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Fusion bonded epoxy mainline and field joint coatings performance from the X100 field trial – A case study

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ABSTRACT

Operating and distribution companies are potentially interested in the use of high and ultra-high strength steels for the transportation of high pressure gas. The ultra-high strength X100 grade steel was commercially developed as a potential option to meet this. However, there has been limited industry wide use of X100 to date.

BP carried out a 2 year field trial to demonstrate the operational capacity and integrity of a large diameter (48 inch/1219 mm) high pressure pipeline constructed from X100 grade steel. The 800 m pipeline was buried in a clay backfill and exposed to wet ground conditions associated with the North of England. Flow pressure cycling was carried out, using water, to simulate 40 years of operational service.

A 200 m section of the pipeline was exposed to three different potential (cathodic protection) zones for the duration of the trial: zero potential, intermediate potential (−850 to −950 mV) and high potential (−1200 to −1300 mV). This section also had damage and defects induced which are typically associated with bad installation and commissioning.

An area of potential concern is the degradation of the mechanical properties (strain ageing) due to the external coating application temperature. Thus, a low coating application temperature is deemed desirable.

The mainline and field joint coatings employed for the trial were fusion bonded epoxy (FBE). Both of these have been used in other BP projects, with a good track record. They were applied at a lower application temperature of 220 °C, compared to the more typical 230–240 °C. The lower application temperature was within the manufacturers approved application and curing temperature range. The lower temperature was used to assess the ultimate performance properties of the mainline and field joint FBE coatings.

Mainline and field joint coating samples were taken from the three different potential zones and extensive testing and characterisation carried out. This paper presents and discusses the results of the testing.

It was found that the different potential zones had negligible effect on the properties of the mainline and field joint coatings. The post-field trial properties of the mainline coatings were unaltered (i.e. same as pre-field trial) despite burial for over 2 years.

Although the mechanical properties (flexibility and impact resistance) of the field joint coatings were acceptable, the coatings' water soak and cathodic disbondment resistance were far inferior to those of the mainline coating. This can be related to the comparably lower adhesion, and directly attributed to the adhesion promoting chromate pre-treatment used for mainline coatings, but not so for field joints. This is stipulated by environmental legislation. This is an area which needs to be addressed prior to X100 being used in any future project.

1. Introduction

There is growing interest within the pipeline industry for the use of high and ultra-high strength steel, such as the X100 grade, for the transportation of high pressure gas. However, it has been shown that the application temperature of the external

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anti-corrosion coating has a detrimental effect on the mechanical properties of the X100 [1,2]. This is termed *strain ageing*.

Application temperature is a critical parameter in the performance of fusion bonded epoxy (FBE) coatings. This has a major influence on the coating's wet and dry adhesion, and cathodic disbondment resistance. In general, a higher application temperature results in a lower melt flow viscosity. This results in improved surface wetting and adhesion, as the FBE flows into the profile created by grit blasting [3–5].

Before ultra-high strength steels such as X100 are widely adopted, it is important that the influence of coating application temperature on strain ageing is better understood. Of particular interest is:

- The effects of FBE application temperature on the mechanical properties of high strength steels.
- The ability to achieve the recommended FBE coating thickness at the lower application temperatures, both in the coating mill and in the field.
- The effect of lower application temperatures on the ultimate properties of the FBE coating.

This paper addresses the latter point. The aim is to establish whether the original pass/fail criteria is still achieved after 2 years burial. Additionally, to determine the effects of a lower application temperature on the properties of the FBE coating.

2. X100 field trial

The X100 field trial would also allow BP to demonstrate the operational capacity and integrity of a large diameter high pressure pipeline constructed from X100 grade material.

The trial involved laying 800 m of large diameter (48 inch/1219 mm nominal bore diameter) pipe in two sections (Section A and Section B). Section A was approximately 600 m in length, and Section B was 200 m in length.

Section B, from which the mainline and field joint coating samples were removed for this investigation, had induced damage associated with bad installation and commissioning. It was subjected to three different potential zones during the operational trial:

(i) Free corrosion potential (structure to electrolyte potential measured with no cathodic protection applied).
(ii) An intermediate polarised potential of −850 to −950 mV (with respect to a copper/copper sulphate reference electrode).
(iii) A high polarised potential of −1200 to −1300 mV (with respect to a copper/copper sulphate reference electrode).

Both Sections A and B were subjected to accelerated internal pressure cycling, where typical service pressure fluctuations were performed over a period of approximately two years, to simulate 40 years of operation.

After approximately two years of pressure cycling in very wet clay soil, Sections A and B were excavated for post test evaluation. This particular investigation focuses on the performance of the FBE mainline and field joint coatings applied to Section B.

3. Mainline and field joint coating application

3.1. Mainline coating

The mainline FBE coating was applied in accordance with an in-house coating specification. The powder was applied over a blast cleaned substrate to Sa 2.5 that had been chromate pre-treated. Pipes were induction heated prior to the FBE powder being applied by electrostatic spraying. To minimise circumferential and axial temperature variations, automated pipe rotation was carried out while passing through the induction heating coils (standard practice). The FBE powder was applied at a maximum application temperature of 220 °C, and to a coating thickness within the range 400–550 microns.

The procedure qualification test (PQT) results performed by the coating applicator are shown in Table 1. The cathodic disbondment results indicate the beneficial effect of chromate pre-treatment of the pipe prior to coating application. This observation is also reported by others [6,7].

3.2. Field joint coating

Prior to the onsite field joint coating, the field induction coil was prequalified at the premises of the applicator. This would enable the coil to have an acceptable circumferential and axial heating profile.

Traditionally, coil cut-off temperatures employed for steel grades X56 to X80 range from 232 to 239 °C. This range allows for good surface wetting to be achieved, even where circumferential and axial temperature variations exist, due to poor coil concentricity or poorly spaced coil windings. The coil cut-off temperature employed for the field trial was 218 °C.

Field joint coating application was conducted in winter. The ambient temperatures at the time of coating varied between 2 and 10 °C. All joints were coated at an induction coil cut-off temperature of 218 °C, measured at approximately the 3 o'clock location using a thermal crayon. The recommended range of application temperature for this powder is 218–253 °C. The powder manufacturer stated that the coating requires approximately 100 s at 218 °C to achieve full cure.

Post heating was considered necessary to achieve full cure of the FBE coating, due to the low atmospheric and application temperatures.

4. Post-field trial evaluation

4.1. Preparation and testing of the mainline and field joint coatings

Three field joints (B2, B9 and B18) were selected for the post-trial evaluation. These joints coincided with the free corrosion, intermediate and high potential regions respectively. Sections of the field joint were removed from the 3, 6, 9 and 12 o'clock locations, as coated and laid, by flame-cutting, and then cold cut into appropriate panel sizes for testing. Fig. 1 shows the cutting plan for the field joint coating. The mainline cutting plan was very similar.

Table 1
Results of the PQTs performed by the coating applicator.

Test	Chromate pre-treatment		No treatment	
	Panel 1	Panel 2	Panel 1	Panel 2
CD at −1.5 V at 65 °C for 48 h (3.2 mm hole)	1–1.9 mm	1–2.0 mm	6.9–8.2 mm	5.0–6.2 mm
CD at −1.5 V at 65 °C for 48 h (6 mm hole)	0–1.2 mm	0.6–1.4 mm	9–11.4 mm	8.8–9.4 mm
Water immersion at 75 °C for 48 h	Rating 1	Rating 1	Rating 1	Rating 1
Flexibility at 0 °C	Pass 2%	Pass 2%	Pass 2%	Pass 2%
Interface porosity	Rating 1	Rating 1	Rating 1	Rating 1