Strength	ASTM D638 @ 50 mm/min	18 M Pa (min)
Elongation (Ultimate)	ASTM D 638	600 % (min)

Table 5: Properties/standards and specified values for Intermediate co-polymer adhesive layer

The properties/standards and specified values for outer polyethylene coating are produced as below:-

PROPERTY	STANDARD	VALUE
Coating Thickness		2500 micron
Density	ASTM D1505	950 kg/m^3
Melt Index	ASTM D 1238	0.25 to 0.45 g/10min
Tensile Strength @ 50 mm/min	ASTM D 638	18 M Pa
Elongation	ASTM D 638	600 % min
Vicat Softening Point	ASTM D 1525	120° C (min)
Melting Point	DSC	120° C (min)
Oxidative Induction Time in Oxygen @ 220° Alum Pan	ASTM D 3895	15 minutes
Hardness (Shore D)	ASTM D 2240	60 (min)
Stress Cracking Resistance	ASTM 1693 Condition (F50)	300 Hours
Moisture Absorbance	ASTM D 1693	0.01 % max
Carbon Black Content	ASTM D1603	1.8 to 2.2 %
Dielectric Breakdown Voltage		30 kV(min)
Creep Number		0.8 to 1.7 g/10mm
Temperature Resistance		-2° C to + 60° C
Low Temperature Resistance		Less then -50° C
Electrical Insulation Resistance	DIN 30670	Over 10^8 ohm/m^2
Carbon Black Particle		Less then 25 micron

Table 6: Properties/standards and specified values for outer polyethylene coating layer

The inspection and tests required for procedure qualification of coated pipe line are produced as below:-

PROPERTY	ACCEPTABLE VALUE	NUMBER OF TESTS
Before Cleaning		
Pipe condition	ISO 5801	10
Chlorides	2 μ g/cm^2	30 (3 x 10x)
Oil Contamination	No Indication of Oil	10
After Cleaning		
Cleanliness	Sa 2 1/2	10
Profile	50 to 100 μm	10
Chloride	2μ g/cm^2	30 (3x10x)
Dust and Oil	No indication of Oil	
Coating Thickness		
FBE	300 to 400 micron	24 (12x2)
FBE +Adhesive + PE	3000μm to 4000μm	120 (12x10)
Holiday		
FBE	Smooth / No Surface Defect	2
FBE+Adhesive+PE	Smooth / No Surface Defect	10

PROPERTY	ACCEPTABLE VALUE	NUMBER OF TESTS
Adhesion / Peel Strength		
FBE	Resistance to peel or Cohesive failure	2
FBE+Adhesive+PE	DIN 30670	5 (Random)
Penetration (Indentation Testing)		
FBE	0.20 mm at 25° C 0.30 mm at 50° C	10 (2x5)
FBE+Adhesive+PE	Original Value	2
Degree of Cure		
FBE	$-2° C \leq \Delta T_g \leq +3° C$	2
FBE+Adhesive+PE		3 (Random)
Flexibility Bend Test		
FBE	No Cracking/Disbondment Pinhole	2
Hot Water Resistance		
FBE	No Disbondment/Blistering After Adhesion Test	1 (Random)
Cathodic Disbondment		
FBE	Average Radius of Disbondment 5mm	2
FBE+Adhesive+PE		3 (Random)
Transverse Electric Resistivity Test		
Outer PE Coating	$10^8 m^2$ after 100 days of Immersion	2
Resistance Of Ultraviolet		
Outer PE Coating	800 Hrs at 60° C in 65% RH	2

Table 7: Inspection and tests required for procedure qualification of coated pipe line

The inspection and tests required for production of coating system are produced as below:-

PROPERTY	ACCEPTABLE VALUE	NUMBER OF TESTS
Before Cleaning		
Pipe condition	ISO 5801	
Chlorides	$2 \mu g/cm^2$	
Oil	No Indication of Oil	
After Cleaning		
Cleanliness	ISO-Sa 2 1/2	
Profile	50 to 100 μm	
Chloride	$2\mu g/cm^2$	
Dust	No indication of Dust	
Oil	No indication of Oil	
FBE Application		
Pipe Temperature	Manufacture required range	Continuous
Coating Thickness	3 mm/min	Each Pipe
Holiday	No Holiday	Each Pipe
Visual Examination		
Thickness of Coating	No Surface Defects	
Longitudinal Welds	No Air Compartment	
Cut Backs	150+0 / 20 mm width, bevel 45°	

Peel Strength		
A: 25° C	35 N/cm Width of Strip Peeled (DIN30670)	1 Per 100 Pipe
At 50° C	15 N/cm Width of Strip Peeled (DIN30670)	1 Per 100 Pipe
Impact Resistance		
Penetration (Indentation testing)	Manufacture Required Range	1 Per 100 Pipe
Cathodic Disbondment		
Cathodic Disbondment	< 5 mm	First and Last Pipe and Interval of 350 Pipes
Hot Water Resistance		
Hot Water Resistance	No Disbondment/Blistering after Adhesion Test	First and Last Pipe and Interval of 350 Pipes

Table 8: Inspection and tests required for production of coating system

Table 7 & 8 elaborate tests for qualification inspection and production inspection. They contain many common tests and standards. The coating procedure shall be qualified by coating five double random lengths in strict accordance with the coating procedure and their specification. The purchaser may appoint its own inspector to witness the production of test pipes and relating inspection and testing. A third party can also be hired depending upon the requirement of purchaser. Whatever the feasibility of inspector, he/she should have comprehensive knowledge of standard/specification, their soul requirement and what those test basically evaluate. There should not be any compromise on those specification and standards as per requisite.

The contractor may choose to use first day production tests for purpose of qualification. Any failure to meet any part of the qualification procedure shall require the Contractor to revise the procedure and repeat the qualification process again.

Production tests are required if there are significant changes in production parameters. These tests should be carried out on frequency defined by a particular standard.

References

1. M/s Mannesmann (MAPEC) coating process description and recommendation (the coated pipe supplied to SSGC in 1989)

2. Site visit Report of the representative of M/s Jotun Powder Coating U.A.E. reference No.97122RJ/97122/June 1997.

3. Specification for 3LPE coating on line pipe for the Contract No.12/003/7111 with M/s Data Steel Pipe Industries-Sadiqabad. (Coating presently under progress).

4. Pipe Coating Systems 3 Layer (Jotun Corro Coat Systems) May 1993.

5. M. Arif Butt, Javaid Ahmad, Arshad Chughtai, Rafiq Ahmad & I.H.Khan "General Overview of 3L Epoxy/PE Underground Pipeline Coating" Journal Faculty of Engineering & Technology 2001-2002.

6. Ijaz H. Khan, Rafiq Ahmad, M. Arif Butt, Javaid Ahmad and Farid A. Malik "Monitoring Coatings Failure and Integrity of Coating-CP System for Pipeline Corrosion Control (Part-I), Journal of Pakistan Institute of Chemical Engineers 2001.

7. Ijaz H. Khan, Rafiq Ahmad, M. Arif Butt, Javaid Ahmad and Farid A. Malik "Monitoring Coatings Failure and Integrity of Coating-CP System for Pipeline Corrosion Control (Part-II), Journal of Pakistan Institute of Chemical Engineers 2002.

8. I.H. Khan, R. Ahmad, M.A. Butt, J. Ahmad and F.A. Malik "Monitoring Coatings Failure and Integrity of Coating-CP system for Pipeline Corrosion Control (Part-I), Journal of Pakistan Institute of Chemical Engineers 2003.

9. Amir Hussain "Characterisation of Substrate-Surface and Coating-Materials using Advanced Analytical Tools" Seminar organized by SSGC at Karachi, 25th Feb. 2007.

List of tables

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