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Strength Development of Epoxy Grouts for Pipeline Rehabilitation

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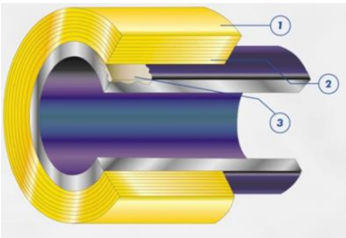
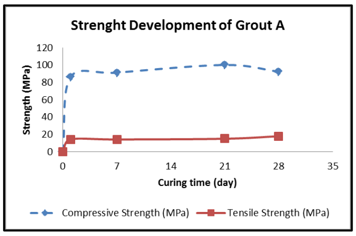
Graphical abstract





Abstract

Polymeric composites are increasingly being used as infill material in civil engineering applications for repairing damaged structures, including corroded pipelines. In repairing damaged pipelines, combination of composite layer and infill materials is a preferable technique used in oil and gas industry. It is desirable for a repair work to be completed in a short period of time. More importantly, as the repair work is done, the structure is expected to back in service soonest possible to minimize the financial loss due to production interference. This paper investigates the development of tensile and compressive strength of two epoxy grouts over 28 days. This research program aims to improve fundamental understanding of this material and its potential application in repairing damaged pipeline. A total of 80 samples with different curing times were prepared based on manufacturer's guideline. The samples were then cured in room temperature for 1, 7, 21 and 28 days before tested using universal testing machine. The trend of strength development over time was studied to identify the time at which the grout can be considered capable of serving in service condition. It was found that the compressive and tensile strength of both grouts greater than 70MPa and 14MPa at 1-days curing time, respectively. The strength is about 80% developed for 1-day curing time. When comparing the properties of the tested grouts with previous studies, both grouts were found to have the potential to be used as infill material for repairing damaged pipeline. In addition, for application of compressive strength and tensile strength less than 70MPa and 14MPa, both grouts can be considered as capable to serve its repair purpose after the grout cured for 1 day.

Keywords: Composite, Epoxy grout, Pipeline, Repair, Strength Development

Abstrak

Penggunaan komposit polimer dalam aplikasi kejuruteraan awam semakin meningkat, di mana ia digunakan sebagai bahan pengisi untuk membaiki struktur yang mengalami kerosakan, termasuklah saluran paip yang berkarat. Dalam proses membaiki kerosakan saluran paip, gabungan lapisan komposit dan bahan-bahan pengisi adalah satu teknik yang lebih digemari dalam industri minyak dan gas. Kerja-kerja pembaikian yang disiapkan dalam waktu yang singkat amat diidamkan. Lebih-lebih lagi setelah kerja pembaikian selesai, struktur diharap mampu beroperasi secepat mungkin bagi mengurangkan kerugian kewangan akibat daripada gangguan pada proses pengeluaran. Kertas ini mengkaji tentang tahap peningkatan kekuatan tegangan dan mampatan selama 28 hari untuk dua jenis epoksi turap. Matlamat kajian adalah untuk meningkatkan pemahaman asas terhadap bahan tersebut dan potensinya untuk digunakan dalam membaiki saluran paip yang mengalami kerosakan. Sebanyak 80 sampel dengan masa pengawetan yang berbeza telah disediakan mengikut garis panduan yang telah ditetapkan oleh pengeluar. Sampel kemudian diawet pada suhu bilik selama 1, 7, 21 dan 28 hari sebelum diuji menggunakan mesin ujian universal. Trend perkembangan kekuatan sampel terhadap masa diperhatikan untuk mengenal pasti tempoh masa epoksi dianggap mampu beroperasi pada tahap yang diperlukan. Kajian mendapati bahawa kekuatan mampatan dan tegangan kedua-dua sampel turap adalah melebihi 70 MPa dan 14

MPa masing-masing pada hari pertama pengawetan. Sebanyak 80% kekuatan telah tercapai untuk masa pengawetan 1-hari. Apabila perbandingan ciri-ciri turap antara sampel turap yang dikaji dengan kajian sebelum ini, kedua-dua sampel turap yang dikaji didapati berpotensi untuk digunakan sebagai bahan pengisi untuk memperbaiki saluran paip yang mengalami kerosakan. Di samping itu, bagi aplikasi di mana kekuatan mampatan dan tegangan kurang daripada 70MPa dan 14MPa, kedua-dua turap tersebut dianggap mampu untuk berkhidmat bagi tujuan pembaikian selepas ia diawet selama 1 hari.

Kata kunci: Komposit, Epoksi Turap, Salur Paip, Baiki, Perkembangan Kekuatan

1.0 INTRODUCTION

Underground pipeline systems, commonly made from carbon steel, are utilised to transport products such as crude oil and gas from one point to another. These pipelines are subjected to deterioration due to several factors, including third party damage, material and construction defects, natural forces and corrosion [1-4]. The deterioration of the steel pipelines caused by corrosion is a common and serious problem, involving considerable cost and inconvenience to industry and to the public. For example, a pipeline rupture caused by external corrosion on May 2015 had an estimated 500-barrel (bbl) of crude oil enter the Pacific Ocean. Even though this incident doesn't cause any fatalities or injuries, the total cost of property damage and clean-up was about $143 million [5]. In 2014, an explosion of an underground pipeline in Kaohsiung, Taiwan killed at least 27 people and injured 286 due to a leaked pipeline [6]. The strength and service life of pipeline will be reduced due to corrosion [7-9]. Therefore, corrosion and metal loss caused failures in pipelines and their repair techniques are the primary interests of researchers all around the world [10-11].

Recently, Fibre Reinforced Polymer (FRP) composite have started to gain the attention of civil engineers. Its effectiveness in strengthening and repairing concrete structures have been proven both experimentally and analytically [12-13]. Besides, several literatures have shown that fibre-reinforced polymer (FRP) composites can be used effectively for the construction and retrofit of marine and underground structures [14-17]. FRP composites have been chosen to repair steel pipelines due to their lightweight, high strength and stiffness, excellent fatigue properties and good corrosion resistance. The acceptance of composite based materials as an alternative to conventional repair materials is evidenced through the recent development of several codes and standards, including ASME PCC-2 [18] and ISO/TS 24817 [19]. Both standards recognized composites as a legitimate repair material. In repairing a defective pipeline, the combination of FRP composite layer and infill material is normally used in the oil and gas industry. Figures 1 shows basic components of a commercially available composite repair system, Clock Spring® repair system: (1) composite sleeve, (2) interlayer adhesive, and (3) infill material.

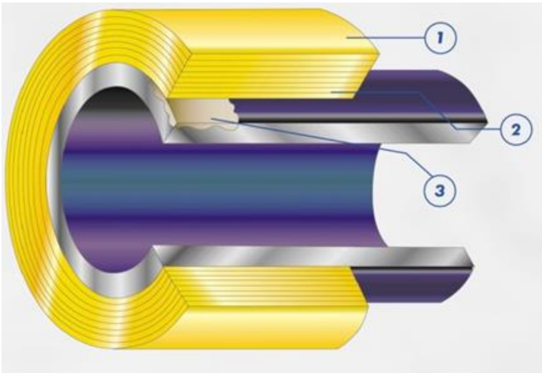


Figure 1 Clock Spring® composite repair system

Adhesive is applied to the surface of pipe and composite and serves as bonding agent. Grout or "putty" is uses as infill material to fill the damaged section in the pipe to provide a smooth surface between composite layer and pipe, while composite strengthens the damaged pipe by carrying the load. In this type of repair, the load, such as internal pressure carried by pipe at the repaired segment is conveyed and shared by outer composite layer through infill material. Thus, the effectiveness of this repair system is largely dependent on the performance of infill material [3].

Polymeric composites are increasingly being used in civil engineering applications to repair and rehabilitate damaged structures. Cement grout with or without polymer modification and epoxy grouts are used as infill materials for rehabilitation works in construction industry. Epoxy based composites are preferable than cement grouts for rehabilitation work that required high strength, fast curing, high early strength and resistance against aggressive chemical environment [20]. The suitability of epoxy grouts in repairing damaged structures is mainly determined by their properties. In addition, these properties are important parameters that used in theoretical prediction and numerical simulation of a composite repair system in determining the performance and behaviour of the repair. Therefore, it is important to characterize the mechanical properties of epoxy putty in order to determine their efficiency as infill materials for a repair system.

It is often desirable for a repair work to be completed in a short period of time. More importantly, as the repair work is done, the structure is expected to resume soonest possible. However, the duration needed for a repair system to be fully functioned is dependent on the maturity of the repair materials. Therefore, it is required to determine the time at which the grouts can be considered as capable of serving in service condition. Owing to that, the motivation of this paper is to determine the strength development of two commercially available epoxy grouts over a period of 28 days. Compressive and tensile strength were determined to investigate the maturity duration of the tested grouts to be considered as suitable for performing pipeline repair.

2.0 METHODOLOGY

Two types of epoxy grouts were selected based on their application and reported properties as per manufacturer's datasheet. Due to commercial confidentiality, the grouts used in this research are named as Grout A and Grout B. Grout A is a three-parts silica filler reinforced epoxy grout which consists of modified epoxy resin, hardener and fine silica sand. On the other hand, Grout B is a two-parts ceramic and steel particle reinforced composite that only consists of modified epoxy resin and hardener. The ceramic and steel filler are premixed in modified epoxy resin, hence the two-parts system.

The preparation of epoxy grouts was carried out as per manufacturer's guideline. Epoxy resin, hardener and silica filler of Grout A were weighed based on ratio recommended in manufacturer's datasheet. An electrical mixer was used to thoroughly mix epoxy resin with hardener in low speed until a smooth consistency in a clean dry container. It was followed by adding the silica filler and mixing all three-parts until a homogeneous grout is obtained. Similar to Grout A, the epoxy resin and hardener of Grout B were weighed according to manufacturer's datasheet. The two-parts were then manually mixed on a dry and clean mixing pan until a homogeneous grout is obtained. Figure 2 shows the mixing process of Grout A and Grout B.

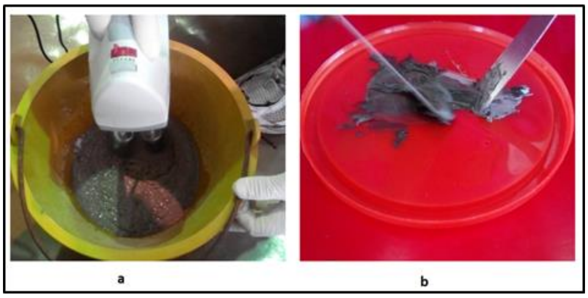


Figure 2 Mixing process of Grout A (left) and Grout B (right)

Compressive and tensile test were carried out based on ASTM D695 [21] and ASTM D638 [22] respectively. Specially designed steel moulds as shown in Figure 3 were used in casting the compressive and tensile test samples of Grout A and Grout B. Since the aim of this research is to determine the strength development over time, the samples were cured in room temperature before tested at 1, 7, 21 and 28 days. All the tests were carried out using INSTRON 25KN universal testing machine. Table 1 summarize the detail of tests conducted on the prepared specimens.

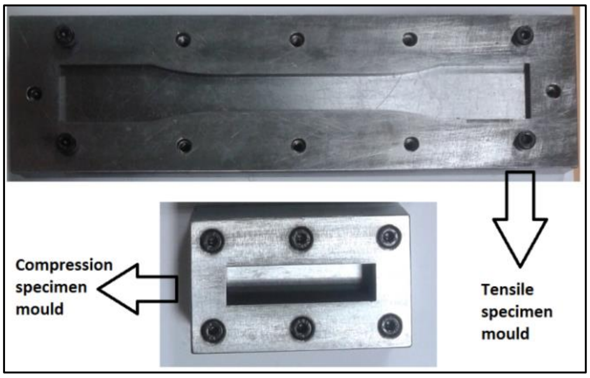


Figure 3 Steel mould for compressive and tensile specimens

Table 1 Summary of tests detail

Test	Compressive	Tensile
Standards	ASTM: D695	ASTM: D638
Number of samples	5	5
Dimensions (mm)	12.7 x 12.7 x 50.8	13.0 x 3.2
Geometry	Prismatic	Dumbbell
Loading rate (mm/min)	1.3	5

3.0 RESULTS AND DISCUSSION

3.1 Strength Development of Grout A

The results of compression and tensile test for Grout A at 1, 7, 21 and 28 days are summarized in Table 2 and Figure 4. The strength values presented in Table 2 are the average maximum compressive and tensile strength before failure of the samples. The compressive and tensile strength were observed to be ranged between 86-100MPa and 14-18MPa, respectively. The compressive strength of 1-day, 7-day and 21-day are about 93%, 99% and 108% of its 28-day strength, respectively. A rapid strength development was observed at initial curing period (up to 1-day) and followed by a gradual increase of strength beyond 1-day strength as can be seen in Figure 4. A similar growth pattern was also observed for tensile strength. All the tested grouts achieved at least 80% of its 28-day strength at day 1. The tensile strength of Grout A is about 15% of its compressive strength which indicating a low tensile-compression ratio. This indicates that Grout A is more suitable for combine loadings systems that required high compressive strength but contribution of tensile strength is relatively small. As an example, in composite repair of externally corroded pipeline, the infill material serves as medium to transfer the stresses on internal surface of pipeline generated by internal pressure (without sharing the load) requires high compressive strength rather than tensile strength.

Table 2 Summary of test results for Grout A

Mechanical properties of Grout A		Compressive Strength (MPa)	Tensile Strength (MPa)
Curing period (days)	**1**	86.31 ± 3.66	14.29± 1.65
	7	91.29 ± 2.65	14.16 ± 2.26
	21	100.10 ± 3.04	15.00 ± 4.17
	28	92.40 ± 4.05	17.91 ± 3.23

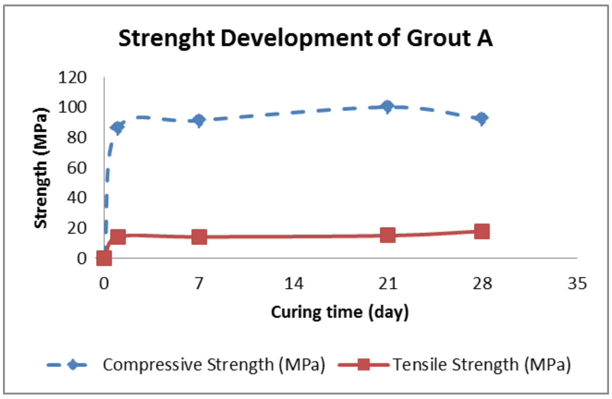


Figure 4 Strength development of Grout A

The strength development of polyester polymer and polymer concrete was studied by Sirimanna *et al.* [23] and Vipulanandan and Pual [24]. The strength development of Grout A exhibits similar trend which is comparable to polymer concrete. This is expected as most of polymeric composites are generally fast curing material [20,23,24], hence the rapid strength development. Besides this, three epoxy grouts studied by Shamsuddoha *et al.* [3] also suggests that a rapid strength development occurred about at three days curing period. Thus, Grout A has high potential to be applied as infill material in damaged structures that subjected to high compressive load and required rapid rehabilitation.

3.2 Strength Development of Grout B

Table 3 and Figure 5 summarize the test results of Grout B over 28 days. The compressive and tensile strength were recorded to be ranged between 73-81MPa and 22-30MPa respectively. The compressive strength of 1-day, 7-day and 21-day are about 100%, 111% and 102% of its 28-day strength, respectively whereas the tensile strength of 1-day, 7-day and 21-day are about 104%, 85% and 78% of its 28-day strength, respectively. The development of compressive strength was found quite constant throughout the curing period where most of the samples show approximate same strength. On the other hand, the highest tensile strength was observed at 1-day cured sample. The strength was gradually reduced at 7-day and 21-day before it increase to 28MPa at 28-day. A higher standard deviation value was observed in tensile strength as compared to compression test results. A comparable trend for higher standard deviation of tensile test result as compared to compressive test results was also observed in study done by Shamsuddoha *et al.* [3]. In general, the strength development trend of Grout B is comparable to Grout A and general polymeric composites. The tensile strength of Grout B is about 35% of its compressive strength which was found slightly different from Grout A. Beside transferring the load, Grout B may has the potential in sharing some loads such as hoop stress of a pressurized repaired pipeline.

Table 3 Summary of test results for Grout B

Mechanical properties of Grout A		Compressive Strength (MPa)	Tensile Strength (MPa)
Curing period (days)	**1**	73.87 ± 2.12	29.88 ± 5.61
	7	81.38± 3.39	24.24 ± 7.15
	21	74.44 ± 3.15	22.40 ± 4.40
	28	73.25 ± 8.19	28.63 ± 1.63

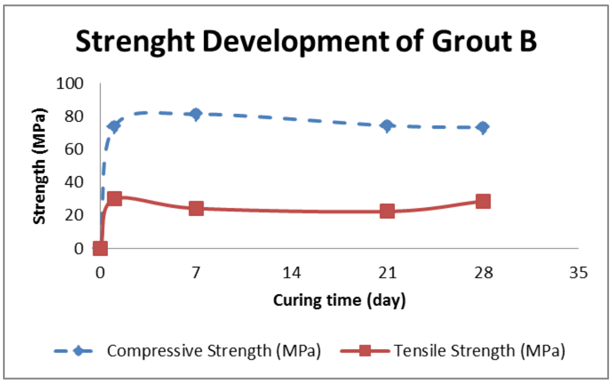


Figure 5 Strength development of Grout B

3.3 Evaluation of Epoxy Grouts for Pipeline Rehabilitation

The typical properties of epoxy grouts suitable to be used for repair and rehabilitation of damaged structures are as shown in Table 4 [25]. Based on the test results, both grouts were found suitable for crack repair of concrete structure which suggested having a compressive strength higher than 40MPa and tensile strength more than 14MPa. As for structural rehabilitation, Grouts A was found suitable in terms of compressive performance while Grouts B has the potential to contribute for resisting tensile load. Polyester based infill materials were found to be suitable by Sirimanna *et al.* [23] for deteriorated piles and the compressive strength was found within the range of 40 to 90 MPa. High compressive strength (85MPa) grout was found suitable to repair fatigue tubular joints by Thandavarmoorthy *et al.* [26]. Shamsuddoha *et al.* [3] carried out the characterization of five commercial epoxy grouts and reported three of it have the potential to be used as infill material for pipeline rehabilitation. Study done by Mattos *et al.* [27] on the metal filler epoxy resins found that the compressive strengths were 56 and 104 MPa while tensile strengths were 59 and 67 MPa. Therefore, Grout A and Grout B has the potential to be used as infill material in composite repair pipeline.

Table 4 Typical properties of epoxy grout for structural 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

4.0 CONCLUSION

Two epoxy grouts were tested under tensile and compression loading condition. The tensile and compressive strength of the two grouts were studied to investigate the strength development over 28 days of curing time. It was found that both grouts exhibit a rapid strength development at early age, 1-day curing time with about 80% of strength achieved. Both grouts show a strength development trend comparable to most polymeric composites that exhibit fast curing and rapid strength development over time. The compressive strength of Grout A (about 86-100MPa) is higher than of Grout B (73-81MPa) over the curing time. On the other hand, tensile strength of Grout B (22-30MPa) was found about one time higher than Grout A (14-17MPa). According to suggested properties by previous studies, both grouts used in this study have the potential to be used for pipeline rehabilitation. In addition, for application of compressive strength and tensile strength less than 70MPa and 14MPa, both grouts can be considered as capable to serve its repair purpose after the grout cured for 1 day. This rapid strength development offers greater advantage over other repair materials in minimizing the service down time, thus provide financial benefits. However, other properties such as flexural strength, bonding strength and thermal properties should be study to gain better insight on the suitability of its application due the fact that pipeline systems are normally subjected to different loading conditions and thermal variation.

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