Jurnal Kejuruteraan 34(6) 2022: 1017-1025
https://doi.org/10.17576/jkukm-2022-34(6)-03

Study of Mechanical and Thermal Properties for Epoxy Grouts Subjected to Seawater Conditioning at Elevated Temperature: Tensile Test and Compressive Test

Muhammad Afhnan Ahmad Temizi[a], Meor Iqram Meor Ahmad[a]*, Nor Kamaliana Khamis[a] & Muhammad Yunus Ahmad Samsudin[b]

[a]*Department of Mechanical Engineering and Manufacturing, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia*
[b]*Merit Technologies Sdn. Bhd, Jalan PJU 3/45, Sunway Damansara, 47810 Petaling Jaya, Selangor*

**Corresponding author: meoriqram@ukm.edu.my*

Received 19 December 2021, Received in revised form 29 January 2022
Accepted 2 March 2022, Available online 30 November 2022

ABSTRACT

Pipelines and risers are major transportation of oil and gas. These components are often exposed to extreme marine environmental conditions that can cause pipelines to fail due to corrosion. Hence, epoxy grouts are used as a coating material on the surface of pipelines and risers for supporting the pipe structure and corrosion prevention. In this case, the efficiency of epoxy grout is important in pipeline rehabilitation. Research on the adaptation of seawater, temperature, and epoxy grouts is carried out to determine the changes in mechanical and thermal properties of the material. The preparation of epoxy grouts was prepared with a mixture of epoxy resins, epoxy hardeners, and aggregates. After the sample compounds have been flattened, the mixture will be put into the mold. The seawater aging process was performed for seven days before conducting laboratory experiments. After the seawater aging process, there were physical changes on the surface of the epoxy grouts which are the epoxy grout become harder and there were voids that can act as stress concentration points that may cause micro-crack on the specimen. Next, tensile (ASTM 638) experiments were performed at different temperatures of 27°C, 40°C, 52°C, 72°C, 80°C and 100°C while the result of compression experiment is based on the literature critique of past journals. Based on the result, the young modulus and ultimate tensile strength of the epoxy grouts are decreased with increasing temperature. The increment of temperature causes the epoxy grouts to become weaker due to the changes in the polymer matrix structure of the epoxy grouts which lead to the failure at low load and shortens the life of the material. In addition, epoxy grouts are amorphous materials where the glass transition temperature determine the mechanical and physical properties of epoxy grouts. Therefore, the results of the study found that the epoxy grouts changed its mechanical properties from brittle to ductile when the temperature is at 72°C. From the comparison between samples immersed and not immersed in seawater, there is a decrease in Young's modulus, ultimate tensile stress and strain due to the effect of seawater reaction. In conclusion, the increment in temperature and seawater adaptation factors affect the strength and durability of epoxy grouts.

Keywords: Epoxy grout; mechanical and thermal properties, seawater adaption, elevated temperature, tensile and compression test

INTRODUCTION

Oil and gas is one of the important industry in determining the global economy. There are three sectors in the oil and gas industry which are upstream, midstream and downstream. Upstream is a sector that is directly involved in the exploration of oil well and the oil extraction process (Nechully & Pokhriyal 2019). Meanwhile, the midstream is a sector that transports the extracted oil and gas to the processing and refining plant. The downstream is a sector that refines the crude oil and purifies the extracted natural gas for commercial distribution. Hence, the main transportation of oil and gas is the pipeline. In the extraction of oil and gas from well, the riser system and its pipeline are the main component for this process since this method is efficient and has less risk. The risers and pipelines commonly suffer from deterioration over time due to defects in material, construction, and connection as well as extreme pressure and corrosion. Most pipeline failure is caused by corrosion either from inside or outside the pipeline due to the exposure to the extreme environment and natural reaction with the seawater (Popoola et al. 2013). On 19 May 2015, there was an oil spill accident in Santa Barbara County, California, United State. There was 2934 barrel of crude oil is leaked from pipeline 901 and it was recorded that 500 bbl crude oil already entered the Pacific Ocean (Eisner 2017). Hence, this tragedy is caused by pipeline corrosion that leads to pipeline failure. This proves that the pipeline needs to be gradually surveyed and do maintenance in order to avoid this kind of accident which can cause a huge loss to the company and contribute serious pollution to the marine environment as well as the ecosystem (Buskey et al. 2016).

The underwater pressure and changes in the sea environment can lead to difficulties in the pipeline rehabilitation process. A conventional method that involves replacing a specific part of the pipeline that required welding on the pipe sleeve is not relevant since it take a lot of time and the risk of accident is high (Abdullah et al. 2019). Hence, composite pipeline rehabilitation is the best approach. The component involved in this method is fiber reinforced polymer (FRP), adhesive and infill material. Epoxy grout is commonly used as the infill material in order to repair the structural damage caused by corrosion and to provide continuous support to the pipeline material structure for increasing the deformation resistance as well as minimizing the distortion on the material structure. The epoxy grout also can be second layer protection since it involves load bearing mechanism to the pipeline (Sing et al. 2019). So, epoxy grouts are one of the important components in pipeline rehabilitation since it has high strength and durability against seawater environment. The efficiency of epoxy grout is important in pipeline rehabilitation. In this research, the mechanical and thermal properties of epoxy grout will be determined by using the tensile test (ASTM 638) and compression test (ASTM D695).

The epoxy grout is exposed to the seawater environment for 7 days before the test is carried out. The seawater adaption process is done to observe and study the changes that occur on the epoxy grout structure. This is to predict the behavior, mechanical and thermal properties of the epoxy grout after being exposed to the seawater environment. This is because the mechanical and thermal properties of the epoxy grout is often used in identifying the efficiency of the pipe rehabilitation process (Granados et al. 2019). Furthermore, epoxy grout is an amorphous material which material that does not have a detectable crystal structure (Mikla & Mikla, 2010). The increasing temperature can change the matrix structure of the amorphous material from a solid state to a viscoelastic state as the temperature is exceeding the glass temperature of the material (Król-Morkisz & Pielichowska, 2018). Hence, the glass temperature of epoxy grout is important to take measure since the research is carried out at an elevated temperature. From Shamsuddoha et al. the glass temperature of epoxy grout is about 60°C to 90°C depending on the concentration of the epoxy resin. In this research, the concentration of epoxy resin is fixed as stated by the supplier. The physical and mechanical properties of the epoxy grout will change after the temperature is exceeding 60°C. Thus, the physical and mechanical properties of the epoxy grout will be investigated at every elevated temperature in order to determine the maximum strength of epoxy grout that is suitable for the pipeline rehabilitation process.

METHODOLOGY

Figure 1 shows the methodology flow chart of this work.

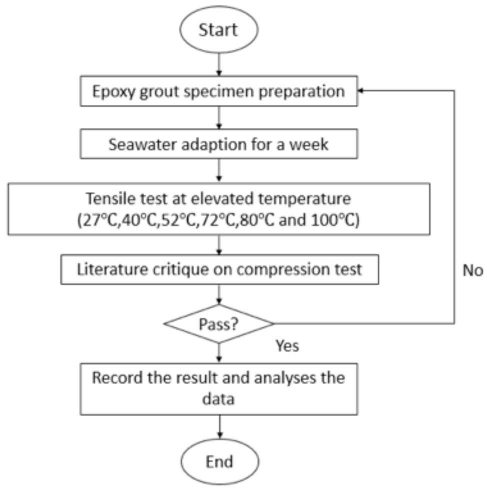


FIGURE 1. Methodology flow chart

1. Preparation OF EPOXY GROUT SPECIMEN

Figure 2 shows the preparation process and Table 1 illustrates the parameter of the specimen according to the ASTM. In the preparation of the specimen, the epoxy, resin, and aggregate are mixed according to the ratio provided by the supplier (1-3). The mixture was blended together with high-speed blending tool until it is well mixed (4). Then, the mixture of epoxy grout is poured into the mold and leave it for 24 hours at room temperature (5-6).

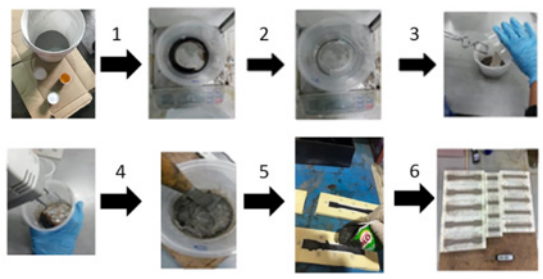


FIGURE 2. Preparation of epoxy grout

TABLE 1. PARAMETER OF THE SPECIMEN

Test	Tensile	Compression
Standard	ASTM D638	ASTM D695
Specimen Number	6	6
Dimension (mm)	13 × 8 × 4	13 × 13×x 50
Geometry	Dumbbell	Prism
Rate of load (mm/min)	5	1.3

2. Seawater adaption

The specimens were immersed in the seawater mixture for 7 days in order to ensure that is a minimum change in the surface structure of the specimen (Rudawska, 2020). Figure 3 presents the process of seawater adaption. The seawater mixture was prepared according to the ASTM D1141 Standard Practice for the Preparation of Substitute Ocean

Water. The salinity of the saltwater must be around 35ppt. The seawater adaption is carried out at room temperature (1-3).

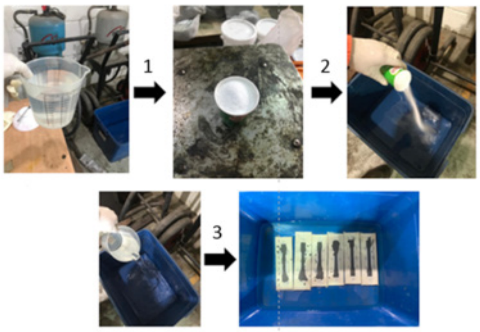


FIGURE 3. Seawater adaption process

3. Tensile test

The tensile test is done on the two types of the specimen, which are specimen that undergoes seawater adaption (Epoxy grout A) and normal specimen (Epoxy grout B) that are shown in Figures 4 and 5. The tensile test is based on the ASTM D638 standard using a 100 kN UTM Instron machine. Table 2 shows the measurement results of the sample parameters and entered into the Bluehill Universal software. The starting values of the load, the speed result point and the experimental speed are given by UTM.

FIGURE 4. Epoxy grout A

FIGURE 5. EPOXY GROUT B

TABLE 2. TENSILE TEST PARAMETER

Parameter	Measurement
Specimen length	164 mm
Gauge length	8 mm
Gauge width	13 mm
Specimen width	21 mm
Specimen height	4 mm
Starting load	20 N
Rate of load	5 mm/min

There are six samples to be tested. Next, the experiment is started at a temperature of 27°C. The specimen of epoxy grout will be pulled until it breaks or fails. The data of tensile strength, elongation, Young's modulus and deformation generated by Bluehill Universal software are recorded. The experiments will be continued with 40°C, 52°C, 72°C, 80°C and 100°C. Before performing the experiment, the specimen will be heated for 10 minutes to ensure that the testing temperature is reached. Figure 6 below show the equipment arrangement for the tensile test that had been done at the different temperature conditions.

FIGURE 6. Tensile test machine at different temperature conditions

4. Compression test

The compression test is referred to ASTM D695 standard. This test is performed using a 100kN UTM Instron machine. The sample parameters of the epoxy grout are recorded as input values in the Bluehill Universal Software. Table 3 shows the measurement results of the specimen parameters.

TABLE 3. Compression test parameter

Parameter	Measurement
Specimen height	50 mm
Specimen lenght	13 mm
Specimen width	13 mm
Rate of load	1.3 mm/min

In the compressive test, the value of compressive strength (CS) of epoxy grout is calculated by using the equation below.

$$CS = \frac{P}{A}$$

where,
CS = Compressive strenght, N/mm^2
P = Maximum load, N
A = Cross sectional area of specimen, mm^2

Then, the sample is placed in the middle between two compression plates. The compression test was started at 27°C with a speed of 1.3 mm/min. The experimental procedure is the same as the tensile test. Next, the UTM machine starts to compress the epoxy grout by placing the load on the top until it fails, and the compression test is stopped. The data of compressive strength, final length, compression modulus is generated by Bluehill Universal software will be recorded. The experiments will be continued at the different temperature conditions starting with 40°C, 52°C, 72°C, 80°C and 100°C. Before performing the experiment, the specimen will be heated for 10 minutes to ensure that the testing temperature is reached. Figure 7 shows the equipment arrangement for the compression test.

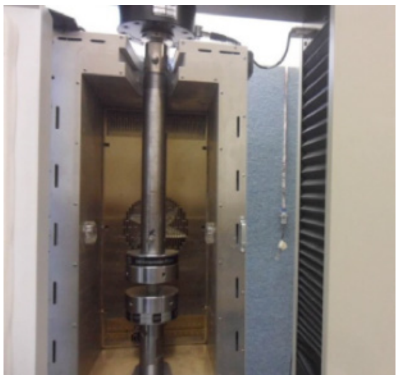


FIGURE 7. Compression test

RESULTS AND DISCUSSION

Before the tensile test is carried out, the effect of the seawater adaption for 7 days on the epoxy grout can be observed clearly.

1. Effect of seawater adaption on the epoxy grout

In a real application, epoxy grout is exposed to the seawater environment and extreme conditions for a long period. Hence, seawater is affecting the structure of epoxy grout. In this case, the epoxy grout is immersed in the seawater mixture for 7 days at room temperature. After finishing the seawater adaption, there are some changes that occur on the structure of epoxy grout A especially on the physical aspect. From the observation, the surface structure of epoxy grout A is a change from black to grey. The surface of epoxy grout A also become coarse. Moreover, there are also small voids on the surface of epoxy grout A. The chemical reaction between seawater mixture and epoxy grout produced sediments on its surface which led to surface structure deterioration, the surface becoming coarser and occurrences of voids (Bordes et al. 2009). Figure 8 show the voids and the surface of epoxy grout A after seawater adaption for 7 days.

FIGURE 8. Surface of epoxy grout A after seawater adaption for 7 days

The height of sediment was measured and it is about 1 mm of sediment formed on the surface of the epoxy grout A. Plus, the color of the sediment differs when compared to the sample. The hardness and color of the sediment are like the epoxy grout has been smeared with concrete mix. The sediment is formed due to the density of filler which is higher than other mixture materials. In the seawater adaption, the filler is heavier, hence it will disperse more at bottom of epoxy grout. So, the upper layer of epoxy grout does not have sufficient filler since the filler is concentrated at the bottom. The imbalance of filler composition in the epoxy grout can affect the mechanical properties. Figure 9 shows the side view and height of sediment on the surface of epoxy grout A.

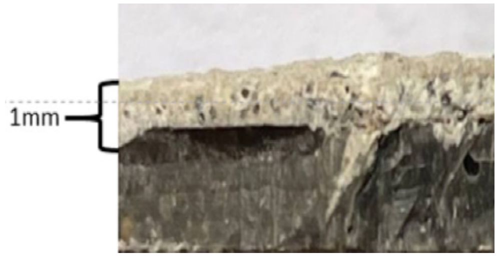


FIGURE 9. Height of sediment on the epoxy grout A

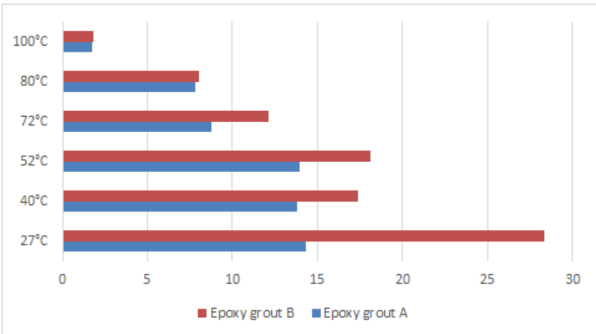
In addition, the voids on the surface and sides of the epoxy grout A are likely to be stress concentration points which can create micro cracks on any part of the specimen. Micro cracks are originated from slip strips in materials that undergo plastic deformation (Darrell, 2001). This causes a crack propagation on the specimen and lead to material failure as the specimen is subjected to the tensile strain that reaches a critical load while conducting tensile tests. Furthermore, Rudawska also stated that from the microscopic observation that there is grey sediment occurring on the surface of Epidian 53/Z-1 epoxy after being immersed into seawater conditioning for a week. The author also stated that the effect of seawater on the surface of Epidian 53/Z-1 epoxy increased over time since the specimen of Epidian 53/Z-1 epoxy is undergoes seawater conditioning for 1 week, 1 month and 3 months. Hence, it is proved that the initial effect of seawater on the physical structure of epoxy grout can be observed after being exposed to seawater for 1 week. Perhaps, the mechanical properties of the epoxy grout A like strength and ductility are reduced due to the seawater adaption effect. Therefore, tensile test is performed on epoxy grout A to investigate the mechanical and thermal properties at different temperature conditions. The tensile test results of epoxy grout A will be compared with the tensile test results of epoxy grout A to ensure the theory stating that samples that have been exposed to seawater environment have low tensile strength and ductility.

2. Tensile test analysis

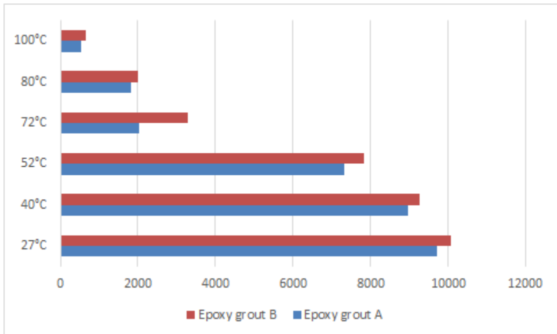
Table 4 shows the result of the tensile test for both epoxy grout. The tensile test is done at different temperature conditions of 27˚C, 40˚C, 52˚C, 72˚C, 80˚C and 100˚C. The data tabulated in Table 4 is used for generating the graph in order to assist in the data analyzing and comparing process.

TABLE 4. Tensile test result of epoxy grout A and B

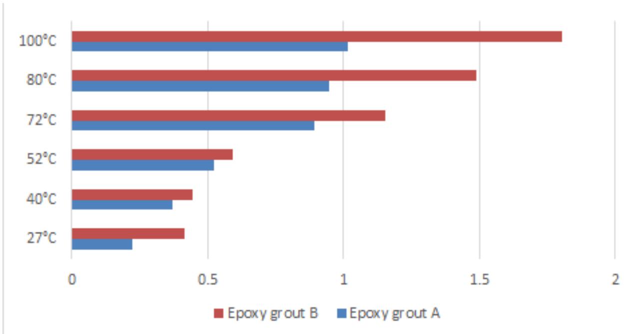
Temperature (˚C)	Ultimate tensile strength (MPa)			Young's modulus (MPa)			Tensile strain (mm/mm)		
	Epoxy Grout A	Epoxy Grout B	Reduction (%)	Epoxy Grout A	Epoxy Grout B	Reduction (%)	Epoxy Grout A	Epoxy Grout B	Reduction (%)
27	14.34	28.35	45.6	9.71	10.05	3.4	0.23	0.42	45.8
40	13.77	17.41	21	8.98	9.27	3.2	0.37	0.45	16.6
52	13.92	18.14	23.3	7.31	7.84	6.8	0.53	0.59	11.3
72	8.80	12.10	27.3	2.04	3.30	7.8	0.89	1.15	22.8
80	7.83	8.01	2.7	1.81	2.01	10.1	0.95	1.49	36.2
100	1.74	1.86	6.7	0.54	0.65	17.2	1.01	1.60	36.7



(b) Ultimate tensile strenght (UTS)



(a) Young's Modulus



(c) Strain

FIGURE 10. Comparison of result between epoxy grout A and B

Based on Figure 10, the epoxy grout B show the highest ultimate tensile strength, young modulus and tensile strain for the overall tensile test as compared with epoxy A. This is because the physical and mechanical properties of epoxy grout A is affected by seawater reaction which can increase the brittleness and decrease the ductility of the epoxy grout by means of void occurrences. In this study, the ultimate tensile strength of the epoxy grout A is decreased from 27˚C to 100˚C as compared with the ultimate tensile strength of epoxy grout B. Then Young's modulus of epoxy grout A also much less than epoxy grout B. From both epoxy grout results; the ultimate tensile strength and Young's Modulus is decreasing with the increasing of temperature. This shows the highest ultimate tensile strength is at 27˚C which is 14.34 MPa for epoxy grout A and 28.35 MPa for epoxy grout B. Meanwhile, the tensile strain is increased along with the elevated temperature. This shows that the elevated temperature is affecting the mechanical properties of the epoxy grout. Moreover, the initial hypothesis in this study stated that the increase in temperature is affecting the polymer matrix of the epoxy grout and resulting in the change in mechanical properties.

In a study conducted by Benedetti et al. in investigating changes in elastic modulus and attraction on epoxy resins for Near Surface Mounted (NSM) - carbon fiber reinforced polymer (CFRP) systems at temperature curing conditions of 20˚C, 30˚C and 40˚C The results of the study found that the increase in temperature caused the bond strength of the polymer matrix structure to decrease. In addition, Shamsuddoha et al. has conducted a study on the characterization of the mechanical and thermal properties of epoxy grout in the repair of composites for steel pipelines. The results of the study conducted using dynamic mechanical analysis (DMA) have shown that the glass transition temperature for epoxy grout is in the range of 60˚C to 90 ˚C. When the temperature applied to the epoxy grout exceeds 60˚C, the polymer matrix structure of the epoxy pavement material changes as the cross-links become increasingly unstable and cause the epoxy grout to become viscoelastic (Król-Morkisz & Pielichowska 2018).

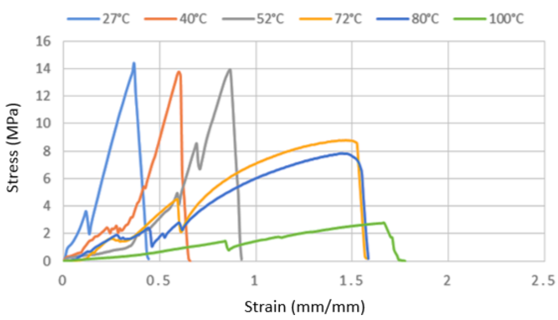
In this case, the decreasing of young modulus means that the elastic properties of the epoxy grout decreased along with the increment of temperature. This causes plastic deformation to occur when material samples are subjected to low loads which lead to mechanical failure in a short time. When Young's Modulus value is low, the ultimate tensile strength of the epoxy grout also becomes low. Therefore, the devaluation of the Yong Modulus affects the ultimate tensile strength. Furthermore, the specimen that has low ultimate tensile strength such as specimen at 72˚C, 80˚C and 100˚C temperature conditions have the highest tensile strain. Both of the epoxy grout shows the same pattern. The increment of the tensile strain indicates that the epoxy grout becomes more ductile as the temperature increases. Ductility is the ability of a material to withstand a large permanent deformation when subjected to tensile loads up to until the material breaks. In addition, ductility can be measured by the amount of strain indicated on the stress-strain curve (Vaidya & Pathak, 2018).

3. Stress-strain curve behaviour

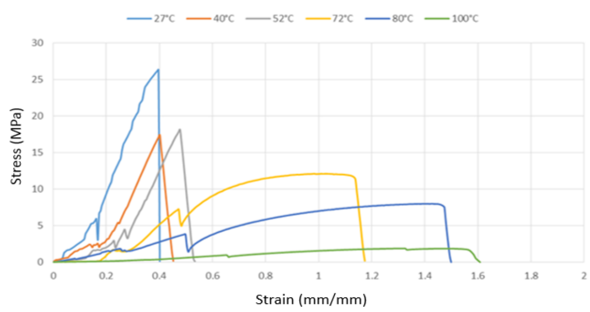
The selected data from the tensile test is used in generating the stress strain curve in order to study the behaviour of epoxy grout as subjected to elevated temperature. Figure 11 show the stress-strain curve for epoxy grout at elevated temperature. The time taken for epoxy grout to break also is tabulated in Table 5.

TABLE 5. Time taken for epoxy grouts to break

Temperature (˚C)	The time taken for epoxy grout to break (s)	
	Epoxy grout A	Epoxy grout B
27	4.3	7.1
40	7.4	8.2
52	10.3	11.6
72	17.4	22.6
80	18.2	29.1
100	23.2	30.6



(b) Epoxy grout A



(a) Epoxy grout B

FIGURE 11. Stress-strain curve of epoxy grouts

In this study, the stress-strain curve is the key in identifying the degree of ductility of epoxy grouts as subjected to the temperatures of 27˚C, 40˚C, 52˚C, 72˚C, 80˚C and 100˚C. At 27˚C, both stress-strain curves show the same pattern that has high tensile stress, but the strain value is less than 0.5 mm/mm. The time for epoxy gout A to fail is about.4.3s while epoxy grout B is about 7.1s. Thus, epoxy grout materials at 27˚C are brittle. Next at 40˚C and 52˚C, samples of epoxy grouts still showed brittleness behaviour. Hence, the epoxy grout is more brittle at the temperature below 52˚C and less ductile as the temperature exceeding 60˚C. At the temperature of 72˚C and above, both epoxy grouts showed changes in the behaviour as referring to the stress-strain curve. According to Shamsuddoha et al. the glass transition temperature for the epoxy grout is in the range of 60˚C to 90˚C. For this case, the change can be observed as the temperature of epoxy grout at 72˚C which is exceeding 60˚C. The degree of ductility of epoxy grout can be proven by the degree of tensile strain. Based on the stress-strain curve, the tensile strain increases, and the ultimate tensile strength of the epoxy grouts decreases. The increment in temperature causes the cross-linked bond of the epoxy grout polymer matrix to become unstable (Król-Morkisz & Pielichowska 2018). Besides, epoxy grout is an amorphous material that has a non - crystalline structure in which atoms and molecules are not arranged in a specific lattice pattern (Mikla & Mikla, 2010). The increase in temperature is able to change the matrix structure of the amorphous material from a solid state to a more flexible and viscoelastic state when the applied temperature exceeds the glass transition temperature of the material. So, the epoxy grout will change its properties from brittle to ductile as temperature increase beyond glass transition temperature. The temperature of the epoxy grouts is increased to 80˚C and 100˚C. The tensile strain also increases and show the ductility of epoxy grout at these temperatures is higher than 72˚C. This physical structure of epoxy grouts also changes to become much more elastic. But the maximum tensile strength and young modulus is decreasing and the lowest ultimate tensile strength is at 100˚C since the epoxy can withstand elastic deformation at low load. This is because, the increment in temperature causes the matrix structure of the epoxy grout to be unstable and the load distribution on the matrix structure is uneven (Turk et al. 2017). Thus, the epoxy grout cannot withstand a high load as the temperature of the epoxy grout increases. This proves that specimens of epoxy grout become very weak at high temperatures.

In terms of the seawater effect, epoxy grout A tends to fail earlier since the specimen is affected by seawater degradation. A comparison of young modulus, ultimate tensile strength and strain are done between both epoxy grouts. Based on the respective stress-strain curves, the ductility, young modulus and ultimate tensile strength of epoxy grout A are lower than epoxy grout B because epoxy grout A is affected by the seawater reaction which causes the sample structure to have voids on the surface which cause micro crack and easily break as subjected to the load. This is why the mechanical properties of epoxy grout A is lower than epoxy grout B. The tensile strain of the epoxy grout A decreased by 22.8% at 72˚C, 36.2% at 80˚C and 36.7% at 100˚C. This means that the adaptation of seawater is able to affect the mechanical properties of the epoxy grout as subjected to elevated temperatures. The behaviour of both epoxy grout is showing the same pattern as the temperature is increasing beyond 60˚C.

4. Review on compression test of epoxy grout

Based on the study conducted by Rudawska which is the study of the effect of salt water on the mechanical properties of epoxy adhesive compounds, Epidian 53/Z-1 epoxy specimens have undergone seawater adaptation process for a week, a month, and three months. Compression tests were conducted after the seawater adaptation process. The following are the results of compression experiments after the samples have been soaked in seawater for one week as subjected to a different level of seawater salinity. The results of compression experiments found that Epidian 53/Z-1 epoxy specimen that does not undergo seawater adaption had higher compressive strength than the specimens that undergoes seawater adaption. In addition, Rudawska has performed different seawater adaptation methods which is the specimens are immersed in different salinity conditions. The results of compression experiments showed that specimens immersed in salinity levels twice of 35% seawater salinity had the lowest compressive strength compared to specimens at salinity levels of 8.75%, 17.5% and 35% seawater. Rudawska has concluded that the compressive strength of Epidian 53/Z-1 epoxy specimen decreases with increasing salt salinity levels. Hence, the decreasing of compressive strength is due to the seawater reaction which causes the changes in the physical structures and degradation of epoxy material. This proves the compressive strength of the epoxy material will decrease as subjected to the seawater. Figure 12 show the compression test result after 1 week of seawater adaption. Hence, the result of this test may show the same pattern as subjected to the elevated temperature.

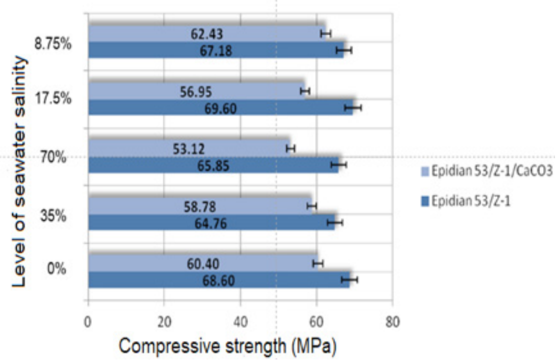


FIGURE 12. Compressive strength of Epidian 53/Z-1 epoxy after 1 week of seawater adaption (Rudawska, 2020)

5. Impact Analysis Of Epoxy Grout On Pipeline Rehabillation

Epoxy grout is a material often used with FRP composites because it has high durability properties. According to ASME PCC-2, the service temperature of epoxy grout for the non-leaking and leaking pipe rehabilitation process shall be not less than 20˚C and 30˚C from the glass transition temperature of the material. From the results of this study, the epoxy grout showed ductile behavior at a temperature of 72˚C which is above the temperature of 60C. So, the most suitable temperature conditions of epoxy pavement material for use in pipeline restoration applications are at 27˚C and 40˚C. Samples at 52˚C are not suitable because the temperature difference gap is less than 20˚C. In addition, Mendis has clarified the appropriate criteria for epoxy grout in pipeline structural rehabilitation applications. These criteria include aspects of compressive strength, tensile strength, and bond strength of epoxy grouts. The table below shows the appropriate properties of epoxy grout for pipeline rehabilitation applications.

TABLE 6. Properties of epoxy grout for repair and rehabilitation

Application	Compressive strength (MPa)	Tensile strength (MPa)	Bonding 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

Merit Technologies Sdn Bhd has stated the criteria for the mechanical properties of epoxy grout in the helicoid epoxy coating system or HC-68 Grout application as shown in the table below.

TABLE 7. Merit Technologies Sdn Bhd criteria properties of epoxy grout

Compressive strength (ASTM C109)	90 MPa at 1 day 100 MPa at 7 days
Compression modulus	2100 MPa
Flexural strength (ASTM D790)	26 MPa at 7 days
Tensile strength (ASTM D638)	14 MPa at 7 days
Modulus of Elasticity (ASTM D580)	8951 MPa at 7 days
Coefficient of Thermal Expansion (ASTM C531)	28.1×10^3
Bond Strength to Steel (underwater) (SA 2.5) (ASTM D 4541) (WJ3) (NACE/SSPC)	>10.5 MPa Average of 8.4 MPa
Water Absorption	0.18%
Pot life	2 hours at 30°C

Based on Table 4, the ultimate tensile strength of both types of epoxy material samples at 27˚C, have met the criteria shown in Tables 6 and 7. Epoxy grout B has an ultimate tensile strength of 28.35 MPa which meets the criteria for the use of pipeline structure rehabilitation stated in Table 6. After exposing the epoxy grout after seven days in a seawater environment, the ultimate tensile strength is 14.34 MPa which meets the criteria in Table 7. Thus, epoxy grout is at a temperature of 27˚C is suitable for pipeline rehabilitation because of the highest tensile strength and can withstand high load. So the performance level of epoxy grout is able to improve the performance of pipeline rehabilitation. This proves that the epoxy pavement grout is able to be the second protective layer of the pipe in the pipe recovery process if the composite layer fails.

CONCLUSION

A study of the mechanical and thermal properties of epoxy grouts on the adaptation of seawater as subjected to elevated temperature was successfully carried out. Findings from this study indicate that the increment in temperature and the seawater adaption affect the mechanical and thermal properties of epoxy grouts. The study was conducted on two types of epoxy grouts specimens which are specimens that were affected by seawater and the other did not affect by seawater. The results of the tensile test analysis found that there are differences, especially in the mechanical properties of epoxy grouts. The ultimate tensile strength and Young's Modulus show a devaluation result as subjected to the seawater adaption and elevated temperature The ultimate tensile strength decrease about 45.6% at 27˚C, 21% at 40˚C, 23.3% at 52˚C, 27.3 % at 72˚C, 2.7% at 80˚C and 6.7% at 100˚C.

The seawater adaption causes a decrease in ductility and increases the brittleness of epoxy grouts. Hence the mechanical properties of epoxy grout A are lower than epoxy grout B due to the seawater reaction that causes the occurrences of voids on the surface structure of epoxy grout which lead to the formation of micro crack and the epoxy grout A may break at lower load as compared to the epoxy grout B. In terms of elevated temperature, both epoxy grouts showed changes in its mechanical properties. At 27˚C, the epoxy grouts have the highest ultimate tensile strength, lowest tensile strain at failing in a short time which indicates the brittleness of epoxy grout. As the temperature is increased beyond 60˚C, the epoxy grouts showed an increment in tensile strain and the devaluation of ultimate tensile strength.

As referring to the stress-strain curve, the epoxy grouts showed the behavior of ductile materials in the presence of elastic and plastic deformation as the temperature exceeded 60˚C. Besides, epoxy grouts are an amorphous material that has a glass transition temperature where there is a change in properties from brittle to ductile as the temperature increases. This happens when the temperature increases, the matrix structure of the epoxy grouts becomes unstable and unable to maintain its shape and becomes more viscoelastic, resulting in the ductile behavior which is shown in the increment of tensile strain. Hence, the epoxy grout cannot withstand a higher load as the temperature increase. That is why Young's modulus as well as the ultimate tensile strength of epoxy grout is decreasing. Thus, the seawater adaption and temperature are affecting the mechanical properties of epoxy grouts. Based on ASME PCC-2, the service temperature of epoxy grout for non-leaking and leaking pipe in the pipeline rehabilitation must not be less than 20˚C or 30˚C from the glass transition temperature. From the results of this study, epoxy paving materials at temperatures of 27˚C are suitable for use in pipe restoration applications because the temperature difference gap is meet with the standard and the mechanical properties of epoxy grout at 27˚C showed much more superior in withstanding the load and act as protecting layer for the pipeline.

ACKNOWLEDGEMENTS

This work is supported by Universiti Kebangsaan Malaysia under Geran Galakan Penyelidik Muda (GGPM), GGPM-2019-059.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Bordes, M., Davies, P., Cognard, J.-Y., Sohier, L., Sauvant-Moynot, V., & Galy, J. 2009. Prediction of long term scorakgth of adhesively bonded steel/epoxy joints in sea water. *International Journal of Adhesion and Adhesives* 29(6): 595–608.

Buskey, E. J., White, H. K., & Esbaugh, A. J. 2016. Impact of oil spills on marine life in the Gulf of Mexico: Effects on plankton, nekton, and deep-sea benthos. *Oceanography*, 29(3): 174–181.

Darrell S. 2001. Handbook of Materials Behavior Models. Academic Press. Section 6.8 - *Multiaxial Fatigue Damage Criteria*: 453-456.

Eidani Nezhad, Abdullah & Ziyaei, Pegah & Zare, Arman. 2019. An overview of marine pipeline repair methods.

Eisner, M. A. 2017. From Santa Barbara to the Exxon Valdez: Policy learning and the emergence of a new regime for managing oil spill risk. In *Policy Shock: Recalibrating Risk and Regulation after Oil Spills, Nuclear Accidents and Financial Crises* (pp. 151–180). Cambridge University Press.

Granados, J. J., Martinez, X., Nash, N., Bachour, C., Manolakis, I., Comer, A., & Di Capua, D. 2019. Numerical and experimental procedure for material calibration using the serial/parallel mixing theory, to analyze different composite failure modes. *Mechanics of Advanced Materials and Structures*.

Król-Morkisz, K., & Pielichowska, K. 2018. Thermal decomposition of polymer nanocomposites with functionalized nanoparticles. In *Polymer Composites with Functionalized Nanoparticles: Synthesis, Properties, and Applications* (pp. 405–435).

Mendis, P. 1985. Commercial Applications and Property Requirements for Epoxies in Construction, SP. ACI Special.

Merit Technologies Sdn Bhd. (624982-P), HC-68 Grout Structural Grout for Helicoid Epoxy Sleeve System. HC-68 Datasheet (Rev.03-06/13).

Mikla, V. V., & Mikla, V. I. 2010. Trap Level Spectroscopy in Amorphous Semiconductors. Trap Level Spectroscopy in Amorphous Semiconductors.

Nechully, S., & Pokhriyal, S. K. 2019. Identifying the relevant variables affecting the adoption of innovative drilling technologies in upstream UAE oil and gas. *International Journal of Advanced Research in Engineering and Technology* 10(2): 542–563.

Popoola, L. T., Grema, A. S., Latinwo, G. K., Gutti, B., & Balogun, A. S. 2013. Corrosion problems during oil and gas production and its mitigation. *International Journal of Industrial Chemistry*. Springer Berlin Heidelberg

Rudawska, A. 2020. The effect of the salt water aging on the mechanical properties of epoxy adhesives compounds. *Polymers* 12(4).

Shamsuddoha, M., Islam, M. M., Aravinthan, T., Manalo, A., & Lau, K. tak. (2013, June). Effectiveness of using fibre-reinforced polymer composites for underwater steel pipeline repairs. *Composite Structures*.

Shamsuddoha, M., Islam, M. M., Aravinthan, T., Manalo, A., & Lau, K. tak. 2013. Characterisation of mechanical and thermal properties of epoxy grouts for composite repair of steel pipelines. *Materials and Design* 52: 315–327.

Sing, L. K., Azraai, S. N. A., Yahaya, N., Zardasti, L., & Md Noor, N. 2017. Scorakgth development of epoxy grouts for pipeline rehabilitation. *Jurnal Teknologi* 79(1): 9–14.

Sing, L. K., Zardasti, L., Noor, N. M., & Yahaya, N. 2019. Mechanical properties of graphene nanoplatelets-reinforced epoxy grout in repairing damaged pipelines. *In Materials Science Forum* (Vol. 962 MSF, pp. 242–248).

Turk, M., Hamerton, I., & Ivanov, D. S. 2017. Ductility potential of brittle epoxies: Thermomechanical Behaviour of Plastically-Deformed Fully-Cured Composite Resins. *Polymer* 120: 43–51.

Vaidya, A., & Pathak, K. 2018. Mechanical stability of dental materials. *In Applications of Nanocomposite Materials in Dentistry* (pp. 285–305).