Polyurethane Coating and Lining on Ductile Iron Pipes

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Abstract: In this technical paper, we will discuss polyurethane linings and coatings to ductile iron pipe for transporting corrosive and abrasive fluids in a sub soil, that is extremely corrosive in nature. The capabilities of ECL (Electrosteel Castings Limited) in this regard will be discussed.

Key words: Polyurethane, lining, coating, ECL, ISI (Indian Standards Institution), test certificates, performance tests, provision, specification.

1. Polyurethane Linings and Coatings

Two types of “special lining and coatings” process are implemented at ECL (Electrosteel Castings Limited) Bansberia Works [1]:

A polyurethane epoxy coating (heavy duty) is applied to the outside wall of the pipe with a polyurethane lining (heavy duty) inside.

- ECL-Bansberia plant was built solely for the purpose of applying “special” types of coatings to ductile iron pipes manufactured at the ECL-Khardah Works. The “special” coatings are designed to give greater external corrosion protection for pipes to be installed in aggressive soil conditions or for greater internal corrosion protection for pipes transporting highly corrosive liquids.

- The pipes which undergo the “special” external coating process are delivered with cement mortar lining already having been applied at the Khardah Works but with the external surface of the pipe uncoated (i.e. no zinc or other external coating on the pipe). The “special” external coating is applied in accordance with BS EN 15189.

- The pipes which undergo the “special” internal lining process are delivered with an external zinc or zinc/aluminium coating having previously been applied at the Khardah Works. The pipes are then internally lined with the “special” standard polyurethane lining. The “special” Internal Lining is applied in accordance with BS EN 15655 - 2018.

  • The bare pipes which undergo both “special” internal lining and external coating are hydrostatically tested at the Khardah Works before being transported to the Bansberia Plant for the “special” coatings and linings.

2. Provisions for Polyurethane External Coating as per BSEN15189-2006

BS EN15189-2006, this document defines the requirements and test methods applicable to factory applied external polyurethane coating (heavy duty) corrosion protection of ductile iron pipes and fittings conforming to EN 545, EN 598 and EN 969 [2].

  • Standard: BS EN 15189:2006 (for PU).
  • Brand: PROTEGOL UR COATING 32-49 (for PU).
  • Manufacturer: TIB Chemicals, Germany (for PU).

3. Testing Sample for Performance Tests

Samples of the following dimensions are cut from coated pipe for performing [Table 1]:

(A) Impact strength  600 mm × 150 mm
Table 1  Testing sample for performance tests.

| Test                      | EN 15189 Ref. Clause | Test Method Ref. Clause of EN 15189 | Sample                  |
|---------------------------|----------------------|-------------------------------------|-------------------------|
| I  Chemical resistance    | 6.1                  | 7.2.1                               | Detached film           |
| II Impact strength        | 6.2                  | 7.2.2                               | Coated pipe sample      |
| III Indentation resistance| 6.3                  | 7.2.3                               | Coated pipe sample      |
| IV Elongation at break    | 6.4                  | 7.2.4                               | Detached film           |
| V  Specific coating resistance | 6.5              | 7.2.5                               | Coated pipe sample      |
| VI Ratio of coating resistance | 6.5              | 7.2.5                               | Coated pipe sample      |

Table 2  Performance tests of PU coating.

| SI No. | Test                | Sample                  | Date of test | Duration | Result |
|--------|---------------------|-------------------------|--------------|----------|--------|
| 1      | Chemical resistance | Detached film           | 15.10.2013   | 200 days | Pass   |
| 2      | Impact strength     | Coated pipe sample      | 05.02.2013   | -        | Pass   |
| 3      | Indentation resistance | Coated pipe sample  | 30.01.2013   | 2 days   | Pass   |
| 4      | Elongation at break | Detached film           | 05.02.2013   | -        | Pass   |
| 5      | Specific coating resistance | Coated pipe sample | 05.02.2013   | 100 days | Pass   |
| 6      | Ratio of coating resistance | Coated pipe sample | 05.02.2013   | -        | Pass   |

Table 3  Performance tests of PU coating with requisite clauses.

| Sl. No. | Parameter                              | Requirement                                                                 | Clause                  | Test method                                      | Clause |
|---------|----------------------------------------|-----------------------------------------------------------------------------|-------------------------|--------------------------------------------------|--------|
| 1       | Chemical resistance                     | Less than 15% weight increase after immersion                               | 6.1                     | Immersion in deionised water                      | 7.2.1.1|
|         |                                        | Less than 2% weight loss after drying                                        |                         | EN ISO 62 method                                 |        |
| 2       | Impact strength                         | 8 J/mm PU-coated pipe barrel                                                | 6.2                     | Dropping weight                                   | 7.2.2  |
|         |                                        | 5 J/mm EP-coated spigot end (see EN 14901)                                   |                         | High voltage test                                 |        |
| 3       | Indentation resistance                  | < 10% at 10 MPa                                                             | 6.3                     | Indentation test                                  | 7.2.3  |
| 4       | Elongation at break                     | > 2.5%                                                                      | 6.4                     | Tensile test                                      | 7.2.4  |
| 5       | Specific coating resistance in 0.1 M NaCl| > 10⁶ Ωm²                                                                  | 6.5                     | Resostovotu test towel method or vessel method    | 7.2.5  |
| 6       | Ratio of coating resistance             | > 0.8                                                                       | 6.5                     | Res. 100 d/res. 70d                               | 7.2.5  |

4. Performance Tests of PU Coating

Performance tests were conducted at ECL, Khardah Works for performance requirements of EN 15189:2006 [Table 2, Table 3].

5. Routine Tests of PU Coating

Routine tests were conducted at ECL, Khardah Works for performance requirements of EN 15189:2006 [Table 4].

6. Type Test Certificates of Polyurethane Coated DI Pipes

Type Test Certificates for Polyurethane Coated DI pipes certified by NSF is attached below [Fig. 1].

7. Specifications for the EIL Project on Effluent Discharge Pipeline

It may be noted that the soil type along the pipe route is generally silty clay/clay/silty sand/sand/silt. The chemical characteristics for soil and ground water is ranging as follows [4].
Table 4 Routine tests of PU coating.

| Sl. No. | Parameters               | Requirements                                         | Clause  | Tests                  | Frequency | Clause |
|--------|--------------------------|------------------------------------------------------|---------|------------------------|-----------|--------|
| 1      | Surface preparation      | SA 2.5 of EN ISO 8501-1                              | 5.1     | Visual                 | 100%      | 7.1.1  |
| 2      | Surface roughness        | Ra > 10 μm                                           | 5.1     | EN ISO 8503-1          | min. 1/shift | 7.1.1  |
| 3      | Appearance and continuity| Uniform and smooth                                    | 5.2.1   | Visual                 | 100%      | 7.1.2  |
| 4      | Minimum coating thickness| (x - 2σ) > 700 microns                               | 5.2.2   | Non destructive instruments error ± 10% | min. 1/shift | 7.1.3  |
| 5      | Pipe ends painted parts  | Length depending on type of socket                   | 5.3     | Appropriate measures   | 10%       | 7.1.4  |
| 6      | Repairs                  | Manufacturer’s written instructions                  | 5.4     | High voltage test      | 100%      | 7.1.5  |
| 7      | Marking                  | Legible and durable                                  | 5.5     | Visual                 | 10%       | 7.1.6  |
| 8      | Non-porosity             | > 70 Shore D                                        | 5.6     | High voltage test instrument | 1 per 1,000 pipes | 7.1.7  |
| 9      | Hardness                 | Hardness test                                        | 5.7     | min. 1/shift           | 7.1.8     |
| 10     | Adhesion                 | > 8 MPa at 23 °C                                     | 5.8     | Punch separation method acc. EN ISO 4624 | 1 per 1,000 pipes | 7.1.9  |

Fig. 1 Type test certificates of polyurethane coated DI pipes [3].

7.1 Soil
- Sulphate (SO₄²⁻): Nil to 95 (mg/L)
- Chloride: 164-506 mg/L
- pH: 7 to 9

7.2 Ground Water
- Sulphate (SO₄²⁻): Nil to 95 (mg/L)
- Chloride: 108-347 mg/L
- pH: 7 to 9
The use of polyurethane coating as per BS EN 15189:2006 has been stipulated having a coating of 1,000 micron.

8. Provisions for Polyurethane Internal Lining as per BSEN15655-1:2018

BS EN15655-1:2018, this document defines the requirements and test methods applicable to factory applied internal polyurethane heavy duty corrosion protection of ductile iron pipes and fittings conforming to EN 545, EN 598 and EN 969 [5].

- Chemical resistance (Clause 6.1) [Table 5]

The chemical resistance is determined by the change in weight of the polyurethane lining in neutral or acid conditions. When tested in accordance with 7.2.3 the weight increase respectively, weight loss shall meet the requirements given in Table 3 when compared to the original weight.

- Indirect impact strength (Clause 6.2)

Due to handling activities, the PU-lined pipes may fall or get impacts from outside with minor plastic deformations which can cause damages on the lining. The minimum impact strength shall be determined in accordance with the test method defined in 7.2.4 with an impact energy $E$ of at least 50 J. The lining shall subsequently show no damage when tested in accordance with 7.1.8 Water use efficiency, Flood and Drainage.

- Resistance to ovalization (Clause No. 6.3)

The requirements of EN 545 or EN 598 shall be applied.

- Elongation at break (Clause No. 6.3)

The elongation at break shall be assessed by testing in accordance with the test method defined in 7.2.6. The lining shall have a minimum elongation at break of 2.5%.

- Glass transition temperature (Clause No. 6.3)

The lining material shall conform to the limits of change in glass transition temperature ($\Delta T_g$) determined by DSC (Differential Scanning Calorimetry).

- Specific electrical resistance of the lining (Clause No. 6.3)

The specific lining resistance of the polyurethane lining shall be assessed by testing in accordance with the test method defined in 7.2.7.

The specific lining resistance of the polyurethane lining after immersion in a 0.1 M NaCl solution for 100 days shall be at least $10^8 \ \Omega \ m^2$. The resistance after 100 days shall not be less than 80% of the value after 70 days if the surface resistance of the lining after 100 days is only one decimal power above the minimum permissible value for 100 days. The test shall be carried out at room temperature ($23 \pm 2$ °C).

- Abrasion resistance (only for waste water application) (Clause No. 6.7)

When tested in accordance with 7.2.8, the pipes shall not have an abrasion depth greater than 0.2 mm after 100,000 movements (50,000 cycles).

Note: In order to test the abrasion resistance of fittings, straight fittings as flanged pipes, etc. may be lined as fittings and tested according to 7.2.7.

- Materials in contact with water intended for human consumption (Clause No. 6.8)

When used under the conditions for which they are designed, in permanent or in temporary contact with water intended for human consumption, the polyurethane lining applied on ductile iron pipes and...
fittings shall not change the quality of that water to such an extent that it fails to comply with the requirements of national regulations.

For this purpose, reference shall be made to the relevant national regulations and standards, transposing EN standards when available, dealing with the influence of materials on water quality and to the requirements for external systems and components as given in EN 805.

9. Type Test Certificates of Polyurethane Lined DI Pipes

Type Test Certificates for Polyurethane Lined DI pipes certified by Bureau Veritas is attached below [Fig.2]

10. Result of Type Test for Polyurethane Internal Coating

Details of inspection activities carried out with respect to scope of work documents reviewed were mentioned below [Table 6].

11. Specifications for the EIL Project on Effluent Discharge Pipeline

The characteristics of fluid properties as provided by EIL for Ankleshwar Facility is provided below [Table 7].

As per the provided effluent characteristics the use of polyurethane lining with 1,500 micron thickness has been stipulated.
Table 6  Result of type test for polyurethane internal coating.

| Sl. No. | Properties                  | Reference standard | MPW requirement      | Test results                  | Document review status           |
|---------|-----------------------------|--------------------|----------------------|------------------------------|----------------------------------|
| 1       | Thickness                   | MPW & BSEN1 5655   | Minimum 1,000 micron | DN200: 1,105 micron          | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 1,070 micron          |                                  |
|         |                              |                    |                      | DN800: 1,085 micron          |                                  |
| 2       | Adhesion                    | BSEN1 5655 Clause 7.1.9 | Greater Than 8 MPa  | DN250: 9.5 MPa               | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 9.4 MPa               |                                  |
|         |                              |                    |                      | DN800: 10.5 MPa              |                                  |
| 3       | Hardness                    | BSEN15655 Clause 7.1.8 | Greater Than 70 Shore D | DN250: 75 Shore D            | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 74 Shore D            |                                  |
|         |                              |                    |                      | DN800: 79 Shore D            |                                  |
| 4.1     | Chemical resistance to effluents (immersion in DM water at 50 °C) | BSEN15655 Table 2 | Less than 15% weight increase after immersion for 100 days | DN200: 4.1% increase           | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 4.0% increase         |                                  |
|         |                              |                    |                      | DN800: 3.6% increase         |                                  |
|         |                              |                    |                      | Less than 2% weight loss after drying for 100 days | DN200: 0.56% decrease           |
|         |                              |                    |                      | DN400: 0.51% decrease        |                                  |
|         |                              |                    |                      | DN800: 0.46% decrease        |                                  |
| 4.2     | Chemical resistance to effluents (immersion in 10% dilute sulfuric at 50 °C) | BSEN1 5655 | Less than 10% weight increase after immersion for 100 days | DN200: 4.4% increase           | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 5.2% increase         |                                  |
|         |                              |                    |                      | DN800: 4.7% increase         |                                  |
|         |                              |                    |                      | Less than 4% weight loss after drying for 100 days | DN200: 0.63% decrease           |
|         |                              |                    |                      | DN400: 0.75% decrease        |                                  |
|         |                              |                    |                      | DN800: 0.66% decrease        |                                  |
| 5       | Indirect Impact Strength    | BSEN1 5655         | No porosity at 50.0 J | No porosity at 51.5 J       | Reviewed and Accepted            |
| 6       | Ovalization resistance      | BSEN15655          | No porosity at minimum 4% Ovalization for DN200 | No damage at 4.8% for DN200   | Reviewed and Accepted            |
|         |                              |                    |                      | 6% Ovalization for DN400     |                                  |
|         |                              |                    |                      | 8% Ovalization for DN800     |                                  |
| 7       | R elongation at Break       | BSEN15655          | > 2.5%               | 4.2% for DN200               | Reviewed and Accepted            |
|         |                              |                    |                      | 5.2% for DN400               |                                  |
|         |                              |                    |                      | 4.1% for DN800               |                                  |
| 8       | Abrasion resistance (50,000 cycles) | BSEN15655 & BSEN598 | < 0.20 mm            | 0.09 mm                      | Reviewed and Accepted            |
| 9       | Light aging resistance (outside Storage for 6 months) | BSEN15655 | Adhesion (> 8 MPa) | DN250: 9.3 MPa               | Reviewed and Accepted            |
|         |                              |                    |                      | DN400: 8.9 MPa               |                                  |
|         |                              |                    |                      | DN800: 9.3 MPa               |                                  |
| 10      | Resin Content of PU material | MPW                | 85% minimum          | More than 85%                | Manufacturer confirmation was noted |

Table 7  Effluent characteristics from Ankleshwar facility.

| S. No. | Parameter                            | Unit   | Value       |
|--------|--------------------------------------|--------|-------------|
| 1      | pH                                   | mg/L   | 6.00 to 9.00|
| 2      | COD (Chemical Oxygen Demand)         | mg/L   | 500         |
| 3      | BOD$_{5}$, 27 °C (Biochemical Oxygen Demand) | mg/L | 100        |
| 4      | Total dissolved solids               | mg/L   | ~10,000     |
| 5      | Total suspended solids               | mg/L   | 100         |
| 6      | Sulphides, as S                     | mg/L   | 5           |
| 7      | Phenolic compounds (as C$_6$H$_5$OH) | mg/L | 5           |
| 8      | Oil and grease                       | mg/L   | 10          |
| 9      | Total residual chlorine              | mg/L   | 1           |
| 10     | Fluoride                             | mg/L   | 15          |
| 11     | Free ammonia                         | mg/L   | ~           |
| 12     | Nitrate nitrogen                     | mg/L   | 50          |
Table 7 to be continued

|   | Name                  | Unit | Value    |
|---|-----------------------|------|----------|
| 13 | Ammonical nitrogen    | mg/L | 50       |
| 14 | Total Kjeldahl Nitrogen | mg/L | 50       |
| 15 | Vanadium              | mg/L | 2        |
| 16 | Selenium              | mg/L | 0.05     |
| 17 | Iron                  | mg/L | 3        |
| 18 | Copper                | mg/L | 3        |
| 19 | Zinc                  | mg/L | 15       |
| 20 | Chromium 6+           | mg/L | 0.1      |
| 21 | Lead                  | mg/L | 0.1      |
| 22 | Cadmium               | mg/L | 0.05     |
| 23 | Temperature           | °C   | Not more than 5 °C above ambient water |
| 24 | Arsenic               | mg/L | 0.2      |
| 25 | Mercury               | mg/L | 0.01     |
| 26 | Manganese             | mg/L | 2        |
| 27 | Nickel                | mg/L | 3        |

12. ISI (Indian Standards Institution)
Marking of DI Pipes

The ISI marking of DI pipes is mandated by the order of Ministry of Commerce and Industry (Department of Industrial Policy and Promotion) dated 25th June 2009.

So, even if a customer does not ask for ISI marked DI pipes, there is no way but the DI pipe manufacturers are bound to supply ISI marked DI pipes as per this order.

In the said Gazette in Sl. No. 3 under heading “Prohibition regarding manufacture, storage, sale and distribution etc.” it is written that [7]:

Quote:

(1) No person shall by himself or through any person on his behalf manufacture or store for sale, sell or distribute ductile iron pressure pipes and fittings which do not conform to the specified standard and do not bear Standard Mark of the Bureau on obtaining certification marks license:

Provided that nothing in this Order shall apply in relation to export of ductile iron pressure pipes and fittings meant for export, which conform to any specification required by the foreign buyer and such specification shall not in any case be less than the specified standard.

(2) The sub-standard or defective ductile iron pressure pipes and fittings, which do not conform to the specified standard shall be deformed by the manufacturer beyond use and disposed off as scrap within three months.

Unquote:

13. Conclusions

Polyurethane Lining should be adopted for corrosive and abrasive fluids and the thickness should be determined based on fluid properties.

Polyurethane Coating should be adopted for corrosive sub-soil and the thickness should be determined based on sub-soil properties.

References

[1] https://www.electrosteel.com/.
[2] BS EN15189-2006. Ductile Iron Pipes, Fittings and Accessories—External Polyurethane Coating for Pipes—Requirements and Test Methods.
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