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ARTERRA™ ultra-high molecular weight polyethylene: a sustainable solution for slurry pipeline transportation

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Abstract

The efficient transportation of slurry through tailings pipelines in the mining sector is crucial for sustainable and environmentally responsible operations. The proportion of power drawn for tailings pipelines out of total pumping systems is significant due to pipeline length and losses. Pipeline losses can therefore become a large contributor to carbon emissions. This paper presents a theoretical comparative study on power draw arising from losses due to friction and weld beads along tailings pipelines in different pipeline materials, namely high-density polyethylene (HDPE) and ARTERRA™ ultra-high molecular weight polyethylene (UHMWPE).

The conventional HDPE connection process produces weld beads at joins which in turn increase turbulence around the bead and create losses. While previous research has often dismissed turbulence-induced losses as negligible, reports from onsite personnel across multiple sites suggest an increase in power draw compared to design expectations, which has been attributed to losses due to weld beads. In response, this study examines the losses using theoretical engineering calculations to quantify and evaluate the significance of these losses, supported by computational fluid dynamics (CFD) modelling.

Unlike HDPE, ARTERRA UHMWPE connections are flanged and therefore, when connected, the pipeline will have no weld beads. In addition, ARTERRA exhibits a lower surface roughness coefficient, resulting in reduced friction losses. The reduced losses decrease the system head, which in turn can present environmental, social and governance (ESG) benefits due to reduced power consumption, depending on the power source. These benefits are quantified both as a financial saving and ESG carbon tonne reduction.

This study aims to provide valuable insights for pipeline development in the mining sector with the goals of enhancing pipeline efficiency, reducing the energy footprint, reducing operational costs and improving pipeline sustainability. Between HDPE and ARTERRA long-distance tailings pipelines, this paper concludes that the observed power draw difference is 13–15%.

Keywords: *tailings, pipelines, friction losses, sustainability, ESG, ARTERRA™, weld beads, UHMWPE, centrifugal pumping, computational fluid dynamics*

1 Introduction

Tailings slurry transportation is a critical aspect of minerals mining operations. Mining companies have a responsibility to transport tailings safely and efficiently to storage or disposal sites. The transportation system's design and material choice influence both energy consumption and the environmental footprint.

Recent advancements in mining processing technologies, such as coarse particle flotation, as well as the need to reduce costs due to lower ore head grades, have led to the production of coarser tailings. Additionally, the practice of separating coarse and fine tailings for dam wall construction requires slurry transport of the coarse fraction of the tailings. These technologies, which are beneficial for minimising costs while maintaining mineral recoveries in mining operations, increase the challenges associated with tailings transport due to the larger particle slurries.

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Traditionally, high-density polyethylene (HDPE) pipelines have been the industry standard for tailings transport. Their popularity stems from their durability, flexibility and cost-effectiveness. However, one issue is that the welding process necessary to join these pipelines introduces weld beads on the interior surfaces. These beads induce disturbances in the flow of the slurry, resulting in localised turbulence. This turbulence increases friction losses, thereby requiring a higher power draw to pump the slurry through the pipeline and reducing overall transport efficiency.

While the impact of these turbulence-induced losses has often been considered negligible in theoretical models, anecdotal evidence from mining operations suggests otherwise. Site personnel have reported increases in power draw that exceed design expectations, which could be due to head losses from weld-induced turbulence. A detailed investigation has therefore been conducted into the effects of weld beads on pipeline efficiency, using both engineering calculations and computational fluid dynamics (CFD) models to estimate head losses.

The design of a tailings pipeline is based on several factors including solids concentration, solids particle size distribution (PSD), mineralogy, volumetric flow rate, the reticulation route and pipeline material selection. These factors influence friction losses in the pipeline, an estimate of which is essential for designing any tailings pipeline system.

ARTERRA™ ultra-high molecular weight polyethylene (UHMWPE) pipelines offer an alternative to HDPE for tailings slurry transportation. UHMWPE pipes are joined by flanges rather than welding and hence do not have internal weld beads. UHMWPE also has a smoother surface and thus lower friction losses. In this paper, by employing a theoretical model and a CFD model that considers variables such as velocity, internal diameter (ID), slurry density and weld bead dimensions, we aim to quantify the energy savings and environmental, social and governance (ESG) benefits associated with UHMWPE pipelines.

2 Pipeline materials

2.1 High-density polyethylene pipelines

HDPE is widely used in tailings slurry transport pipelines within the mining industry due to its durability and cost-effectiveness. HDPE pipes are typically joined using heat fusion welding.

The HDPE base material has a molecular weight typically ranging between 2×10^5 to 5×10^5 g/mol. The molecular weight of a material has a direct influence on the material's ability to resist abrasion.

As noted above, the internal weld beads resulting from butt welding of HDPE pipe disrupt the smooth flow of the slurry, causing higher energy consumption and accelerated localised wear as indicated in Figure 1. Inconsistent weld quality can further exacerbate these issues, affecting overall pipeline efficiency. Often wear patterns will be seen next to the beads or further down the pipeline.

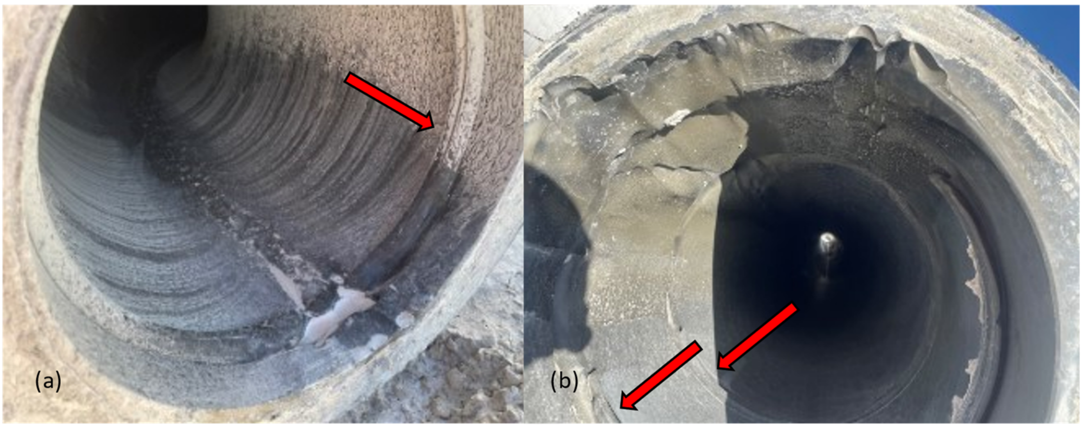


Figure 1 Wear effects of weld beads in high-density polyethylene (HDPE) pipes: (a) HDPE slurry pipe cut at profile next to a weld bead; (b) HDPE pipe with two visible weld beads and significant wear around the bead

A significant limitation of HDPE pipelines is the standardisation of pipe sizing. HDPE pipes are manufactured to specific nominal sizes, which restricts the ability to optimise the ID to achieve the ideal velocity for slurry transport with minimum losses.

2.2 ARTERRA ultra-high molecular weight polyethylene pipelines

UHMWPE is emerging as a superior alternative to traditional HDPE in the transportation of tailings slurry within the mining industry. ARTERRA is a registered trademark of Weir. Historically, UHMWPE has been used in the marine industry and for navigation buoys. The material is highly resistant to biofouling, tough and corrosion resistant, and minimises scaling. UHMWPE in more recent times has been extruded into pipe. The UHMWPE material for ARTERRA pipelines has been specifically formulated for high-wearing mining pipelines, with over 120 formulations tested to maximise abrasion resistance and wear life while remaining commercially attractive. With a molecular weight of 35×10^5 g/mol, over seven times that of HDPE, ARTERRA offers exceptional properties that address many of the limitations inherent in HDPE pipelines. The high molecular weight and molecular structure results in superior abrasion resistance, extending the pipeline's operational life and reducing maintenance and replacement frequency.

ARTERRA UHMWPE pipelines are extremely smooth, with a material roughness of 0.0002 mm. This can create benefits not only in scaling but also in reducing the friction losses in a pipeline which affect the total dynamic head, particularly with slurries where design velocities are greater than 3.5 m/s. ARTERRA pipelines are also joined using flanges, thus eliminating the need for internal weld beads, which further minimises turbulence and friction losses.

An important advantage of ARTERRA is its flexibility in design. ARTERRA pipelines can be manufactured from the ID out, allowing for optimised ID selection tailored to specific design requirements. This flexibility enables designers to achieve optimal flow conditions and pressure reductions more effectively, unlike standardised HDPE pipe sizes, which are more restrictive and costly to adjust. UHMWPE also has a higher strength than HDPE, reducing the required wall thickness for a given pressure rating and potentially allowing UHMWPE to replace steel pipes in some cases.

3 ARTERRA ultra-high molecular weight polyethylene versus high-density polyethylene pipeline investigation

3.1 Case study tailings overview

To illustrate the practical implications and benefits of optimising tailings slurry transport through material selection, a case study outlining a typical pipeline used to transport copper-gold tailings from a processing plant to a tailings storage facility is used. This example provides a framework to understand the theoretical analysis and comparative results. The pipeline is 10 km long with an assumed zero static head, thus providing a representative scenario of the challenges faced in longer-distance tailings transport. The tailings slurry and pipeline properties are shown in Table 1.

Table 1 Tailings slurry and pipeline properties

Description	Units	Value
Length of pipeline	m	10,000
Static head	m	0
Flow rate	m^3/hr	1,514
Specific gravity of solids	t/m^3	2.71
Particle size distribution (P80)	µm	140
Particle size distribution (P50)	µm	75
Solids concentration by weight	%	64.0
Solids concentration by volume	%	39.6

It is noted that commonly in pipeline design, a factor of scouring will be applied to the surface roughness of the pipeline material. However, for comparison purposes, the roughness values of new pipes are used.

3.2 Pipeline design calculations

The pipeline design calculations are essential to accurately determine the friction losses, head losses and overall energy requirements for the transportation of tailings slurry. This section outlines the methodology and calculations used, focusing on the specific parameters provided.

The pipeline under consideration has an ID of 403 mm, with a total length of 10,000 m.

The pipeline is designed to transport the slurry at a flow rate of 1,514 m^3/hr. With an ID of 403 mm, the design velocity of the slurry through the pipeline is 3.3 m/s.

3.3 Friction loss calculations

The friction losses per section were calculated using the Darcy–Weisbach formula (Equation 1).

$$\Delta \mathrm{H} = f \times \frac{\mathrm{LV}^2}{2\mathrm{gD}} \tag{1}$$

where:

ΔH = head loss per (m)

f = Darcy–Weisbach friction factor (Equation 2)

L = length of the pipe (m)

V = velocity of the slurry (m/s)

g = acceleration due to gravity

D = diameter of the pipe (m).

The Darcy–Weisbach friction factor was calculated using the Moody approximation (Equation 2). Moody's approximation is ideal for smooth pipes where the relative roughness is between 0 and 0.01 and displays a turbulent flow regime with a Reynolds number (Re) greater than 4,000 (Piegorsch 1989).

$$f = 0.0055\left[1 + \left(2 \times 10^4 \times \frac{\varepsilon}{D} + \frac{10^6}{Re}\right)^{\frac{1}{3}}\right] \quad (2)$$

where:

f = Darcy–Weisbach friction factor

ε/D = relative roughness of the pipe

Re = Reynolds number.

Table 2 Pipeline size

	Units	HDPE*	ARTERRA UHMWPE**
Pressure rating	PN	25	25
Nominal size	NB	560	N/A
Internal diameter	mm	403	403
Minimum wall thickness	mm	75.7	48
Pipeline roughness	mm	0.0015	0.00022
Relative roughness	–	3.722×10^6	0.546×10^6
Reynolds number	Re	449,438	449,438

*high-density polyethylene **ultra-high molecular weight polyethylene

A notable limitation of HDPE pipelines is the pressure restriction and the standard sizing. The ID of ARTERRA UHMWPE pipelines is set by design and completely customisable as opposed to standard dimensions. For this comparative example, the IDs are equivalent. Due to the inherent properties of UHMWPE, the wall thickness required to achieve the PN25 pressure rating is 48 mm compared to the 76 mm of HDPE.

3.3.1 Losses due to weld beads

Losses in the HDPE pipeline are broken down into losses due to friction and losses due to weld beads. Losses due to weld beads were calculated using Equation 3 from the *Handbook of Hydraulic Resistance* (Idelchik 2007). This formula represents turbulent losses where Re is greater than 10×10^3 due to a thick-edged orifice in a straight tube, as depicted in Figure 2.

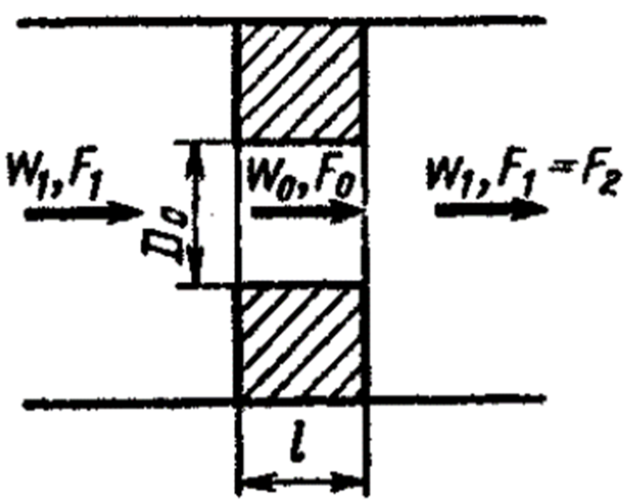


Figure 2 Thick-edged orifice in a straight tube (Idelchik 2007)

$$K = \frac{\Delta P}{\rho V^2} = \left[0.5\left(1 - \frac{D_O}{D_1}\right)^{0.75} + \tau\left(1 - \frac{D_O}{D_1}\right)^{1.375} + \left(1 - \frac{D_O}{D_1}\right)^2 + f\frac{1}{D_h}\right]\left(\frac{D_1}{D_O}\right)^2 \tag{3}$$

where:

K = coefficient of pressure loss

ΔP = pressure drop across weld bead(Pa)

ρ = density of fluid (kg/m^3)

V = velocity of the slurry (m/s)

D_O = diameter of orifice

D_1 = diameter of pipe

τ = coefficient Equation 4

f = Darcy–Weisbach friction factor (Equation 2)

D_h = hydraulic diameter = *D* for round pipes.

$$\tau = (2.4 - l) \times 10^{\vartheta} \tag{4}$$

$$\vartheta = \left. 0.25 + 0.535\left(\frac{l}{D_h}\right)^8 \middle/ 0.05 + \left(\frac{l}{D_h}\right)^7 \right. \tag{5}$$

where:

l = length of orifice = 2H (Equation 6).

The weld bead size is calculated according to the international standard *ISO 21307: Plastics Pipes and Fittings — Butt Fusion Jointing Procedures for Polyethylene (PE) piping systems* (ISO 2001) (Equation 6). The bead dimensions are as shown in Figure 3 (ASTM International 2010).

$$H = 1 + 0.15 \times \omega \tag{6}$$

where:

H = minimum weld bead height

ω = wall thickness of the pipe.

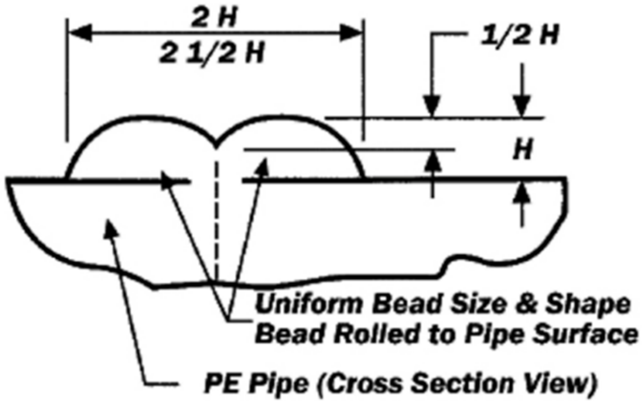


Figure 3 Butt Fusion Bead Dimensional Guideline (ASTM International 2010)

By applying Equation 3 to the weld bead dimensions, the resultant coefficient of loss is 0.10.

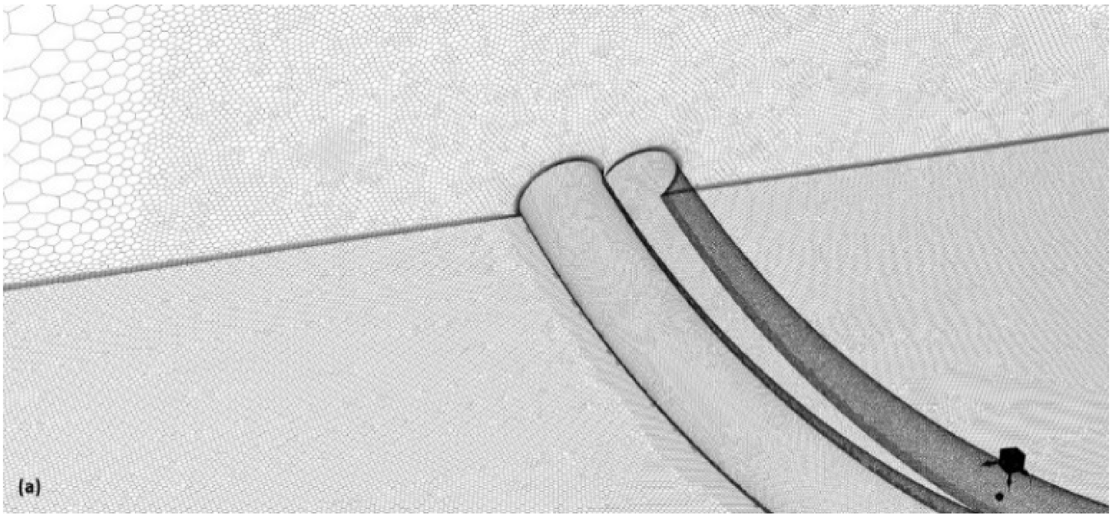
3.3.2 Weld bead computational fluid dynamics modelling

To validate the theoretical weld bead loss calculations, a weld bead was modelled using CFD techniques, with the same slurry and pipeline properties used for the above calculations.

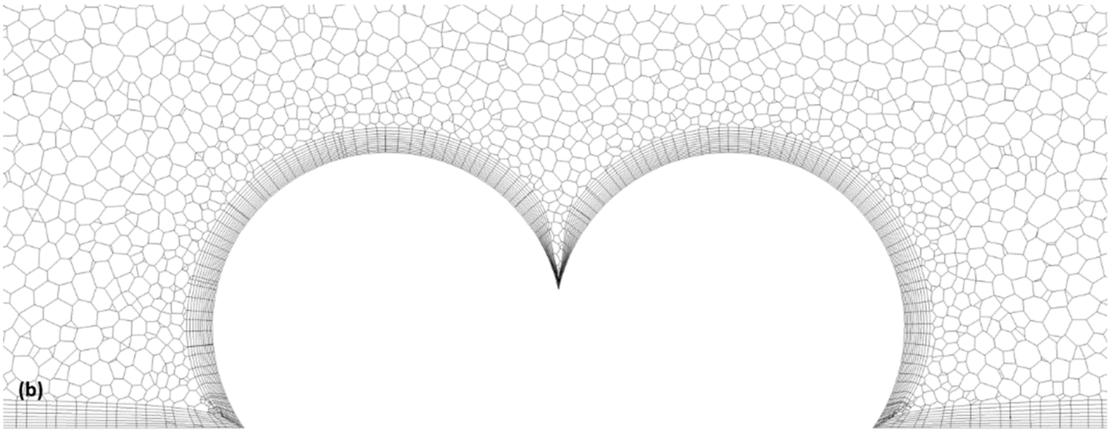
3.3.2.1 Computational fluid dynamics model set-up

The weld bead geometry was modelled and meshed in Ansys Fluent using a hexagonal honeycomb structure (Figure 4). A fine mesh was adapted in this case, along with a boundary layer mesh, to capture the detail flow around the weld bead. A high quality CFD mesh improves the accuracy of the flow field modelled. This allows for improved accuracy of the calculated quantities derived from CFD-simulated results.

For an initial set of simulations, a water-only case that represented analysed flow conditions was modelled in this paper.



(a)



(b)

Figure 4 Weld bead computational fluid dynamics hexagonal mesh. (a) Surface mesh in 3D; (b) Mesh around the weld bead with the boundary layer mesh zoomed in on and shown in 2D

3.3.2.2 Computational fluid dynamics results

Using the input condition described above, a CFD flow field was simulated (Figure 5). This shows the wake region behind the weld bead, and Figure 6 shows the smaller wake between the weld bead joint and in front of the weld joint. In general, these results shows that the weld bead generates some level of turbulence and flow resistance.

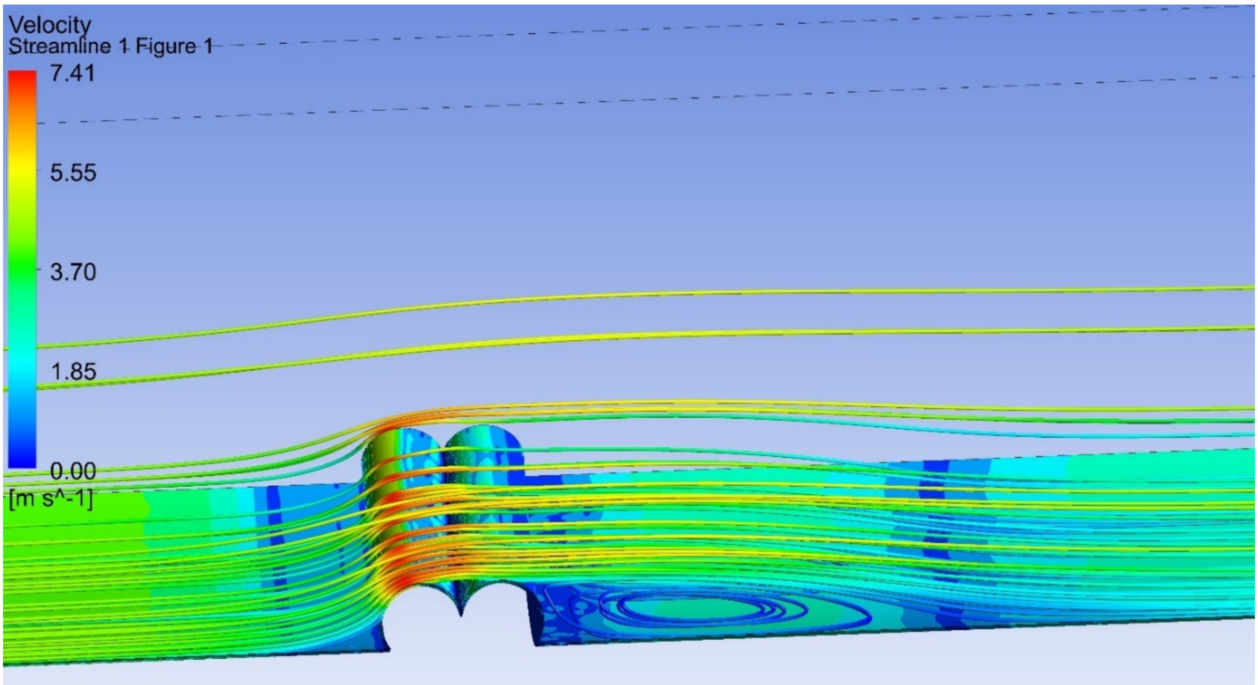


Figure 5 Computational fluid dynamics simulated flow past a weld bead: 3D view of flow streamline coloured by flow velocity

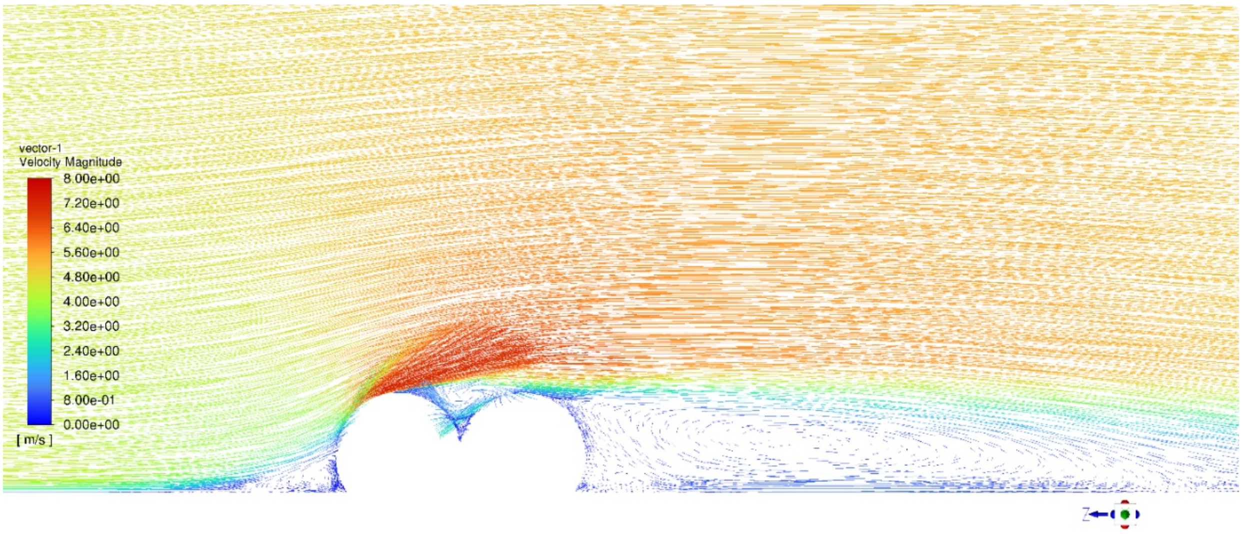


Figure 6 Computational fluid dynamics simulated flow past a weld bead: flow streamline in 2D cross-section view coloured by flow velocity

As shown in Figure 7, the velocity range around the bead increases to about 7.5 m/s, over double the design velocity of 3.3 m/s, creating a turbulent region around it. These velocity flow field and streamline plots show that when the flow passes the weld beads it narrows over a short distance beyond the weld bead (Figure 6) to form what is generally known as a *vena contracta*, similar to the flow past an orifice with rounded edges.

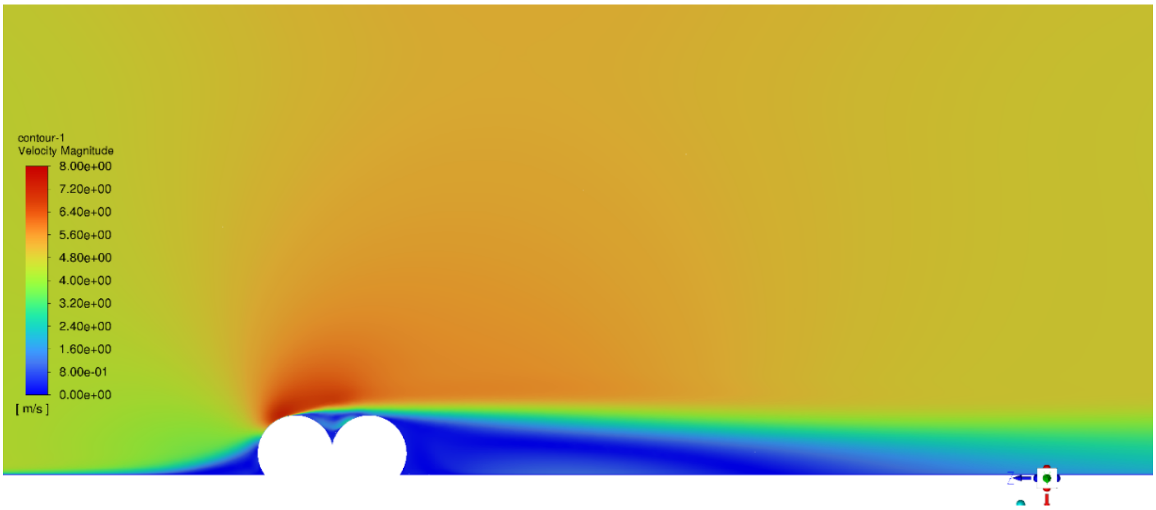
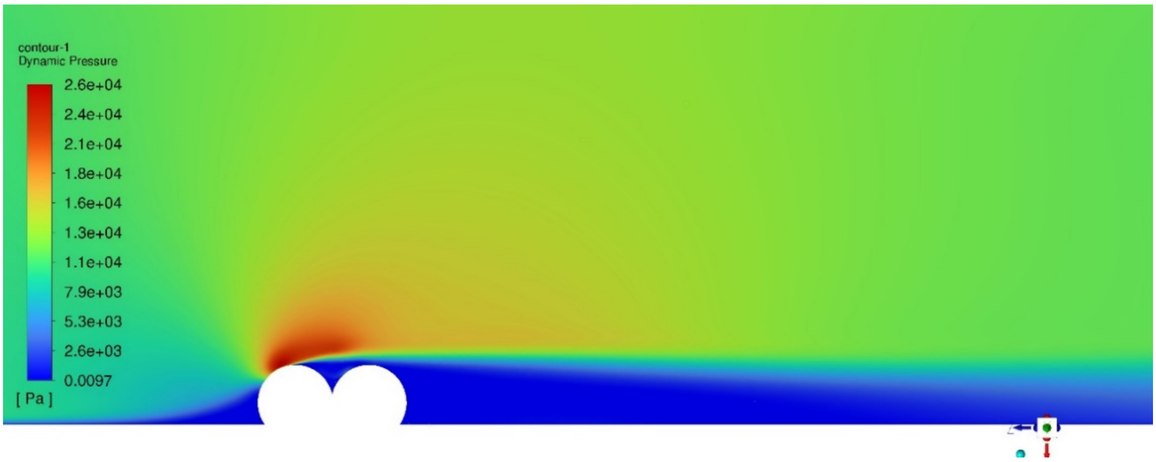


Figure 7 2D cross-section plot of flow velocity magnitudes

Figure 8 shows CFD-modelled static and dynamic pressure across the weld bead. The pressure drop is used to calculate the loss coefficient. These pressure fields are comparable to what is observed in the flow fields past the orifice.



(a)

(b)

Figure 8 2D cross-section plot of (a) dynamic and (b) static pressure

These CFD results can be used to calculate losses due to a weld bead using Equation 7, initially introduced in Equation 3.

$$K = \frac{\Delta P}{\rho V^2} \quad (7)$$

where:

K	=	pressure loss coefficient
ΔP	=	pressure drop across weld bead(Pa)
ρ	=	density of fluid (kg/m^3)
V	=	velocity of the slurry (m/s).

Applying Equation 7 to CFD results, the K value is 0.09.

4 Results

The loss coefficients derived from calculations and CFD modelling are 0.10 and 0.09, respectively. This verifies the calculated model as the K values are within 10% of each other. For the purposes of this paper, losses due to weld beads will be calculated using the calculated K value of 0.10. The differences in head loss due to weld beads for this example are 28.8 m and 25.4 m for calculated and CFD-modelled, respectively.

Results from the friction loss calculations and weld bead losses are shown in Table 3. In this example there are five weld beads per 100 m, at 20 m intervals.

Table 3 Pipeline head losses

	Units	HDPE*	ARTERRA UHMWPE**
Friction head loss	m	175.4	174.5
Head loss due to weld beads	m	28.8	0
Static head	m	0	0
Total head losses in the pipeline	m	204.2	174.5

*high-density polyethylene **ultra-high molecular weight polyethylene

The relative difference in calculated head requirements for HDPE and ARTERRA UHMWPE is almost 30 m over the 10-km pipeline length. Head losses are directly related to pumping power requirements.

The comparative power requirements are quantified over a year in Table 4. With a plant availability of 90% for both pipeline options, there are 7,889 total pumping hours per year. The cost of grid electricity to the mine site is AUD 0.14/kWh. Power requirements differ between pipeline materials by 2.1 MWh per annum, which is 14.5% of total power. This equates to savings of 1,418 t of carbon and AUD 302,436 per annum by implementing the ARTERRA UHMWPE pipeline instead of an HDPE equivalent.

Table 4 Pumping power per system

	Units	HDPE*	ARTERRA UHMWPE**
Absorbed power per system	kW	1,883	1,609
Absorbed power per year	kWh	14,854	12,694
Power cost per year	AUD	2,079,607	1,777,171

*high-density polyethylene **ultra-high molecular weight polyethylene

Losses due to weld beads increase exponentially with pipeline velocity, as shown in Figure 9. Common tailings pipeline velocities are 1.5 to 4.5 m/s, as shown in blue. Losses due to weld beads range from negligible at low velocities to significant in high velocity pipelines.

Coarser grind sizes and/or transport of the coarse fractions of tailings requires higher transport velocities to prevent settling. With increasing velocity, weld beads in the pipeline play a larger role in both design and operational considerations, namely increased power consumption, wear and turbulence.

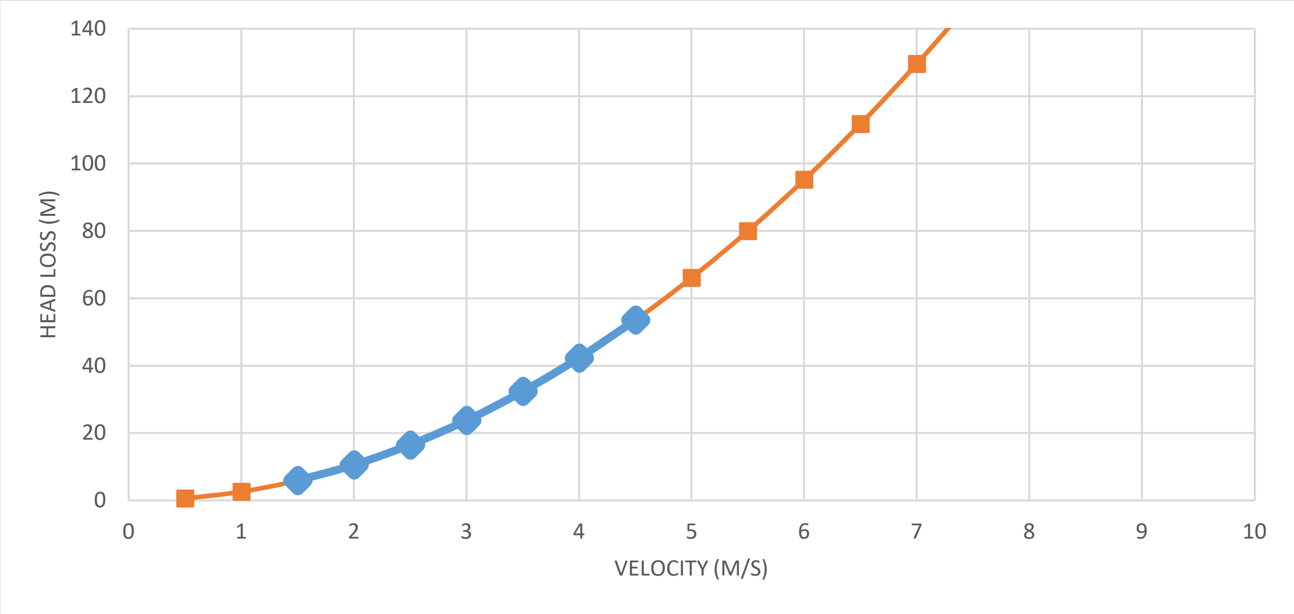


Figure 9 Head loss in a pipeline with increasing velocity

The ability to specify an ID of ARTERRA UHMWPE, and therefore match the optimum design velocity, minimises the system head. The effect of velocity on pump power costs is shown in Figure 10. The percentage difference in power drawn per system (MWh), and ESG carbon tonnes per annum saved, are shown in Figure 11.

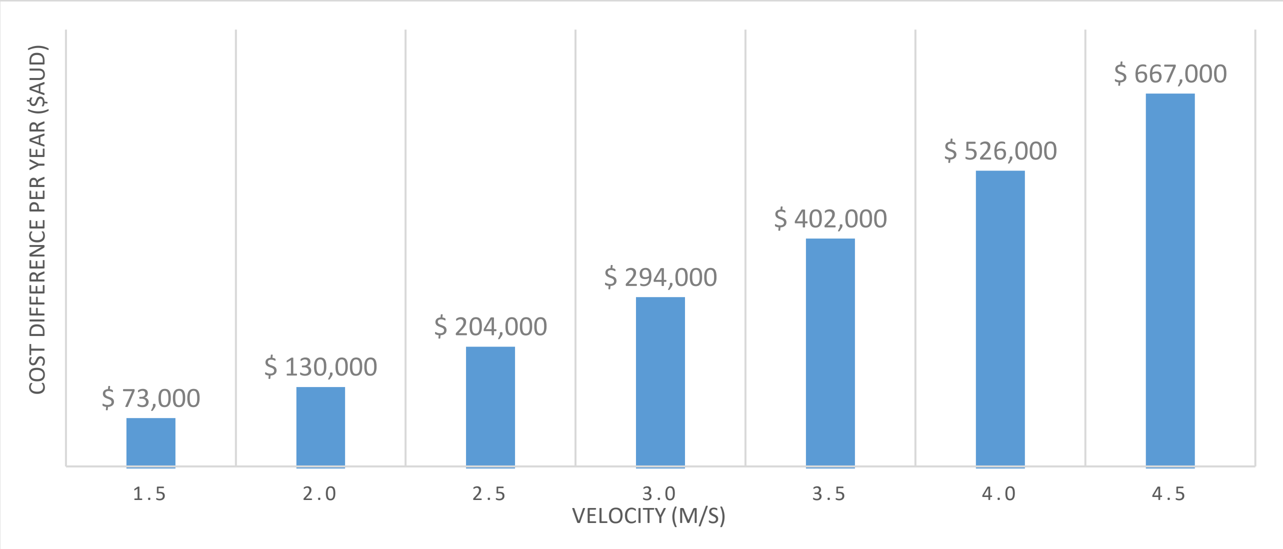


Figure 10 Cost savings per annum using an ARTERRA pipeline instead of high-density polyethylene with increasing velocity

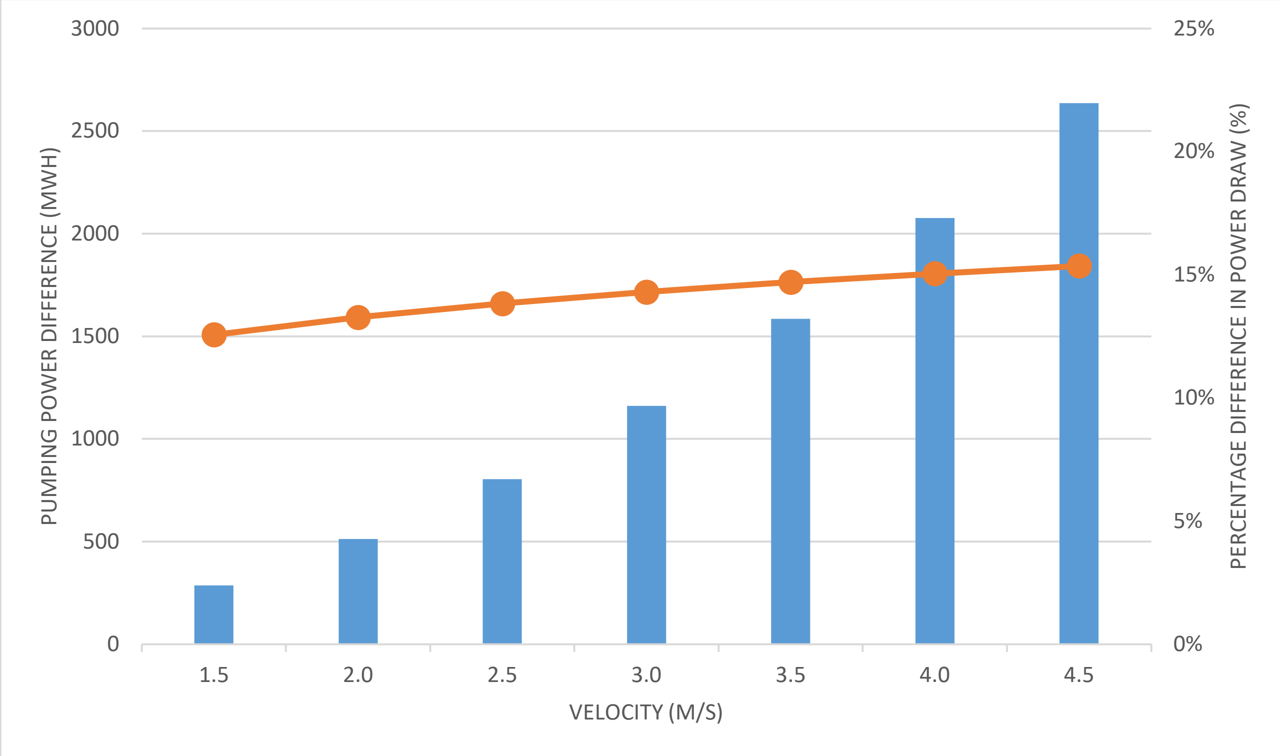


Figure 11 Difference in pumping power and percentage power draw between ARTERRA and high-density polyethylene pipelines

5 Discussion

The comparative analysis of HDPE and ARTERRA UHMWPE pipelines for tailings slurry transportation reveals several critical insights into the efficiency and sustainability of these materials.

The findings from this study highlight the significant impact of weld bead-induced turbulence on power consumption in HDPE pipelines: a factor often overlooked in theoretical models but evident in practical observations from mining operations.

ARTERRA UHMWPE pipelines, with their flanged connections and smoother internal surfaces, offer a promising alternative to traditional HDPE pipelines. The absence of weld beads and the lower surface roughness coefficient of UHMWPE result in reduced friction losses, leading to lower power consumption and improved flow efficiency. These benefits translate into financial savings and ESG advantages, with a notable reduction in carbon emissions.

The case study of a 10 km pipeline transporting copper-gold tailings demonstrates the practical implications of material selection on pipeline efficiency and sustainability. The theoretical models and calculations presented in this paper underscore the potential for significant energy savings and operational cost reductions through the adoption of UHMWPE pipelines.

One of the most significant findings is the impact of weld beads on the efficiency of HDPE pipelines. The presence of weld beads in HDPE pipelines introduces localised turbulence, which increases friction losses and, consequently, the power required to pump the slurry. This effect is particularly pronounced at higher velocities, where the turbulence induced by weld beads becomes more significant. The results indicate that, for the example used, HDPE pipelines experience an additional 29 m of head loss due to weld beads over a 10 km pipeline length, compared to UHMWPE.

The resulting power consumption for UHMWPE pipelines is significantly lower than that for HDPE pipelines, with a reduction of 2.1 MWh per annum (14.5%). This translates to a decrease of 1,418 t of carbon emissions and an annual cost saving of AUD 302,436. These savings highlight the potential for ARTERRA UHMWPE pipelines to contribute to more sustainable operations.

Another advantage of ARTERRA pipelines is that they can be manufactured with customised IDs to optimise design velocity and so further reduce head loss.

While the study is based on theoretical and modelled results, it provides a solid foundation for further research and practical experimentation. Future studies could explore the long-term effects of weld bead geometry on wear and localised wear points in pipelines, as well as the impact of increasing pipeline roughness over time.

The findings of this study have important implications for the future design and selection of pipeline materials in the mining industry. The demonstrated benefits of UHMWPE pipelines in terms of reduced friction losses, lower power consumption and cost savings make them a compelling alternative to traditional HDPE pipelines. As mining operations continue to adopt new technologies and face increasing pressure to reduce their environmental footprint, the adoption of UHMWPE pipelines represents a strategic opportunity to enhance pipeline efficiency and sustainability.

6 Conclusion

In conclusion, the shift towards coarser tailings in the mining industry, driven by advancements in processing technologies and the practice of using coarse tailings for dam wall construction, underscores the growing importance of addressing pipeline losses due to weld beads. As slurry velocities increase to accommodate larger particle sizes, the efficiency of tailings transport becomes increasingly compromised. Therefore, it is imperative for the industry to develop and implement strategies to mitigate these losses, ensuring the sustainability and efficiency of mining operations in the future.

The adoption of ARTERRA UHMWPE pipelines represents a strategic opportunity for the mining industry to enhance pipeline efficiency, reduce energy consumption and achieve sustainability goals. By addressing the limitations of traditional HDPE pipelines, UHMWPE offers a pathway to more sustainable and cost-effective tailings slurry transportation.

Acknowledgement

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