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Paste fill mix and cost-optimisation efforts at Olympias mine

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Abstract

Olympias is an underground mine located in Chalkidiki, Northern Greece, and it is owned and operated by Hellas Gold Single Member S.A., a wholly owned subsidiary of Eldorado Gold Corporation.

The mine extracts a high-grade polymetallic deposit using the drift and fill (DAF) mining method. Cemented paste fill has been implemented as the predominant backfilling method at Olympias mine. Cemented paste backfill is an integral part of the mining cycle and constitutes a major component of underground mining costs.

During paste system commissioning and initial operations, a high-density paste backfill mix, meeting the high target strengths (1 MPa before vertical exposure and 4 MPa at 28 days curing age) and required flow properties, was developed by incorporating superplasticiser admixtures. Following a revised environmental impact assessment in 2022, the current minimum required backfill strength for DAF mining method is 0.5 MPa for sidewall exposures and working floors, and 1.5 MPa for sill pillars, respectively. The current production schedule and DAF cycle require paste fill achieving strength of 0.5 MPa within three days curing age.

This paper presents results of the recent extensive laboratory test work and mix optimisation efforts for developing cost-effective paste fill mix designs that improve the economic viability of the mine while delivering operational efficiency and sustainability.

These efforts have contributed to approximately 16% cost reduction per cubic metre of paste fill and there is still room for further improvement as mining and backfill optimisation efforts are ongoing.

Keywords: *drift and fill, cemented paste fill, yield stress, mix design optimisation, cement types*

1 Introduction

1.1 Mine location

Olympias mine is situated within the Kassandra Mines complex on the Chalkidiki peninsula in northern Greece's Macedonia province. Located about 90 km east of Thessaloniki and easily accessible via the national road network, the complex includes the operational Olympias mine, the currently in care and maintenance Madem Lakkos and Mavres Petres mines, and the under-development Skouries copper-gold porphyry deposit. Figure 1 (Eldorado Gold Corporation 2023) illustrates the Kassandra Mines complex, with the Olympias property boundary highlighted in green.

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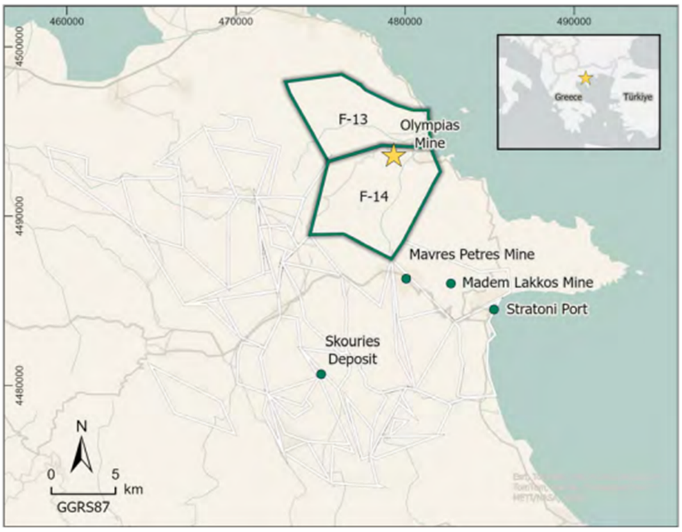

Figure 1 Kassandra Mines concessions and Olympias property concession numbers F-13 and F-14, totalling an area of 47.27 km² **(Eldorado 2023)**

1.2 Mineralisation and geology

The Olympias deposit is a gold-rich polymetallic carbonate-hosted replacement massive sulphide deposit located 6 km north of the Stratoni fault zone (Siron et al. 2019). It is hosted by a sequence of quartzo-feldspathic biotite gneiss interlayered with graphitic marble and amphibolite, bounded to the east by a massive body of megacrystic plagioclase-microcline orthogneiss (Kalogeropoulos et al. 1989; Siron et al. 2016). The orebody is localised in a structurally complex zone where marble is deformed by ductile and brittle structures. Sulphide mineralogy consists of coarse- and fine-grained lenses of sphalerite-galena-pyrite that transition into pyrite-rich intervals and arsenopyrite, which grades into arsenopyrite-bearing and boulangerite-bearing siliceous breccias. The massive sulphide orebody plunges shallowly to the southeast (Siron et al. 2018), with sulphide lenses primarily controlled by the ductile-brittle Kassandra fault and sub-horizontal ductile shear zones. Olympias mine is an underground mining facility, extracting ore from three main zones: East, West and Flats (Figure 2).

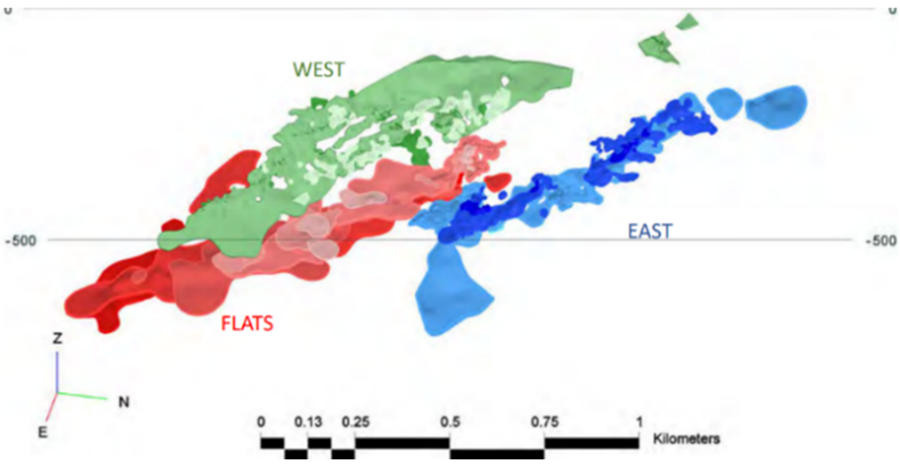

Figure 2 Mineralised domains (Eldorado 2023)

The East Zone spans 750 m horizontally and 310 m vertically, dipping 20–25° to the southeast, with mineralised layers 10–15 m thick. The West Zone spans 1,500 m and plunges southeast, featuring three branches of mineralised layers and additional massive sulphide mineralisation near the surface. Thicknesses range from several metres to 15 m, dipping 30–35° northeast. The lower portion dips between 45° and 65°, with a horizontal extent of about 800 m and a vertical rise of 205 m. The Flats Zone, between the east and West Zones, extends 1,250 m and contains layers up to 15 m thick.

1.3 Mining method and production

Olympias mine has complex geology and variable rock conditions including weak zones, particularly near the hanging wall contact in the West Zone along the Kassandra fault. The East Zone has competent but fragmented rock, while the Flats Zone conditions range from fair to excellent. Olympias currently employs the transverse and longitudinal overhand drift and fill (DAF) mining method due to the high variability of the rock conditions. However, both double cut DAF and longhole stoping are considered as viable future options where the orebody geometry and rock conditions permit their application. Current underground development aims to increase the mine's production rate from the current 470,000 tonnes per annum (tpa) to 650,000 tpa (Figure 3). Olympias has a projected mine life of 15 years.

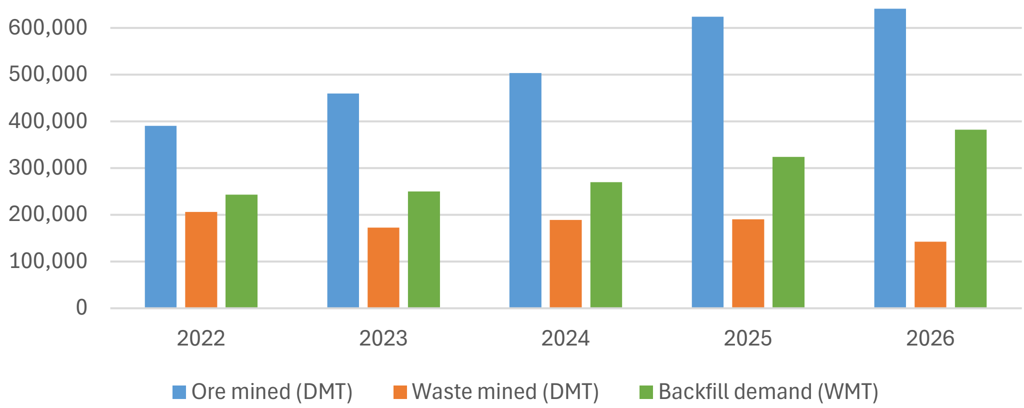

Figure 3 Mine production and backfill demand

1.4 Ore processing and tailings disposal

Run-of-mine ore is stockpiled by type and grade for blending near the three-stage crushing plant. A front-end loader feeds ore into the primary crusher. The comminution circuit features a ball mill operating in a closed circuit with hydrocyclones and a flash flotation cell. The discharge from the ball mill is processed in the flash flotation cell to recover rapidly floating liberated lead. The overflow from the hydrocyclones is directed to a sequential selective flotation circuit which includes three separate flotation circuits designed to recover lead and silver, zinc and gold-arsenopyrite-pyrite respectively. Concentrates are thickened, filtered and either bagged for shipping or trucked to Stratoni port for overseas shipment. Filtered tailings with 15–20% moisture are utilised in the paste plant for paste fill while any excess is sent to a dry stack tailings facility.

1.5 Mining directive and backfill design

Backfill is applied as soon as feasible after creating an opening. In areas with multiple ore drives, tight filling prevents excessive open back spans when mining adjacent drifts. All drifts are filled after ore extraction and before developing adjacent openings. In DAF mining, fill is exposed vertically between side-by-side cuts and horizontally below sill level cuts. Strong backfill is essential for recovering sill pillars and ensuring stability during man-entry mining. Strength estimates for safe vertical and undercut exposures are based on typical stope geometries, fill parameters and safety factors. The fill composition is customised according to stope geometry, exposure timing and groundwater inflow.

The minimum target unconfined compressive strength (UCS) is as follows:

- working floor – 500 kPa
- sidewall exposures – 500 kPa
- engineered backs: undercuts – 1,500 kPa
- fill that is not going to be exposed – 200 kPa.

2 Paste fill system

2.1 Paste plant and system rates

The paste plant, located above the northern section of mine, has two tailings feeding options. The first option utilises a bank of disc filters (three operational, one on standby) to process thickened flotation tailings, which are stockpiled for paste fill. The second option reclaims pressure-filtered tailings from the process plant. The usage ratio between the two options is two parts pressure-filtered tails to one part disc-filtered tails. The tailings feed nominal capacity is 40 tonnes per hour. Filtered tailings are transported to the paste mixing plant via the mixer feed conveyor. Ingredients, including cement dosed by the dry weight of the feed, are added to a dual-shaft continuous mixer. The resulting paste is pumped into the underground reticulation system through a positive displacement piston pump capable of delivering 42 m^3/h. The average pump rate at the paste plant is currently 33 m^3/h, up 9% from 2023 to 2024 due to system optimisations.

2.2 Paste reticulation and placement

The paste reticulation system (Figure 4) includes permanent main trunkline sections with inter-level boreholes and level pipelines, semi-permanent extensions to stope accesses and temporary high-density polyethylene lines in production drifts. The main trunkline, made of 5-inch (127 mm) steel pipes with 130-bar capacity, runs from surface boreholes along the east ramp and –173 connection drive, branching into the east, West and Flats mining areas. The system includes flow metres, pressure gauges and diversion valves for monitoring and control. The total reticulation length exceeds 8,500 m, with a maximum paste delivery distance of 2,125 m. The friction loss factor ranges between 8–12 kPa/m. Due to the horizontal reach of the West and Flats areas, the paste system has a low aspect ratio of depth to lateral distance. Given the constraints imposed by the paste delivery system and the difficult nature of Olympias tailings, the required flow properties for the high-density paste fill to meet target design strengths cannot be achieved unless admixtures are used.

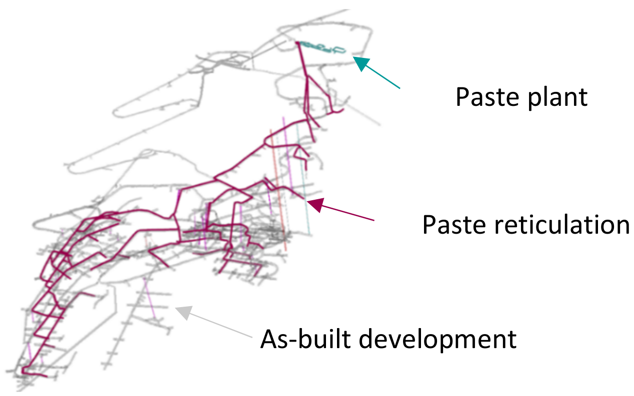

Figure 4 Olympias mine paste reticulation system (isometric view looking northwest)

2.3 Paste fill mix design

Paste fill has been employed at Olympias mine since September 2018. The conditions set forth in the technical study approved at that time required the paste fill material to achieve a strength of 1 MPa before vertical exposure and 4 MPa within 28 days. A comprehensive testing program was conducted at Olympias mine, leading to the formulation of a paste fill mix consisting of 75% solids concentration by weight (C_w) incorporating 12.5% by weight of total solids ($\%_{bwosd}$) cement and a suitable amount of superplasticiser (SP) to achieve the desired rheological properties while accounting for the limitations of the delivery system.

In 2022 a revised environmental impact assessment (EIA) was approved. According to the revised EIA, the mandated target strengths at Olympias mine were adjusted to 0.5 MPa before vertical exposure and 1.5 MPa for fill material in the sill drifts serving as the back of an open drift below. Additionally, the mine planning restrictions necessitate rapid vertical exposures, with mining adjacent to paste-filled drifts typically occurring after three days of curing.

A paste fill mix design optimisation program was established based on the less stringent strength requirements. This program aimed to identify the most effective mix design that met the strength requirements specified by the new EIA while also accommodating the restricted re-entry time necessitated by high production demands, all at the optimal cost.

2.4 Paste fill material properties

The methodology involved a comprehensive examination of the paste material properties to assess the consistency of the developed mixtures. Tailings samples were collected from the paste plant stockpile. Each sample (≤ 1,000 kg) was mixed thoroughly to ensure homogeneity prior to testwork. About 10 kg of homogenised tailings per sample were oven dried and deagglomerated using a 425 µm screen, to produce samples for tailings characterisation. The sample size was reduced using a splitter for fine aggregates with an opening size of 15 mm. The determination of material properties included X-ray diffraction (XRD), chemical analyses and specific gravity (SG) determination of the tailings, particle size distribution (PSD) assessments, and the evaluation of the SP content necessary to achieve the desired yield stress (YS) of the paste fill (YS profiles of cemented tailings with and without SP). All tests, except XRD analysis, were conducted onsite.

2.4.1 Mineralogy

The XRD analysis reveals that the mineralogy of Olympias (OLM) tailings is highly variable (Table 1).

Table 1 X-ray diffraction analysis of full plant tailings

Mineral or mineral group	Mass% (1)	Mass% (2)	Mass% (3)	Mass% (4)	Mass% (5)	Mass% (6)	Mass% (7)	Mass% (8)
Pyrite	3	2	3	3	12	9	2	4
Arsenopyrite	1	2	1	2	3	3	1	2
Galena	0	0	1	< 1	1	1	< 1	1
Clay mineral	< 1	1	1	1	1			< 1
Chlorite	< 1	< 1	0	0	0	0	< 1	< 1
Annite-biotite-phlogopite	2	2	2	2	2	< 1	< 1	1
Kaolinite	3	2	2	2	2	2	1	1
Muscovite group-illite						2	2	
Muscovite	2	1	1	1	1			1
Calcic amphibole	1	< 1	< 1	< 1	0	1	< 1	< 1
Plagioclase	4	6	2	2	2	3	2	1
K-feldspar	4	5	7	6	3	2	2	3
Quartz	26	25	18	23	20	20	25	23
Bassanite	1	1	1	1	1	1	1	1
Dolomite and/or ankerite	14	14	21	12	15	11	19	18
Siderite type carbonate	0	2	2	2	2	0	0	3
Calcite	23	23	31	26	31	17	14	18
Amorphous material	15	13	7	17	4	29	30	23
Serpentine								< 1

2.4.2 Chemical analysis

Base metals chemical analysis of OLM tailings is performed internally using inductively coupled plasma–optical emission spectroscopy (ICP_OES) techniques. Total sulphur (S) and total carbon (C) are determined by infra-red (IR) combustion using LECO CS 744 analyser. Table 2 presents the SG, the moisture content and the chemical composition of eight samples of OLM tailings. Overall, the chemical analysis reveals a complex composition of the tailings, with notable concentrations of lead, zinc, arsenic, iron, manganese, sulphur and calcium.

Table 2 Physicochemical analysis of the Olympias tailings

Sample	Specific gravity	Pb (%)	Zn (%)	Fe (%)	Mn (%)	Al (%)	As (%)	Mg (%)	Ca (%)	S (%)	C (%)	Moisture (%)
1	2.83	0.44	0.59	2.06	0.61	0.17	0.58		10.74	3.22	4.34	20.16
2	2.69	0.26	0.27	2.27	1.45	0.14	0.59		11.41	3.00	4.92	15.88
3	2.78	0.46	0.37	2.86	1.66	0.13	0.79		12.34	3.39	5.04	14.68
4	2.85	0.37	0.32	2.65	1.75	0.11	0.69		11.60	3.31	4.77	15.90
5	2.87	0.47	0.74	5.98	1.79	0.09	1.07	1.59	12.88	7.05	5.10	15.61
6	2.91	0.95	1.07	5.30	0.53	0.18	1.54	1.36	11.22	6.81	4.39	15.73
7	2.79	0.48	0.38	1.57	0.71	0.14	0.46	1.97	11.37	2.42	4.79	18.13
8	2.88	0.65	0.49	2.34	2.46	0.15	0.88	1.69	12.68	3.13	5.32	17.22

2.4.3 Particle size distribution

PSD analysis of the total tailings was conducted using conventional sieving and laser diffraction by the Malvern Mastersizer 2000 model (Hydro 2000G, Fraunhofer method). The PSD results, illustrated in Figure 5, indicate that the full plant tailings exhibit variability, largely due to the different ore types processed at the plant. The fraction of material finer than 10 µm ranges from 9.4 to 16.5%, while the fraction finer than 20 µm varies from 16 to 24%. This indicates variability in the fineness of the tailings across samples. In general, the tailings material used for paste fill production must contain at least 15% of fine particles (< 20 µm) to retain sufficient water to form a paste (Henderson & Revell 2005). The PSD results confirm that Olympias paste fill has a coarse tailings particle gradation (Figure 5).

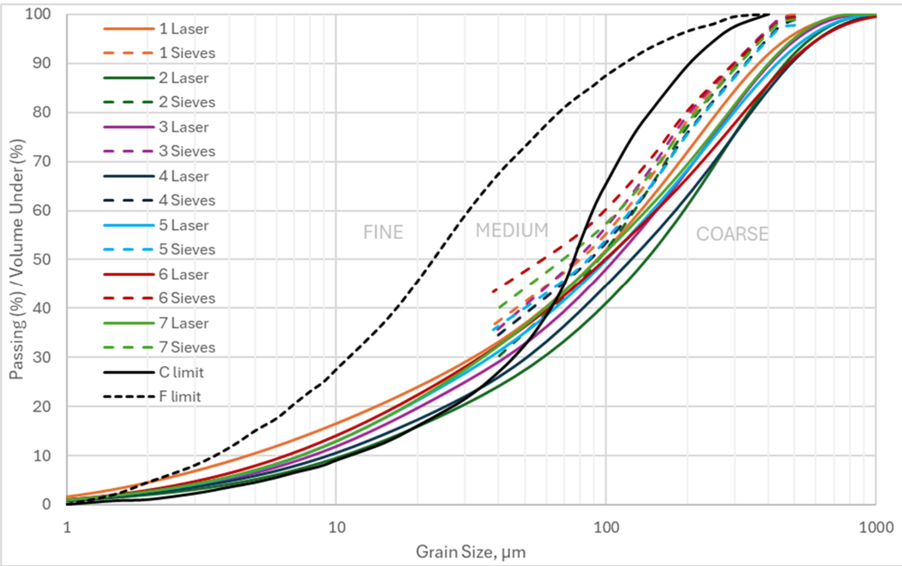

Figure 5 Olympias tailings particle size distribution

2.4.4 Cement characteristics

The characteristics of the examined cement types are summarised in Table 3. The higher the Blaine value, the higher the cement fineness. Cement fineness promotes reactivity and strength development but may have an adverse effect in rheology and SP consumption The sulphate content, expressed as SO_3, is lower than 3.5% and the chloride content is lower than 0.14% for all the tested cement types. The density is 3.08 for CEM II and CEM III and 3.11 g/cm^3 for CEM IV.

Table 3 Physical and chemical properties of cement types (Heracles General Cement Company 2022, 2023a, 2023b, 2023c, 2023d, 2023e)

Cement type	Blaine (cm^2/g)	Clinker (%)	CaO (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	K2O (%)	Na_2O (%)	LOI (%)	IR (%)
CEM II/B-M (P-W-L) 42.5N	4,730	65–79	58.2	17.3	5.1	2.9	2.1	0.5	0.51	9.1	3.5
CEM III/B 42.5N SR	4,400	20–34	46.9	28.3	9.8	3.7	5.6	0.3	0.43	0.8	0.5
CEM IV/B (P) 32.5N SR	5,530	45–64	45.9	29.9	7.2	3.0	2.3	1.1	1.04	6.5	22

2.5 Paste fill rheology

Rheological flow characterisation tests were conducted using a rotational viscometer (HAAKE Viscotester IQ) to measure the YS of various paste fill mixtures containing 0, 10 and 12.5% cement by total dry solids, without any SP admixtures. These tests were performed across a range of solids concentrations to evaluate their flow properties (Figure 6).

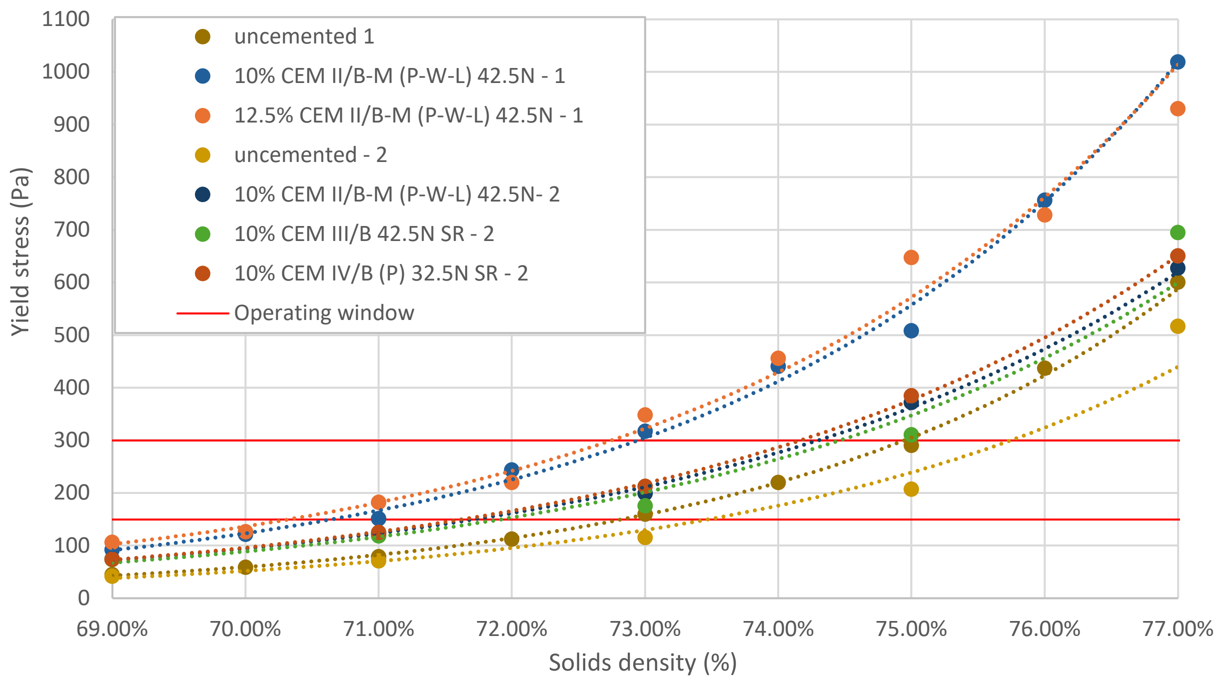

Figure 6 Yield stress profile for total tailings paste fill

YS, defined as the minimum force required to initiate flow, was measured using a rotational rheometer (Thermo Fischer Scientific, HAAKE Viscotester IQ) with a vane spindle (FL22) at a rotational speed of 0.2 rpm. The optimum YS is the maximum value at which the fill can meet the required target strength while flowing to the stope without obstructing the reticulation pipeline. For Olympias mine, the target design YS operating window is set at 150–300 Pa, with an operating range of 200–350 Pa.

Figure 6 demonstrates that the two samples of tailings tested (different particle size and mineralogy), as well as the type and amount of cement, significantly influence the YS profiles of the backfill. The results indicate that paste fill containing coarser tailings and coarser cement types (Blaine values, cm²/g: CEM III < CEM II < CEM IV) exhibits improved flow characteristics.

3 Paste fill mix optimisation

3.1 Testwork methodology

The required quantities of cement, tailings and water for each batch were measured and mixed thoroughly at a target constant solids concentration. A reference YS was then measured with a rotational viscometer. If the reference YS exceeded 300 Pa, SP was added to enhance flowability for pumping. The cement content was defined as the ratio of the dry weight of cement to the total dry weight of the mix, while SP dosage was expressed as $\%_{bwosd}$. Strength tests utilised 70 mm-diameter by 140 mm-length cylinder samples, cured in a humidity-controlled room (T = 20 ± 2°C, relative humidity (RH) ≥ 95%). All the experiments were conducted in triplicate and the mean UCS values were presented in the results. The UCS tests were conducted using a 50 kN load capacity compression tester (Controls Group, Uniframe Model), at a displacement speed of 1 mm/min. At least four curing ages were tested: 3, 7, 28 and 112 days. For some mixes there were also tests for 14, 180 and 360 days.

The testing plan consisted of several stages:

1. Mix design matrix. A matrix was developed combining four solid mass concentrations (71, 73, 75 and 77% Cw) with six cement addition rates (2.5, 5, 7.5%, 10, 12.5 and 15%) to evaluate strength at different curing times, using CEM II/A-M (W-L) 42.5R, the same sample of tailings and process water (PW). The tests confirmed that the 71–5% mix design was the most cost-effective, achieving the required 0.2 MPa for non-exposure drifts. It was also identified that only mixtures with cement rates above 7.5% $_{bwosd}$ met the strength requirements of 0.5 MPa and 1.5 MPa within the desirable curing time.
2. Cement type change. The cement type was switched to CEM II/B-M (P-W-L) 42.5N. High cement rate mix designs were repeated with the same sample of tailings (sample 1 in Tables 1 and 2) and PW, and two additional solid mass concentrations (67 and 69%) were tested to explore the possibility of eliminating superplasticiser.
3. Financial evaluation. The most cost-effective mix design achieving the required strength at the desired curing time was determined to be the 75–10%, incorporating the same amount of SP as the 75–12.5%.
4. Validation tests. A series of validation tests with a 75–10% mix was conducted using various tailings samples (samples 1–8) and PW, referencing the 75–12.5% design to assess reliability despite tailings variability.
5. Further testing. After validating the new mix design (75–10%), both this and the potentially further optimised 73–10% option were tested with two additional cement types: slag cement (CEM III) for enhanced long-term strength and durability, and pozzolanic cement (CEM IV) for cost efficiency. The same sample of tailings (sample 4) and PW was used.

3.2 Rheology

The fill mixtures were proportioned with different SP dosages to reach the target YS. Figure 7 illustrates the rheological behaviour of cement-based mixtures at different cement rates (%) with varying solid mass concentrations, mixed with sample 8 of tailings and PW, before and after the addition of the superplasticiser. The red horizontal lines indicate the ‘operating window’, a range within which the YS values ideally should fall. This operating window serves as a benchmark for acceptable or optimal performance. The test results demonstrate that, for cement rates between 7.5 and $15\%_{bwosd}$, the required amount of SP per mix is mainly influenced by the solid mass concentration rather than the cement rate. Additionally, through the validation tests, it was confirmed that tailings characteristics play a significant role in rheology, i.e. finer tails and tails containing more clay minerals and phyllosilicates require higher SP dosage. The rheology tests indicate the following:

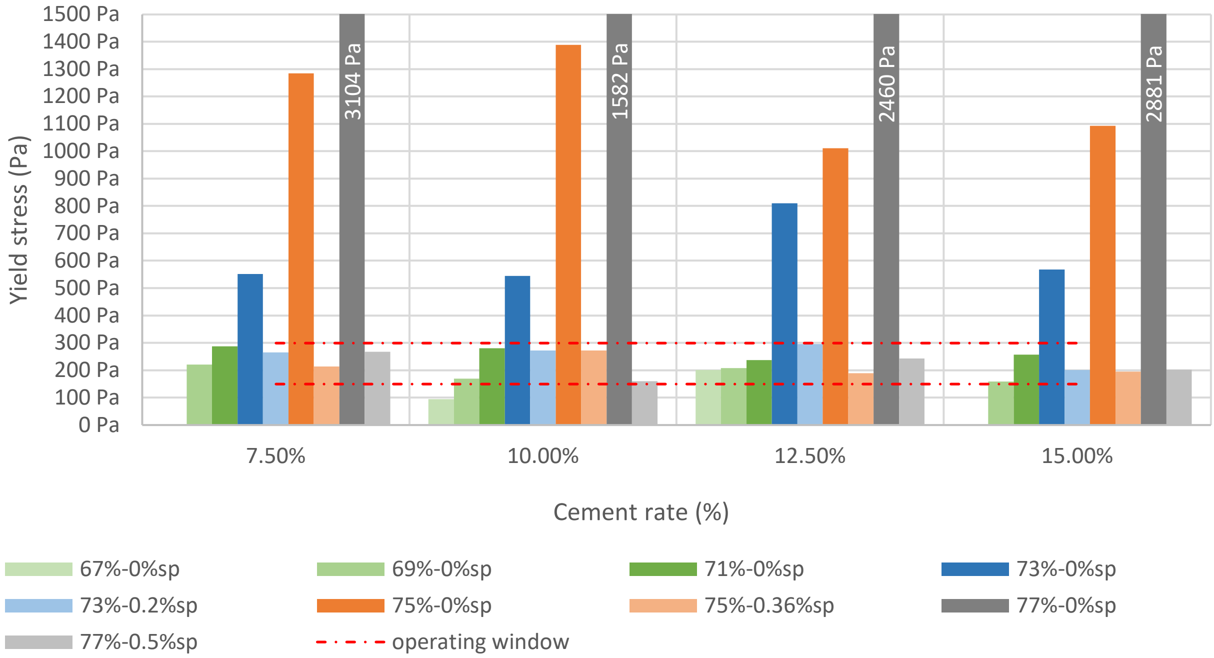

Figure 7 Rheology of alternative mix designs, before and after superplasticizer addition (tailings sample 8)

- Paste fill with solid mass concentration up to 71% is pumpable without any SP.
- For a solid mass concentration of 73%, the YS ranges between 550 and 800 Pa. An average of $0.20\%_{bwosd}$ SP is required to reduce the YS to 200–300 Pa.
- For a solid mass concentration of 75%, the YS ranges between 1,000 and 1,400 Pa. An average of $0.36\%_{bwosd}$ SP is required to reduce the YS to 200–300 Pa.
- For solid mass concentration of 77%, the YS ranges between 1,600 and 3,100 Pa. An average of $0.50\%_{bwosd}$ SP is required to reduce the YS to 200–300 Pa.

3.3 Strength results

The strength results of the mix designs using CEM II/B-M (P-W-L) 42.5N are shown in Figure 8. The only mix designs that reach 0.5 MPa within three days and exceed 1.5 MPa in the long-term, while using less cement and/or SP than the 75–12.5% mix, are the 75–10% and 73–12.5% mixes. These mixes are suitable for both vertical exposure within three days, as per the current mine planning guidelines, and for undercut exposures. The 77–7.5% mix achieves 0.5 MPa in three days but falls short of 1.5 MPa in the long-term, making it suitable only for sidewall exposure.

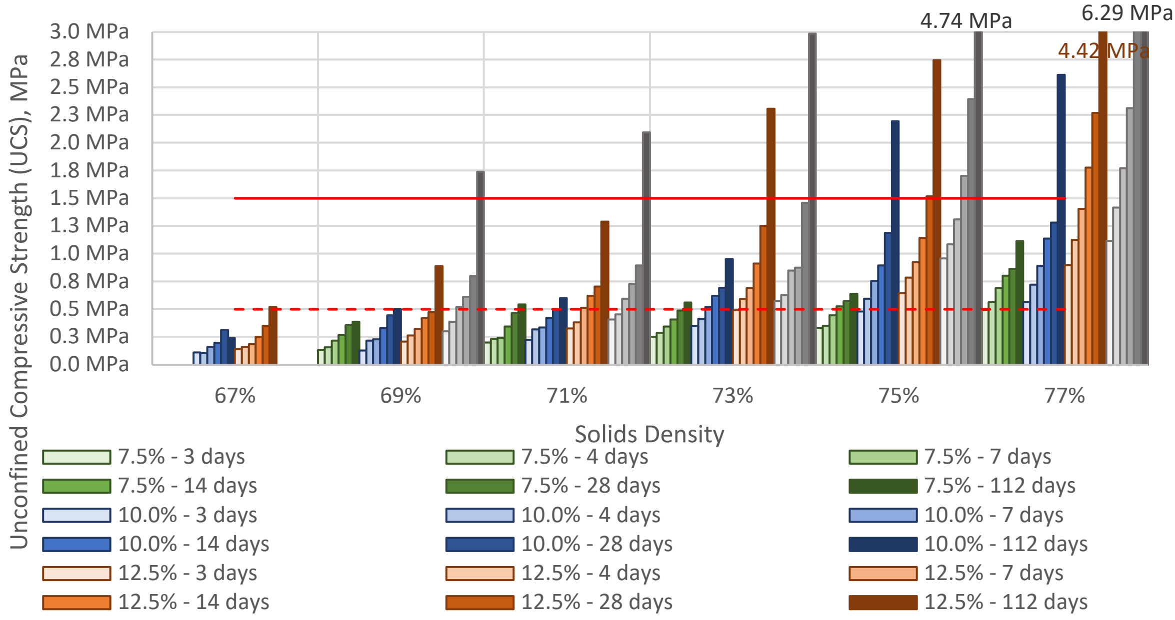

Figure 8 Unconfined compressive strength results of the mix designs tested (tailings sample 8, SP = 0.2%$_{bwosd}$, 0.36%$_{bwosd}$ and 0.5%$_{bwosd}$ for 73, 75 and 77% solids density, respectively)

Given the high variability of tailings, the performance of the 75–10% mix design was tested using seven different samples of tailings and PW, simulating its application at the paste plant. The 75–12.5% mix design was also tested with the same tailings and PW samples as a reference. The strength results from the validation tests after three and 112 days of curing, along with the lead and zinc content of the tailings used, are shown in Figure 9.

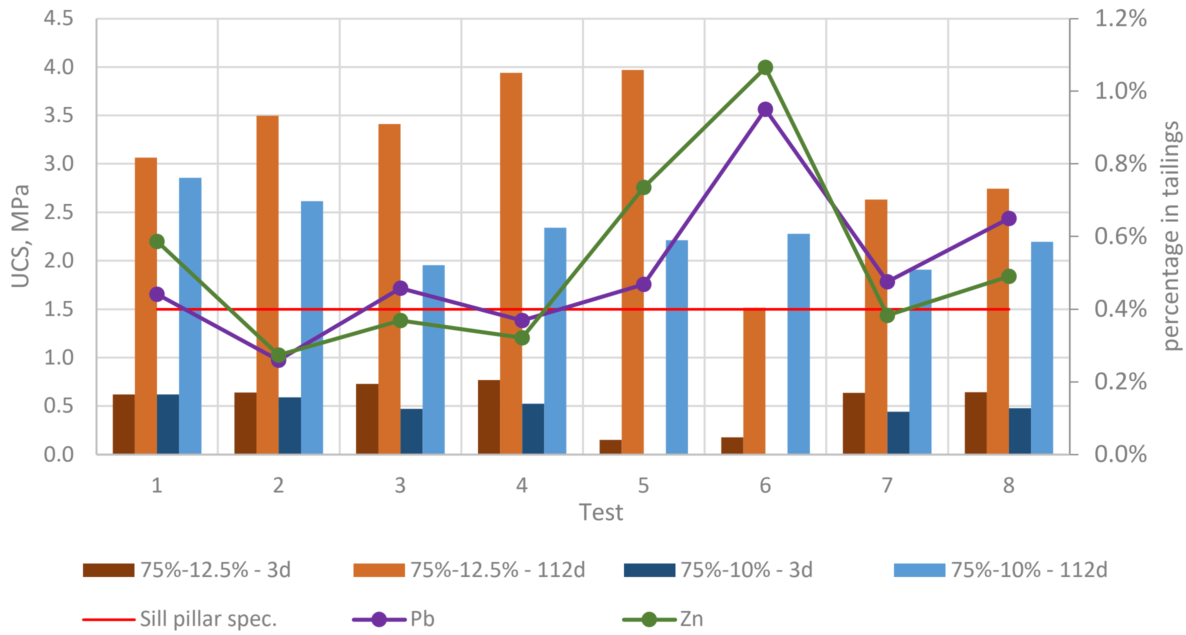

Figure 9 Impact of the lead and zinc content of tailings on the strength of the paste fill (tailings samples 1–8)

The validation tests demonstrate the following:

- The 75–12.5% mix design achieves a higher strength than required.

- The optimised mix design, 75–10%$_{bwosd}$, which contains 20% less cement, meets the required strength while significantly reducing the environmental footprint. This is due to a reduction in CO_2 emissions associated with cement production and a 3% increase in tailings consumption, leading to a decrease in tailings haulage and disposal at the tailings management facility.
- Figure 9 indicates retardation of paste fill strength for tailings with high lead and zinc content (samples 5 and 6) for both the applied (75–12.5%) and the optimised (75–10%) mix designs. So, the properties of tailings and the PW impact on the UCS of the paste fill material. Therefore, for both mix designs, there are instances where the required early strength (0.5 MPa) may not be achieved within three days of curing (due to retardation), but within four to five days instead.
- The rheology of the paste is also influenced by tailings variability, with YS without SP ranging from 700 to 1,700 Pa, so the SP dosage is given as a range rather than as a single value. The SP amounts in both mix designs are nearly identical, ranging from 0.19 to 0.42%$_{bwosd}$, with an average of 0.31%$_{bwosd}$.

The 75–10% mix design has been implemented successfully at Olympias mine since January of 2024.

The strength results of the cement screening tests for the optimised mix design 75–10% and the potentially further optimised 73–10% mix are presented in Figure 10. Each mix was dosed with the required SP amount to achieve a target YS = 250 ± 25 Pa.

Through these tests it was confirmed that:

- CEM IV/B (P) 32.5N SR has similar performance to the currently used CEM II/B-M (P-W-L) 42.5N.
- CEM III/B 42.5N SR has a delay in strength development compared to the other two cement types, but has a significantly higher performance after seven days of curing.
- From the UCS graph (Figure 10) it can be assumed that CEM III/B 42.5N SR could achieve 0.5 MPa in five days of curing for both 75% and 73% solid mass concentrations.
- SP consumption is different per type of cement (the finer the cement, the higher the SP consumption).

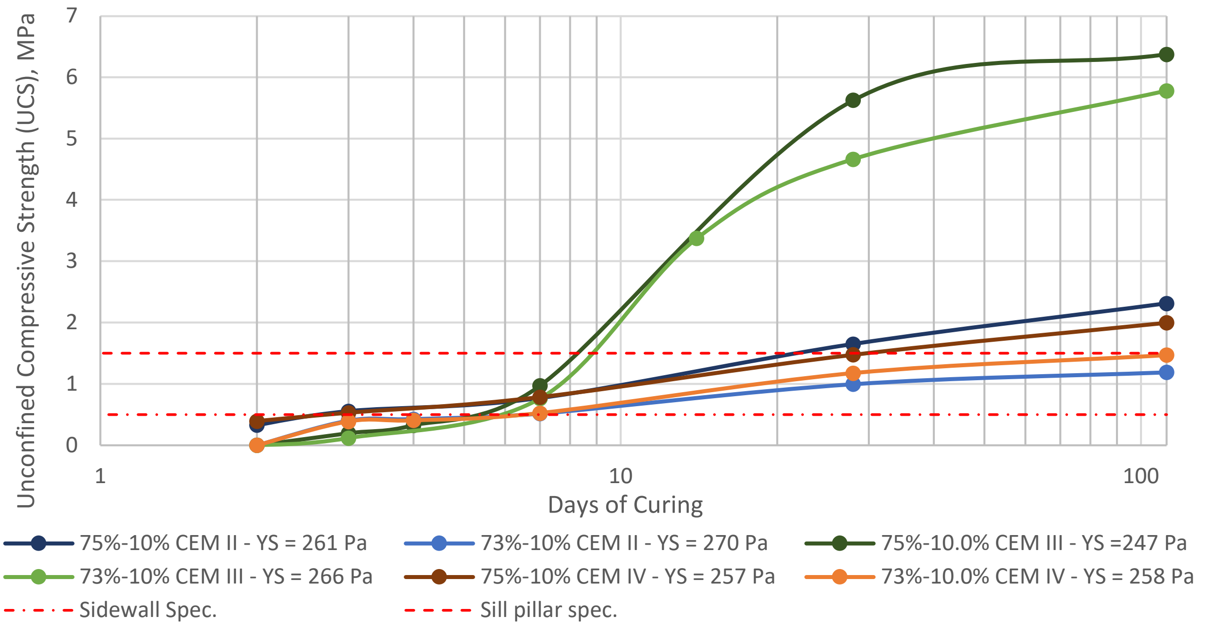

Figure 10 Strength development of 75–10% and 73–10% mix designs with three cement types (tailings sample 4)

3.4 Cost analysis and expected benefits

A financial evaluation of alternative mix designs compared to the reference mix, 75–12.5%, was conducted to identify the most cost-economic mix. An analysis of results meeting the target strengths and offering cost optimisation compared to the 75–12.5% mix design is shown in Figure 11. The 75–10% is the most economical option achieving early and long-term target strength. The 77–7.5% mix design was not adopted as it does not achieve the required strength for sill pillars, but there is potential in using it for non-sill pillar drifts.

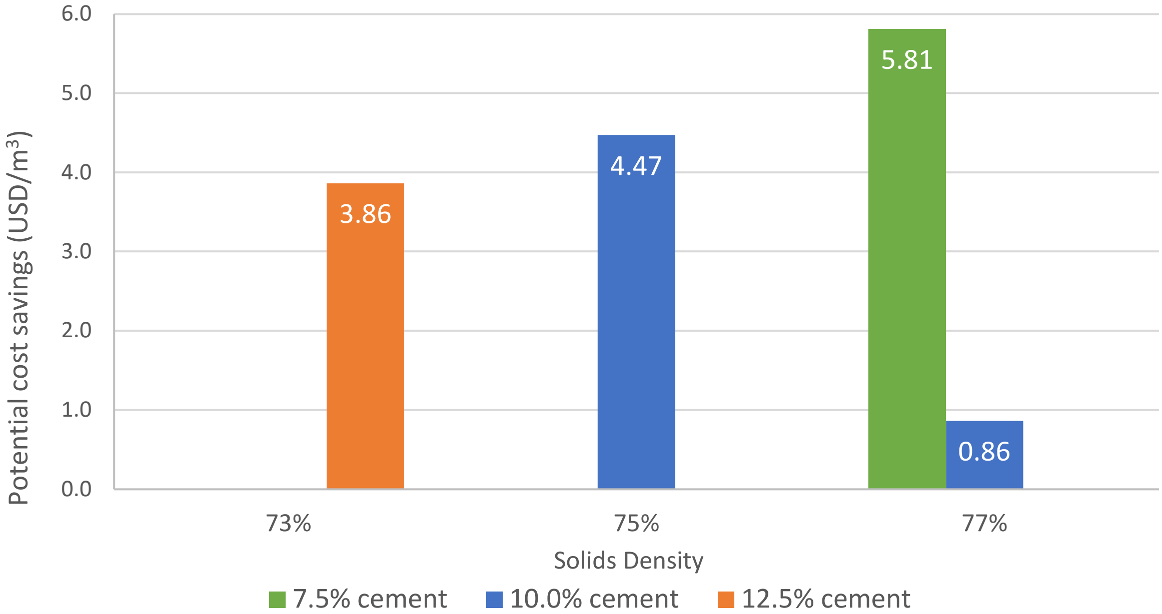

Figure 11 Financial evaluation of alternative mix designs with CEM II/B (P-W-L) 42.5N (tailings sample 8)

Table 4 provides a summary of the savings per cubic metre of paste for each of the optimised mix designs compared to the 75–12.5% mix design. Positive values indicate cost savings and negative values, cost increase.

Table 4 Alternative optimised mix designs compared to the 75–12.5% mix design

	75–10%	**77–7.5%**
Tails consumption/m^3	3%	11%
Cement/m^3	20%	37%
SP/m^3	0%	-46%
Savings/m^3	16%	18%

Cost evaluation of cement screening tests for the 75–10% and 73–10% mix designs compared to the cost of the optimised mix design, 75–10% CEM II/B-M (P-W-L) 42.5N, is provided in Figure 12. The optimal cement selection should be based on the cement type that meets the required target strengths at the lowest operating cost (Backfill Geotechnical Mining Consultants Pty Ltd 2023).

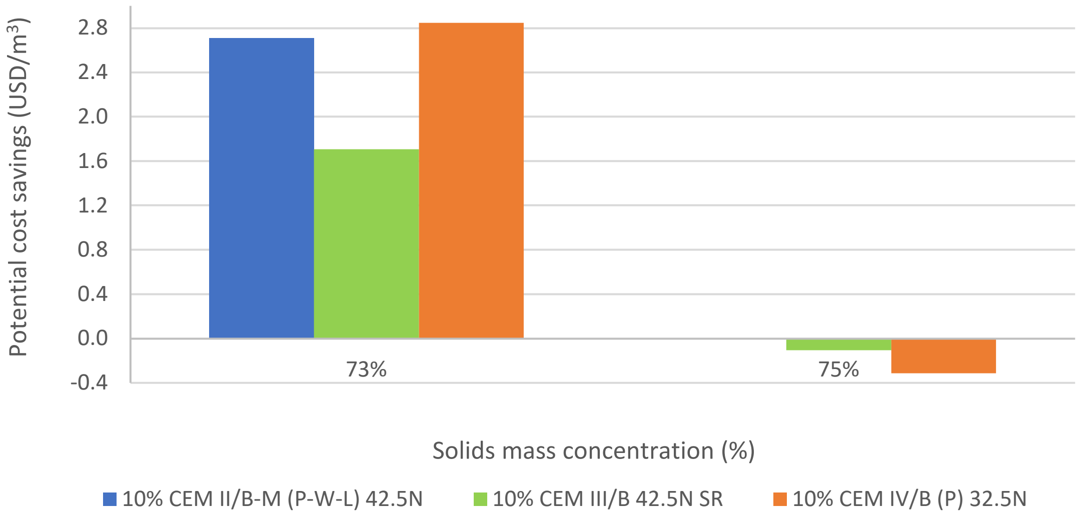

Figure 12 Financial analysis of cement screening tests: 75% & 73–10% mix designs (tailings sample 4)

The economic analysis indicates the following:

- The unit price of CEM IV/B (P) 32.5N SR is 3% lower than the unit price of the currently used CEM II/B-M (P-W-L) 42.5N. However, when CEM IV/B (P) 32.5N SR is used, the SP consumption to achieve the required rheology is higher, hence the cost of 75–10% CEM IV/B (P) 32.5N SR mix is 1.5% higher than the cost of 75–10% CEM II/B-M (P-W-L) 42.5N. So the substitution of CEM II/B-M (P-W-L) 42.5N by CEM IV/B (P) 32.5N SR may not actually contribute to cost optimisation. This must be confirmed by more tests.
- The unit price of CEM III/B 42.5N SR is 3% higher than the unit price of the currently used CEM II/B-M (P-W-L) 42.5N, but the SP consumption is reduced when compared to the CEM II/B-M (P-W-L) 42.5N. The SP consumption for the 75–10% CEM III/B 42.5N SR mix is not low enough to result in overall cost optimisation compared to the 75–10% CEM II/B-M (P-W-L) 42.5N mix.
- The 73–10% CEM III/B 42.5N SR mix design seems to achieve 0.5 MPa in five days of curing and offers a further 9.5% cost optimisation compared to the 75–10% CEM II/B-M (P-W-L) 42.5N mix design. When the mine expands into multiple areas, there will be more flexibility with the production schedule. Availability of additional production faces will be increased, allowing for extended (beyond three days) curing time for the paste fill. Hence, the implementation of 73–10% CEM III/B 42.5N SR mix design will be feasible.
- The 73–10% CEM IV/B (P) 32.5N SR mix seems to achieve 0.5 MPa in five days of curing and offers a further 14% cost optimisation compared to the 75–10% CEM II/B-M (P-W-L) 42.5N mix design. However, it achieves exactly 1.5 MPa in 112 days, so it may not be suitable to mine below a backfilled drift in case of degradation of paste strength.

Table 5 presents potential further optimisation, compared to the 75–10% CEM II/B-M (P-W-L) 42.5N mix design, for future application. Positive values indicate cost savings and negative values, cost increase.

Table 5 Further optimised mix designs compared to the 75–10% CEM II/B-M (P-W-L) 42.5N mix design

	77–7.5% CEM II/B-M (P-W-L) 42.5N	73–10% CEM III/B 42.5N SR
Tails consumption/m^3	8%	–5%
Cement/m^3	21%	5%
SP/m^3	–46%	46%
Savings/m^3	3%	9.5%

4 Conclusion

Olympias mine has been utilising paste fill since September 2018, initially requiring a strength of 1 MPa before vertical exposure and 4 MPa at 28 days curing age. Following a revised EIA in 2022, these targets were adjusted to 0.5 MPa before vertical exposure and 1.5 MPa before horizontal exposure. A comprehensive optimisation program led to a cost-effective paste fill mix design consisting of 75% solids, 10% cement and 0.31%$_{bwosd}$ superplasticiser, capable of achieving the revised strength requirements within the required curing period. The analysis of the tailings revealed variability in mineralogy and chemical composition, with significant impacts on rheology and strength development due to factors such as the presence of hydrophilic clay minerals and heavy metals that cause strength retardation. Extensive testing validated the optimised mix, showing it meets the necessary strength criteria while reducing environmental impact and cement usage, thereby improving the overall sustainability of the operation. These initiatives have resulted in an approximately 16% reduction in cost per cubic metre of paste fill, and there is still the potential for additional mix design enhancements and costs savings as efforts to optimise mining and backfill are ongoing.

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