Paste 2026 – AB Fourie, M Horta, M Oliveira & S Wilson (eds)

doi:10.36487/ACG_repo/2655_57

From rheology to reality: how intelligent software is transforming backfill design and execution

Jacob Armstrong [a,*], **Jose Quiala** [b]

[a] *MineSmart Solutions, UK*

[b] *Leeville Mine, Nevada Gold, USA*

Abstract

Wilson (2022) described the need to customise backfill specifications for each stope, challenging the long-standing practice of adopting a 'one-size-fits-all' approach. A persistent issue in backfill operations has been the limitations of traditional hydraulic modelling, combined with insufficient understanding of the relationships between strength, time, and rheology. Addressing these challenges, the development of Backfill Pro by MineSmart Solutions provides a transformative tool for engineers and operators, allowing precise tailoring of backfill properties for specific stopes.

By leveraging laboratory and operational QA/QC data, the software determines the rheological properties necessary for reliable pipeline transport and calculates binder requirements to achieve target strength within a defined timeframe. This ensures accuracy in binder dosing, reducing both underdosing and overdosing – a common cost and performance challenge.

This paper builds upon the foundational theory outlined by Wilson (2022), presenting a case study from the Leeville underground gold mine in Nevada. The study demonstrates how Backfill Pro's latest features were applied in practice, showing the software's effectiveness as a data-driven and efficient solution for modern backfill operations.

Keywords: *Backfill Pro, rheology, hydraulic modelling, stope fill, binder optimisation*

1 Introduction

Mine backfilling remains a critical component of safe and efficient underground mining, supporting both geotechnical stability and the economic recovery of ore. Despite its importance, the design and operation of backfill systems have historically relied on generalised specifications and conservative binder dosing strategies, often leading to sub-optimal performance and unnecessary costs.

The complexity arises from the interplay between 3 key factors:

- Rheology: the flow behaviour of the slurry as it travels through the underground pipe (reticulation) network.
- Strength development: meeting geotechnical design strengths within a target curing time.
- Hydraulic transport: ensuring that the material can be delivered without excessive pressure losses, plugging, or excessive wear on pipelines.

The interaction between these factors is shown in Figure 1. In the top right corner is the relationship between uniaxial compressive strength (UCS) strength and the water:binder ratio for 3 different curing periods: 3, 28 and 180 days. A line is plotted at 350 kPa up to each curing period to determine the required water:binder

* Corresponding author. Email address: jacob@minesmart.io

ratio. In the bottom left hand corner is the relationship between yield stress and mass concentration with lines plotted at 150 Pa and 250 Pa, representing a 'thin' and 'thick' material respectively.

The water:binder ratio and the mass concentration can be used to calculate the actual binder content as a percentage of total dry solids, shown in the top left image, for each combination of curing duration and yield stress.

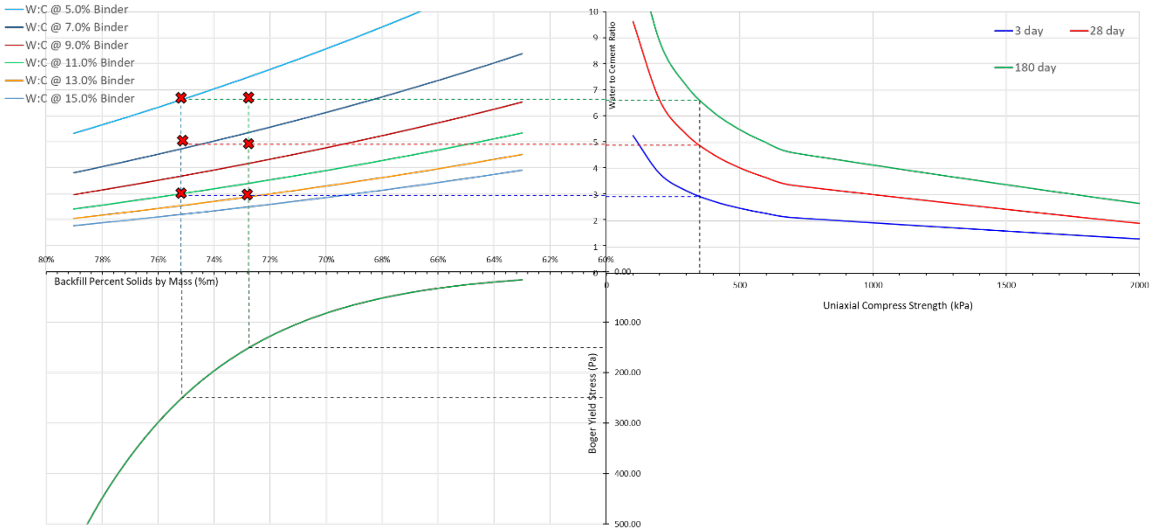

Figure 1 Tripartite graph showing uniaxial compressive strength to water:binder correlation (top right), yield stress to mass concentration (bottom left) and mass concentration to water:binder correlation (top left)

Wilson (2022) highlighted the inefficiencies created by generic backfill recipes or specifications, arguing for stope-specific optimisation. In response, MineSmart Solutions, a software company established by Paterson & Cooke to develop intelligent mining solutions, created Backfill Pro, a platform designed to make rheology-driven backfill design a practical reality for operators.

This paper presents design and calculation logic behind Backfill Pro, recent software innovations, and a case study demonstrating its application at the Leeville Mine, USA, where the system has been adopted to streamline operations and improve performance.

2 Background: challenges in backfill system design

Traditional backfill system design often suffers from:

- Static specifications: many operators rely on fixed design targets across multiple stopes. For example, some mines will have fixed mass concentration targets, ignoring the reticulation length or differences in tailings characteristics, leading to excessive slack flow or potentially blockages. Alternatively, others will have fixed binder percentages for mixes, irrespective of the backfill solids content, ignoring the impact of water on the cured strength, leading to stopes being over or under dosed.
- Reactive QA/QC: quality control programs in conventional systems tend to focus on verifying backfill properties after placement, especially in conjunction with poor recipe creation as described above. This reactive approach leads to operational delays and increases rework or remediation costs.
- Limited integration: hydraulic modelling, rheological characterisation, strength design and mine models are often developed in isolation by different engineers, software platforms, or at different project stages. This fragmented approach means that backfill operators will often be using out of date or incomplete information, leading to inefficient or incorrect mix designs.
- Cost inefficiencies: conventional design conservatism, often a necessity in the absence of modelling tools, leads to unnecessary binder consumption and inflated material costs. Conversely, inadequate

hydraulic predictions can result in line blockages, leading to delays to filling, or excessive slack flow, which adds additional wear to the system, reducing its operational life.

The industry has long recognised the need for a unified approach, but tools capable of integrating rheology, strength, and hydraulics into one predictive framework have been lacking.

3 Hydraulic modelling theory

Paste backfill is typically a time-independent, non-Newtonian, homogeneous fluid that follows the Herschel–Bulkley fluid model shown in Equation 1.

$$\tau = \tau_y + K\gamma^n \tag{1}$$

where:

τ = shear stress (Pa)

τ_y = yield stress (Pa)

K = fluid consistency index (Pa·s)

γ = shear rate (s^{-1})

n = flow behaviour index.

The Herschel–Bulkley fluid model can describe a range of different fluids depending on the input parameters, as described below in Table 1 and shown visually in Figure 2. As paste has both a yield stress and viscosity, it is typically classified as a Bingham plastic.

Table 1 Parameters for Herschel–Bulkley model

Liquid	τ_y	K	n
Newtonian	= 0	= Newtonian viscosity	= 1
Pseudoplastic	= 0	= fluid consistency index	< 1
Dilatant	= 0	= fluid consistency index	> 1
Yield-pseudoplastic	> 0	= fluid consistency index	< 1
Bingham	> 0	= plastic viscosity	= 1

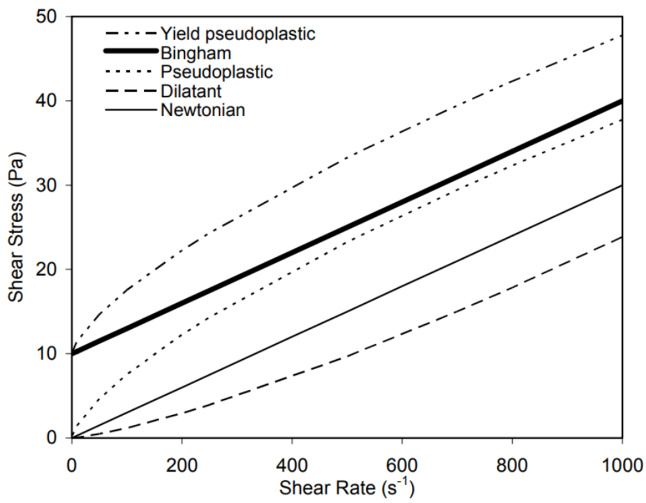

Figure 2 Various time independent liquids described by the Herschel–Bulkley model

As the fluid flow model is a generalised equation for the fluid, it is not directly solvable. The below equation, first presented by Govier & Aziz (1972), is a generalised formula to solve a Herschel–Bulkley fluid.

$$\frac{8V}{D} = \frac{4n}{\tau_o^3}\left(\frac{1}{K}\right)^{\frac{1}{n}}\left(\tau_o - \tau_y\right)^{\frac{n+1}{n}}\left[\frac{\left(\tau_o-\tau_y\right)^2}{3n+1} + 2\tau_y\frac{\left(\tau_o-\tau_y\right)}{2n+1} + \frac{\tau_y^2}{n+1}\right] \quad (2)$$

where:

V = fluid velocity (m/s)

D = internal pipe diameter (m)

τ_o = wall shear stress (Pa)

τ_y = yield stress (Pa)

K = fluid consistency index (Pa·s)

n = flow behaviour index (–).

This is then simplified where n = 1, such as for a Bingham plastic, to the Buckingham equation:

$$\frac{8V}{D} = \frac{\tau_o}{K_{BP}}\left[1 - \frac{4}{3}\left(\frac{\tau_{yB}}{\tau_o}\right) + \frac{1}{3}\left(\frac{\tau_{yB}}{\tau_o}\right)^4\right] \quad (3)$$

where:

V = fluid velocity (m/s)

D = internal pipe diameter (m)

τ_o = wall shear stress (Pa)

K_{BP} = Bingham plastic viscosity (Pa·s)

τ_{yB} = Bingham yield stress (Pa).

This can be solved iteratively for wall shear stress which can then be correlated to pressure loss via the momentum equation below:

$$\tau_o = \frac{D}{4}\left(\frac{\Delta P}{\Delta L}\right)_f \quad (4)$$

where:

τ_o = wall shear stress (Pa)

D = internal pipe diameter (m)

$\left(\frac{\Delta P}{\Delta L}\right)_f$ = frictional pressure gradient (Pa/m).

The model calculates pressure loss for a specific combination of yield stress, velocity, and pipe diameter. Since yield stress can be directly correlated with mass concentration, and velocity is determined by flow rate and pipe diameter, it becomes possible to iterate across a range of mass concentrations for each pipe size at a given flow rate to predict the corresponding friction losses.

Initially, laboratory-derived relationships between mass concentration, yield stress, and viscosity are used to translate the homogeneous flow equation inputs into an optimised mass concentration. As operational data accumulates – specifically, measured pressure losses for known mix recipes – these initial lab-based correlations are progressively refined to reflect site-specific behaviour. Over time, this continuous calibration not only improves the accuracy of pressure loss predictions but also enables users to detect changes in slurry rheology.

3.1 Binder optimisation

As described in Abrams' law (Abrams 1918), the strength of a cementitious product is inversely related to the mass ratio of water-to-binder with the lower the ratio, i.e. less water per unit binder, the higher the strength. Therefore, to minimise the amount of binder required to achieve the desired strength, either the curing time must be increased, which is usually not possibly due to mining schedules, or the amount of water in the backfill must be minimised.

The correlations between the water:binder and UCS of a mix can be determined by lab-based testwork. A range of different mix recipes with varying water and binder content are created, cast into cylinders, and cured for specific intervals. These cylinders are then crushed, with the breaking force then measured for each.

The results of each crushed cylinder can be plotted against its water:binder ratio at each curing period to produce a curve, as shown in Figure 3. A trendline can be plotted through these results to give an equation that describes the relationship for each curing period.

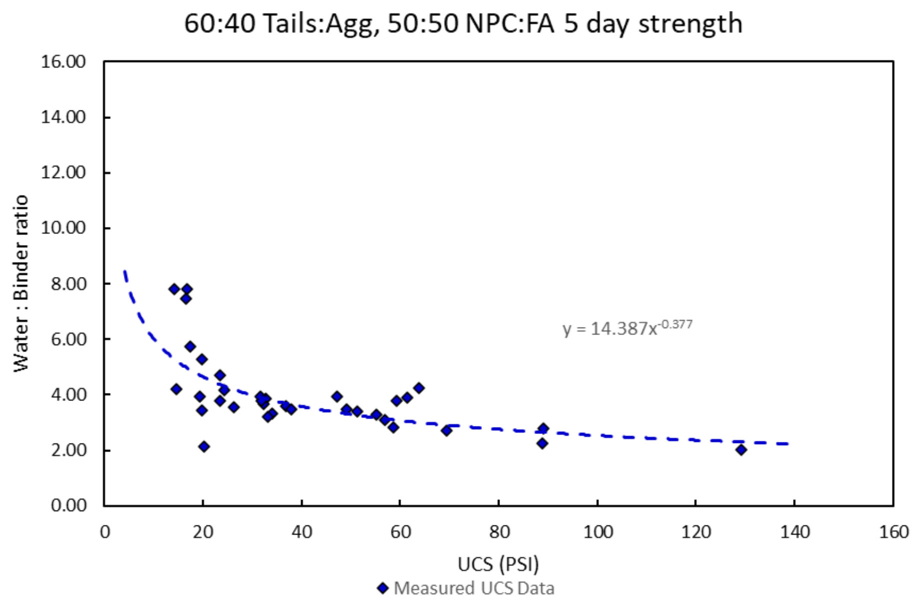

Figure 3 Uniaxial compressive strength versus water:binder ratio for a backfill containing 60% tailings (Tails) and 40% aggregate (Agg), with a 50:50 normal Portland cement:fly ash (NPC:FA) binder (5-day strength)

Typically, this process is undertaken during the study phase of a project and is then further supported by an operational QA/QC system whereby samples of paste are taken from each pour, cured and broken to give up to date correlations. In practice, it is rare for this ongoing QA/QC data to be used to update UCS correlations used in mix designs, missing an opportunity to refine existing correlations or show changing material properties over time.

4 The Backfill Pro solution

Backfill Pro integrates laboratory data, operational QA/QC, and predictive modelling into a single platform. Its core capabilities include:

4.1 Hydraulic optimiser

Backfill Pro can utilise Equations 1–4 to calculate friction gradient for a given mix design, throughput and routing. Starting at the end of pipe with zero pressure, as it is open to atmosphere, the pressure loss is equal to the friction gradient of the spool multiplied by its length. If this is continued for each spool back to the surface, a value for total pressure loss can be calculated which is the pressure required to reticulate the mix through the pipe network.

The pressure loss can then be converted into head and plotted onto a graph above the elevation profile. This is referred to as the hydraulic grade line, the gradient of which is equal to the friction gradient for that pipe. If the pressure rating of the pipe is also plotted in head, the graph can show when a system is over pressured or in slack flow.

The optimiser iterates over various mix designs to find the highest mass concentration that can be pumped within the pumps' operating limits whilst being below the pipes' pressure rating over its full route. This optimised mix will have the highest concentration of tailings returned underground, the least amount of additional water and the least amount of binder, as described below. Figure 4 shows an example of a hydraulic grade line where a line is drawn in slack flow (yellow), overpressure (green), and optimised (blue).

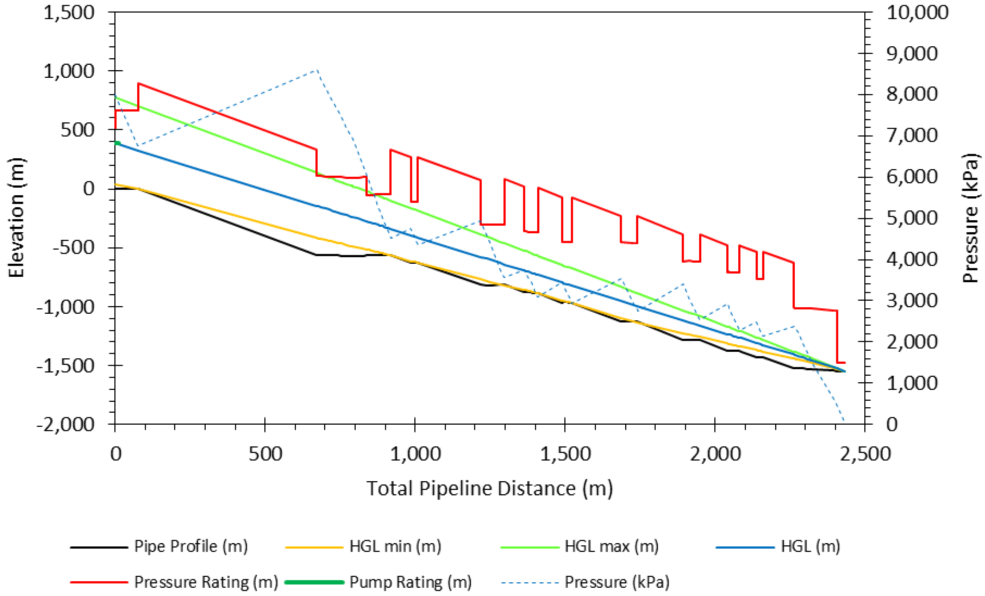

Figure 4 Example hydraulic grade line (HGL)

4.2 Binder optimisation

Backfill Pro calculates the water-to-binder ratio required to achieve target strengths within a specified curing period. The hydraulic optimiser, described above, then determines the maximum feasible mass concentration that remains below the allowable pump pressure and prevents overpressure anywhere within the reticulation system. Because higher mass concentrations correspond to lower water contents, the resulting mix will require the minimum binder necessary to meet the specified strength target while maintaining safe and efficient pipeline operation.

4.3 Wear prediction

As pours get created in Backfill Pro, the software automatically tracks the flow of material through each pipe spool. Users are then able to add wear rate observations from set points around the mine in the form of thickness measurement of different pipes. These can be used to determine wear rates at each observation point that can then be applied to other parts of the system, improving confidence in pipeline maintenance.

As pours are scheduled in advance, perhaps as a function of mid-term planning, the wear for each spool can be forecast based on the planned backfill flows through different sections of the system. This improves preventative maintenance scheduling and reduces reactive failure maintenance which is disproportionately more costly. Regular wear tracking can also provide an indication of material changes which may also be observed in other parameters such as rheology.

4.4 Quality assurance and quality control

As outlined in Section 3.1, maintaining up to date correlations between the water:binder ratio and UCS is essential for accurately determining binder requirements. Equally important is ensuring that the backfill has developed sufficient strength prior to exposure during subsequent stoping operations. Traditionally, these UCS measurements are recorded by laboratory teams and reviewed periodically by backfill engineers to verify compliance with design criteria. Often, however, the data are recorded and then only interrogated after a failure or unplanned event, missing the opportunity to make progressive system improvements.

Within Backfill Pro, QA/QC data can be entered directly by laboratory personnel and automatically indexed against each individual pour. This enables continuous refinement of the UCS to water:binder correlations as new data are accumulated, allowing users to observe long-term trends, identify drifts in material behaviour, and detect outliers that may indicate process variability.

Because UCS results are spatially linked to their corresponding pours, operators can readily visualise historical QA/QC data within the context of the mine layout. The system also indicates if any recorded strengths fall below the specified design threshold, ensuring that low strength zones are quickly identified and addressed before they impact mining operations.

4.5 Responsive software

Backfill Pro provides a dynamic environment where operators can simulate and evaluate a range of operational scenarios in real time. Leveraging its integrated data foundation, the software allows users to test the impact of varying binder types, tailings characteristics, and curing periods on both hydraulic and strength performance outcomes.

Further to this, Backfill Pro also allows users to model changes to the reticulation network such as different routes or different pipes. This could be due to blockages in part of the network or additional length of pipes, such as friction loops, to increase friction at the bottom of borehole to reduce slack flow. Additionally, different pipe types can be modelled to assess the impact that increasing or decreasing the inner diameter pipeline has on friction loss or how a different pressure rated pipe may allow a larger operating range.

By drawing upon validated laboratory correlations, historical pour data, and live plant measurements, Backfill Pro can predict how each scenario will influence pressure losses, achievable mass concentrations, and resulting UCS. This capability enables backfill engineers to assess trade-offs such as reducing binder content versus increasing curing time before implementing changes in the field.

Through these tools, Backfill Pro transforms the decision-making process from reactive adjustment to proactive design, helping operators maintain optimal performance across varying material inputs, plant conditions, and mining schedules.

4.6 Data available for all

All data within Backfill Pro, including laboratory results, backfill recipes, stope details and completion notes, are stored within a centralised database, ensuring consistent access and availability across teams.

Operators, engineers, and management personnel can generate and access data that link pour-specific QA/QC results directly to the corresponding stopes, providing a clear audit trail for compliance and performance verification. Visual dashboards and spatial data allow users to contextualise results within the mine layout, improving transparency and cross-departmental collaboration. This includes an approval process for each pour, giving managers access to all necessary information while providing a clear audit trail for future reviews.

5 Case study: Leeville

5.1 Introduction

The Leeville underground gold mine, located on the Carlin Trend in northern Nevada, USA, is one of Nevada Gold's key underground operations, producing ore from a series of deep, high-grade deposits. Situated approximately 32 km northwest of Carlin, Nevada. The mine is accessed via shaft and decline systems extending to depths exceeding 1,200 m. Like many mature underground mines, Leeville relies on a combination of longhole stoping and paste backfilling to maintain ground stability, minimise dilution, and maximise ore recovery.

The mine's technical teams make extensive use of Deswik for mine planning and design. The platform contains critical spatial data, including stope layouts and reticulation routes. However, hydraulic analysis is currently performed separately in Excel, requiring engineers to manually transfer pipe lengths, diameters, and elevation data from Deswik into calculation spreadsheets. This disconnected workflow increases the potential for data entry errors and makes it difficult to iterate or validate hydraulic predictions efficiently.

Similarly, QA/QC data for paste curing is captured and maintained independently in a separate spreadsheet, with results manually cross-referenced against stope schedules and binder recipes. As a result, engineers and operators must perform manual lookups when designing paste recipes or reconciliations to verify compliance or diagnose issues, slowing decision-making and limiting visibility across teams.

5.2 Backfill Pro integration

Backfill Pro was rolled out to Leeville mine in July 2024. All its reticulation data was added from the existing Excel system, aligning Backfill Pro with the current hydraulic modelling. This gave Leeville, for the first time, direct visualisation of how their Excel-based reticulation was modelled. This was later compared and adjusted to a direct import from Deswik of the current pipe network, ensuring that both hydraulic model and actual network were identical.

5.3 Improvements

Historically, Leeville relied on binder percentage as the primary control metric for backfill design and QA/QC. While simple to track, binder percentage does not account for the effect of water content on curing and strength development, as described in Section 3.1. The backfill rheology was adjusted to suit the reticulation routing to the stope by changing the water content, but without any way of determining the revision to binder dose. This often led to overly conservative binder additions, resulting in higher costs and variable strength outcomes.

Figure 5 shows the historic UCS data points for various binder percentages, shown in blue, as measured by Leeville. To determine the binder percentage to use, the UCS values for each binder percentage were averaged, shown in red on the same graph.

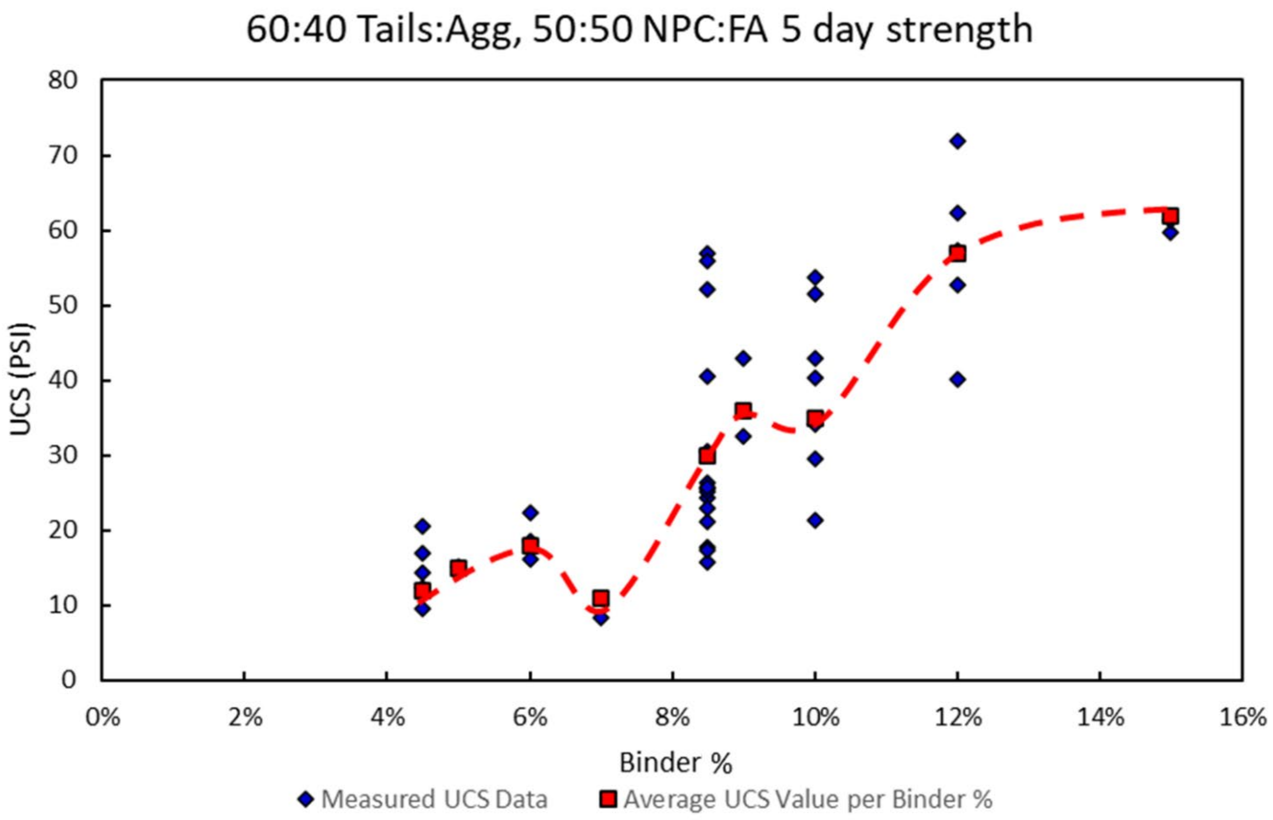

Figure 5 Historical 'best fit' of uniaxial compressive strength (UCS) data against binder % for a backfill containing 60% tailings and 40% aggregate (Agg), with a 50:50 normal Portland cement:fly ash binder (5-day strength)

The problem with this method, as highlighted by the graph, is that there is a large variance for each binder percentage due to the effects of water on the curing strength, and that some averages show lower UCS strength than a lesser binder, i.e. 7% binder results in 10 psi while 6% binder is 18 psi.

By reframing mix designs and QA/QC analysis around water:binder ratios, the mine now captures a more accurate picture of expected UCS development. Figure 3 shows the same data as Figure 5 but reframed to present water:binder ratio instead of binder percentage. A strong correlation is now shown and the variance seen in Figure 5 is gone. The equation of the best fit curve can then be used to accurately predict the required water:binder ratio for a given UCS value, which in combination with the mass concentration, can be used to calculate the binder percentage.

This approach enables engineers to optimise mixes without overdosing, reducing unnecessary binder consumption and without underdosing, causing delays to the mining schedule while improving forecast accuracy.

A major challenge for Leeville, common across the industry, was the fragmentation of backfill data. Planning schedules, mix designs, QA/QC test results, and reticulation models were often kept in separate spreadsheets or departments, making it difficult to validate performance, reconcile design targets with field results, or make rapid adjustments when conditions changed.

Backfill Pro addressed this challenge by consolidating all relevant data into a single, accessible platform. Engineers, QA/QC teams, and plant operators can all access current stope schedules, target mix designs, test results, and hydraulic models in one interface. This transparency ensures that actual UCS test data can be directly compared against design requirements, closing the loop between planning and execution. The result is a more agile, collaborative process where mix designs can be adjusted confidently, and production and cost forecasts can be generated with greater reliability.

This unified, data-driven approach has not only improved confidence in achieving strength and schedule targets but has also streamlined communication between teams. With all relevant information accessible and auditable, Leeville can focus on running its backfill system rather than searching for data and ensuring sustainable long-term performance.

6 Discussion

The integration of rheology, strength development, and hydraulic modelling into a single intelligent platform represents a step-change in backfill system design and operation. Backfill Pro enables engineers to move beyond disconnected spreadsheet-based workflows, allowing system behaviour to be evaluated holistically and visually. However, the effectiveness of this integration remains dependent on the quality of input data. Accurate laboratory testing, representative rheological characterisation, and disciplined QA/QC processes are essential to ensure that model outputs remain reliable. Without ongoing calibration against plant and underground performance, the benefits of the platform may be diminished.

Table 2 shows a comparison of a range of recently completed stopes at Leeville. As the mine previously used Paterson & Cooke’s hydraulic model for rheology calculations, the mass concentration is consistent across approaches. The primary improvement offered by Backfill Pro lies not in altering these fundamental inputs, but in enabling rapid visual verification of reticulation routes, simplified testing of alternative delivery paths, and straightforward expansion into new mining areas. These capabilities significantly reduce the effort required to assess operational changes and support more proactive decision-making.

The most significant difference between the 2 approaches is observed in binder content selection. Under the previous workflow, operators tended to adopt conservative binder percentages due to the large variance in predicted strengths at small changes in binder content, as illustrated in Figure 5. For example, when targeting a UCS of 22 psi at 5 days, the legacy method predicted 18 psi at 6% binder, 11 psi at 7%, and 30 psi at 8.5%. This variability resulted in the routine selection of 8.5% binder, even though, depending on mass concentration and curing conditions, a binder content closer to 6% may have been sufficient.

This conservatism is reflected in Table 2 which shows consistently higher binder contents selected using the Excel-based approach compared to Backfill Pro. When applied across multiple stopes, these differences translate directly into material cost savings, assuming a binder cost of USD 130 per tonne. Importantly, Backfill Pro enables these reductions while maintaining required strength performance, reducing reliance on overly conservative design margins.

Table 2 Comparison of Backfill Pro and Excel results, assuming a binder cost of USD 130/tonne

Stope	Mass concentration (%)	Water:binder	Curing duration days	Strength (psi)	Backfill Pro binder (%)	Excel binder (%)	Stope volume (ft^3)	Cost saving (USD)
1	77.6	3.4	7	46	8.5	11.0	208 545	29,544
2	77.9	6.3	56	44	4.5	6.0	230 000	19,625
3	76.4	3.1	7	59	10.0	12.0	114 700	12,592
4	75.9	3.7	180	151	8.5	9.5	66 100	3,575
5	78.5	3.2	14	80	8.5	9.5	83 500	4,825

Despite these advantages, opportunities remain for further enhancement of the platform. Future developments could include tighter coupling between real-time plant data and model calibration, automated sensitivity analysis to quantify uncertainty in binder selection, and expanded support for non-ideal operating conditions such as segregation, temperature effects, or transient events. Incorporating probabilistic design tools could further assist operators in balancing risk and cost when selecting binder contents.

For the Leeville team, Backfill Pro's ability to bridge rigorous engineering theory with day-to-day operational requirements was a key driver of success. The platform has demonstrated that meaningful cost reductions and improved design confidence are achievable, provided there is sustained commitment to data quality, validation, and continuous improvement of the underlying models.

7 Conclusion

Traditional backfill design practices that rely on fixed binder contents and simplified hydraulic assumptions can lead to inconsistent strength performance, increased operational risk, and elevated costs. Backfill Pro addresses these limitations by integrating rheology, hydraulic modelling, and strength prediction into a single, data-driven workflow. By establishing mix designs according to water:binder ratio, mass concentration, and curing strength, the software enables stope-specific optimisation rather than broad, conservative specifications.

The case study at Leeville demonstrates that this approach delivers tangible benefits. The transition from binder-percentage-based control to water:binder driven design reduced variability in UCS outcomes and improved confidence in achieving target strengths within required mining schedules. At the same time, the system's ability to identify the highest feasible mass concentration for each stope resulted in meaningful reductions in binder consumption, translating directly into operational cost savings. Equally important, centralising QA/QC, reticulation data, and pour history has improved communication between engineers, operators, and planning teams, enabling proactive decision-making rather than reactive adjustment.

Acknowledgement

The authors wish to thank Leeville and the backfill operations team for their collaboration and insights, as well as Paterson & Cooke for their technical development of Backfill Pro.

References

Abrams, D 1920, 'Design of concrete mixtures', *Minutes of the Annual Meeting of the Portland Cement Association*, Structural Materials Research Laboratory, Lewis Institute, Chicago.

Govier, G & Aziz, K 1974, 'The flow of complex mixtures in pipes', *Journal of Fluid Mechanics*, Van Nostrand Reinhold Company, New York.

Wilson, SC & Leacy, PWJ 2023, 'Optimal paste backfill specification development', in GW Wilson, NA Beier, DC Sego, AB Fourie & D Reid (eds), *Paste 2023: Proceedings of the 25th International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 294–306, https://doi.org/10.36487/ACG_repo/2355_22