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The Influence of Resin Thickness on Bolt Bending

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ABSTRACT: Load transfer mechanism of bolt has been the subject of increased research for more than three decades, particularly with regard to resin thickness. The influence of increased resin thickness on axially loaded bolts has been widely reported and documented, however there remains a lack of clear understanding of the bolt-resin and rock interaction with different resin thickness particularly when the bolt is sheared. Accordingly, this study is aimed to examine the effect of resin thickness on the bolt-grout-concrete interaction under double shearing conditions. The bending and shearing characteristics of bolts were conducted both in the laboratory and in 3D numerical simulation, and with and without different pretension loads. Both the strength of the concrete and bolt pretension load had been found to have major influence on the shear resistance and shear displacement of the reinforced concrete in all resin thickness. Also, the strength of the surrounding concrete was found to play a greater role than the grout thickness, particularly when the bolt is in pretension.

1 INTRODUCTION

Fully grouted rock bolts are widely used in both civil and geotechnical engineering constructions as reinforcement elements. A fully grouted bolt in intersection with a joint plane increases the resistance to shear across the joint. Many researchers have undertaken significant research in the numerical and laboratory methods to study the mechanical behaviour of bolted rock joints, and much of the theoretical studies were undertaken using various available approaches such as the finite element and finite difference methods. Bolts can be installed as passive or as active pre-tensioned support element. However, there is an ongoing debate on the methodology of bolt installation with regard to bolt pretensioning. When bolts installed in underground excavations or in surface mining, they are loaded both axially and laterally depending on the movement direction of the reinforced unstable rock block.

Research on sheared surface reinforcement has been the subject of research that is being pursued with increasing vigor in recent years, ever since the benefits of full encapsulation was realized. Numerous experimental and numerical studies were undertaken over the past three decades to investigate the mechanical behaviour of fully grouted rock bolt in rocks and in bolt shearing conditions. The works of Dulacska (1972), Bjurstrom (1974) Azuar (1977), Hass (1976,1981), Hibino and Motojima (1981), Dight (1982), Spang and Egeer (1990), Ferrero (1995), Pellet and Boulon (1998), Kharchafi and et al (1998), and Grasselli (2004), Aziz et al (2004) are well documented.

The effect of resin thickness is one of most important factors to transfer the maximum load from bolt to the rock. When a bolt is loaded axially by pushing/pulling through the resin thickness, thicker resin layers show minimum load transfer. Several authors conducted this research in the past, (Fabjanczyk, Hurt, & Hindmars, (1992); Aziz and Webb (2003); Aziz 2004). However, to understand the effect of resin thickness while bolt is laterally loaded under shearing effect, there appears to be a lack of reporting on the subject. Thus, in this study the laboratory tests and numerical simulations were conducted to she light on this aspect of bolt -resin and rock interaction. Double shear laboratory tests were carried out only in 27 mm hole diameter and 22 mm bolt diameter. The laboratory study was then supported by extensive numerical simulations with different resin thickness, material strength and bolt pretensioning was undertaken. This paper highlights the effective role that the resin thickness in different rock strengths and pretensions could play in rock reinforcement.

2 LABORATORY TESTS

The general set up of the double shear box unit in a testing machine is shown in Figure 1, Double-jointed concrete blocks were cast for each double shearing test. Two different strengths concrete blocks, at 20MPa and 40MPa, were cast to simulate two different strength rocks. The concrete/bolt assembly was then mounted in a steel frame shear box specifically fabricated for this purpose. A base platform that fitted into the bottom ram of the Instron Universal Testing Machine, capacity 500 kN, was used to hold the shear box. A predetermined tensile load was applied to the bolt prior to shear loading. This acted as a compressive/confining pressure to simulate different forces on the joints within the concrete. The three nominated tension forces used were 20kN, 50kN and 80kN. Axial tensioning of the bolt was accomplished by tightening simultaneously the nuts on both ends of the bolt. The applied axial loads were monitored by two hollow load cells mounted on the bolt on either side of the block. Figure 2 and 3 show the load deflection trend in 20 and 40 MPa concretes respectively in different pretensions installed in 27 mm hole diameter. As they show higher concrete strength and pretension load leads higher shear resistance. Figure 4 displays yield load increase as a function of pretension load in concrete 20 MPa. This relation behaves as a power function. The axial load on the bolt increased with increasing the shear load. The rate of axial load increase is on the rise once the elastic range is exceeded.

Figure 5 shows the relationship between the axial loads developed and shear displacement in high strength bolt (ultimate tensile strength around 330 kN) installed in 40 MPa concrete. From the graph it can be seen that the axially induced load on the bolt at low level of pretensioning, is higher than that of high level of pretensioning. The possible reason is attributed to lower confinement resistance, causing the bolt to deform much more readily, with an increase in axial load of the bolt as the bolt is clamped at both ends.

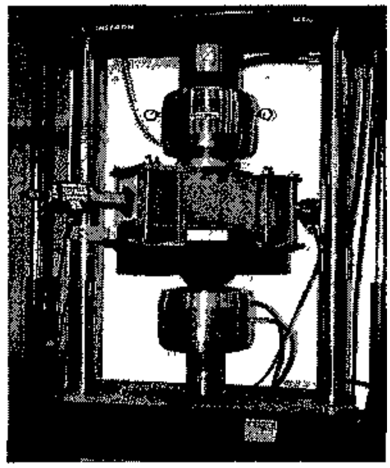

Figure 1.General set up of double shear box in Instron machine

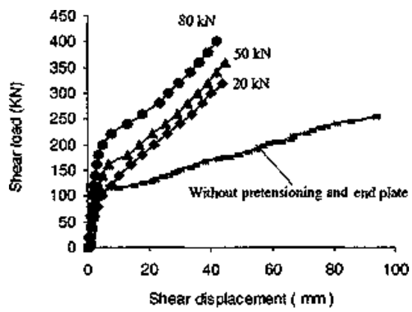

Figure 2. Shear load -shear displacement trend in bolt surrounded with 20 MPa concrete and 27 mm hole diameter

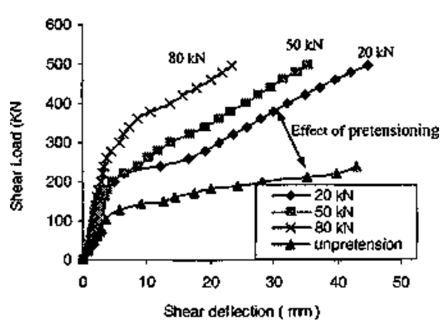

Figure 3. Shear load versus shear deflection in different pretensioning with 40 MPa concrete and 27 mm hole diameter

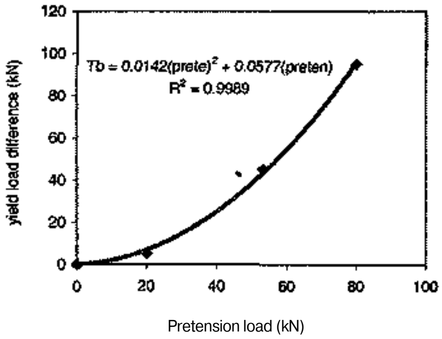

Figure 4. Yield load increase versus pretension load in 20 MPa concrete

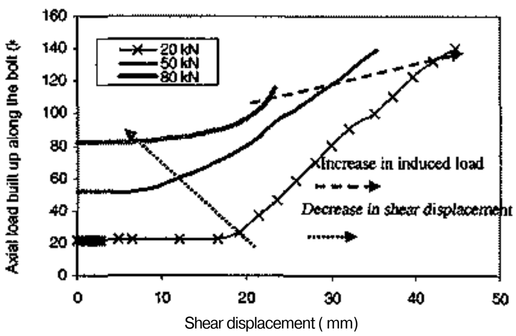

Figure 5. Axial load build up along the bolt as a function of shear displacement in 40 MPa concrete and different pretension loads

3 3D NUMERICAL SIMULATION

3D simulation of the bolt shearing process was conducted using ANSYS version 8.1 package. Numerical simulations were carried out in 20 and 40 MPa concrete and in different resin thickness. The objectives were to examine the strains and stresses developed in different resin thickness and various pretension loads of 20, 50, and 80 kN. A large number of numerical models were created, to describe different resin thickness in different pretensions and rock strength. The confirmation of the numerical simulations with laboratory results is shown in Figures 6. It can be seen that the numerical simulations were found to be in close agreement with the experimental results.

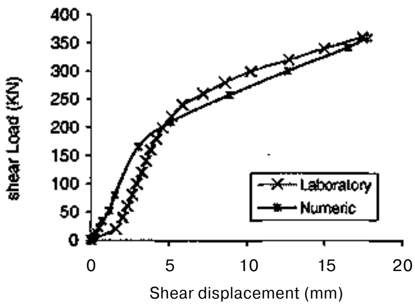

Figure 6. Load-deflection in 20 kN pretension load in 40 MPa concrete

Following the system calibration, a number of 3D numerical simulations were then carried out in 20 and 40 MPa concrete blocks in both un-pretension and pretension loads of 20, 50 and 80 kN. This FEM of the reinforced structure subjected to the shear loading was used to examine the behavior of bolted rock joints, such as; strength of material, pretensioning and resin thickness. Parameters considered were, the three governing materials (steel, grout, and rock) with two interfaces (bolt - grout and grout - rocks). Using (ANSYS, Version 8.1), it was possible to simulate specifically the elasto-plastic materials and contact interfaces behaviors. The stress-strain relationship of steel was assumed as bilinear kinematics hardening model and the modulus of elasticity of strain hardening was accounted as one hundredth of the original value. Figure 7 shows finite element mesh for a quarter of the model. The elastic properties of materials are displayed in table 1.

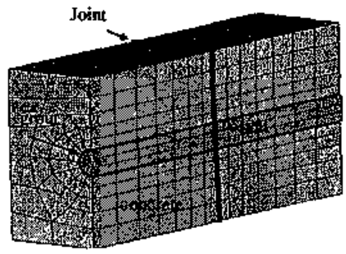

Figure 7. Three-dimensional meshed model of a quarter section of the composite concrete/resin and bolt

Table 1: Elastic material properties

Material	UCS (MPa)	E (GPa)	Poisson's Ratio
Concrete 1	20	20	0.2
Concrete 2	40	32	0.2
Resin Grout	60	12	0.25
Steel	330kN	200	0.3

Numerical modeling was carried out in different resin thickness of, 1.5, 2.5 and 5 mm, in borehole diameters of 25, 27 and 32 mm respectively. Figures 8 and 9 show the created gap among interfaces in thin and thick resin layer.

From the figures it can be seen that with increasing the shear load, the grout layer becomes separated from the bolt and concrete in the tension zones and is compressed at compression zone. The separation gap occurred in all resin thickness. The gap in thin resin layer is more extensive than the thick resin layer and also changes in stresses, strains and displacement along the bolt and surrounding materials are different. With the bolt is bent, and the gap is increased, and the contact pressure is removed. However, at the compression zones in the vicinity of shear joint, reaction stress will result. Because of extensive output results from numerical simulations, only a few figures are provided in this paper. Figure 10 shows the value of induced strain along the bolt in shear direction around the grout 1.5 mm thick. Compared to thick resin the level of strain, in both tension and compression zones, is higher and the resin is fragmented with low shear load.

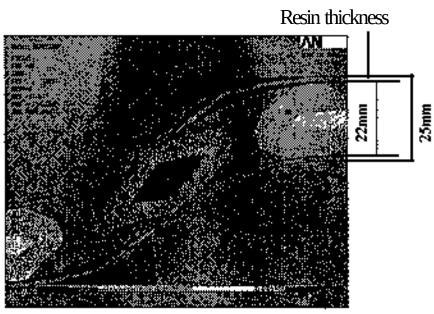

Figure 8- Shear stress and created gap in 1.5 mm resin thickness with 20 MPa concrete without pretensioning

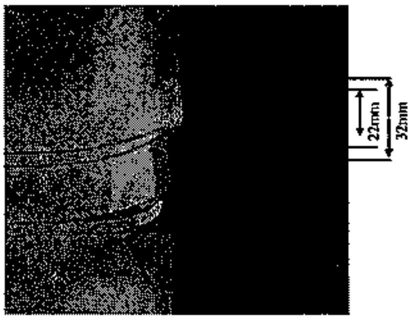

Figure 9. Model deformation and created gap between interfaces in 5 mm resin thickness

Figure 11 shows the plastic strain in shear direction along the thick resin layer in 20 MPa concrete. The value of the strain in the vicinity of the shear joint, is high, thus causing a complete damage in resin layer. Figure 12 displays the value of induced strain along the bolt axis through the resin in 40 MPa concrete with 80 kN pretension.

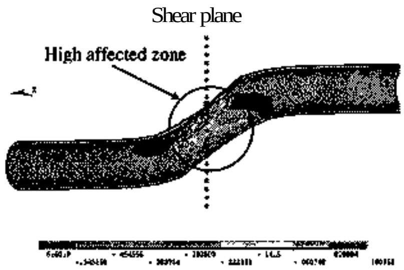

Figure 10. Plastic strain in shear direction along thin grout layer in 20 MPa without pretensioning

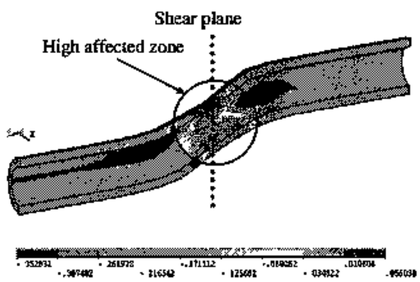

Figure 11. Plastic strain in shear direction along thick grout layer in 20 MPa concrete without pretensioning

Figure 13 shows, there is a dramatic increase in strain change in the resin layer in the vicinity of shear joint.

The value of strain, at both the axial and lateral directions in the vicinity of shear joint plane, was above the elastic yield point of the resin, which is a clear indication that the strength of resin is exceeded.

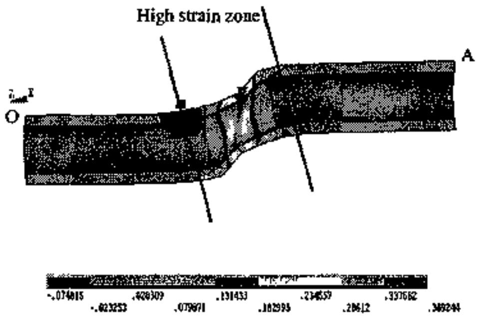

Figure 12. Axial plastic strain along the thick resin layer in 40 MPa concrete with 80 kN pretensioning

Figure 14 shows the trend of induced stress and concrete deflection along the bolt axis through the concrete block. It shows that the stresses around the concrete block are high at the edges in the vicinity of shear joint, thus inducing longitudinal fractures in the concrete blocks. This was also observed at the experimental results, and was common to all resin thickness and concrete strengths.

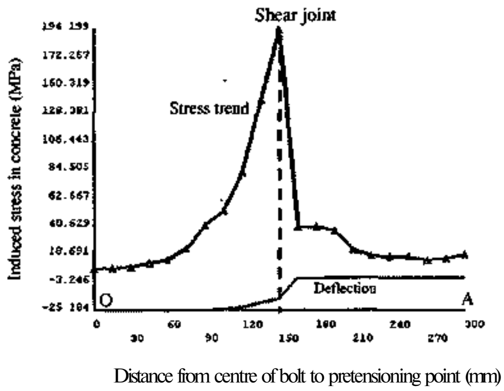

Figure 14. Yield stress trend in concrete with 40 MPa strength and thick resin without pretension effect

The rate of strain changes along the bolt, with thick resin thickness in 40 MPa concrete and without pretension, is shown in Figure 15. It was found that the outer layer of the bolt was yielded, however, the middle part of the bolt cross section remained in the elastic state in different concrete strength.

Moreover, with increasing the bolt pretension load, the area of tensile strain expanded and distributed to the middle of the bolt.

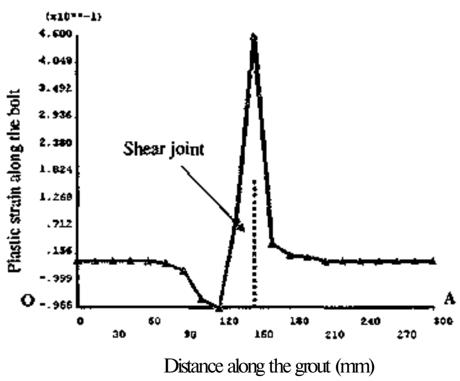

Figure 13. Plastic strain along the thick resin layer in axial direction of the bolt in 40 MPa concrete without pretensioning

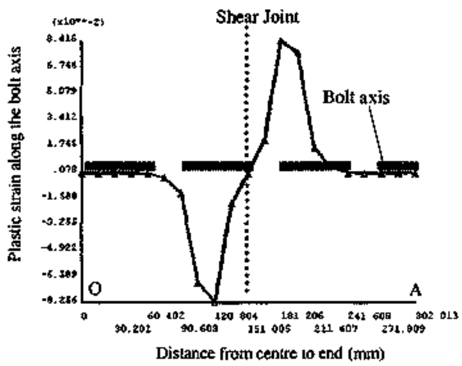

Figure 15- Trend of axial strain along the bolt in high resin thickness (5 mm) surrounded by 40 MPa concrete

4 THE EFFECT OF RESIN THICKNESS ON INDUCED STRESSES

The value of induced stresses in bolt was evaluated m different resin thickness The behaviour of the concrete and grout were assumed as an isotropic linear material and the behaviour of steel bolt was assumed non-linear hardening The effect of various concrete, grout and bolt modulus of elasticity m different resin thickness was investigated using the numerical simulations Shear stress trend as a function of concrete modulus in different resin thickness is shown in Figure 16 The shear stress along the bolt in thick resin layer is lower than in thin resm layer This trend was reduced with increasing concrete modulus Figure 17 displays induced tensile stress versus grout modulus in soft concrete and in different resin thickness The induced tensile stress along the bolt was decreased with increasing resm thickness and grout modulus

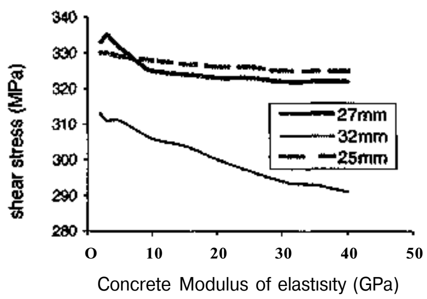

Figure 16- Induced shear stress versus concrete modulus of elasticity m different resin thickness

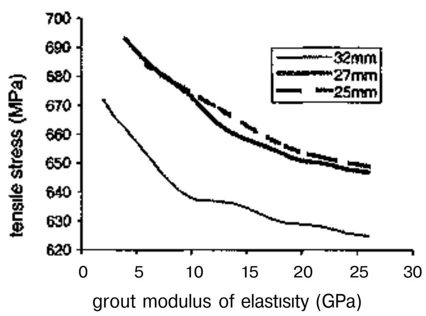

Figure 17- Induced tensile stress versus grout modulus of elasticity in soft concrete

Figure 18 shows the effect of concrete modulus on shear displacement in different resm thickness Concrete strength has great effect on shear displacement in all resm thickness However, no significant change m shear displacement in high strength concrete was observed The value of shear displacement in thin resin layer is higher than thick Iayei As Figure 19 shows the influence of grout modulus is more effective than the concrete modulus in shear displacement for the variety of resin thickness

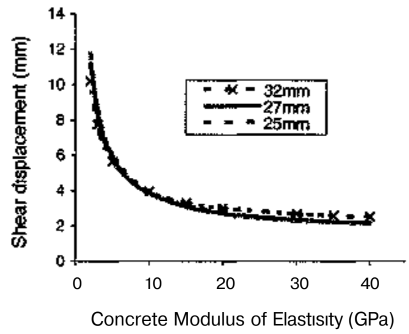

Figure 18- Shear displacement versus concrete modulus m different resm thickness

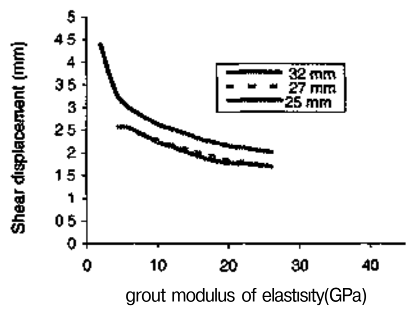

Figure 19 Shear displacement versus grout modulus of elasticity in different resin thickness

5 RESULTS AND CONCLUSION

This paper demonstrated that the resm thickness plays a prominent role in bolt shearing across joints and bedding planes Resm thickness role in shear is less significant in comparison to the conventional axial loading and load transfer characteristics What is important and influencing the bolt shear is the strength of resm in relation to the medium strength

The foilowing are some of the conclusions drawn from model simulations

- The influence of grout modulus is more effective than the concrete modulus m shear displacement for the variety of resin thickness
- Tensile and compression strains and shear displacement were slightly reduced with increasing resin thickness
- The plastic strains perpendicular to the bolt axis inside the grout were reduced with increasing resin thickness
- Compression and tensile strains along the bolt axis in concrete interface were slightly reduced with increasing resin thickness, and
- The strength of the surrounding concrete has greater influence in shear resistance, and shear displacement than the resin thickness, when bolt is loaded laterally

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