TECHNICAL SPECIFICATION

EXTERNAL FUSION-BONDED EPOXY POWDER COATING FOR LINE PIPE

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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1. INTRODUCTION

1.1 SCOPE

This DEP specifies the minimum requirements and the test procedures for factory-applied external fusion-bonded epoxy powder coating of steel pipes, bends and fittings used for buried or submerged pipelines, and includes the material, application, inspection, repair, handling and storage requirements.

This DEP replaces Standard Specification L-5-1/2/3 issued in September 1986.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, oil and gas production facilities, and supply/marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, installation, and commissioning or management of a project or operation of a facility. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for and on behalf of the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

The **Applicator** is the party which applies the fusion-bonded epoxy powder coating system in the coating plant.

A **batch** is the amount of materials produced within one uninterrupted production run of maximum 8 hours under constant production conditions.

Chemical pre-treatment is the treatment of the blast-cleaned pipe surface with a chemical solution (e.g. phosphate, chromate) before application of the first coating layer to improve the adhesion of the coating to the substrate.

The **Coating Contractor** is the party which is ultimately responsible for the coating operation which may include supply of coating materials, application of the coating and transport of uncoated and coated line pipe as specified in the relevant contract. The coating contractor may be the Applicator, the Coating Manufacturer, the Line Pipe Manufacturer or the Pipeline Construction Contractor.

The **Coating Manufacturer** is the party which manufactures the epoxy powder and, if applicable, additional coating materials supplied to the Applicator.

The **coating system** is the specific combination of pre-treatment, primer and powder coating meant to have the corrosion protection properties as described in this DEP.

A **holiday** is a defect penetrating through the coating to the steel pipe surface, of such dimensions that it is detectable using the specified procedures.

The **Line Pipe Manufacturer** is the party which manufactures or supplies the line pipe to be coated.

The **Pipeline Construction Contractor** is the party responsible for the construction of the pipeline in the field.

A **shift** is a set of pipes coated in one production run of which the beginning and end coincide with a change in personnel. In the context of the quality control procedures of this DEP, the maximum duration of a shift is 10 hours.

A **Unit of Production** is, unless otherwise specified, a set of pipes coated in one production run on the same coating line, having the same nominal diameter and wall thickness and coated with the same coating products. Breaks in production caused by equipment or plant breakdown, factory shutdown, or any break in production exceeding three days shall be the end of a production run. Subsequent start-up constitutes a new unit of production.

1.4 ABBREVIATIONS

FBE - Fusion Bonded Epoxy

HSE - Health, Safety and Environment(al)

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section is shown in brackets. Other documents referenced in this DEP are listed in (10).

2. GENERAL INFORMATION

2.1 COATING SYSTEM DESCRIPTION

The coating system described in this DEP shall be manufactured using FBE powder as the main coating material, using suitable surface preparation and application techniques to obtain the coating properties required for the intended installation and operating conditions.

2.2 INFORMATION TO BE SUBMITTED BY THE PRINCIPAL

The Principal shall submit all technical information to the Coating Contractor regarding the project, in particular the installation and operating conditions.

This information shall include as a minimum:

- Project name;
- The type of coating required;
- The maximum operating temperature of the pipeline;
- The pipeline diameter and wall thickness;
- The applicable line pipe specification;
- The geographical area (land/sub-sea);
- Expected ambient temperatures during installation;
- Installation method;
- Soil and backfill conditions for land pipelines;
- Sea bed trenching, laying and burial conditions for sub-sea pipelines;
- Subsequent coatings to be applied (weight coating, insulation);
- Requirement for anti-slip treatment;
- Requirements for temporary protection of pipe ends;
- Types of cathodic protection.

The Principal shall indicate whether a specific brand of coating shall be used or whether the selection of coating shall be made by the Coating Contractor.

The Principal shall indicate whether, and to what extent, he intends to witness coating application and quality control.

2.3 INFORMATION TO BE SUBMITTED BY THE COATING CONTRACTOR

The Coating Contractor shall submit information to the Principal on the coating system to be used. This information shall include as a minimum:

- System identification (4.1);
- Manufacturer's data (4.2);
- System qualification information (4.3);
- Coating application procedures related to pipe diameter and wall thickness;
- The name(s) of the proposed Coating Applicator(s);
- Applicator's qualification information (4.4);
- Quality plan.

The Coating Contractor shall confirm that the coating system is suitable to be used under the specified conditions (2.2).

3. COATING SYSTEM REQUIREMENTS

3.1 GENERAL

The coating system shall be suitable for the installation and operating conditions of the pipeline as specified by the Principal (2.2).

The Coating Contractor shall demonstrate that the coating system will fulfil the requirements before production starts. This shall be done by following the coating qualification procedures (4).

Any modification of a qualified coating system shall require re-qualification of the modified system.

The Contractor shall demonstrate that the coating, as applied during normal production, fulfils the requirements by effective quality control procedures in accordance with (5).

3.2 COATING MATERIAL

3.2.1 Supply of epoxy powder resin

Each batch of epoxy powder supplied to the Applicator shall be tested by the Coating Manufacturer for the properties specified in (4.2.1). Each batch shall be accompanied by a certificate in accordance with ISO 10474 type-3.1.B or equivalent stating the results of the tests and that the results are in accordance with the Manufacturer's product specification.

The Applicator shall submit certified copies of all certificates to the Principal if requested.

Material which is not traceable to satisfactory test certificates shall not be used.

3.2.2 Identification of epoxy powder resin

The Applicator shall ensure that all materials supplied for the coating operation are suitably labelled with the following information:

1. The name of the Coating Manufacturer;
2. Type of material;
3. Relevant Coating Manufacturer's product specification;
4. Batch number;
5. Date of manufacture and expiry date;
6. HSE information to comply with international regulations;
7. Recommended storage conditions and time.

Material which is supplied without the above information shall not be used.

3.2.3 Sample retention

Three samples of 50 g each shall be taken from each batch of powder. These samples shall be marked and stored by the Applicator under conditions such that the powder does not deteriorate. The Principal may request tests on these samples up to six months after delivery of the last coated pipe of the order, or later if agreed between Applicator and Principal.

3.3 PIPE SURFACE PREPARATION

The pipe surface shall be free of all surface contamination. Oil, grease and other contaminants shall be removed before blast cleaning by a suitable solvent or detergent. Salt contamination, chemical cleaning agents and remaining detergents shall be washed off using potable water. The pipe surface shall be dried before blast cleaning.

The pipe surface shall be cleaned of mill scale, rust and other foreign matter by a blast-cleaning or other abrasive cleaning method to achieve a minimum surface cleanliness of Sa $2^1/_2$ in accordance with ISO 8501-1 (6.2.1). The surface profile shall be "medium" in accordance with ISO 8503-2 (6.2.1) or as otherwise specified by the Coating Manufacturer (including test method). For stainless steel pipes, stainless steel or non-ferrous abrasives shall be used for blast-cleaning.

During blast-cleaning the pipe surface temperature shall be more than 3 °C above the dew point. The pipe surface temperature shall always be more than 5 °C. The relative humidity shall not be greater than 85%.

Abrasives shall be stored and used dry. Expendable abrasives shall not be recycled.

The maximum residual chloride level on the blast cleaned surface shall be 50 mg/m^2 in accordance with ISO 8502-2 (6.2.1).

Immediately after blast-cleaning, all remaining weld spatter and irregularities shall be removed from the pipe surface by chiselling and/or grinding. Any treated surface with an area larger than 25 cm^2 shall be re-blasted to the cleanliness and roughness as specified above.

No repairs to the pipe shall be made without a procedure agreed by the Principal.

After any grinding or mechanical repairs the remaining wall thickness shall be checked and compared with the minimum requirements of the line pipe specification. Pipes not meeting the minimum wall thickness shall be rejected.

Before coating, the pipe surface shall be cleaned of all dust and foreign matter using clean dry compressed air or vacuum cleaning. The compressed air shall be free of any trace of oil.

3.4 COATING APPLICATION

Blast-cleaned pipes shall be coated within 4 hours. Pipes delayed beyond this period, or pipes showing any visible rust stains, shall be blast cleaned again.

The application of the coating shall be in accordance with the Coating Manufacturer's application procedures.

During the coating process the preheating temperatures shall comply with the requirements given in the application procedures. The maximum pipe temperature shall be 280 °C. Heating equipment shall be controlled to maintain uniform temperatures throughout the coating process.

The use of recycled powder from the same batch shall be permitted but it shall not exceed 20% of the total powder mix at any time. Recovery shall be automatic and continuous. This powder shall be processed through magnetic separators and sieves and then uniformly mixed with fresh powder.

The sequence of use of the batches of epoxy powder shall be in the order in which they were manufactured.

Different brands of powders shall not be mixed.

During coating the bevelled ends of the pipes and the pipe bore shall be protected against mechanical damage and from contamination with coating material.

Each pipe end shall be left uncoated over a length of 80 mm ± 15 mm unless otherwise specified.

If specified by the Principal (2.2), uncoated pipe ends shall receive a temporary protective coating for transit.

If the Manufacturer requires to post-cure the coating on the bends and fittings this shall be done in an oven for a maximum time of 15 minutes at a maximum temperature of 250 °C. Following such a curing process, the bend or fitting may be allowed to cool to ambient temperatures in air as an alternative to water quenching.

3.5 FINISHED COATING SYSTEM

3.5.1 Visual appearance

The coating shall be free from blisters, visual holidays, scratches or any other irregularities and shall have a uniform colour and gloss.

3.5.2 Coating thickness

The thickness of the cured FBE coating shall be 475 µm ± 75 µm.

For pipes which are to be coated later with concrete weight coating using an impingement technique without an intermediate barrier coating for mechanical protection, the thickness of the cured FBE coating shall be 725 ± 75 µm.

The thickness of the cured FBE coating applied on bends and fittings shall be not less than 400 µm and shall be not more than 1000 µm.

The coating thickness shall be measured in accordance with (6.2.2).

3.5.3 Holidays

The coating system shall be free from holidays which are indicated when tested in accordance with (6.2.3).

3.5.4 Adhesion

The adhesion of the coating system shall be such that any attempt to remove the coating shall result in a cohesive break in the coating material and not in an adhesive failure of the coating/substrate interface. Testing shall be carried out in accordance with (6.2.4).

3.5.5 Impact resistance

The impact resistance of the coating system at ambient temperature shall be more than 1.8 Joules when tested in accordance with the procedure in (6.2.5).

3.5.6 Flexibility

The flexibility of the coating shall be such that holidays do not appear when tested in accordance with the procedure in (6.2.6).

3.5.7 Hot water resistance

After exposure to hot water in accordance with the procedure in (6.2.7) the coating shall show no evidence of blistering or disbonding and shall show no failure of adhesion when tested in accordance with (6.2.4).

3.5.8 Cathodic disbonding resistance

Cathodic disbonding tests shall be carried out in accordance with (6.2.8) at a test temperature related to the operating temperature as specified in Table 1. The duration of the test for coating qualification shall be 28 days. After the test, the maximum radius of disbonding shall be less than the value given in column 3 (28 days) of Table 1.

For quality control purposes (5.9) the duration of the test shall be 48 hours and the radius of disbonding shall be less than the value in column 4 (48 hours) of Table 1.

TABLE 1 Cathodic disbonding resistance for FBE pipeline coating systems

Operating temperature, °C	Test temperature, °C	Maximum disbonding radius, mm	
		28 days Qualification	48 hours, Quality Control
<20	20 ± 5	5	3
20-60	60 ± 5	10	5
60-80	80 ± 5	10	5

3.5.9 Degree of cure

The degree of cure shall be determined by differential scanning calorimetry in accordance with (6.1.1). The ΔTg value shall be between -2 °C and +3 °C.

3.5.10 Microscopic examination

A sample of the applied coating shall be examined for the presence of foaming, voids and contamination in accordance with the procedure in (6.1.2). The maximum degree of foaming shall be 2 on the scale given in (6.1.2), both through-film and across-film. The coating shall be free of contamination by foreign matter.

4. COATING SYSTEM QUALIFICATION

Before a coating system may be applied in a production run, the Contractor shall submit all necessary data as indicated in (4.1) and (4.2) and shall ensure that both the coating system and the Applicator have been qualified in accordance with the procedures in (4.3) and (4.4).

4.1 SYSTEM IDENTIFICATION

The Coating Contractor shall submit all necessary details to identify the coating system, which shall include:

1. System designation or trade name;
2. Name of Coating Manufacturer;
3. Nominal total coating thickness;
4. Specification of pre-treatment chemicals;
5. Relevant international/national coating standard approvals;
6. Approvals for previous projects for Shell Group Companies;
7 Recommended storage and shelf life of coating materials;
8. Colour of the coating;
9. HSE data sheets.

4.2 COATING MANUFACTURER'S DATA

The Coating Contractor shall submit to the Principal technical data, obtained from the Coating Manufacturer, on the coating system and its materials.

4.2.1 Basic properties of the epoxy powder resin

4.2.1.1 Infra-red scan

An infra-red spectrogram, carried out by using a standard KBr disc, shall be submitted for comparison with all subsequent batches produced.

4.2.1.2 Particle size analysis

The particle size distribution analysis shall be carried out accordance to ISO 8130 part 1. The Coating Contractor shall confirm that the particle size is suitable for the electrostatic spraying equipment used by the proposed Applicator.

4.2.1.3 Density

The density of the powder shall be measured in accordance with ISO 8130 part 2 or ISO 8130 part 3.

4.2.1.4 Curing schedule and gel time

A curing schedule shall show the gel time and minimum curing time required for full curing of the coating at various recommended application temperatures. The gel time shall be determined in accordance with ISO 8130-6.

4.2.1.5 Moisture content

The moisture content of the powder shall be determined using ISO 8130 part 7 and shall not exceed 0.5% by mass.

4.2.1.6 Storage stability

The storage stability of the epoxy powder shall be determined in accordance with ISO 8130 part 8.

4.2.1.7 Thermal analysis

A thermal analysis shall be made using differential scanning calorimetry in accordance with (6.1.1) to determine the glass transition temperatures and the enthalpy of curing of the

powder.

4.2.2 Chemical pre-treatment

If any chemical pre-treatment of the blasted steel is carried out the following data shall be submitted:

1. Generic type of chemical;
2. Preparation, concentration etc.;
3. Application procedure, including spreading rate (m^2/litre) and drying times.

4.3 COATING SYSTEM QUALIFICATION

Before a coating system may be specified for an application, the Coating Contractor or the Coating Manufacturer shall apply for qualification of the coating system. The qualification shall be carried out according to the following procedures:

The Coating Contractor or the Coating Manufacturer shall submit all data specified in (4.1) and (4.2).

The Coating Contractor or the Coating Manufacturer shall show that samples of the proposed coating system applied on pipes or plates of the same material and nominal wall thickness (see Note 2 below Table 2) as the pipes to be coated under the contract have been successfully subjected to the tests as specified in column 4 "System Qualification" of Table 2.

The number of samples to be tested, the finished coating requirements and the test procedures are given in Table 2.

The tests shall be carried out by an independent test laboratory or, if approved by the Principal, by the Coating Manufacturer. The Principal shall specify if the coating application and the tests are to be witnessed by the Principal.

If agreed by the Principal, previous qualification data may be used provided that the referred tests have been carried out using the same coating system (4.1), the same coating process and samples of the same material and nominal wall thickness (Note 2) as specified in the contract.

With the approval of the Principal, tests carried out in accordance with other coating standards may be used insofar as their procedures are the same or more stringent than the procedures in this DEP. Such information shall include full reports on test procedures and results and be signed by the laboratory representatives and certification body.

4.4 APPLICATOR QUALIFICATION

Before production application of a coating system may commence, Applicators shall be qualified to apply the coating system. The qualification shall be carried out according to the following procedures:

4.4.1 Coating process and Applicator selection

The Coating Contractor shall submit to the Principal information on the required coating process and recommended Applicators. The information shall include:

1. Description of the coating process;
2. Pipe cleaning procedure and pipe surface preparation (cleanliness, profile, chemical treatment, etc.);
3. Pipe heating and temperature control;
4. Type of chemical pre-treatment, if any, including time of application and concentration;
5. Cure times and quenching details;
6. Recommended Applicators;
7. Coating repair procedures.

4.4.2 Coating plant

Each recommended Applicator shall submit details of the coating plant, including:

1. Layout diagram of the coating plant and pipe routing scheme;
2. General description of the equipment available to carry out the coating process;
3. Details of process control and inspection equipment, required for the coating process such as temperature control, thickness control, holiday testers, laboratory equipment;
4. Details of the pipe handling and transport equipment and procedures;
5. Applicator's quality control procedures.

4.4.3 Applicator qualification

After approval of the process and plant details (4.4.1, 4.4.2) and before production starts, the Applicator shall submit evidence that he has successfully applied the coating system before on pipes of the same nominal diameter (see Note 1 below Table 2) and wall thickness (Note 2) as those to be coated under the contract and that the product complied with the requirements of (Section 3) this DEP for the tests indicated in Table 2 column 5 "Applicator qualification". This shall be demonstrated during pre-production testing, when the Applicator shall coat at least five pipes with the proposed coating system which shall be subjected to the tests given in Table 2. These tests may be carried out in the Applicator's own laboratory, witnessed by the Principal (if specified by the Principal) or by an independent laboratory. The results of the tests shall be reported to the Principal, signed by the head of the laboratory. Pre-production testing may be waived at the Principal's discretion on the basis of a successful qualification within the previous 18 months using the same coating system applied to the same thickness on pipes of the same material, the same nominal diameter (Note 2) and wall thickness (Note 1) as for the project.

When this DEP is used for the coating of bends and/or fittings, the Applicator shall perform the pre-production testing on one straight length of pipe. The required qualification tests for bends and fittings are given in Table 2.

When chemical pre-treatment is to be used for the coating system, the Principal may request that part of the pre-production testing shall be carried out on chemically treated pipe and the remainder on untreated pipe, in order to ensure that the FBE powder is of a quality essential to long-term coating performance. This may be done by partly treating each length of pipe. In this case the coating on both the treated and untreated surfaces shall pass the tests.

TABLE 2 Minimum qualification requirements for FBE pipeline coatings

Property	Section	Test Method	System Qualification	Applicator Qualification	Bends/ Fittings	Repairs
Cleanliness of blast cleaned surface	(3.3)	(6.2.1)	each sample	each sample	each sample	each sample
Surface profile	(3.3)	(6.2.1)	each sample	each sample	each sample	-
Pipe surface temperature	(3.4)	-	each sample	each sample	each sample	each sample
Appearance	(3.5.1)	visual	each sample	each sample	each sample	each sample
Coating thickness	(3.5.2)	(6.2.2)	each sample	each sample	each sample	each sample
Holiday detection	(3.5.3)	(6.2.3)	each sample	each sample	each sample	each sample
Adhesion	(3.5.4)	(6.2.4)	2 samples	5 pipes	1 sample	1 sample
Impact resistance	(3.5.5)	(6.2.5)	2 samples	5 pipes	1 sample	-
Flexibility	(3.5.6)	(6.2.6)	2 samples	2 pipes	-	-
Hot water resistance	(3.5.7)	(6.2.7)	2 samples	2 pipes	1 sample	-
Cathodic disbonding resistance	(3.5.8)	(6.2.8)	2 samples	2 pipes	1 sample	-
Degree of cure	(3.5.9)	(6.1.1)	2 samples	5 pipes	1 sample	-
Microscopic examination	(3.5.10)	(6.1.2)	2 samples	5 pipes	1 sample	1 sample
System identification	(4.1)	-	Submit to Principal	-	Submit to Principal	Submit to Principal
Manufacturer's data	(4.2)	-				
Coating process and plant data	(4.4.1 - 4.4.3)	-	-	Approved by Principal	Approved by Principal	Approved by Principal

NOTES: 1. "The same nominal diameter" in the context of this DEP means in the same diameter range defined as:
Group 1: under 300 mm diameter
Group 2: 300 up to 600 mm diameter
Group 3: 600 up to 900 mm diameter
Group 4: 900 up to 1200 mm diameter
Group 5: more than 1200 mm diameter.

2. "The same nominal wall thickness" in the context of this DEP means that ±25% deviation from the pipe wall thickness is allowed.

5. QUALITY CONTROL

5.1 GENERAL

During production application of the coating, the Applicator shall carry out the quality control activities needed to ensure that the coating is stored and applied in accordance with the approved coating application procedures and that the final product complies with the requirements of this DEP.

The minimum quality control tests to be performed shall be as indicated in Table 3.

The minimum quality control requirements for bends and fittings and for coating repairs are also given in Table 3.

Records of all quality control test results shall be kept in accordance with (8).

5.2 IDENTIFICATION OF EPOXY POWDER RESIN

The Applicator shall ensure that all materials supplied for the coating operation have been marked in accordance with (3.2.2). Material that is not marked shall be removed from the site.

5.3 AMBIENT CONDITIONS

The Applicator shall measure the ambient conditions at regular intervals during blasting and coating and keep records of prevailing temperature, humidity and dew point. If the conditions are outside the limits specified in this DEP, the process shall be suspended until the required conditions are met.

5.4 INSPECTION BEFORE BLASTING

Before surface preparation starts, each pipe shall be visually examined for dents, laps, defective bevels and other defects to avoid the coating of unserviceable pipes. Defective pipes shall be removed from the coating line for repair or, if repair is not possible, rejection.

The pipe surface shall be visually checked for contamination with salts, oil or grease. Contaminated pipes shall be cleaned again.

5.5 INSPECTION AFTER BLASTING

Each pipe shall be inspected for surface cleanliness. Pipes which do not comply with the

requirements in (3.3) shall be rejected or blast-cleaned again.

The surface roughness shall be measured at regular intervals and on the first 5 pipes following each change of blast-cleaning material. If the surface roughness is outside the specified limits, the blasting material shall be checked and replaced as necessary. The affected pipes shall be reblasted.

At regular intervals the blasted surface shall be checked for chloride contamination (6.1). If contamination of the surface occurs, the quality of the blasting material and process shall be examined. The affected pipes shall be washed with potable water and dried.

5.6 APPLICATION TEMPERATURES

The temperature of the pipe surface shall be continuously monitored and recorded using suitable instruments, e.g. infrared sensors. The instruments shall be calibrated daily.

The monitoring instruments shall be independent of the temperature control equipment. Any deviation from the recommended application temperature range shall be rectified. If immediate rectification is not possible, the production shall be stopped until the cause of the problem has been removed.

Any pipes coated during the duration of the temperature deviation shall be identified by marking and subjected to additional quality control tests to check curing (5.10), impact and adhesion properties (5.8).

5.7 APPEARANCE, THICKNESS AND HOLIDAYS

Each coated pipe shall be visually checked for imperfections and irregularities of the coating (3.5.1) and coating thickness (3.5.2). Pipes that do not comply with the requirements shall be marked and removed from the coating line for repair or recoating. If subsequent pipes do not comply with the requirements, the coating process shall be checked or stopped to remove the cause of the problem. Pipes having a coating of insufficient thickness shall not be repaired by overcoating.

After coating, each pipe shall be checked for cleanliness of the pipe ends and damage of the bevelled ends. Damaged bevels shall be repaired using procedures approved by the Principal.

Each coated pipe shall be checked for the absence of holidays (3.5.3).

For a 12 metre pipe length the maximum allowable number of holidays to be repaired shall be as follows (for other pipe lengths a proportional number shall be applicable):

- up to 300 mm pipe diameter : 4 per pipe
- 300 mm up to 600 mm pipe diameter : 6 per pipe
- 600 mm pipe diameter and above : 8 per pipe.

If the number of holidays per pipe exceeds the figures stated above the coating shall be removed, and the pipe shall be reblasted and recoated. If two consecutive pipes are rejected for this reason, the coating process shall be checked to determine the cause of the high holiday rate. If the cause is not resolved after further rejection of consecutive joints the complete process shall be stopped for full investigation.

All holidays detected shall be repaired in accordance with the qualified repair procedure (7).

Holidays caused by metal surface defects shall require the removal of the defect by grinding or filing of the defect prior to application of the repair material. No repairs shall be made that violate the applicable line pipe specification. Under no circumstances shall a steel defect be overcoated with repair material.

5.8 ADHESION AND IMPACT TESTING

At the rate stated in Table 3, pipes, bends, fittings and repairs shall be randomly selected and subjected to the adhesion test and impact test. After testing the coating shall be repaired in accordance with the qualified repair procedure (7).

5.9 FLEXIBILITY TEST, HOT WATER TEST AND CATHODIC DISBONDING TEST

Test samples shall be prepared for the flexibility test, the hot water test and the cathodic disbonding test at the rate stated in Table 3. A sample of sufficient length for all the tests shall be cut from one end of a selected pipe.

After cutting of the test sample, the remaining pipe joint shall be marked with the remaining length and the coating cut-back and the pipe bevel shall be reinstated in accordance with (3.5).

The tests shall be started as soon as possible after coating to allow for adjustment of the coating process if necessary.

5.10 DEGREE OF CURE AND MICROSCOPIC EXAM

At the rate stated in Table 3, coated pipes, bends, fittings and repairs shall be selected and a coating sample taken from the item for the cure test and microscopic examination. The cure test shall be carried out in accordance with (6.1.1) and the ΔTg value shall be between

-2 °C and +3 °C. The microscopic examination shall be done in accordance with (6.1.2). The maximum degree of foaming shall be 2 on the scale in Figure 1. The damage caused by the sampling shall be repaired.

5.11 ACCEPTANCE OF DEFECTS

In the event of the test pipes/samples failing to meet the requirements of sections (5.8), (5.9) and/or (5.10), preceding pipes coated after the last acceptable test pipe/sample and the pipes coated following the failed pipe shall be suspect and shall be marked for further testing.

The Applicator shall propose and agree with the Principal a test programme to trace any of the suspect pipes affected by the same failure. Further testing shall involve inspection and examination similar to that carried out on the original rejected test pipe(s). Based on the test results, the final acceptance or rejection of the suspect pipes shall be made by the Principal.

No pipes shall be dispatched from the coating yard before the quality control results have been approved by the Principal.

The Principal retains the right to reject any shift's or day's production if the reject rate of that production is more than 10% and/or if sample tests are found to be outside the specification in this DEP.

In addition, the Applicator may be required to stop production and carry out a full investigation into the source of the problem; he shall submit the results to the Principal before receiving permission from the Principal to recommence production.

5.12 TRACEABILITY OF PIPES AND COATING

The Applicator shall ensure that individual pipes are fully traceable during and after the coating process. If the serial number of the pipe as given in the pipe mill is removed or obliterated, then it shall be reapplied. The Applicator's own serial number shall be indicated on the pipe and records shall be kept to identify the sequence and time of coating and the batch of epoxy powder used for each pipe.

TABLE 3 Minimum quality control requirements for fusion-bonded epoxy pipeline coatings

Property	Para.	Test Method	Pipes	Bends & Fittings	Repairs
Epoxy powder	(5.2)		each batch of powder	each batch of powder	-
Ambient conditions	(5.3)		every 2 hours	every 2 hours	every 2 hours
Surface condition before blasting	(5.4)	Visual	each pipe	each item	each repair
Blast-cleaning materials and process			once per shift or related to (5.5)	once per shift	-
Cleanliness of blast-cleaned surface	(5.5)	(6.2.1)	each pipe	each item	each pipe
Surface profile	(5.5)	(6.2.1)	4 pipes per shift	each item	each repair (visual)
Surface cleanliness, chlorides	(5.5)	(6.2.1)	one pipe per 100 (minimum one pipe per day)	one item per 100	-
Pipe surface temperature	(5.6)	-	continuous	each item	each repair, if applicable
Appearance	(5.7)	visual	each pipe	each item	each repair
Coating thickness	(5.7)	(6.2.2)			
Holiday detection	(5.7)	(6.2.3)			
Pipe ends	(5.7)	visual			-
Adhesion	(5.8)	(6.2.4)	one pipe per 50 (minimum one pipe per day)	one item per 50, (min. one item per unit of production	one repair per 50 or part thereof
Impact	(5.8)	(6.2.5)			
Degree of cure	(5.10)	(6.1.1)			-
Microscopic examination	(3.5.10)	(6.1.2)			-
Flexibility	(5.9)	(6.2.6)	one pipe per 200 (minimum one pipe per unit of production)	-	-
Hot water	(5.9)	(6.2.7)			
Cathodic disbonding	(5.9)	(6.2.8)			

6. INSPECTION AND TEST PROCEDURES

6.1 PROPERTIES OF THE EPOXY RESIN

6.1.1 Thermal analysis

A thermal analysis shall be made using differential scanning calorimetry in accordance with ASTM D 3418, to determine the glass transition temperature (Tg) and the enthalpy (Hr) of the curing of the powder.

For the 'as-supplied', uncured powders (4.2.1.7) three scans shall be made to determine the glass transition temperatures (Tg_0, Tg_1 and Tg_2) and the enthalpy (Hr).

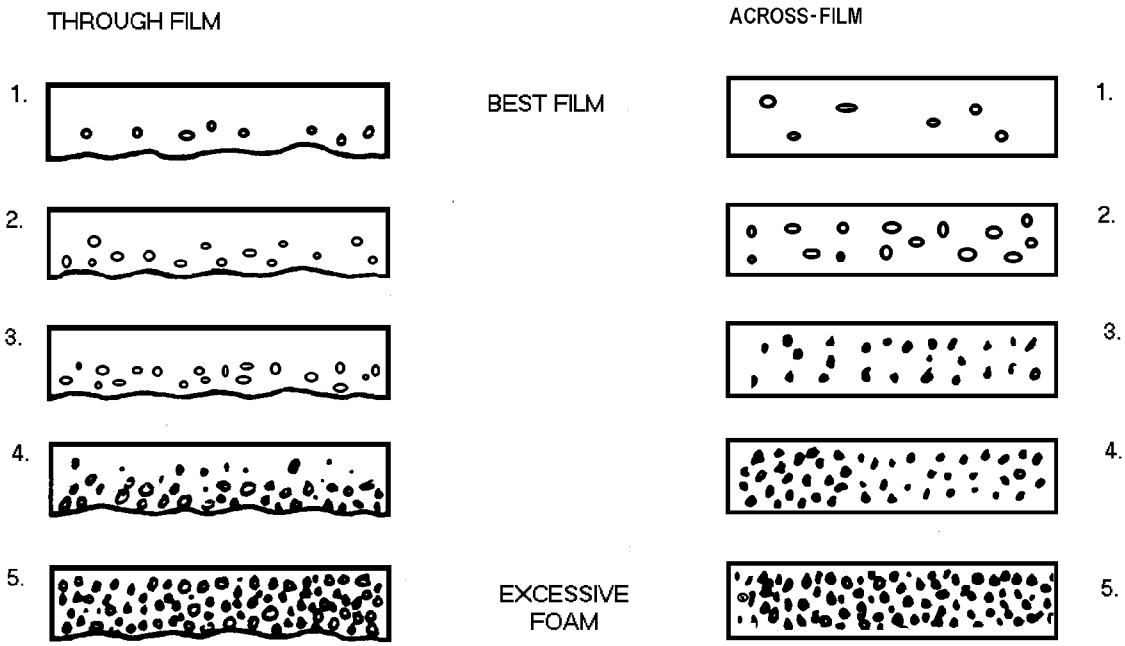
For the samples of the applied coating (5.10) two scans shall be made to determine the glass transition temperatures Tg_1 and Tg_2, respectively. The degree of cure is related to the difference between Tg_1 and Tg_2 which shall be determined as:

$$\Delta Tg = Tg_2 - Tg_1$$

6.1.2 Microscopic examination

A cross-section and the coating-steel interface of the cured film shall be examined under a magnification of 30x-40x. This may be done on chips of coating removed from test pipes for production quality control. The presence of foaming and voids through-film (section perpendicular to the pipe surface) and across-film (section parallel to the pipe surface) shall be rated according to the pictorial scale in Figure 1. Any other contamination at the coating interface shall be reported.

FIGURE 1 Degree of foaming of FBE film



6.2 COATING APPLICATION

6.2.1 Surface finish after blast-cleaning

The surface finish after blast-cleaning shall be inspected by visual comparison according to the following International Standards:

Surface cleanliness: ISO 8501-1.

Surface profile: ISO 8503-2.

The surface profile comparator shall comply with ISO 8503-1 and shall be calibrated before every unit of production in accordance with ISO 8503-3 or ISO 8503-4.

Chloride contamination shall be determined using ISO 8502-2.

6.2.2 Coating thickness

The coating thickness shall be measured using a thickness meter based on Eddy Current or electromagnetic techniques in accordance with ISO 2808, method 6A or 6B.

Magnetic thickness gauges shall not be used, either for qualification testing or for quality control purposes.

The thickness gauge shall be calibrated at least once per shift. Calibration shall be carried out on a steel plate of similar thickness as the pipe wall using plastic shims of the same thickness as the nominal coating system.

For quality control purposes (5.7) a minimum of twelve thickness checks shall be made at approximately one quarter, one half and three quarters of the length of each pipe and at the 3, 6, 9 and 12 o'clock positions around the pipe. For submerged arc welded pipe one of these circumferential positions shall be on top of the weld.

6.2.3 Holidays

A holiday test shall be performed using an adjustable high-voltage holiday tester having an audible and visual alarm. The scanning electrode shall consist of a metal brush or coil spring, fitting the diameter of the coated pipes.

The earth connection shall be made directly on the pipe.

The test voltage shall be set at 2.2 kV and 3.6 kV for nominal coating thicknesses of 475 and 725 µm, respectively.

The test voltage shall be calibrated at least twice per shift using a high-voltage meter.

When the holiday test is carried out the external pipe surface shall be free of moisture.

The electrode shall be moved over the pipe surface with a speed of not more than 0.3 m/s. The whole of the pipe surface shall be covered by the test.

When the holiday test is used for the impact resistance test (6.2.5), a metal brush shall be used to inspect the impacted surface.

6.2.4 Coating adhesion

The adhesion of the coating on a pipe shall be determined at a random location by the following method:

Using a sharp and pointed knife, two incisions of approximately 15 mm in length shall be made through to the steel surface to form an 'X' with an angle of intersection of

approximately 30 degrees. Commencing at the intersection, an attempt shall be made to lift the coating from the steel substrate using the blade of the knife.

An adhesive break-away from the point of intersection of more than 2 mm, or brittle break-away of flakes of more than 2 mm constitutes a failure.

Refusal to peel, or a cohesive break less than 2 mm long entirely within the coating, constitutes a pass.

Cohesive failure caused by voids in the coating leaving a honeycomb structure on the steel surface also constitutes a failure.

6.2.5 Impact resistance

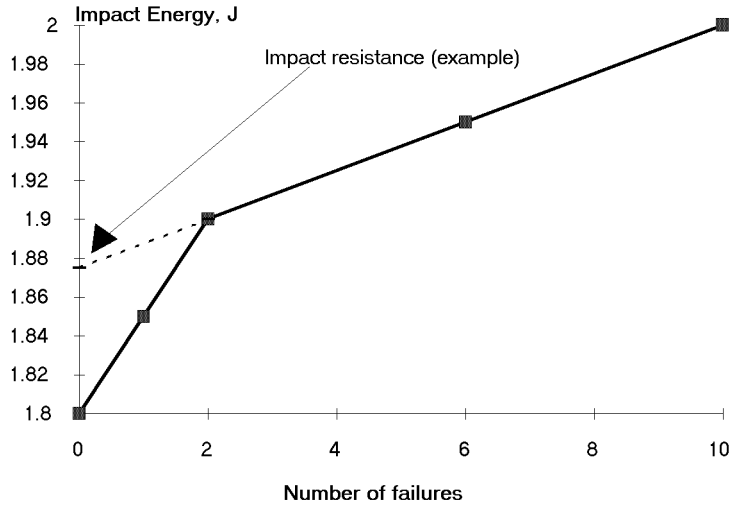
Before the test the pipe surface shall be tested for the absence of holidays (6.2.3).

The impact test shall be performed using a falling weight impact testing machine as described in ASTM G 14. The falling weight shall have a smooth hemispherical head with a diameter of 25 mm. The pipe sample shall be placed horizontally, supported directly under the impact area to avoid the effect of elastic response of the pipe. The testing machine shall be placed in a vertical plane perpendicularly on the top of the pipe surface.

Each test shall comprise a series of 10 impacts, using a combination of weight and height corresponding to the predetermined impact energy. The impacts shall not be on pipe welds, coating overlaps or within 1.5 x DN or 300 mm, whichever is smaller, from the edge of the coating. The impacts shall be at least 50 mm apart. The impacts shall be tested for the presence of a holiday in accordance with (6.2.3). The number of holidays shall be noted.

For the determination of the impact resistance for prequalification testing, 5 or more series of 10 impacts shall be made using a range of impact energy settings above and below the expected value. Two series of tests with the higher impact energy shall show defects and at least one series with the lower energy setting shall show no defects. A graph shall be plotted of the number of impacts versus the impact energy, see Figure 2. The graph shall be extrapolated towards the Y-axis as shown in Figure 2 and the value at the point of intersection with the Y-axis shall be reported as the impact resistance.

FIGURE 2 Example of impact resistance plot



For the purpose of quality control testing, one series of 10 impacts shall be made with the impact energy set at the specified minimum requirement (3.5.5). No failures of the pipe coating shall be found during the holiday test of the impact points. If holidays are found, two pipes coated immediately before and two pipes coated immediately after the failed pipe shall be tested and shall show no failures. If these pipes fail, the coating process shall be stopped and the cause investigated and removed before production is resumed. All pipes coated since the last successful impact test shall be considered suspect and shall be impact-tested individually or rejected.

6.2.6 Flexibility test

Samples shall be cold-cut from a coated pipe and shall be subjected to a bend test.

For pipe diameters of 300 mm and above four strips 300 mm long x 50 mm wide shall be cut in the longitudinal direction of the pipe.

For pipe diameters less than 300 mm, four rings shall be cut with a width of 50 mm.

The samples shall be free from holidays (6.2.3).

At 0 °C a 2% strain, and at 20 °C a 3% strain, shall be induced in the coating of the sample.

Two tests shall be carried out at each temperature.

The deflection loading rate during bend testing shall be (25 ± 2) mm/min.

Strip samples shall be bent using a mandrel, either using a 3-point bending or a cantilever arrangement.

The mandrel sizes shall be selected according to the following formula:

$$D = \frac{t(1 - s)}{s}$$

where:

D = mandrel diameter (mm)
t = specimen metal wall thickness (mm)
s = 0.02 at 0 °C
0.03 at 20 °C

The ring samples shall be squeezed in accordance with ASTM G 70 to obtain a strain factor of 0.02 and 0.03 respectively.

As a guide, the length of the reduced axis after squeezing shall be:

$$d_2 = \frac{d}{\left(\frac{s}{t} \times d\right) + 1}$$

where:

d = the pipe diameter (mid-wall to mid-wall) before squeezing, mm
d_2 = the length of the reduced axis (mid-wall to mid-wall) after squeezing, mm
t = the pipe wall thickness (mm)
s = 0.02 at 0 °C
0.03 at 20 °C

After bending, the pipe coating surface shall be examined for the presence of holidays (6.2.3). The coating shall be deemed to have failed the test if any holiday is detected.

6.2.7 Hot water test

A coated sample of 200 mm x 100 mm machined from a ring of the coated pipe shall be immersed in tap water at 85 °C for 5 hours.

The bare edges of the sample shall be coated to prevent ingress of moisture beneath the coating.

Directly after the 5 hours' exposure the coated sample shall be removed from the water bath and allowed to cool to ambient temperature. The coating shall then be examined visually and the adhesion shall be tested and judged in accordance with (6.2.4).

6.2.8 Cathodic disbonding resistance

The cathodic disbonding resistance of the coating shall be tested as follows:

The test sample shall be free of holidays when tested in accordance with (6.2.3).

A sample of coated pipe shall be taken of sufficient length and with approximately the same diameter as the production pipe.

A 6 mm hole shall be drilled in the coating, using a flat faced mill. The hole shall penetrate not more than 0.5 mm into the pipe steel. The hole shall be at least 50 mm from any weld.

The sample shall be placed inside an electrolytic cell or an electrolytic cell shall be constructed on the pipe surface. All metallic parts other than the test defect shall be sealed from the electrolyte using a resin or other suitable compound. The volume of the cell shall be at least 250 ml.

The cell shall be filled with a 3% sodium chloride solution. The pH shall be maintained between 6 and 8.5 throughout the test. The pH shall be measured once every 96 hours.

An inert auxiliary electrode (e.g. platinum wire or mesh) shall be placed in the electrolyte, remote from the test defect.

A saturated calomel reference electrode (SCE) shall be placed in the electrolyte with the tip 10 mm from the test defect.

Using a potentiostat, the electrochemical potential of the steel shall be polarised to (-1500 ± 10) mV with respect to the SCE. This potential shall be maintained throughout the test.

The current required to maintain the potential shall be continuously recorded.

The duration of the test shall be 28 days, after which the sample shall be removed from the cell and examined.

For quality control purposes the duration of the test shall be 48 hours (5.9).

For tests at elevated temperatures, the temperatures shall be controlled as follows:

If the sample is immersed in the cell, the solution, including the sample, shall be kept at the test temperature by placing the cell in a thermostatically controlled water bath.

If the cell has been constructed on the pipe sample, the steel sample shall be placed in a thermostatically controlled furnace or sand bath which also covers the top surface of the sample with at least 1 cm of sand. The furnace or bath shall be adjusted to maintain the required test temperature on the pipe surface in the test defect.

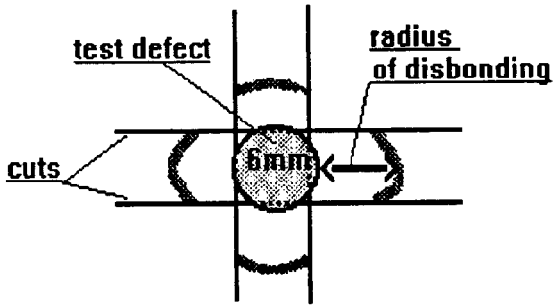
During tests at elevated temperatures, suitable reflux coolers shall be used to prevent evaporation of the test electrolyte.

At the end of the test period the sample shall be rinsed with fresh water and wiped dry.

Two cuts shall be made through the coating in the longitudinal direction of the pipe and two similar cuts made in the circumferential direction, each pair of cuts being 5 mm apart and approximately following the tangent of the test defect. The length of the cuts shall extend to approximately 20 mm each side of the defect, see Figure 3.

Using a knife, the strips of coating between the cuts shall be peeled from the pipe surface as far as possible starting at the test defect. The distance over which the coating is detached and the metal is exposed, measured from the edge of the original test defect, shall be recorded for all four directions. The radius of disbonding shall be the arithmetic mean of the four measurements. A photograph of the test sample after testing, showing the disbonded area, shall be included in the test report.

FIGURE 3 Determination of the radius of disbonding



7. COATING REPAIR

The Contractor shall submit detailed procedures for coating repairs.

All coating repair procedures shall be qualified under both coating system qualification (4.3) and Applicator qualification (4.4). Minimum qualification requirements are given in Table 2.

These procedures shall contain as a minimum:

- repair of surface defects;
- repair of holidays, scratches and small defects (e.g. using a melt stick);
- repair of damages due to quality control testing, typically adhesion testing, impact testing (5.8) and film sampling (5.10);
- removal of rejected coating and cleaning the pipe to the required standard for recoating;
- testing to prove the effectiveness of the repairs.

The maximum total surface area per pipe that may be repaired is 50 cm^2. Pipes requiring larger repairs shall be re-coated.

Pipes having insufficient coating thickness shall not be repaired by overcoating.

All pipes that have been repaired shall be fully re-examined in accordance with the quality control procedures (5). Minimum quality control requirements for repairs of small defects and damages are given in Table 3.

Records shall be kept of all repaired pipes and shall include the repair and re-test details.

8. DOCUMENTATION

The Contractor shall keep accurate records of all relevant data of the coating process.

This documentation shall include:

- Copies of the coating system information as specified in (2);
- Copies of qualification information as requested in (4);
- Copies of, or reference to, all procedures for coating of the pipes;
- Serial numbers of all pipes as given by the Line Pipe Manufacturer (e.g. by copies of the pipe mill data sheets);
- Serial numbers as given by the coating Applicator (if applicable) related to the Manufacturer's serial numbers;
- The order of coating, the day and shift of coating of each pipe;
- The batch numbers of the coating materials, the day and time of loading of each batch;
- Serial numbers of rejected pipes and the reason for rejection;
- Records of any repairs;
- The results of all quality control testing (5);
- Records of temperatures during the coating process for each pipe, with the processing time of every tenth pipe, shall be marked on the temperature chart with the pipe number;
- Names and signatures of the responsible persons for the coating process and quality control.

This document shall be submitted to the Principal after completion of the coating works together with the testing and inspection instruments calibration certificates.

9. HANDLING, STORAGE AND TRANSPORT OF BARE AND COATED PIPE

9.1 GENERAL

The Coating Contractor shall take receipt of the pipes, delivered by the Line Pipe Manufacturer and shall keep a record of the serial numbers of the delivered pipes. Upon receipt, the pipes shall be inspected for transport damage or other defects. Damaged pipes shall be separately stored and reported to the Principal. Repairs shall only be carried out after approval by the Principal.

During the various stages of the complete coating process, the Coating Contractor shall ensure that all pipes shall be handled, stored and transported in such a manner that no damage is caused to the pipes and the applied coating. Instructions by the Line Pipe Manufacturer and/or the Coating Manufacturer shall be followed. The following instructions shall also apply:

9.2 HANDLING OF PIPES

Bevel protectors and/or end caps as installed by the Line Pipe Manufacturer shall be re-installed after coating and before handling of the pipes.

Lifting of pipes shall only be carried out using slings, lifting hooks or vacuum lifters, fitted with suitable spreader bars. Chains shall not be used to lift pipes. Wire ropes shall not be used to lift coated pipes. Hooks shall be padded with soft material to prevent damage to the bevelled ends.

Lifting trucks or front end loaders shall have soft padded forks or grips to prevent damage to pipes or pipe coating.

Coated pipes shall not be rolled or dragged over the ground.

Pipes shall not be lifted in bundles without prior approval by the Principal. When more than one pipe is lifted, separate slings or hooks shall be used for each pipe and coated pipes shall be provided with soft padding between the pipes.

For handling of stainless steel pipes, handling and transport equipment and conveyors shall be padded to prevent contact with carbon steel.

9.3 STORAGE AND STOCKPILING OF PIPES

Pipes shall be stored in designated areas. Pipes shall not be stored with other consignments or pipes for other contracts.

Pipes shall be stacked only to such height that damage or deformation to the pipes due to the weight of other pipes shall not occur. Coated pipes shall be stacked only to such height that no damage to the coating occurs.

Pipe supports shall be spaced such that no bending of pipes occurs. Pipe supports shall be made of soft padded wooden bolsters or sand rows, free of stones, covered with plastic sheets. The pipe surface shall be at least 150 mm clear from the soil.

Piles of pipe shall be secured by wooden wedges or ground pins, provided with adequate padding to prevent coating damage, and of sufficient size to prevent collapse of the piles.

Coated pipes shall be stacked using soft separators such as rubber pads, or tyre tread.

When stored outdoors, pipes shall be placed at a small angle to allow drainage of any rain water from the inside of the pipes.

9.4 TRANSPORT OF COATED PIPE

Coated pipes shall be prepared for transport or shipment in accordance with API RP 5L1 or API RP 5LW, whichever is applicable. During transportation, pipes shall be stacked and secured such as to prevent movement, abrasion and/or peening.

10. REFERENCES

In this DEP, reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.

AMERICAN STANDARDS

Recommended practice for railroad transportation of line pipe	API RP 5L1
Recommended practice for transportation of line pipe on barges and marine vessels	API RP 5LW

Issued by:
American Petroleum Institute
Publications and Distribution Section
1220 L Street Northwest
Washington DC 20005
USA.

Standard test method for transition temperatures of polymers by thermal analysis	ASTM D 3418
Standard test method for impact resistance of pipeline coatings (Falling weight test)	ASTM G 14
Standard test method for ring bendability of pipeline coatings (Squeeze test)	ASTM G 70

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INTERNATIONAL STANDARDS

Paints and Varnishes - Determination of film thickness	ISO 2808
Coating Powders:	
Part 1: Determination of particle size distribution by sieving.	ISO 8130-1
Part 2: Determination of density by gas comparison pyknometer (referee method)	ISO 8130-2
Part 3: Determination of density by liquid displacement pyknometer	ISO 8130-3
Part 6: Determination of gel time of thermo-setting coating powders at a given temperature	ISO 8130-6
Part 7: Determination of loss of mass on stoving	ISO 8130-7
Part 8: Assessment of the storage stability of thermo-setting powders	ISO 8130-8
Preparation of steel substrates before application of paints and related products - visual assessment of surface cleanliness. Part 1: rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings	ISO 8501-1
Preparation of steel substrates before application of paints and related products; Tests for the assessment of surface	

cleanliness. Part 2: Laboratory determination of chloride on cleaned surfaces	ISO 8502-2
Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates:	
Part 1: Specifications and definitions for ISO surface profile comparators for the assessment of abrasive blast cleaned surfaces	ISO 8503-1
Part 2: Method for the grading of surface profile of abrasive blast-cleaned steel - Comparator procedure	ISO 8503-2
Part 3: Methods for the calibration of ISO surface profile comparators and for the determination of surface profile - Focusing microscope procedure	ISO 8503-3
Part 4: Methods for the calibration of ISO surface profile comparators and for the determination of surface profile - Stylus instrument procedure	ISO 8503-4
Steel and steel products - Inspection documents	ISO 10474

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