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Efficient paste mix designs using new generation backfill admixtures: perception versus reality

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Abstract

Backfilling mined out stopes with cemented paste has become the standard in most modern, long-hole stoping and cut-and-fill operations globally. The implementation of large-scale paste production plants and efficient underground paste reticulation systems contributed significantly to maximised ore extraction, higher levels of mine-scale geotechnical stability, larger degree of automation and last, but not least, to a more conscious management of mine processing waste. However, paste backfilling comes at a cost.

Binder costs alone amount to 70–80% of total operating costs of paste plants depending on the strength requirements and characteristics of tailings used for backfilling and it is not uncommon that underground paste filling contributes up to 20% of the overall cost structure of an underground operation. With a view towards improving the paste mix designs and keeping cement consumption under control, new generation paste backfill admixtures have been developed over the past years. The mine backfill industry can be compared to the concrete industry 40 years ago, when high performance admixtures started to emerge for landmark projects, where exceptionally high concrete qualities and specific, fresh concrete properties were required (Aitcin & Wilson 2015). These high range water reducers quickly transformed the construction industry and pushed concrete applications to new, previously unknown limits.

This paper intends to give an overview of the reality of admixtures in the mine backfill industry and their performance and justification in modern paste backfill plants with pump driven reticulation systems. Data from different paste plants around the globe has been compiled for this study, covering different deposit types, strength requirements and pumped paste mix designs. The study illustrates the powerful effect paste backfill admixtures can have on standard paste mix designs and their potential to reduce binder consumption substantially by remaining within the required strength and workability limits of the paste to improve the overall cost structure of backfill operations.

Keywords: *paste fill, admixtures, binder, optimisation, mining, backfill, early strength, cycle time, efficiency, Sika, mining, underground, rapid development, cement saving, cement reduction, cost performance, mix*

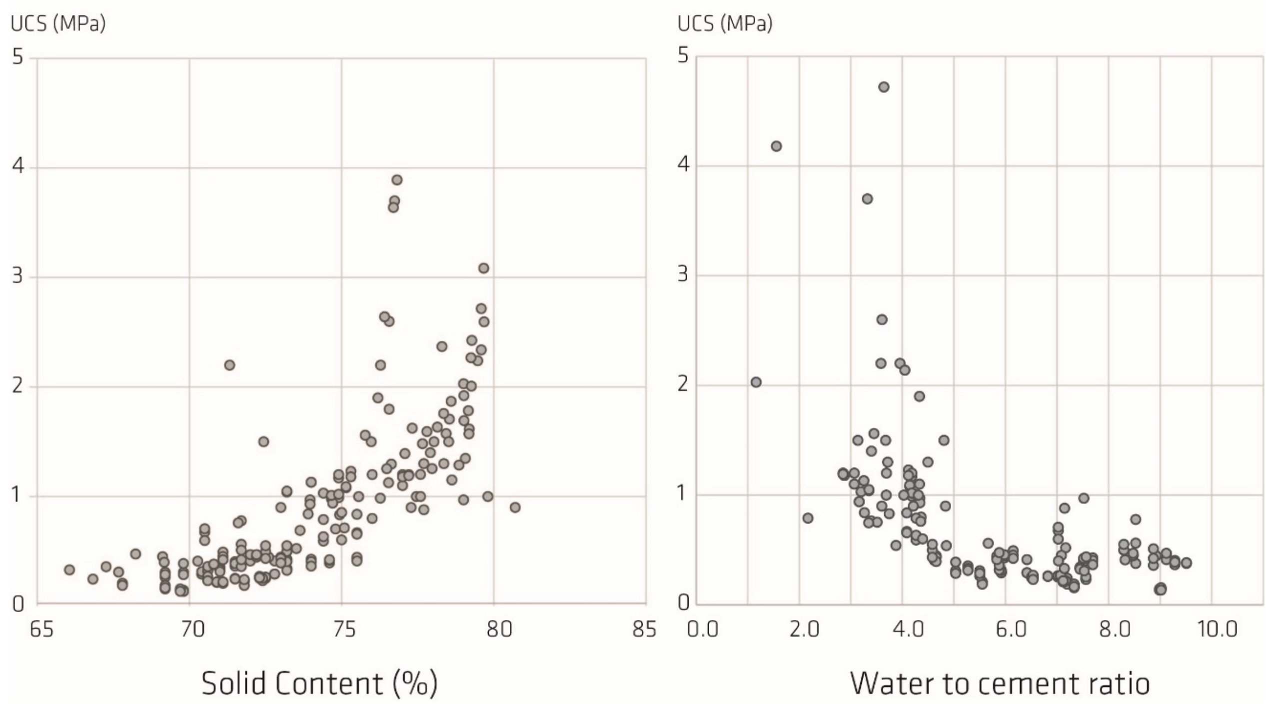
1 Introduction

High range superplasticizers—with the ability to significantly reduce water out of a given concrete mix while maintaining the workability but strongly influence the strength and durability characteristics of concrete—were introduced to the global construction industry by the late 1990s (Ramachandran et al. 1998). Today, the fundamental reason to develop and utilise such superplasticizers in nearly every day, mass-produced concrete is the strong and lasting effect of a lower water content, or lower water-to-binder ratio to be more specific, on concrete. As an example, in order to produce a 25 MPa concrete, it is necessary to use around 300 kg of cement without the use of an admixture. In contrast, when a 75 MPa concrete is produced, 450 kg of cement is needed plus some litres of superplasticizer to reduce the water-to-binder ratio. Hence, while using only 1.5 times as much cement, the strength of the concrete triples (Aitcin & Flatt 2016).

Similar to concrete, cemented paste is a cementitious system too, sharing similarities with concrete. The fact that reducing the water-to-binder ratio in concrete has a positive effect on strength development at a given cement content and is even more pronounced in a water-saturated or a water-oversaturated system like a cemented paste, where the water to binder ratio is of an order of magnitude larger than in concrete. Reducing water in such systems has a very strong effect on the strength development of the paste fill (Erismann et al. 2016).

Today, this simple principle, which is illustrated in Figure 1a, has only partly found its way into the mine paste backfill industry where the use of such admixtures is not standardised and very often, no admixtures are used at all, in order to improve the cost performance of paste backfill (Erismann et al. 2017). Figure 1b illustrates that oversaturated paste mixes of water-to-binder ratios of 5 and higher have a poor correlation between the added amount of binder and strength development. This obviously represents a challenge in meeting strength requirements in wet paste mixes.

This paper should help to address this shortcoming by presenting three case studies from mines where admixtures are used and have a very positive effect on the quality and performance of the pumped backfill system. The three mine sites are completely unrelated to each other from a geographical, mineralogical, structural and ore-forming process point of view. By choosing such different cases, the authors would like to emphasise how important a proper admixture selection is by looking at the mineralogical and physical footprint of these deposits and hence, the generated tailings which are the base of the produced backfill mix. By far the most common goal while using admixtures is to increase the solid content of the fill, which in turn should have a positive effect on strength development, as illustrated in Figure 1. As yield stress is positively correlated with the solid content of the fill, e.g. the higher the solid content, the higher the yield stress (Silva 2017; Sofra 2017), increasing the solid content of the fill is expected to have an effect on the pumping pressure within the reticulation system of the mine. However, actual pressure data from the mines could show that this is not necessarily the case. In combination with admixtures, a pressure reduction can be achieved while strongly increasing the solid content at the same tame. This will be illustrated using the three case studies.



(a) (b)

Figure 1 (a) Paste solid content versus uniaxial compressive strength. Data from several paste plant projects; (b) Relationship of water-to-cement ratio and the uniaxial compressive strength

2 Methodology

For this paper, data from three different paste plants was collected over a period of three years. The mines where these paste plants are installed are located in North America, West Africa and Europe and are hosted by three different deposit types. The mine located in North America is a typical Carlin-type deposit. The mine in Europe is widely referred to as a sedimentary exhalative (SEDEX) type deposit and the one in West Africa is a gold deposit of orogenic type which is very common in this part of Africa (Partington & Williams 2000). Despite the differences in terms of ore-forming processes, alteration mineralogy, mineralisation type and host lithology, these deposits also share similarities to a certain extent.

Particle size distribution, as well as full phase mineralogical composition analyses, were conducted at the Sika Technology laboratories in Zürich, Switzerland. Mineralogical analytics were done using scanning electron microscopy to identify and confirm major and minor mineral phases and then quantify them using X-ray diffraction. All mines utilise large tonnages of cemented paste fill and have different requirements in terms of early and final strength development as well as workability of the fill. Strength of the fill was tested according to the mine’s specifications, usually testing the uniaxial compressive strengths after 7, 14, 28 and 56 days. As common in many mines, workability is tested using standard concrete slump cones to measure the slump of the produced paste. Workability of the paste is related to yield stress and measuring the slump has proven to be a viable method to get an indication of the actual yield stress of the paste (Silva 2017). These workability limits often range in the 7–10 in slump range (17–25 cm) (Erismann et al. 2017). Measuring the slump and final flow table spread is appropriate for an indication of the actual yield stress (Silva 2017), this test method remains the most common at mine sites. Special attention was also given to the behaviour of pumping pressure, both on surface and underground where possible and where the reticulation system is equipped to measure such data.

3 Admixture selection

Selecting the right admixture for a certain paste is crucial to optimise the cost performance of a paste backfill system (Erismann et al. 2017). This can be illustrated based on the chosen ore deposit types described in Figure 2 where the simplified geological sections are shown. These deposits show the following characteristics:

1. SEDEX polymetallic (lead, zinc, silver, copper) deposits in Europe: these deposits are derived from an ancient, sub-seafloor, hydrothermal vent that deposited metals upon cooling and redox reactions of hydrothermal brines in contact with seawater on, or close to, the seafloor (McKibben & Hardie 1997). There is usually a distinct footwall alteration associated with these deposits. In this case, it is an intense potassic alteration, rich in Na_2O and K_2O with associated minerals such as muscovite and biotite.

2. Orogenic, shear-hosted gold lode deposits: This deposit type is a major host for gold globally. In this particular case, the gold bearing shear-zone is defined by a highly strained and brecciated narrow zone that is heavily altered at either side of the shear including alteration products such carbonate, silica, albite, pyrite, chlorite and hematite.

3. Carlin-type, limestone/dolomite hosted gold deposit: This deposit type is characterised by the calcareous dominated host lithology and the distinct alteration features that can directly be linked to hydrothermal fluids responsible for the introduction of gold alongside alteration features such as carbonate dissolution, argillic alteration and silicification (Hausen & Kerr 1968; Radtke et al. 1980; Bakken & Enaudi 1986).

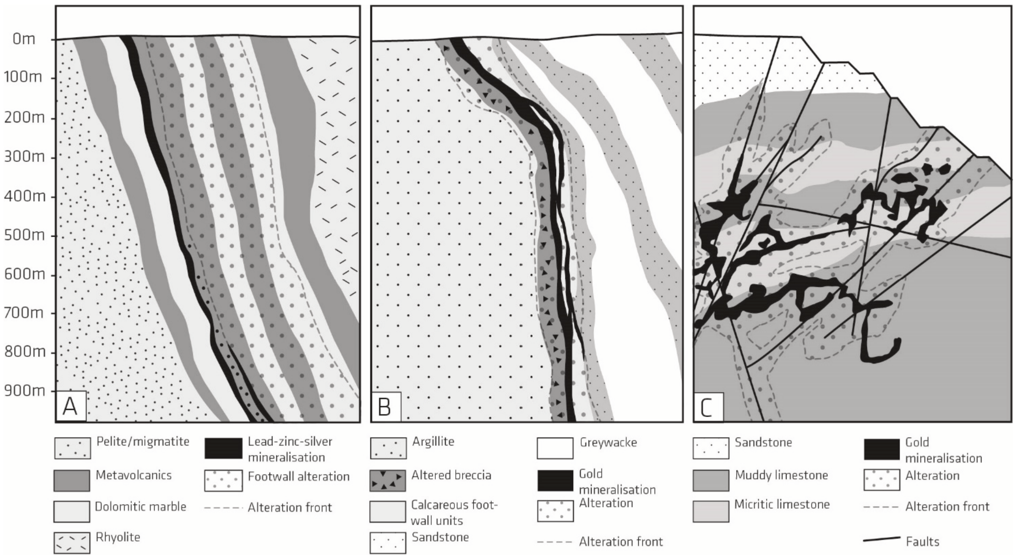


Figure 2 Simplified geological sections for the three deposits (A, B and C) showing main lithological units as well as extent of alteration

The alteration mineralogy of these systems is important with regards to the effectiveness of the used admixture. The effectiveness can be fairly easily tested by performing yield stress measurements (using a viscometer or rheometer) or by measuring the slump and flow table spread of different admixtures with a certain paste. A strong rheological impact on a given paste correlates with a strong plastification and hence a large increase of the flow table spread and slump. Furthermore, much lower yield stresses for both rheometer and viscometer measurements should result. This selection process resulted in three different admixture types that were used for these deposits. The exact selection criteria will not be described in this paper, however, the presence of phyllosilicates in all three deposits, as well as the dominating calcareous phases in deposits B and C, are strongly influencing the compatibility of certain polymers for these specific tailings. An overview of the mineralogical composition and hence the overall chemistry of the deposits is shown in Table 1, where percentage composition for a certain mineral phase is given. Particle size distributions of the three different mine tailings is shown in Figure 3. Mine A has the coarsest tailings and mine C has the finest sieve fractions with 80% of tailings passing the 50 µm fraction.

Table 1 Mineralogical composition of the three deposits. Values indicate the volume percentage of contained minerals. Alteration minerals are indicated in bold black. Minerals that might originate from the original host lithology, as well as an alteration product, are indicated by the blue colour

		A: SEDEX type	B: Orogenic type	C: Carlin type
Quartz	SiO_2	31.4	25	51.5
Sulphides	FeS_2, $CuFeS_2$, FeS, PbS, ZnS, FeAsS	1.9	1.3	
Muscovite	$KAl2AlSi_3O_{10}(OH)_2$	**8**		**11.9**
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	**10**	**1.3**	
Chlorite	$(Fe,Mg,Al,Zn)_6(Si,Al)_4O_{10}(OH)_8$	**7.2**	**5.9**	
Calcite	$CaCO_3$		1.4	15.8
Dolomite	$CaMg(CO_3)_2$		15.7	15.7
Orthoclase	$KAlSi_3O_8$	22.8		
Albite	$NaAlSi_3O_8$		47.8	
Diopside (Mg-rich Pyx)	$CaMgSi_2O_6$	14.2		
Cordierite	$Mg_2Al_4Si_5O_{18}$	**5.5**		
Hematite	Fe_2O_3		**1.7**	**3**
Illite	$(K0.65)Al_2(Si_3Al0.65)O_{10}(OH)_2$			**1**
Bassanite	$CaSO_4$ 1/2H_2O			7.1
Admixture type		**A**	**B**	**C**

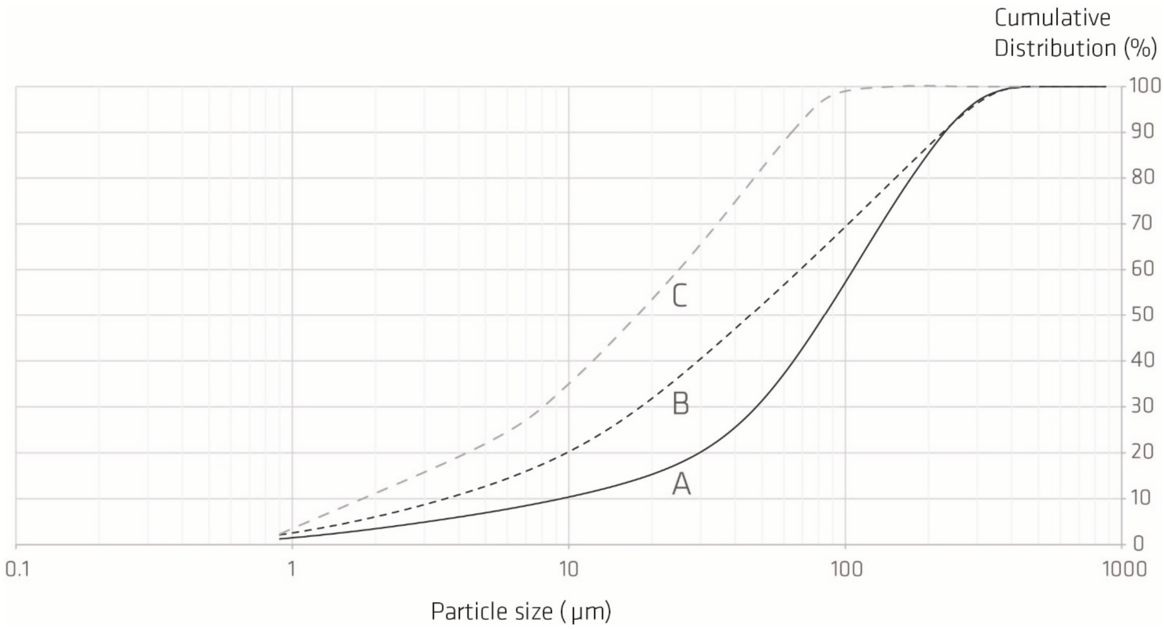


Figure 3 Particle distribution of the three mine tailings used for this study

4 Influence of admixtures on paste: results

4.1 Solid content

Once a suitable admixture has been identified for a paste backfill project, the reaction of the paste plant—once the admixture is dosed into the batched- or continuous-filling process—is usually a strong decrease of torque in the twin shaft mixer. This decrease in torque is indirectly measured by the decrease in energy that the mixer draws to mix a certain volume of paste contained in the mixer. Modern paste plants have a fixed energy range that the mixer is supposed to work in, in order to provide a paste consistency that is suitable to pump through the paste reticulation system. Once the energy draw falls below this pre-defined limit, water addition is automatically reduced. The same occurs once energy levels increase above the pre-defined limit. If this is the case, water is added to the mix in order to bring the workability of the paste into the desired window. As admixtures usually reduce the yield stress of paste significantly, mixing is usually easier once the admixture is added, the energy level drops, water is being reduced and the solid content goes up.

This rapid interaction is illustrated in the next section where the increase in overall solid content of the paste is illustrated once the admixture dosing starts.

4.2 Pumping pressure

This section will show data from the three paste backfill plants. It is real time data over a certain testing period where the admixture was dosed into the system. Continuous dosing pumps were used to dose a specific amount of admixture that was pre-defined during extensive lab trials in order to achieve a certain water reduction and hence, the paste mix gains strength. Figures 4, 5 and 6 display water addition to the mixer, behaviour of pumping pressure on surface and underground, and admixture dosage and development of the solid content of the mix during the trial period. The labels along the X-axis refer to the time during the trial (hour on the clock). The more admixture is dosed into the system, the higher the reduction of added water. In some cases, the water addition stops completely and the solid content of the paste approaches the solid content of the filter cake. Additional values indicated along the X-axis indicate samples that have been taken to evaluate the uniaxial compressive strength after 28 days. Strength values are shown in MPa below the label. These strengths were derived from standard strength testing procedures defined by the respective mine site, taking cylinder-shaped samples and testing them after 28 days for uniaxial compressive strength at the mine site. The recorded data from the paste plants generally showed stable line pressure or decreasing line pressure after the plant reached a new equilibrium with a steady admixture dosage. This was generally the case for the above ground pressure as well as underground line pressure. The pressures decreased despite the increase in solid content due to the strong water reduction, as shown in Figures 4, 5 and 6. The admixture dosage ranged from 0.4 to 2% by weight of cement and the dosed volume is indicated as litres per minute in the below graphs (Figure 5 and 6). Pressure spikes do occur once admixture dosing starts and the plant reacts on the lowered yield stress, which is indicated by the lower torque value of the mixer with instant water reduction as seen in Figure 6. These pressure spikes during the start-up phase are most likely related to the insufficient regulation of water addition/reduction into the mixer. This is discussed in more detail during the discussion of this paper.

Cement content for A, B and C plant trials were 6% for A (Figure 4), 5% and 12% for B (Figure 5) and 8% for C (Figure 6). Workability of the paste was measured using a standard slump cone. At all three sites, this slump test has been used to track workability of the paste throughout the observation span. Remaining within the defined slump limits was a requirement for all sites and was maintained at all time.

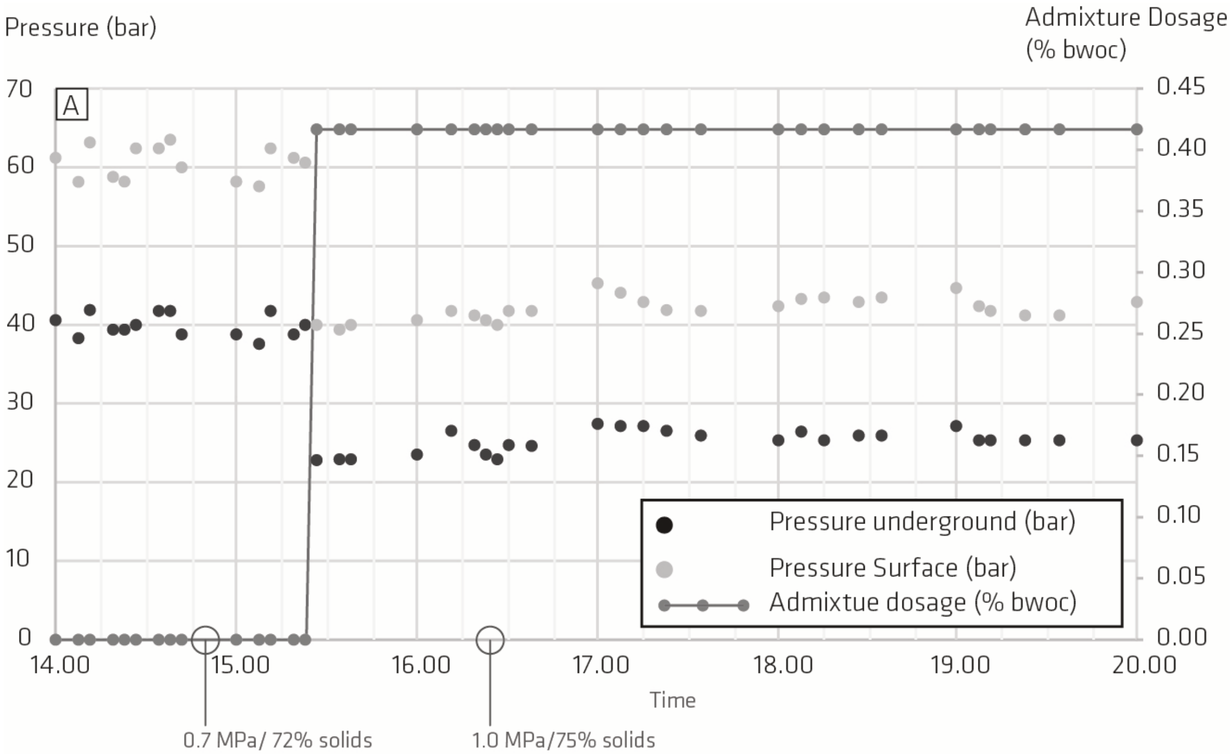


Figure 4 Development of pumping pressure for the sedimentary exhalative (SEDEX) deposit (Project A) for paste line pressure on surface and underground, before and after the dosing of admixtures. Results are for a paste mix containing 6% cement. Samples for 28 days uniaxial compressive strength were taken from a paste with a 72% solid content and from a 75% solid content

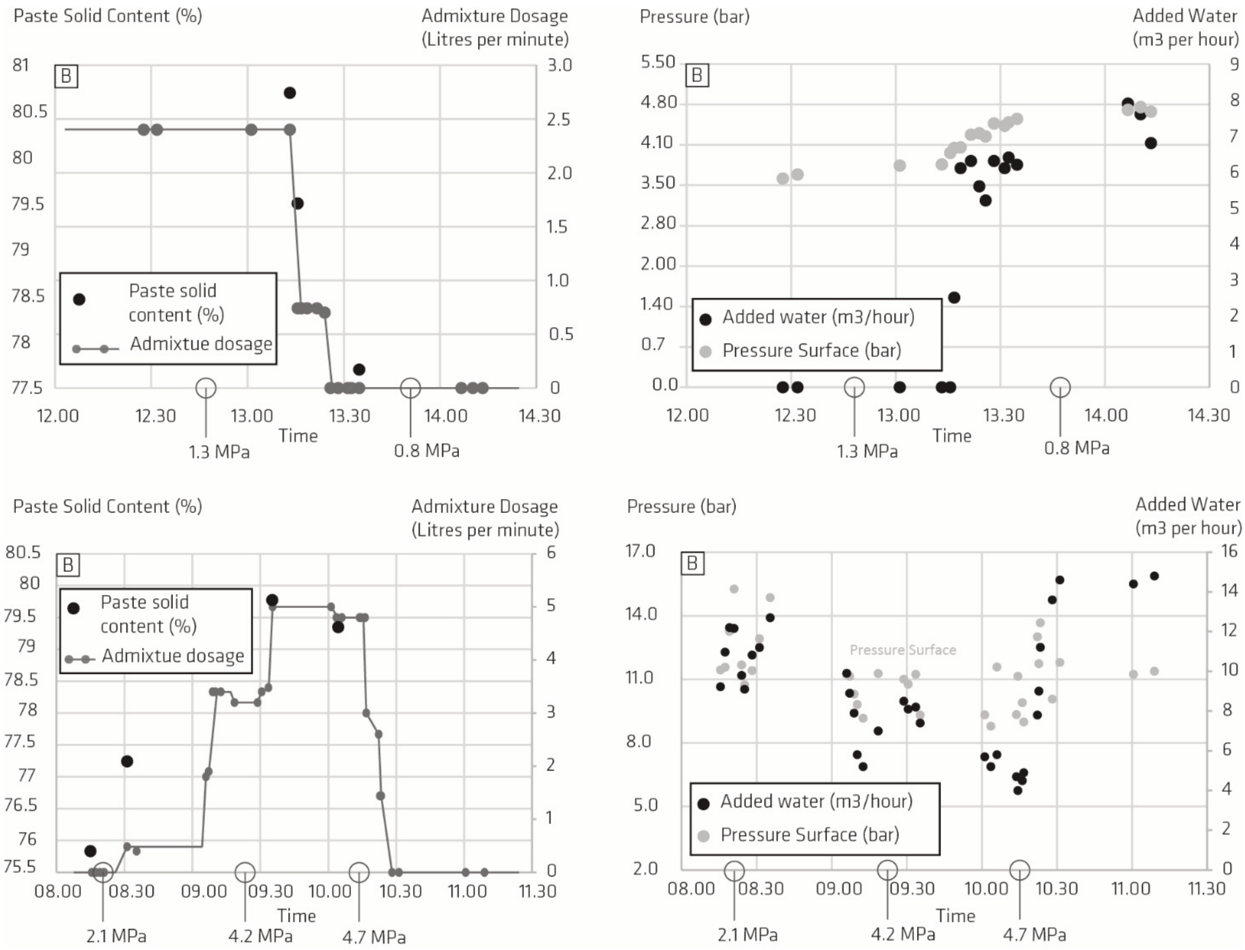


Figure 5 **Development of pumping pressure on surface for the orogenic gold project (Project B). Results are for a paste mix containing 5% cement (upper diagram) and 12% cement (lower diagram). Upper and lower diagram shows admixture dosage and corresponding solid content, water and pressure data**

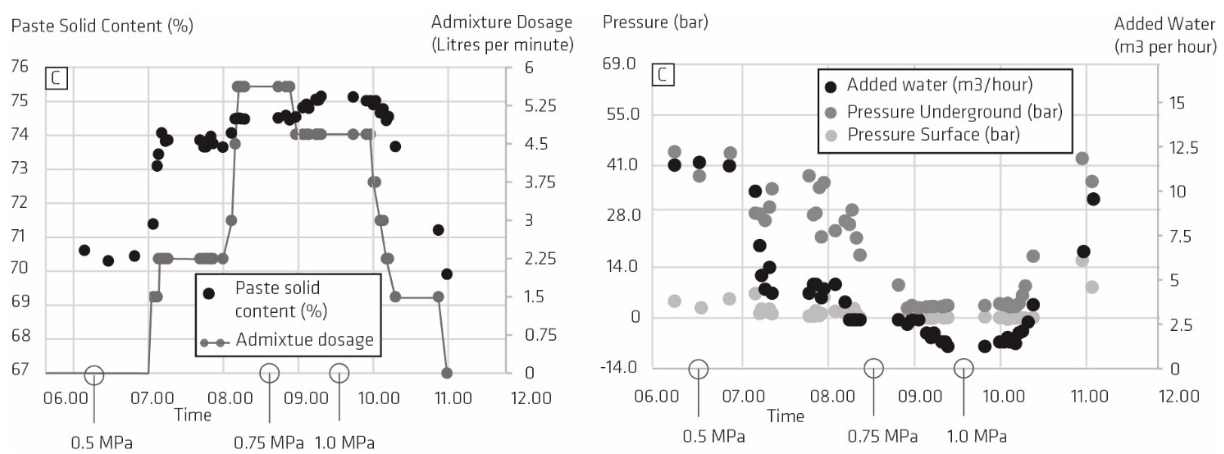


Figure 6 **Development of pumping pressure on surface for the Carlin-type gold project (Project C) with and without dosing of admixtures. Results are for a paste mix containing 8% cement**

4.3 Uniaxial compressive strength

During the trials, the plants were running at different cement additions and varying admixture dosages. The admixture dosage always targeted a maximum water reduction while maintaining the workability limits (specified slump range of the mine). From the three plant trials, A, B and C samples were taken on a regular basis over the whole period of the trials. These samples were taken from the continuous mixer once the mix stabilised at the given input parameters such as admixture dosage, water addition and line pressure. Standard plastic cylinders were filled with paste, sealed and stored in the climate chamber for the specified time. For each sample, two control samples were taken to ensure statistical confidence. Uniaxial compressive strength testing took place at the mine site following the standard quality control procedure of the mine. During the trial period, mixer energy limits have not been altered. Hence one could assume that strength results from the various paste mixes correspond to similar yield stress levels.

The strength results from all three sites are illustrated in Figure 7. The dotted line represents strength results shown along the Y-axis for different cement additions shown as weight percent of cement along the X-axis. Reducing the water has a strong effect on strength development at a given cement content in the paste. As already seen in Figures 4, 5 and 6, a strong water reduction in the paste mix very often results in doubling of the strength at a given cement addition. The increase in strength is especially pronounced at higher cement dosages, as can be seen in Figure 7. Early strength development (seven days strength) have been substantially higher when using admixtures compared to the reference samples without admixtures. However, these results are not included in this study. For higher cement additions such as paste fill mixes of 8% cement or more, all three paste projects show a cement reduction potential of up to 50%. For lower cement additions, the cement reduction potential is smaller.

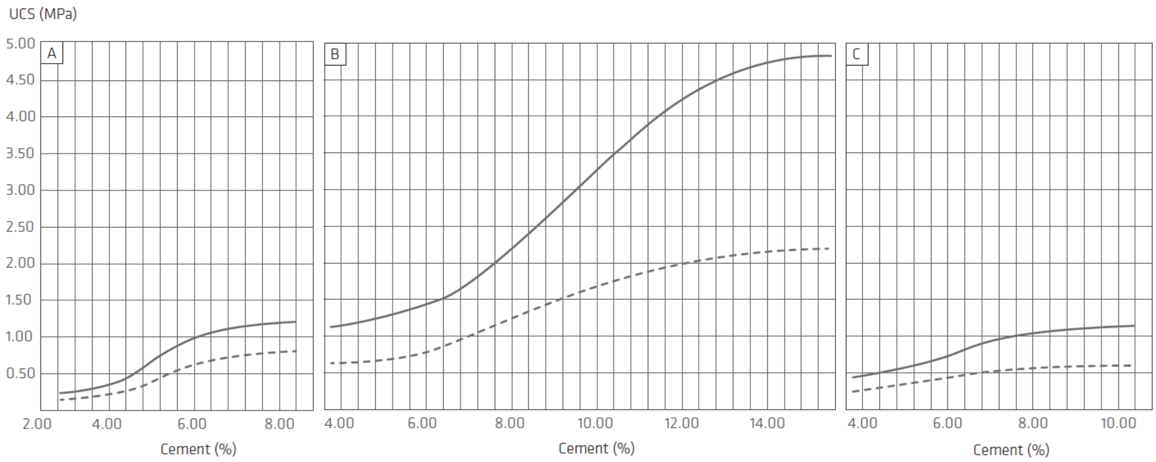


Figure 7 28-day strength results for project A, B and C for different cement contents in the paste fill. All results from mine sites. Dotted line displays results without admixtures, solid line the results with the use of admixtures

5 Discussion

High water-to-binder ratios in paste designs are common and water-to-binder ratios above five represent a challenge to achieve the needed strengths for a certain paste fill. This is mainly due to the oversaturated properties of such fills and the associated limited strength values even at high cement additions. The effect of admixture dosing into the paste stream has a strong influence on a range of properties of the produced paste. Strength development of the paste with increasing solid content is very favourable, both in terms of the early strength development (after a few days) as well as the final strength after 28 and 56 days. Such strength gains allow for strong cement reduction in the fill to reach the designed strength requirements of the fill especially at higher cement additions. The cement reduction potential observed in the described projects range from 20–50%. As the solid content of a paste mix is the driving factor for strength development at a given cement content, the ability of a suited admixture to strongly reduce yield stress of a paste is providing the precondition to reduce the water content of the fill.

Despite the fact, that the solid content was increased in all of the described cases, slump values tended to be elevated throughout the observation period, indicating that water could be withdrawn further. In two of the three plants, water addition to the mixer was reduced to almost zero with no further water reduction potential. Hence, the potential to increase the solid content and strength further reached the limit, unless improvements are made at the dewatering units (cone thickeners, vacuum disc filters) to produce a drier filter cake. In each of the three cases described in this paper, the admixture overcompensates the effect that the increase in solid content had on the line pressure of the reticulation system with pressures dropping well below the limits that were observed prior to the addition of admixtures. This can be mainly related to the detrimental effect that excessive water has on a pumped paste mix. An oversaturated paste tends to segregate and free water leads to elevated pressure levels compared with mixes that contain less water.

Pressure spikes have been recorded in each of the described operations. These pressure spikes were mainly related to the time period when the admixture dosage started. This reflects the strong and almost instantaneous impact the admixture has on the yield stress of the paste mix, which triggers immediate reduction of added water to the mixer. As the control of the water addition is often not sensitive enough (poorly controlled valves), the system tends to over-mitigate changes of the mixer torque and water is withdrawn too quickly. This can cause in short term pressure spikes. For example, in project A, the mixer release time to the feed-hopper of the piston pump is linked to a certain paste yield stress which is, again, linked to the energy draw of the mixer. As admixtures lead to a strong fall-off of mixer energy, these release times were triggered much faster causing the hopper fill levels to rise and the pump to pump faster, which resulted in an increase of paste line pressure. This side effect was solved by fixing the hopper release time and this resulted in a continuous pumping speed. Strength gains across the described cases were significant and material cement reductions could be achieved for each project. Very favourable economics were achieved for all three projects factoring in the reduced cement consumption and cost of admixture. Cement reduction compensates well for the additional cost of the admixture and has a very positive effect on the overall cost performance of the paste fill system. The overall economics strongly depend on available cement prices, admixture effectiveness and dosage and the ability of the paste plant to provide a good quality and dry filter cake. Furthermore, strength development is faster due to better, more rapid, and complete cement hydration which allows for faster stope cycle times. However, this data is not included in this paper. Furthermore, as cement consumption is among the largest driver for CO_2 in underground mining operations, cement reduction in the paste fill will materially improve this important emission balance. Last, but not least, a higher solid content of the fill will allow more placement of tailings underground.

6 Conclusion

Oversaturated fills with water-to-binder ratios of higher than five represent a challenge for a paste operation as elevated binder contents will not really improve the strength anymore. Paste backfill admixtures proved to have a powerful effect on paste mixes once a suitable admixture was identified based on the physical and chemical properties of tailings. Admixtures are well suited to upgrade paste mix designs by increasing the solid content of the mix that usually goes hand-in-hand with higher achieved strength at the same binder content. All three cases presented in this paper showed strong cement reduction potential after admixtures had been implemented. Cement reduction potential is in the order of 20–50%, depending on the strength requirement of the fill. Pumping pressures remained constant or were reduced despite the much increase solid content of the paste mixes. The cost performance of paste plants can be greatly improved by using latest admixture technology and by evaluating a well-suited admixture.

References

Aitcin, P & Flatt, R 2016, *Science and Technology of Concrete Admixtures,* Woodhead Publishing, Cambridge, p. xxi.

Aitcin, P & Wilson, W 2015, 'The sky's the limit', *Concrete International*, vol. 37, issue 1, pp. 53–58.

Bakken, B & Einaudi, M 1986*, '*Spatial and temporal relations between wall rock alteration and gold mineralization, main pit, Carlin gold mine, Nevada, U.S.A', in A Macdonald, A (ed.), *Proceedings of Gold '86, an International Symposium on the Geology of Gold*, Geological Association of Canada, St. John's, pp. 388–403.

Erismann, F, Kurz, C & Hansson, M 2016, 'The benefits of incorporating admixtures into mine paste backfill', in S Barrera & R Jewell (eds), *Proceedings of the 19th International Seminar on Paste and Thickened Tailings,* Gecamin, Santiago, pp. 76–86.

Erismann, F, Kurz, C & Hansson, M 2017, 'Translating paste backfill admixture results from the laboratory into the field', in A Wu & R Jewell (eds), *Proceedings of the 20th International Seminar on Paste and Thickened Tailings*, University of Science and Technology Beijing, Beijing, pp. 190–198.

Hausen, D & Kerr, P 1968, '*Fine gold occurrence at Carlin, Nevada',* in J Ridge (ed.), *Ore Deposits of the United States, 1933-1967, The Graton-Sales Volume, The American Institute of Mining*, Metallurgical, and Petroleum Engineers, Inc., New York, pp. 908–940.

McKibben, M & Hardie, L 1997, 'Ore-forming brines in active continental rifts', in HL Barnes (eds), *Geochemistry of Hydrothermal Ore Deposits*, Wiley Interscience, New York, pp. 877–930.

Partington, C & Williams, P 2000, *'*Proterozoic lode gold and (iron)-copper-gold deposits: a comparison of Australian and global examples'*, Reviews in Economic Geology,* vol. 13, pp. 69–101.

Radtke, A, Rye, R & Dickson, F 1980, 'Geology and stable isotope studies of the Carlin gold deposit, Nevada', *Economic Geology*, vol. 75, pp. 641–672.

Ramachandran, V, Malhotra, V, Jolicoeur, C & Spiratos, N 1998, *Superplasticizers. Properties and Applications in Concrete,* Materials Technology Laboratory, CANMET, Ottawa.

Silva, M 2017, *Contribution to Laboratorial Determination of Rheological Properties of Paste Backfill, Zinkgruvan and Neves-Corvo Case Studies*, MSc thesis*,* Technico Lisboa, Lisbon.

Sofra, F 2017, 'Rheological properties of fresh cemented paste tailings', in E Yilmaz & M Fall (eds), *Paste Tailings Management*, Springer, Cham, pp. 33–57.