2023

Practical evaluation of the impact of resin curing time on rock bolt load transfer

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PRACTICAL EVALUATION OF THE IMPACT OF RESIN CURING TIME ON ROCK BOLT LOAD TRANSFER

Kent McTyer[1]

ABSTRACT: The use of resin anchored rock bolts is an established means of reinforcing the roof and sides of underground mines and tunnels. However, the installation method requires rigor on the part of bolting equipment operators to achieve the optimum outcome. One such factor – resin curing time – has long been thought to influence the efficacy of the installed bolt. The efficacy is ultimately measured by the load transfer of the rock-resin-bolt bond. This study discusses the results of testing of pre-tensioned resin-anchored rock bolts. This was achieved using full-scale resin bolts installed into vertical grout-filled steel test pipes on a surface drill rig with the finished bolts then cut into sections and load transfer measured using the push-test method. The key parameter investigated was the influence of resin curing time prior to the application of pre-tension. The results confirm that the degree of curing influences load transfer. This outcome confirms that both resin type, and site-specific conditions, should be evaluated and then incorporated into the bolt installation guidance provided to bolting operators.

INTRODUCTION

This study discusses an often-overlooked aspect of resin anchored bolting – resin curing time. It is estimated that almost all the underground coal mines in Australia employ resin anchored bolts or cables that require a pause in the bolt or cable rotation on completion of mixing to allow the resin anchor to fully cure before applying pre-tension. However, the impact of premature tensioning on the ultimate load transfer of the bolt has not been fully investigated.

A common observation made during underground inspections of installed ground support is that the bolt tail length can vary between minimal (5-10mm), moderate (10-100mm), and long (>100mm). The length of bolt tail that occurs after tensioning can be a function of roof strata lift during tensioning, however, where the roof strata is competent, bolt tail length may be the result of the bolt pulling through the still-curing resin column. The current study aimed to understand the influence of the bolt pulling out of the resin and thus provide industry with guidance on the importance of ensuring the resin is fully cured before pre-tension is applied.

The theory tested is that pulling the bolt through the still curing resin anchor will cause some degree of reduction in the strength of the rock-resin-bolt bond. This comes from the understanding that the polymerisation of rock bolt resin occurs rapidly, and that interrupting the curing by inducing movement of the bolt (and consequently resin) will weaken the finished molecular structure of the resin (Altouyan, et al 2003). This weakened molecular structure would then result in a weaker rock-resin-bolt bond strength. Rapid resin cure times make laboratory testing of resin in isolation difficult if not impossible to conduct with any degree of repeatability. Thus, the test method chosen was to install bolts on a drill rig and simulate the underground conditions of both partially cured anchor, and fully cured anchor, before applying pre-tension.

Determination of the degree of resin curing was quickly observed by measuring the length of roof bolt tail that protruded below the nut after tensioning. A finished bolt with no or little bolt tail length suggested the resin column was fully cured and resisted bolt pull-out during tensioning. Conversely, the observation of a moderate or long bolt tail suggested the bolt pulled through the still-curing resin anchor. After installation the grouted cylinders containing the bolts were then sectioned, and load transfer estimated using the push test method.

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METHOD

The bolt installation and test techniques were developed over several years to evaluate resin-bolt systems used in coal mines (Evans 2016, McTyer 2019, McTyer 2020). Drilling and installation of resin-anchored bolts was conducted using a coal mine equivalent Sandvik D0100 drill rig (**Figure 1**).

Figure 1: DSI Underground drill rig (grouted cylinder positioned above rig – left image)

1500mm-long test bolts were resin anchored into 101.7mm outer diameter, 93.7mm inner diameter steel cylinders with a length of 1500mm (**Figure 2**). The steel cylinders were filled with approximately 80MPa (>28 day cured) cementitious grout. A 20mm-diameter PVC tube was used to form a pilot hole to ensure the drill hole remained located in the centre of the cylinder. The same 28mm-diameter PCD drill bit was used to drill all holes before resin-bolt installation. The drilled holes simulate underground drilling and bolting conditions in a homogenous strata-type. Electronic records of bolt RPM and displacement were taken during bolt installation. After bolt installation the length of bolt tail was measured.

Bolts were installed in the grout-filled cylinders then sectioned for load transfer testing by the push-test method. Each sectioned sample length was 150mm (**Figure 2**). Due to the resin capsule length of 500mm, and the 100mm of over drilling (due to pilot hole), only the top four push test samples were used for results comparison. Push-testing was chosen as it provides the load-transfer profile along the entire resin encapsulated bolt length. Single speed resin of 500mm length was used. 500mm-long resin capsules were used as this is half of a commonly used 1000mm capsule which typically comes in a 50/50 two-speed configuration, and because this study was focussing on the effect of tensioning on the upper fast-set portion of the resin anchor. Logically, the slow-set time resin was not used as it will be unaffected by bolt pull through as it will not be near the polymerisation phase at the time of tensioning.

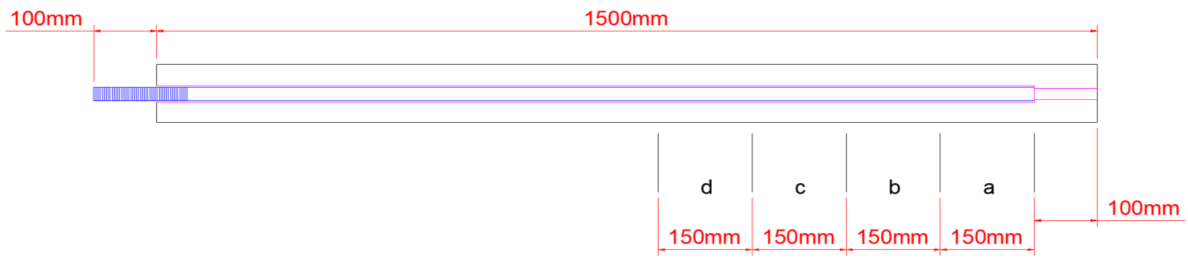

Figure 2: Push test sample arrangement

Push tests were performed on a calibrated Universal Test Machine (UTM) located in the DSI Underground test laboratory (**Figure 3**). Load was applied at a standard rate of 10mm/minute. Tests were ceased when displacement of 10mm was achieved. The test methods used are judged reliable and repeatable when comparing resin anchored bolts. Further, the method allows for relatively rapid sample preparation and testing.

Figure 3: Testing samples using the push test method

RESULTS

Tests were conducted on three 500mm-long resin capsule formulations (**Table 1**). Bolts were installed with rotation hold (cure) time adjusted to produce bolts with no/minor bolt tail length, moderate bolt tail length, and long tail length. A total of 27 bolts were used for the purposes of this testing.

Table 1: Resin capsule specifications used during testing

Resin Identifier	Supplier	Resin Origin	Mastic: Catalyst
Type A	DSI	Europe	70: 30
Type B	DSI	Australia	80: 20
Type C	DSI	Australia	93: 7

Bolt installation and bolt tail length records

Each bolt installation was recorded for bolt RPM and displacement. An example plot is shown in **Figure 4** showing three bolts installed using Type A resin capsules employing a nine second cure time. Note the minor additional upward bolt movement at the completion of mixing. This additional feed was required to ensure the bolt, plate and nut were located firmly against the base of the grout-filled cylinder. This technique ensured all measured nut travel due to tensioning was the result of the bolt pulling through the still-curing resin column.

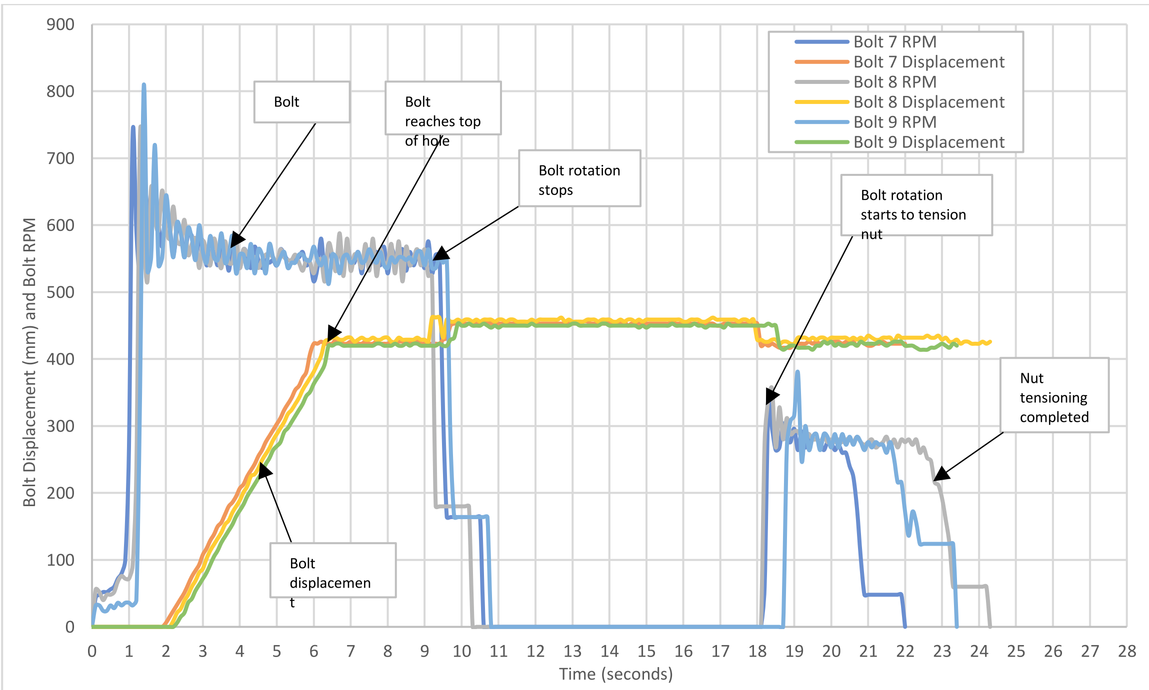

Figure 4: Recorded drill rig RPM and displacement of three Type A resin installations (9 second cure time)

Bolt tail length was measured after bolt installations. It was observed that for the Type A resin bolts a resin curing time of ten seconds produced very short bolt tail length (**Figure 5**). The figure also illustrates that a resin curing time of five seconds resulted in the nut tensioning causing the bolt to be pulled through the still curing resin.

Figure 5: Bolt tail length for 10 second (Bolts 1 to 3) and 5 second (Bolts 4 and 5) rotation cure time before applying pre-tension to the bolt nut

From the electronic records the results of the bolt installations are summarised in **Table 2**.

Table 2: Average installation results of each test specification

Resin Type	Cure Time (seconds)	Spin to Top (seconds)	Insertion Rate (mm/sec)	Spin at Top (seconds)	Rotation Hold Time (sec)	Nut Tension time (sec)	Bolt Tail Length (mm)
Type A	5	4.5	100	3.8	5.3	8.5	110
Type A	9	4.3	106	4.0	8.9	3.3	50
Type A	10	4.3	104	4.0	10.6	1.0	5
Type B	10	4.1	111	3.7	10.1	3.8	38
Type B	12	4.2	110	4.0	12.1	4.9	59
Type B	15	4.3	104	3.7	14.9	0.6	5
Type C	STS	3.9	115	7.8	0	2.3	36
Type C	2	4.0	113	3.5	1.9	6.1	87
Type C	10	3.9	115	4.0	10.1	0.8	8

Table 2 shows the average result from three bolt installations of each of the nine tests. Insertion rate was approximately the same for all tests and bolt RPM was approximately 550 RPM. It is noted that the Type C spin to stall installation procedure resulted in a longer spin at the top of the hole before bolt stall occurred. Overall, the major trend seen was that increased resin curing time as measured by rotation hold time resulted in a reduction in bolt tail length. Importantly, in all cases the plate, dome ball and nut were hard up against the base of the steel pipe when tensioning was initiated. Thus, any bolt tail length resulting from tensioning was a function of the bolt being pulled out of the still curing resin anchor. In the case of both the Type A and Type B resins, premature nut tensioning produced substantially longer bolt tails. The Type C spin to stall resin produced a shorter bolt tail when subject to greater total resin mixing time (approximately 12 seconds) compared with a shorter mixing time with a short cure time. Finally, while the installation results highlight the different curing time of the Type A, B and C resin formulations, they all saw a similar behaviour in terms of increased curing time resulting in a decrease in bolt pull-out.

Bolt load transfer

A total of 27 bolts (three of each test specification) were cut into 150mm-long sections for push testing. All bolts were allowed to cure for greater than seven days before push testing. Due to the 500mm resin capsule length and 100mm over-drilled holes, there were four push test samples per bolt with full resin encapsulation. The four 150mm-long samples represent the upper 600mm of the bolt. After testing, peak push out load was averaged at each of the four intervals from the three bolts (**Table 3**). The data is plotted in **Figures 6, 7 and 8**.

Table 3: Average peak push out load by resin type and interval

Resin Type	Cure Time (seconds)	Average of Three Peak Push-Out Loads by Interval (kN)				Average Load from all 12 samples (kN)
		800-950mm	950-1100mm	1100-1250mm	1250-1400mm	
Type A	5	69	159	202	90	***130***
Type A	9	198	188	176	130	***173***
Type A	10	220	243	214	148	***206***
Type B	10	61	99	110	93	***91***
Type B	12	90	109	89	80	***93***
Type B	15	89	97	91	88	***91***
Type C	STS	70	130	121	90	***103***
Type C	2	46	102	121	109	***94***
Type C	10	94	97	103	88	***95***

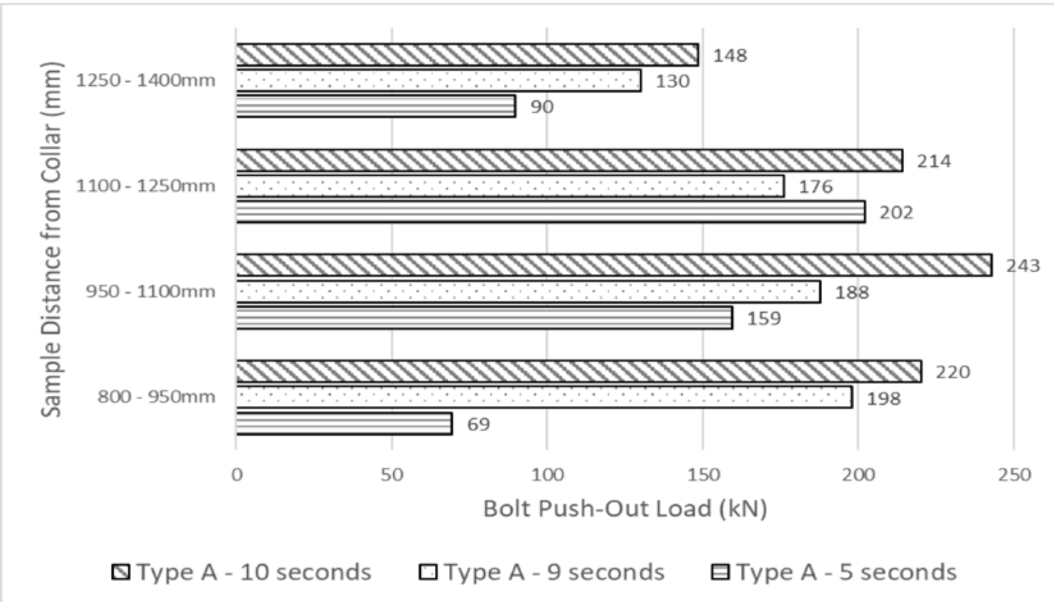

Figure 6: Type A resin curing time and average peak push-out by interval

It was noted that a degree of variability exists between individual peak push load tests – even of the same resin type and curing time. However, the calculation of averages removes some of the inherent variability. Further, the results seen in **Table 3** and **Figures 6, 7 and 8** indicate that trends can be confidently determined. The trends being both the overall load transfer difference between resin types, and the influence of curing time on bolt pull through and load transfer.

Peak push out load was clearly different between the Type A resin and the Type B and C resins. When allowed nine or ten seconds of curing time, the Type A resin saw between 30% and 100% higher load transfer than the Type B and C resins. While not documented in terms of influence on ground behaviour, the logical conclusion is that the Type A resin would positively contribute to ground stabilisation above and beyond the ground stabilisation effect provided by either the Type B or C resin anchors. When comparing the Type B and C resins, the Type C resin returned a slightly higher load transfer of approximately 10% - however, this may be within the inherent variability of the test method employed. A final trend evident in all resin types was that the highest load transfer was typically seen in the two middle samples (950-1250mm) with a reduction in load transfer in the top interval and bottom interval. This reduced load transfer in the upper interval may be explained by the tendency for the collection of resin capsule film causing gloving in the upper portion of the bolt. While the reduction in load transfer in the lower interval may be explained by the impact of bolt tensioning on the still curing resin of the lower 150mm.

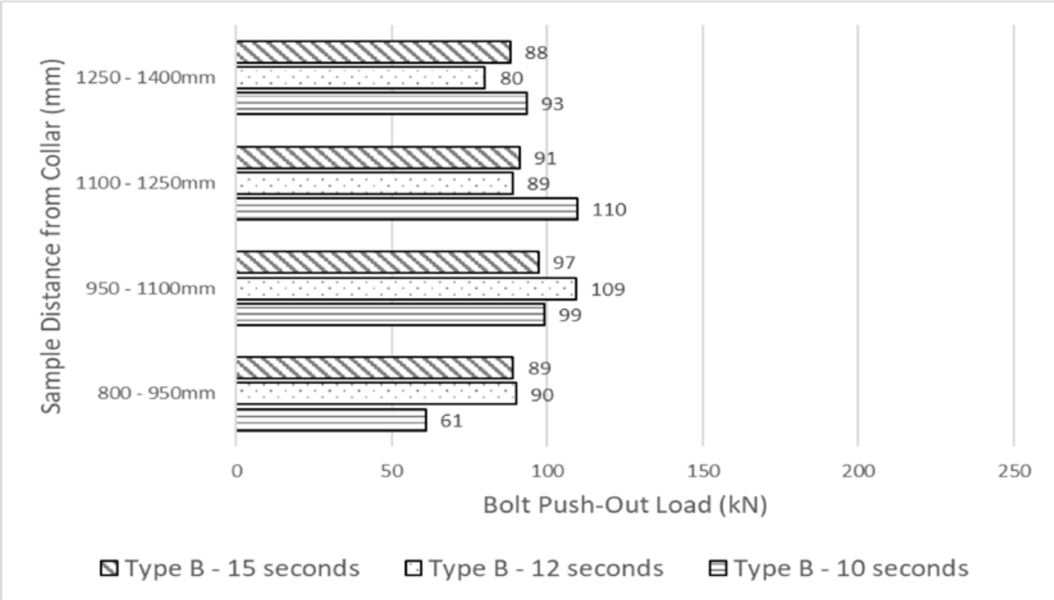

Figure 7: Type B resin curing time and average peak push-out by interval

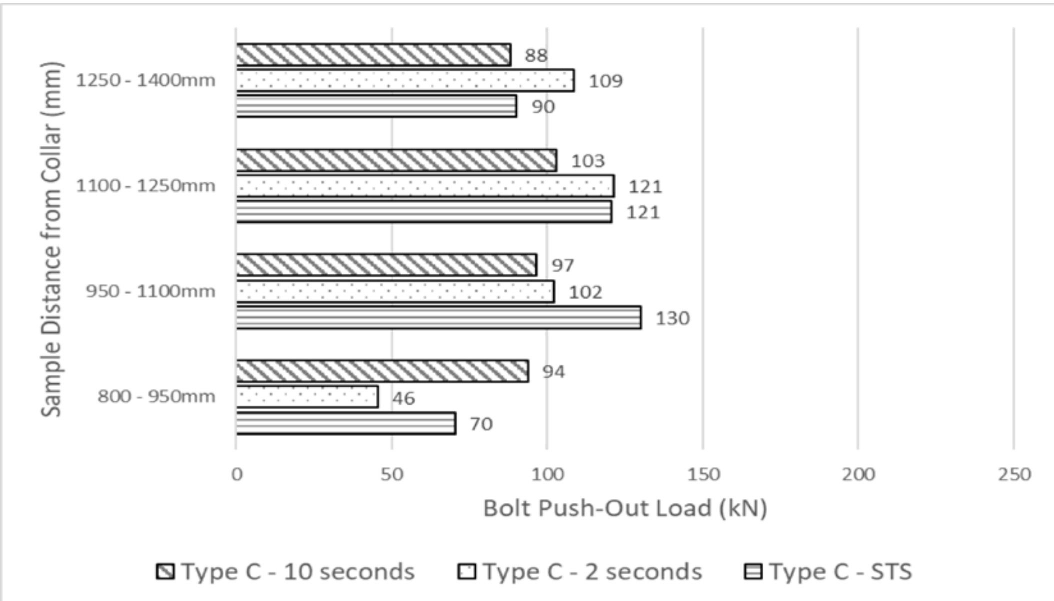

Figure 8: Type C resin curing time and average peak push-out by interval

The influence of resin curing time and bolt pull-through during tensioning was most evident for the Type A resin. The ten second curing time (no tail) produced the highest load transfer, with an approximately 20% reduction with moderate tail length (nine second curing), and an approximately 40% reduction when long tails were produced (five second curing). It is noted, however, that even when long tails were produced using the Type A resin its load transfer outperformed both the Type B and C resins. The influence of resin curing time and bolt pull-through on load transfer was most evident for all resin types in the lowest 150mm interval. When a short curing time was used the lowest 150mm saw a load transfer reduction of approximately 70% for the Type A, 35% for the Type B and 50% for the Type C resins. A potential reason for seeing the most significant reduction in load transfer in the lowest 150mm (and not the other intervals) may be the timing of resin curing along the column. A possible explanation is that the resin at the top of the bolt was not yet in the critical polymerisation phase and thus final strength was less affected when vertical movement of the bolt occurred during nut tensioning. In comparison, the resin at the lowest interval may have been in a different phase of polymerisation more critical to final strength development when tensioning and bolt movement occurred. This theory is supported both by the fast-setting nature of the resin and the additional three or four seconds of resin mixing received by the lowest interval.

CONCLUSIONS

The study aimed to identify the influence of resin cure time on rock bolt load transfer. This was achieved by practical tests that simulate resin-anchored rock bolt installations underground and then laboratory tests to determine the effect on load transfer. The results of testing found that different resin specifications require different curing times to minimise the roof bolt pulling through the resin column during tensioning. The three resin specifications returned some interesting trends in load transfer when using the push test method. The Type A resin returned close to double the load transfer of the Type B and C resins. Notably, the Type A resin was more adversely affected by bolt tensioning before full resin curing than either the Type A or Type B resin, but always returned higher load transfer despite this. Finally, the most adversely impacted bolt interval by premature tensioning was the lowest interval closest to the collar (roof level). This suggests the resin in this lowest interval was at a critical polymerisation stage when tensioning and bolt pull out occurred.

The results suggest mine management and staff should not only consult the manufacturers recommendations for mixing and curing times, but also should evaluate the resin performance in underground installation conditions. There is strong evidence that insufficient resin curing time will result in longer bolt tails and a reduction in load transfer. Conversely, allowing the resin to fully cure will result in shorter bolt (or cable) tails and optimise load transfer in the important upper portion of the bolt. Bolt or cable tail length can easily be observed underground by both operators and supervisors and used to guide optimal bolt installation practice.

REFERENCES

Altounyan, P, Bugden, A, O'Connor, D, and Berry, R, 2003. Developments in Improving the Standard of Installation and Bond Strength of Full Column Resin Roofbolts, In Proceedings of the 22nd International Conference on Ground Control in Mining, WV.

Evans, D, 2016. Spin to Stall Bolting Systems – A Review of Validation Standards, In Proceedings of the Coal Operators Conference, Wollongong.

McTyer, K, 2019. Assessment of key parameters on load transfer during development of a spin-to-stall resin bolt system, In Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2019 Coal Operators Conference, Mining Engineering, University of Wollongong, 18-20 February.

McTyer, K, 2020. The effect of elevated temperature on resin-anchored rock bolts, In Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2020 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February.