

TECHNICAL NOTE

INFILL MATERIALS OF EPOXY GROUT FOR PIPELINE REHABILITATION AND REPAIR

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Abstract: The oil and gas industry uses carbon steel pipelines as the basic element in transporting crude oil and gas. These pipelines are subjected to deterioration due to several factors, including third party damage, material and construction defects, natural forces and corrosion. Deterioration of underground pipelines due to corrosion can lead to serious pipeline failures such as leakage and explosion. Hence, methods to repair such damage have been developed in order to extend the durability of pipelines. This paper reports on the current development of infill materials of epoxy grouts used for pipeline external repair. Assessment of the defects should be completed by pipeline operators to identify list of parameters including pipeline operating characteristic, geometries and materials of pipeline, and configuration and location of pipeline to make the best option of repair techniques. Therefore, selection of an appropriate rehabilitation system is crucial in preventing the future failure of pipeline structure. A simple guideline is required to optimize the information in the selection of suitable materials for pipeline repair works. The selection of suitable materials will help in preventing the future failure of pipeline structures due to inappropriate selection of infill materials.

Keywords: *Pipeline, epoxy grout, infill materials, deterioration, repair and rehabilitation*

1.0 Introduction

Steel pipelines are the most efficient and the safest ways to transport natural resources like oil and gas over long distances. According to Central Intelligence Agency (2013), there are over one million kilometers of pipelines laid around the world and more new pipelines are expected to be installed in the future. However, steel pipes that are laid underground can go through an adverse deterioration in the form of corrosion, crack, wearing, buckling, gouging, leaks and rupture. Corrosion and metal loss are the most susceptible weaknesses of steel pipe (Francis, 1994; Frankel, 1998; Noor *et al.*, 2008 & 2010; Yahaya *et al.*, 2011; Narayanan and Sohaimi, 2013). A corroded pipeline will reduce the strength and eventually reduce its service life. Hence, corrosion and metal

loss cause failures in pipelines and their repair techniques is one of the prime interests of the researchers all over the world (Shamsuddhoha *et al.*, 2013a).

2.0 Epoxy Grout

To date, continuous efforts are put by numerous institutions and companies to develop their very own R&D and commercial composite repair products. Although the products made by different companies and research institutes world widely have different performance from each other, its composite material repair system mainly includes three parts: (i) high strength glass fiber or carbon fiber reinforcing materials; (ii) adhesive materials with high curing speed and high performance; and (iii) high compressed strength material for pipeline defects filling that conveys the load (Ma *et al.*, 2011). Figure 1 shows basic components in composite repair system: (1) Fiber-reinforced polymer (FRP sleeve), (2) interlayer adhesive, and (3) grout.

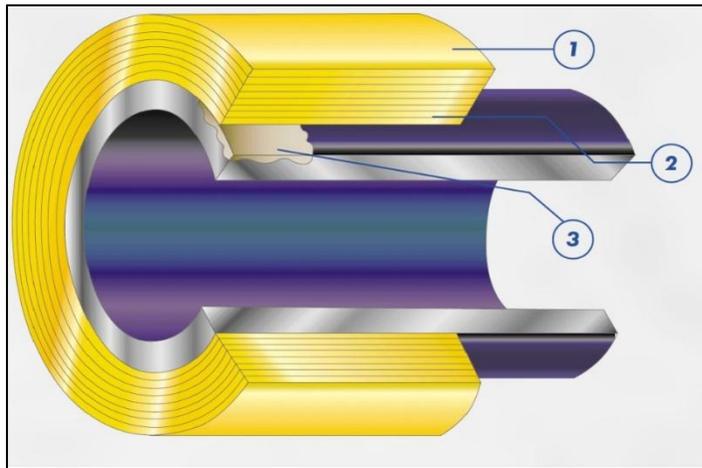


Figure 1: 1-FRP Sleeve; 2-Interlayer Adhesive; and 3-Grout.

According to ISO/TS 24817, infill material is defined as the material used to repair surface imperfection prior to the application of composite sleeve (ISO, 2006). Grouts and “putty” are commonly used infill materials. These materials are generally made of epoxy resin. Metal or mineral fillers are used to modify the mechanical, curing and shrinkage properties of the infill. The concept is filled the defect area and provides a smooth surface between composite sleeve and pipe.

In case of material loss either by corrosion or gouging, grout or putty is used to ensure a smooth bed for the composite layer. The grout is to provide a continuous support by the introduced infill layer that can minimise the radial deformation and transfer the load from pipe to the outer shell. The load, e.g. internal pressure carried by pipe at the repaired segment will be conveyed and shared by outer composite sleeve through infill material. The composite is the primary load carrying component in the repair segment while infill material serves as important bridge to provide a smooth load transfer. Figure 2 shows a simplify illustration of the load transfer in the system.

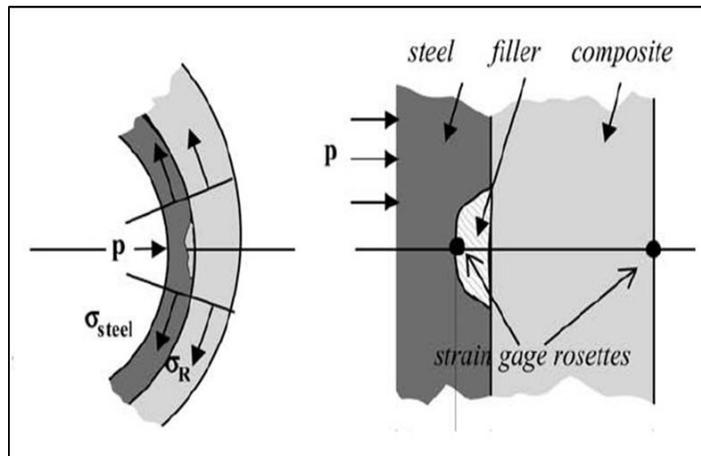


Figure 2: Load transfer mechanism (Source: Freire *et al.*, 2007).

3.0 Properties of Epoxy Grout

In FRP repair system, the properties of grouts are significant parameters which are required in the prediction of the behaviour of a repair system for an optimum design. Therefore, it is crucial to characterize the mechanical and thermal properties to determine their efficiency as infill materials in the repair. A technical insight into an epoxy-grouted hot tap fittings technology for pipeline repair was described by Vu *et al.* (2011) where the compressive, tensile and flexural strengths specified in that article were 75, 23 and 50 MPa, respectively. Duell *et al.* (2008) used an epoxy based grout and epoxy wetted flexible carbon wrap to repair the pipes, which had undergone 50% thickness losses on the asymmetric and localised defects. In that study, both numerical and experimental results showed that the grout will be subjected to compressive stress of about 33 MPa when the system is at a pressure of 44 MPa.

In another study, Mattos *et al.* (2009) investigated with an alternative repair system using two grout systems: silicon steel alloy filled polymers and oligomers, and epoxy

resins with aluminum powder. The compressive strengths of the above materials were 56 and 104 MPa while tensile strengths were 59 and 67 MPa, respectively. Polyester based infill materials were found to be suitable by Sirimanna *et al.* (2012) for deteriorated piles and the compressive strength was found within the range of 40 to 90 MPa. Shamsuddoha *et al.* (2013b) carried out the characterization of five commercial epoxy grouts and reported three of it has the potential to be used as infill material.

Even though several properties have been investigated in previous works, shrinkage effects on thickness of infill materials did not considered. Polymer can shrink during curing (Li *et al.*, 2004; Haider *et al.*, 2007). Resin when used in thick sizes can experience residual stresses and thus affect the load transfer performance. According to ASME PCC-2 (2006), the service temperature of a repair component of non-leaking and leaking pipes should not be 20°C and 30°C less than the glass transition temperature (T_g), respectively. Moreover, an evaluation of their thermal properties of the components of the repair is also important, as polymers exhibit degradation at elevated temperature. However, detail characteristics of the infill material were left out in the previous works, thus demand additional investigation for better understanding the mechanical and thermal properties of epoxy grouts (Shamsuddoha *et al.*, 2013a).

4.0 Evaluation of Epoxy Grout for Pipeline Rehabilitation and Repair

Mendis (1985) state that all the tested grouts having a compressive strength of more than about 40 MPa have the potential to be used in crack repairs. According to Thandavamoorthy *et al.* (2001), a high performance grout with the compressive strength of 85 MPa is suitable to rehabilitate fatigue damaged tubular joints. Thus, epoxy grouts with compressive strength within this range have the potential for composite repair of steel pipelines. In addition, the tensile and flexural loads are also the governing forces in a pipe repair. The dominant force in a pipe repair is circumferential load which acts as a tensile stress along the hoop direction in the components of the repaired section. Table 1 shows the relevant mechanical properties suggested for different range of repair and rehabilitation works. Therefore, the selection of the grout should be based on the suitability of the properties of the grouts in in situ applications.

Table 1: Typical properties of epoxy grout for repair and rehabilitation (Mendis, 1985)

| Applications | Compressive strength (MPa) | Tensile strength (MPa) | Bond strength (MPa) |
|---|----------------------------|------------------------|---------------------|
| Bonding dissimilar materials | - | 10 - 55 | 7 - 35 |
| Concrete crack repair | 41 - 97 | 14 - 55 | 14 - 35 |
| Structural rehabilitation | 83 - 97 | 28 - 48 | 28 - 41 |
| Foundation and heavy machinery applications | ≥ 97 | - | 15 - 28 |

5.0 Conclusion

Most of the R&D and commercially available composite repair systems consist of composite sleeve, adhesive and infill material of epoxy grout to offer great advantages in strength. Based on the preceding researches, it is possible to identify the properties needed for infill materials which are compatible with other repair elements. The mechanical and thermal behaviour of the grouts will aid in understanding the suitability of the properties of the grouts in *in situ* applications to repair damaged pipeline. Although few researchers have investigated some properties of the commercialized infill materials, the works are mainly focused on the mechanical properties such as compressive and tensile strength (Duell *et al.*, 2008; Mattos *et al.*, 2009; Sirimanna *et al.*, 2012; Shamsuddhoha *et al.*, 2013b). In addition to the existing pipeline design codes and standards, there is no clear guideline and standards of the required properties of infill material according to the type and severity of damage. It is important to compile systematically the properties of infill material as a practical guideline to improve the efficiency of repair works by having a right selection of infill material according to operational condition and the defects. New research with significant impact on the advancement of composite repair technology for damaged steel pipeline is vitally required. By bringing all of the general requirements within one single document, the pipeline industry can recommend to pipeline operators the minimum requirements in the selection of infill material of epoxy grouts as part of the composite repair system to repair deteriorating pipelines.

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