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Quantifying the Creep Behavior in Polyester Resin and Grout

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Abstract: Creep of in-situ rock bolts have been apparent and problematic since their introduction in the mining environment. If enough creep is experienced, the bolt has the possibility of failure leaving the opportunity for roof instability. In an attempt to quantifying the creep behaviour in polyester resin and cement grout, laboratory testing procedures were developed. It was decided that two separate tests would provide the data needed to fulfil the scope and objectives. The tests chosen were UCS machine deformation testing and Laboratory Short Encapsulation Pull Test (LSEPT).Based on past research in the scope of the project, a methodology was developed along with measuring techniques to accurately monitor the deformation. Based on the data analysis, the displacement for each sample from the pull test suggested that water based resin deforms the most under an induced load whereas grout tends to deform the least. The long term creep test yielded a peak strain of 0.72% and 1.11% for oil and water based resin respectively. Further calculations concluded that oil based resin had the highest resistance to failure with a shear strength of 8.47 MPa, whereas water based resin yielded a shear strength of 4.51 MPa and grout had a shear strength of 5.5 MPa.

Key words: creep, polyester resin, grout, deformation, displacement, strain, shear strength

1. Introduction

Rock bolts and cables bolts have become one of the main forms of support for most geotechnical excavations in the modern age. It is used due to the high level of successful implementation over the past few decades. Rock bolts consists of a steel rod inserted into a drill hole with an anchor at one end and face plate and nut at the other. Once in the hole, the void around the bolt is filled with a bonding material which bonds the bolt to the surrounding rock mass. The bolt is then tensioned to a specific load to support the excavation. Cable bolts are installed in the exact same manner, however the cable consists most commonly of 7 wire strands woven together to form a strong steel cable [1].

Various studies and tests have been done to evaluate and test the performance of bolts in the underground environment. Limited tests however, have been conducted on the specific subject of bolt creep. Creep is defined as a measure of deformation due to an induced stress which is less than the yield stress [2]. The key area associated with creep within the bolting process is the bonding interface between the bolt and the surrounding rock mass. Since the bolts are pretensioned to a specific load, they can experience deformation sometime after the installation. The creep in roof bolts generally leads to the loosening of bolt caps which can result in localized instability of the roof.

Bolts can be anchored in a couple of different ways. Mechanically anchored bolts comes in two forms, slot and wedge bolts or expansion shell bolts, both of these anchor themselves in the strata by the means of expanding when installed. These bolts however, had many problems that led to lost efficiency from anchoring in weak sedimentary layers and a considerable amount of creep was experienced especially when blasting took place. In an attempt to

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overcome some of these problems, chemically anchored bolts were introduced. The main objective of these bolts was to improve overall bolt performance. The performance was greatly improved as early tests demonstrated an increase in support stiffness [3]. The stiffness of the chemical supports was improved due to the increased anchorage length and bond strength between the bolt and rock interface. Polyester resin is mostly used as the chemical anchor for rock bolts. Resin relies on its shear strength to resist bolt movement within the bore hole. It is important for the bolt-resin and the resin-rock interface to bond properly as this would affect the stiffness of the support [1].

2. Similar Trails

As part of a time-dependent deformation project, the University of Wollongong (UOW) undertook testing using two commonly used cement grout products. The project was aimed at testing the uniaxial compressive strength (UCS), elastic modulus and creep of each sample. All the samples were tested in the lab using a standard test developed by the UOW. Both samples were loaded to 100kN in compression for 15 min. It was found that the samples did not experience any significant creep in the short term with the highest recorded strain value being only 0.27%. The difference in creep experienced between the two samples was found to be only 0.04%, which is a very insignificant value. The main limitation of this test, is that the creep was measured over a very short period of time, 15min.Therefore, the standard test procedure in this paper would be used in the research project but would be adjusted to test the long-term creep effects of various grouts and resins [2].

The International Journal of Rock Mechanics and Mining Sciences posted an article which discussed the performance testing of fully encapsulated resin bolts. A test was developed to quantify performance of these bolts based on some field-testing and mostly laboratory load-displacement results. The bolts were installed in an underground environment and were overcored to retrieve samples ready for laboratory testing. Testing of overcored samples gives a good indication of the geological characteristic within the study area and it provides an indication of stiffness, peak load and residual loads. Overcoring also provides other important information regarding the bolt system such as resin mixing effectiveness, problems with gloving, resin migration and over drilling of holes. Some very fractured samples were recovered from the study area however, short samples of 300 mm, in sections where the rock is less fractured, was prepared for laboratory testing.

The paper concluded that the weakest region in the bolt encapsulation is the toe area. Results proved that bolts experienced more deformation at this location due to poor mixing and it suggested that the performance of a bolt is highly dependent on the resin mix quality and bolt plating. By knowing this, special attention should be given to these areas when preparing samples for testing in the proposed project. The journal overall has relevant information which supports aspects of the project however, test were done using the same resin. This means that different types of resins could not be compared which is one of the objectives in the proposed project [4].

Both these trails on grout and resin samples were found relevant to the project since they address key areas to which special consideration should be given. The experimental investigation on grout proved that it should behave brittle and subsequently experience small amounts of creep. It also provided insight to an experimental procedure for creep testing. The trail on resin performance concluded that the strength is highly depended on the mix quality and thus by knowing this, poor mixing practice can be minimised to ensure maximum strength when testing is conducted.

3. Methodology

The University of Wollongong published a paper on creep in 2016 in which some industry standard test procedures were used to test creep effects in grouts.

Wollongong established a method in which 50 mm cube samples are loaded in a UCS machine at a 100 kN load over a time period of 15 min. The 100 kN or 62.5 MPa load was induced within the first minute of loading meaning the loading rate is very fast. The disadvantage of this procedure is that it tests creep over a very short-term period. Thus, in order to test creep over a longer time period, the test method used as part of this project was based on the test from Wollongong but adjusted to a time period of one month. The test procedure would be repeated three times for two different resin samples.

Based on a review of deformation testing, a second procedure was developed as part of this project to test the total amount of displacement experienced by an encapsulated bolt. Past studies by Aziz et al. (2014) [5] concluded that strength increases with curing time thus, the second procedure aims to quantify the amount of creep experienced if load is applied early after bolt installation. The LSEPT, was chosen to evaluate creep using a pull out load which is based on an industry pretension of 8 t. Samples would be encapsulated such that the bond length is 100 mm. This test would be carried out over a period of one week with regular measurement intervals.

3.1 Deformation Testing (UCS Machine)

The deformation testing was conducted using a UCS machine with strain gauges attached to each sample. Test samples are 50mm cube in size. The testing procedure is as follows and Fig. 1 shows the test schematic:

(1) Prepare three samples of the same type (resin or grout) in a 50mm cube mould and make sure they are the same dimensions.

(2) Attach two strain gauges to each sample that feeds back to a data logger.

(3) Set up the samples in the UCS machine one above the other. Ensure that the samples are directly aligned vertically.

(4) Set up the data logger to start recording data.

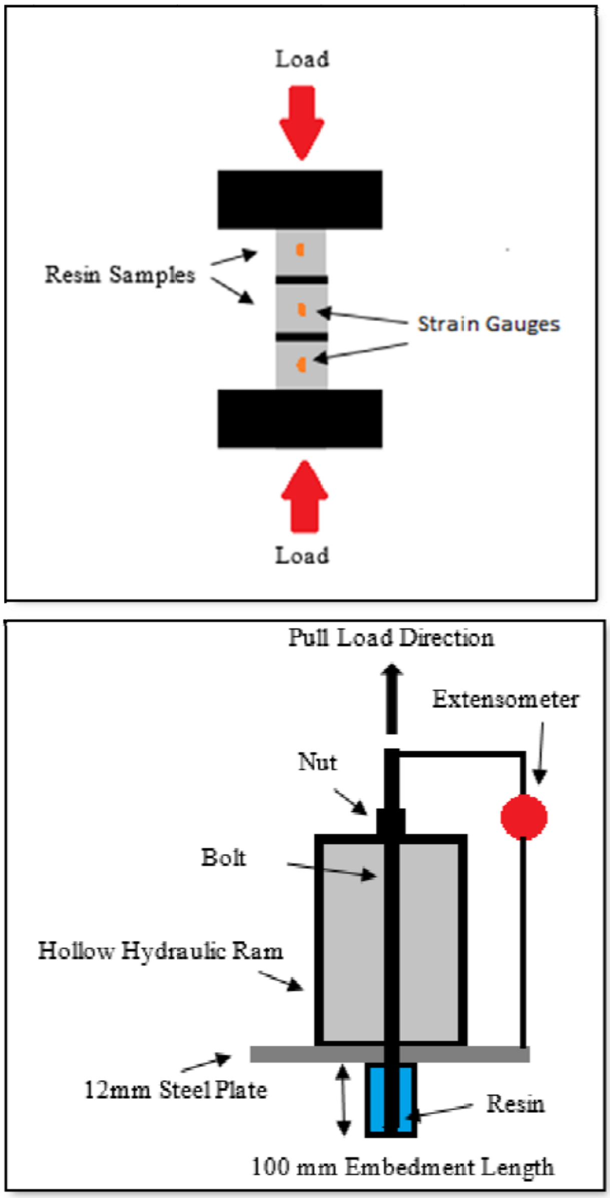

Fig. 1 UCS test schematic.

(5) Set the UCS machine to a 75kNload with a loading cycle of 10 kN/min.

(6) Leave samples loaded for up to a month to record long-term creep effects.

(7) Repeat the above steps once for each material type.

3.2 Rock Bolt Pull Out Test

The rock bolt pull out test was carried out over a period of one week and the interest in this test is to quantify creep of the bond materials relative to each other. The test procedure is as follows and Fig. 2 shows the test schematic:

(1) Prepare a 100 mm long threaded steel cylinder of 27 mm diameter and a rock bolt, 440 mm in length, for each test material.

(2) Mix the bonding material according to industry guidelines and standards.

(3) Centre the rock bolt in the cylinder and pour mixture for the full length of cylinder. Wait until resin/grout is fully set before proceeding to load the sample.

(4) Set sample in load rig. Apply a constant load of 8 t (80 kN).

(5) Measure drop in pressure and deformation daily for a week at a time.

(6) Record data in a table for each of the samples.

(7) Repeat this test three times for each material type to acquire consistent data.

4. Experimental Results

4.1 Long Term creep

The recorded data from the data logger and logbook was combined in the excel spreadsheet to produce a graph showing the deformation over the 28 days of the test. During the test is noted that four of the strain gauges exceeded the maximum designed strain however, enough data for each sample was recorded to produce valid results. Fig. 2 below displays the strain of the oil and water based samples over the duration of the test.

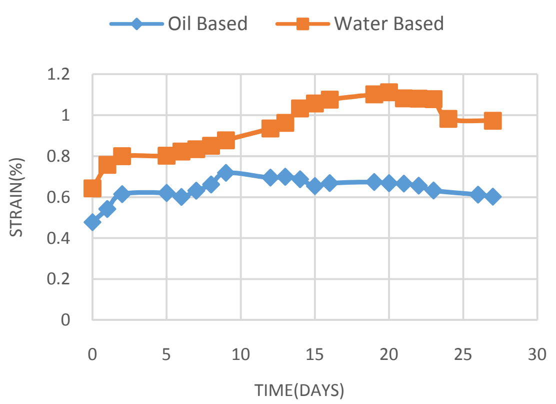

Fig. 2 Long term creep.

It can be seen from the graph that both the water and oil based samples experienced similar strain trends. After the initial loading of the samples, the strain increased to a peak value which thereafter, it reduced to a residual strain. The peak strain obtained for the water and oil based was 1.11% and 0.72% respectively. The nature of the graph shows that quite a significant amount of strain is experience within the initial stages of loading on the sample. The strain experienced during first loading cycle is called initial elastic strain.

The second phase in long term creep is known as primary creep. This can be seen in Fig. 3 from day one till about day six. The rate of creep is high during the early stages of this phase but decreases with time. The third phase, called steady-state creep, is where the rate of deformation follows a near linear increasing trend. This can be seen from roughly day six till day nine for oil based resin and from day five till day 17 for water based resin. During this stage in the test a peak strain was reach. The final stage of creep was not showcased in Fig. 2 and is known as tertiary creep. During this stage the rate of creep tends to increase rapidly as microstructural damage had sufficient time to propagate and generally culminates in failure. It is believed that the microstructural damage develops during the steady-state phase and once the rate of creep increases due to the interaction between the micro fractures, the material enters the tertiary creep stage [6].

During the test done as part of this project, the resin did not experience a tertiary stage which follows the standard trend. From Fig. 2 it is evident that during the final stage the strain was steady for a few days which thereafter, the rate decreased to a final residual value. This can be seen as an error encountered during the experimental testing. Since the UCS machine could not sustain a constant load over the duration of the test, the load was reapplied to 75 kN before every measurement was taken. This partial unloading and loading influences the total strain experienced by the sample.

Fig. 3 gives a graphical representation of the concept behind loading and unloading of a sample.

As seen in Fig. 3, the steady unloading of a sample results in stress relaxation over time which leads to a reduction in strain. This reduction is known as strain restoration. Repeating the stress relaxation for a number of cycles would yield a peak and residual creep strain. The results from the long term creep test show exactly this, confirming that the effects of stress relaxation was the reason for the experimental creep graph only partly representing the trend from a standard creep graph. The residual strain was found to be 0.97% and 0.60% for water and oil based resin respectively.

4.2 Pull Out Test

The results gathered from the pull test was analysed to show the difference in displacement, shear strength, peak load and strain experienced by each of the three materials. A total of three tests were completed on each of the materials. The total displacement for each sample was recorded during the seven days of testing. After each test, the samples were loaded until failure which was dictated by a rapid increase in deformation with no increase in load. To conclude the validity of the test the failure interface was identified. For the pull test to be valid, failure needs to occur between the material and bolt interface. Each of the test samples failed in this manner, thus ensuring the validity of the tests. None of the oil based resin samples failed under the normal testing conditions. Each sample deformed for a full seven days without failure. Fig. 4 displays the deformation results obtained for the three oil based resin samples.

The results for each of the oil based samples, as displayed in Fig. 4, were found to be fairly consistent. All three samples followed very similar deformation trends over the duration of the test and experienced a maximum displacement between 1.5-2.5 mm. The samples for water based resin showcased a higher displacement when compared to the oil based. The trend for the samples were fairly consistent and were near linear. Fig. 5 displays the displacement results for each of the water based samples.

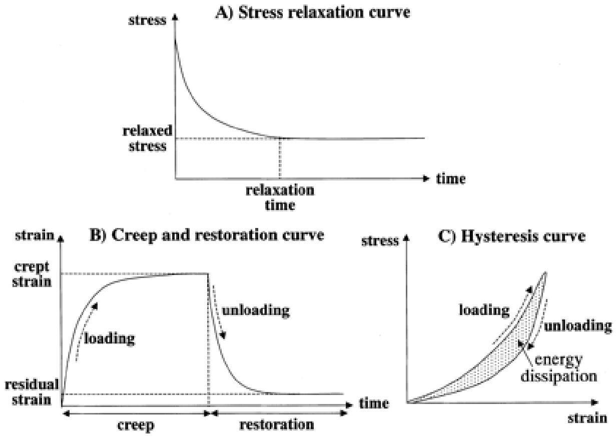

Fig. 3 Strain effects of loading and unloading on a material [7].

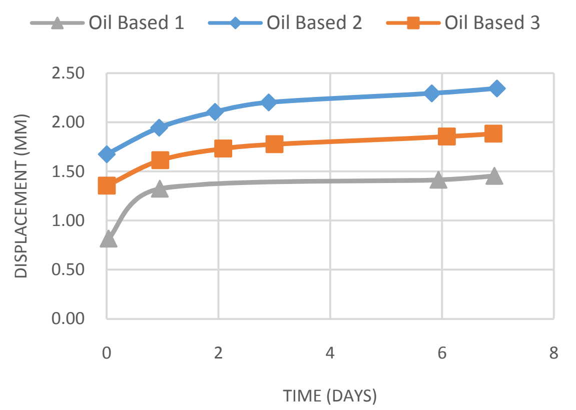

Fig. 4 Pull test results for oil based resin.

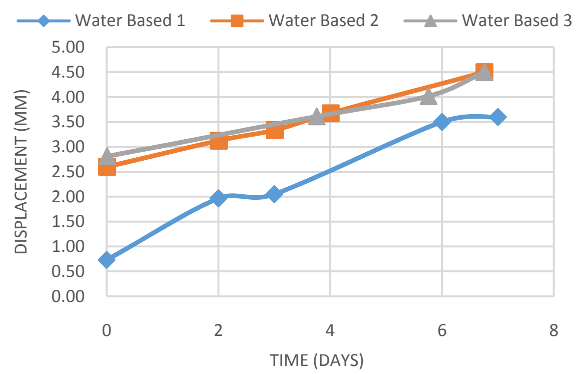

Fig. 5 Pull test results for water based resin.

As seen in Fig. 5, the results from the water based samples were linearly increasing. Samples two and three showed very similar results with both trends being near linear. These two samples also experienced the highest displacement of all the tested samples from the pull out experiment. Initially, three water based samples from the pull test failed prematurely. After this, three additional samples were casted for testing and their results were used in the analysis. The premature failure in the water based samples could have been caused by the presence of air bubbles in the resin mixture. The water based resin blend was found to be more pasty than the oil based mixture which in turn makes it harder for air to escape the resin.

Two of the three samples tested for grout did not fail under the test conditions. The grout was found to behave more brittle than the resin samples. Fig. 6 graphical shows the results.

Fig. 6 shows the deformation experienced by each of the grout samples over the test duration of seven days. It can be seen that the rate of deformation is fairly linear for most of the samples. The third sample, which failed prematurely during the second day of the test, showcased the same trend as observed in the early stages of the second sample. The relative slow increase in deformation for the samples shows that the grout is quite brittle when compared to the resin samples.

Fig. 7 displays the average creep trend for each of the materials. From the graph it can be seen that the oil based resin and grout samples yielded very similar results and showcased a low creep rate. The water based samples had the highest rate of creep and produced a near linear increasing trend. These samples also experienced the highest displacement at failure. In contrast, the grout samples yielded the lowest creep rate and consequently had the lowest displacement at failure of the three materials.

4.3 Shear Strength and Strain

To further compare the test samples to one another, the shear strength and peak strain was calculated for

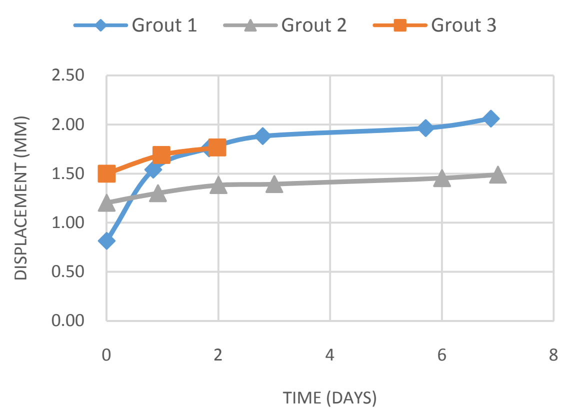

Fig. 6 Pull test results for grout.

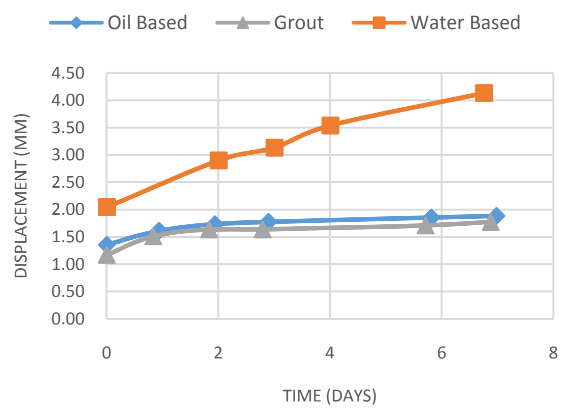

Fig. 7 Average creep trend for each material.

each of the materials. To ensure accuracy, the peak strain was calculated by subtracting the elastic elongation of the bolt itself under the peak load. This ensured that the true displacement in the test material was used for the strain calculation.

The shear strength was calculated based on the embedment length, bolt embedded surface area and the peak load experienced by the sample. It is know that failure from a pull test is largely caused by shear, but has some component of torsional unscrewing [8]. Due to the complexity of analysing torsional unscrewing of the bolt, failure was assumed to be caused by shear only. Fig. 8 below displays the averaged shear strength calculated for each of the materials.

It is clear from the results that the oil based resin yielded the highest shear strength out of the tested materials. It experienced peak failure loads of 135 kNon average which is much higher than the 72 kN and 90 kN experienced by the water based resin and grout respectively. The grout samples yielded an average shear strength of 5.5 MPa, which was slightly higher than the water based resin but lower than the oil based resin. Subsequently the water based resin yielded the lowest shear strength of 4.5 MPa. Fig. 9 displays the associated peak strain experienced by each of the materials.

The strains experienced by the samples are representative of the overall material stiffness. The rate of creep was found to be highest for the water based resin and lowest for the grout. The calculated peak strain for each material suggests that the grout is most brittle, the oil based resin is more brittle than the water based but more ductile than the grout and the water based resin is most ductile. Therefore meaning that under an induced axial load, water based resin would experience the highest amount of deformation out of the three materials. In summary, the results found from the pull test suggests that the oil based resin has the highest shear strength and subsequently has the highest resistance to failure. The water based resin was found to be the weakest in terms of shear strength and behaved most ductile out of the three materials and the grout samples yielded the lowest creep rate and lowest peak strain.

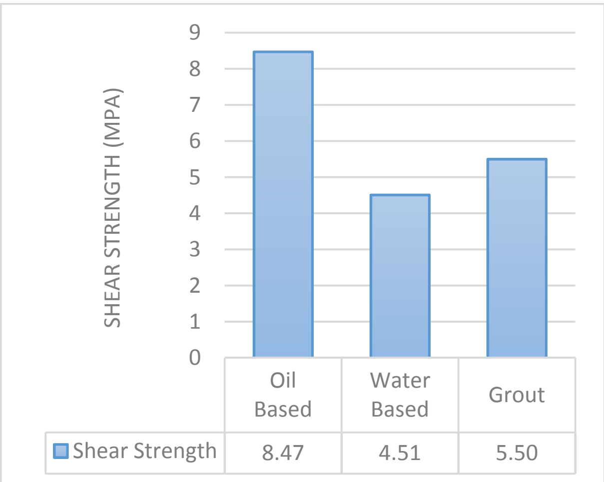

Fig. 8 Shear strength of bonding materials.

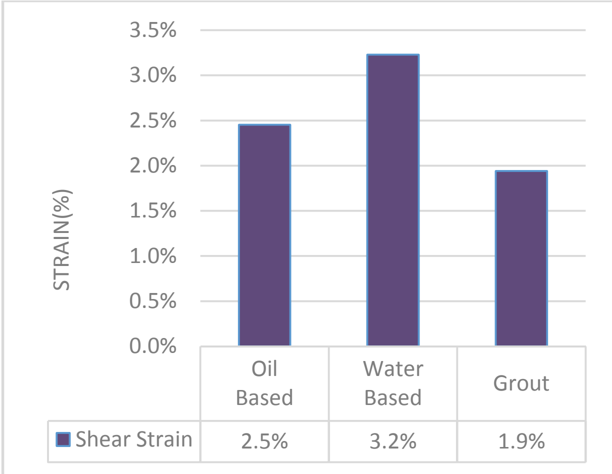

Fig. 9 Shear strain of bonding materials.

4.4 Influencing Factors

Factors that had the possibility of influencing the outcomes of experiments were identified. These factors were identified to be a combination of or be related to mixing practises, mixing ratios, ideal conditions and equipment limitations. Research concluded that bonding material strength is greatly affected by the quality of mixture. All the samples for this project were mixed by hand. Each batch of material was mixed for at least 2 min before pouring it into the mould. In industry, the bonding material is mixed with high speed mechanical mixers to ensure that the components are properly blended together. Since mixing was conducted by hand during the sample preparation stage, some components might have not been thoroughly mixed resulting in a decreased material strength. This could have lead to some form of inaccuracy in the test results.

It is also important to note that the ratios used for mixing plays a vital role in the performance of the materials, especially in-situ. For example, grout is mixed beforehand with a large mechanical mixer and is then pumped into the borehole. This means that the mixture quality should be good which enhances material performance. The resin on the other hand is mixed inside the borehole for only a few seconds, which means the mixtures can vary quite significantly in terms of quality. This varying quality in the mixing of resin is very hard to get consistent due to the amount of factors influencing the physical mixing. These include but are not limited to borehole diameter, borehole roughness, glove fingering and drill operator, to only name a few. The perfect ratio of mastic to catalyst for a consistent mixture would be 50:50. This means there is the same amount of mastic as there is catalyst. However, the resins used in this project had a mix ratio of 93:7 for oil based and 80:20 for water based. From these mixing ratios, one would expect that given the same environmental conditions, the water based resin should have a better mix quality due to the ratio being closer to 50:50 when compared to oil based resin. This means that although the experimental results show that oil based resin, when perfectly mixed, might be stronger than water based, this might not be the case in-situ since the mixing quality has a higher chance of being good in the water based resin than in the oil based.

Another important factor to consider is that the results obtained from the experimental investigation was conducted in what is called an ideal environment. Most of the factors in an ideal environment can be controlled. This means that influencing factors such as improper mixing, glove finger and borehole inconsistencies has been minimised to obtain peak results for each of the materials. Further in-situ testing of the resins and grout could provide varying results due to the introduction of the other external influences.

Limitations in the available equipment for the experimental testing procedure had a big influence on the number of samples tested and also the accuracy of the results that were obtained. For the long term creep test, carried out in the UCS machine, only three samples of each type could be tested at a particular time. With this test having a duration of 4 weeks, it makes getting consistent results through repetition very time consuming. Having access to only one UCS machine limited the amount of tests that could be carried out during the timeframe of the project. Another aspect of the UCS machine that influenced the results is the fact that the load of 75 kN could not be sustained for the duration of the test.

The load had to be reapplied before every measurement was taken. This introduced stress relaxation which lead to the test not following a standard creep curve. For the pull test, the equipment was found to be performing well overall however, the load on the bolts were reapplied to the required load of 80 kN between measurements and since only one hydraulic ram was available for conducting the pull test, only three samples of each material could be tested in the project timeframe. In terms of measurements, load readings were conducted based on the hydraulic gauge attached to the ram. A load cell for more accurate measurement of the applied load was only acquired during the final stages of testing.

5. Conclusions and Recommendations

Time-dependent deformation as a result of an induced load which is less than the yield strength of a material can be referred to as creep. The creep can be presented on a graph showing the amount of strain experienced over time. Resin bolt performance testing showed that the weakest region in the bolt encapsulation is the toe area. This is directly related to poor mixing practices thus, special attention should be given to mixing for sample preparation.

Long term creep testing on water and oil based resin yielded a peak strain of 1.11% and 0.72% respectively. The trend of creep in this case did not conform to a standard creep curve since stress relaxation was introduced due to loading and unloading of the samples over the duration of the test. From the rock bolt pull test it was concluded that grout behaved most brittle while the water based resin behaved most ductile. The peak strain experienced by the samples were 2.5%, 3.2% and 1.9% for the oil based, water based and grout materials respectively. The highest shear strength was recorded for the oil based resin at 8.47 MPa. This compared to the 5.5 MPa for grout and 4.51 MPa for water based clearly shows that the oil based resin resisted the highest load. The peak average load at failure for each of the samples were 135 kN, 72 kN and 90 kN for the oil based, water based and grout respectively. The bonding material found to experience the highest amount of creep was the water based resin and the lowest amount was recorded for the grout.

Based on the conclusions drawn, it is recommended that:

- Further tests be done on each of the bonding materials to increase the consistency of the current results and especially for the water based resin. Obtaining multiple repetitions of the same test would ensure that the results gathered are accurate for the specific material.
- Improved equipment be acquired that overcomes the mentioned limitations. Especially the limitation of not being able to sustain a constant load.
- Bonding materials be tested in-situ. This will introduces a range of external factors not easily controlled and may produce different results. These results can then be used to directly relate to industry.
- When making cube samples, the moulds be vibrated to release any trapped air bubbles as this would reduce the amount of strain error encountered during the test.
- Mechanical mixers be used during sample preparation to ensure each of the resin and grout batches are blended thoroughly.
- The effects of industry install techniques on the shear strength of the material be analysed through borehole testing.

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