ISSN 2176-3135

TOWARDS THE DEVELOPMENT OF DESIGN CRITERIA FOR REDUCED WEAR IN IRON ORE TRANSFERS*

Dusan Ilic [1]
Thomas J. Hicks [2]

Abstract
Conveyor system wear of belts and transfers attribute to a significant proportion of the maintenance costs and lost productive hours when handling hard abrasive ores at high unit rates typical of the iron ore industry. The recent growth phase has seen a rapid increase in mine and export capacity, with many new and upgraded plants operating at high throughput and utilisation. Subsequently, the industry has progressed to an optimisation phase, seeking to maximise production capacity and reduce maintenance costs with minimal capital spend. To support this, a programme of modifying designs was executed to improve conveyor transfer chute and belt life, which identified a need to challenge the industry practice for specification of designs to improve the functionality of the installed equipment. While acknowledging the importance of selecting the highest wear resistant materials for the intended application, this paper investigates design criteria related to decreasing conveyor transfer and belt wear. Of focus is a shift in the manner in which designs are specified, from specifications primarily governing geometrical constraints, to those meeting technical and functional requirements aimed at producing optimum geometry for a given set of material handling parameters. An assessment of transfer design criteria is presented.
Keywords: Transfer; Design; Conveyor belt; Wear.

[1] *B.Eng. (Mech.), PhD, Senior Consulting Engineer, TUNRA Bulk Solids, Newcastle Institute for Energy and Resources, The University of Newcastle, Shortland, NSW, Australia.*
[2] *B.Eng. (Mech.), Principal Engineer, Bulk Materials Handling CoE, Bechtel, Brisbane, QLD, Australia.*

ISSN 2176-3135

1 INTRODUCTION

Conveyor system transfers are generally designed to have sufficient height to allow for re-direction of the primary ore stream to vertical via a deflector and training of the material flow in the direction of the receiving conveyor via a sloped chute rear wall. In addition to management of the primary stream, chutes must also capture fine material from the primary and secondary belt cleaners. Iron ore transfer chute walls are typically designed with minimum angles of 65 to 70° to prevent build up and chute blockage caused by cohesive material with limited consolidation pressure. Additional features, which compromise ideal chute geometry, include the requirement for sampling equipment, bifurcated chutes feeding multiple conveyors, or pre-existing geometrical limitations.

High rates of wear of chutes and belts contribute significantly to plant operating costs (typically in the order of USD1-2 million per annum per conveyor for high capacity iron ore operations); frequently result in failure to achieve planned shutdown intervals and, often require ad-hoc maintenance or “patching” of the chutes to remain operational until the planned shutdown. Lost production from undertaking such work can have a significant impact on the profitability of the plant and introduces safety risks through the execution of unplanned work.

In addition to the immediate effect of maintenance for wear in chutes, it is common for the severity of chute condition to be underestimated prior to commencement of a shutdown, often resulting in overrun or unsatisfactory maintenance. Both of these outcomes cost the operations significantly through loss of production.

A recent programme of works undertaken to achieve a step change in the performance of transfers for one site identified areas in which the chutes were optimised for handleability of a broad spectrum of material types, at the expense of performance when handling the process specific material type. All of the chutes investigated had each been designed in compliance with specifications that included strict geometrical requirements, but with limited performance based criteria.

Capital projects have typically been executed by means of an EPCM contract, with high levels of owner team engagement throughout the detailed design phase. Alternative contracting models such as EPC are currently being explored by the industry; these models reduce the ability of the owner team to influence the design post award, thereby increasing the criticality of the design specifications for the mine or application specific material properties.

2 ASPECTS OF WEAR IN MATERIALS HANDLING

Wear of materials is a subject that has been studied extensively by many authors for more than a century. It is argued that the two classical theories of greatest applicability to the topic of this paper stem from that of Reye [1] and Archard [2]. Reye hypothesised that wear, which occurs at the interface between two contacting surfaces due to a load, is proportional to the pressure applied to the surface. He also considered the volume of removed material was proportional to the energy dissipated within that material due to relative motion of the two contacting surfaces. Archard presented a theoretical approach relating the volume of removed material over a sliding distance to the area of contact, which in turn is proportional to the applied normal load and the hardness of the softer material. Other factors that may or may not influence wear include angle of impingement; contact area; particle shape and size; surface asperities; friction; hardness; temperature; and, thermal conductivity.

ISSN 2176-3135

Researchers have also postulated and investigated microscopic level molecular changes on the intrinsic behaviour and influence on exhibited wear mechanisms. For the purpose of this paper, these factors are considered microscopic, and are all influenced to a similar level by the macroscopic effects of impact pressure and velocity.

In bulk materials handling, particularly transfer chutes and conveyor belts, wear arises due to two main mechanisms: impact (or erosion) through normal load; and, abrasion (or shear) through relative velocity. The occurrence of these mechanisms could be individual or in harmony, and some of the difficulty associated with quantifying the influence of transfer design on equipment life lies in the accurate determination of the relevant proportions of each. A previous study of wear mechanisms in the handling of iron ore, in particular regarding impingement angle, can be found in Donohue et al [3].

The main aspect associated with wear in view of Reye's and Archards theories investigated herein is simply velocity; notably, this is also the property, which the designer has the greatest ability to influence. This study reviews the development of transfer design criteria through an analysis of velocities, and examines alteration of flow conditions to reduce the loads acting on wearing surfaces and hence prolong equipment life. In his assessment of wear by particulates, lower velocity as a means of reducing wear has also previously been concluded by Hutchings [4], perhaps amongst many others. The ultimate result is a review of the methodology in which transfer chute designs are specified. The mechanics of wear and range of theories and approaches available can then be subsequently used to predict the benefit likely to be achieved.

3 PRINCIPLES FOR OPTIMAL TRANSFER CHUTE DESIGN

Based on pioneering work by Roberts [5], the primary objectives of transfer chute design for optimum flow are summarised below, along with practicalities involved in their industrial application:

- Selection of most favourable wall lining material based on flow property testing results - lowest friction, highest wear resistance. This aspect is also dependent on economics as wear liners can be extremely expensive;
- Selection of transfer head height and geometry related to satisfying operational criteria. Specific to the iron ore industry, this is dependent on satisfying the general minimum chute inclination in the order of 70°;
- Minimising impact angles between the material stream and transfer chute geometry. This is related to minimising wear in smooth wall liner chute designs;
- Centralised flow as a means of minimising occurrence of belt mis-tracking and spillage. This is generally more difficult to achieve with a rock-box design;
- Sufficient chute wall angles (slope) to guarantee flow at the specified rate under all conditions, minimising flow retardation and preventing blockage. The subsequent effect is a minimum inclination angle and therefore minimum transfer head height;
- Matching as closely as possible inline component of bulk solid material stream velocity at exit of the chute and loading to the velocity of outgoing conveyor belt. It will become evident that this is generally outside of consideration when designing for steep chute angles due to excessive velocities required; and,
- Minimising normal component of bulk material velocity at loading point thereby reducing impact wear on the belt. Effectively a maximum head height limit must

ISSN 2176-3135

also form part of the design criteria. This is difficult to achieve if designing to match belt speed, if restricted by transfer orientation or steep loading angle.

On closer inspection of the above it is evident that distinction in priority needs to be given to specific objectives over others i.e. minimising normal velocity vs. matching belt speed. This must be performed in view of the material characteristics and operational criteria of the particular application being designed.

4 MODELLING TECHNIQUES

Regarding the application of continuum mechanics together with Discrete Element Modelling (DEM) in the analysis of transfer chute interactions, the reader is referred to Ilic [6]. From Roberts [5] and Ilic [6], the equations used in the analyses of Section 5 are presented below. In a straight chute, assuming constant equivalent friction, μ_E, the velocity, V, of the material stream at a distance, s, down the incline is given by:

$$V = \sqrt{{V_o}^2 + 2 \cdot a \cdot s} \qquad (1)$$

Where acceleration $a = g \cdot (cos\theta - \mu_E \cdot sin\theta)$ with θ being the chute inclination from the vertical. For internal shear flows, exhibited with the rock-box type chutes, μ_E is related to the effective angle of internal friction, δ, of the bulk material handled through $\mu_E = sin\delta$; whereas for chutes with smooth liners μ_E is related to the wall friction angle, ϕ_w, through $\mu_E = tan\phi_w$. In the free-fall section of the transfer, the velocity of the material stream at a drop height, h_f, is approximated by:

$$V = \sqrt{{V_o}^2 + 2 \cdot g \cdot h_f} \qquad (2)$$

Where g is gravitational acceleration. The impact pressure, at loading P_{vi}, is given by:

$$P_{vi} = \rho \cdot V_N^2 \qquad (3)$$

Where ρ = material bulk density and V_N = material normal velocity component at loading point. The belt wear parameter, W_a, expressing the rate of abrasive wear on the belt may be established as follows:

$$W_a = \mu_1 \cdot \rho \cdot V_N^2 \cdot (V_B - V_L) \qquad (4)$$

Where μ_1 = friction coefficient between bulk material and conveyor belt, V_B = belt speed and V_L = bulk material loading velocity in direction of outgoing belt travel. Extending the analysis to include the inclination of the outgoing belt, α (to the horizontal), Eqn. (4) may be expressed as a function of the non-dimensional wear factor, N_WB:

$$W_a = \mu_1 \cdot \rho \cdot V_B^3 \cdot N_WB \qquad (5)$$

Where $N_WB = [(V_R \cdot A)^2 \cdot (1 - V_R \cdot B)]$, $V_R = V_E / V_B$, A = $Sin(\psi+\alpha)$, B = $Cos(\psi+\alpha)$, ψ is the chute cut-off angle (chute angle to the horizontal) and V_E = bulk material velocity at exit of chute (or at loading point).

ISSN 2176-3135

5 INVESTIGATION OF TRANSFER VELOCITIES

The practicalities associated with developing an association between wear and velocity is investigated in view of the direct relationship between normal velocity, V_N, and impact pressure: the applied load causing wear. This relationship is illustrated in Figure 1 for a typical iron ore transfer with a 70° chute angle and horizontal outgoing belt where V_N is maximum when loading velocity is equal to belt speed. The figure demonstrates that in order to minimise abrasive belt wear through matching bulk material and belt speed, extremely high velocities are required, in turn resulting in high impact pressures exerted not only on the belt, but also on the chute components. Therefore, it is simply not feasible to optimise the interaction between chute and belt for this criterion if the current practice of incorporating a steep angled chute is applied. It is also to be noted that should the requirement to match belt speed become criteria for designing steep angled rock-box transfers, then this would result in extremely poor performing chutes, particularly if it was achieved through an increase in head height. Therefore, it is important to realise that balancing chute and belt wear through management of ore stream velocities is likely to result in the optimum arrangement. Whilst not the topic of this paper, similar attention to ore velocities is also required to prevent chute blockage as indicated in Figure 1.

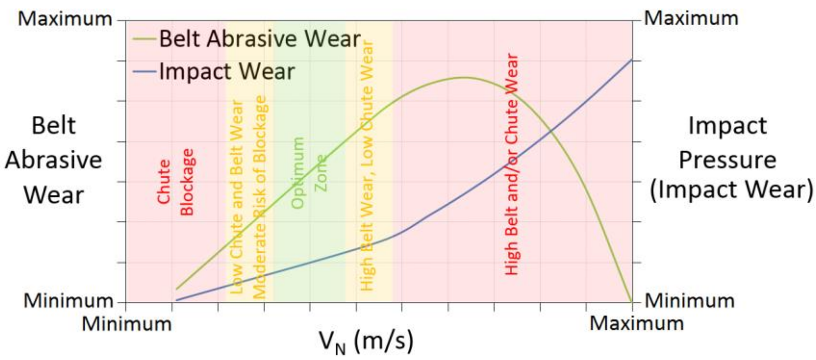

Figure 1. Belt Wear and Impact Pressure Relationship to Normal Velocity, V_N

To highlight the association to transfer head heights, Figure 2 presents the free fall and sliding velocities for a range of initial velocities. Appreciable values of 10.0 m/s and higher can be observed for head heights over 3.0 to 4.0 m.

Investigating further, Figure 3 shows velocities at chute exit, V_E, required for matching outgoing belt speed, V_B, of 4.0 to 6.0 m/s with respect to chute inclination at exit (or cut-off angle, ψ). Figure 3 a) shows the V_E required to match belt speed ($V_L = V_B$) and Figure 3 b) shows V_E required for loading velocity to be 50% of belt speed ($V_L = 0.5{\cdot}V_B$). The results presented in Figure 3 a), in view of those shown in Figure 2 b) highlight the impracticality and fictitious goal of matching belt speed with chutes of steep inclination. The data is presented in a different light in Figure 4 a), which shows the loading velocity to outgoing belt speed ratio (V_L/V_B) and the corresponding non-dimensional wear parameter, N_WB, on the outgoing belt. The graph indicates that maximum abrasive wear on the outgoing belt occurs when V_L is somewhere between 55 and 85% of V_B. The data also shows wear increasing with cut-off angle and outgoing belt inclination. This suggests that for minimum belt wear, loading velocity must be either higher than 85% or below 40 to 50% of V_B, the former being entirely impractical to achieve with chutes of steep inclination. In considering this, it must be noted that a minimum V_E to ensure reliable transfer and flow without build-up or blockages occurring must also be satisfied. The corresponding plot and relationship

ISSN 2176-3135

of V_E/V_B is presented in Figure 4 b). The results show V_E for a 70° chute inclination must be either lower than V_B or at least three times greater than V_B for reduced wear. In taking into consideration N_WB, it is important to bear in mind that wear associated with impact is directly related to V_N, which approaches maximum as V_L approaches V_B (previously illustrated in Figure 1). Summarising the data presented, a case can be argued for low loading velocities as a means of reducing wear on the outgoing belt. The argument can also be extended to head height if its dependence on velocity is also taken into consideration.

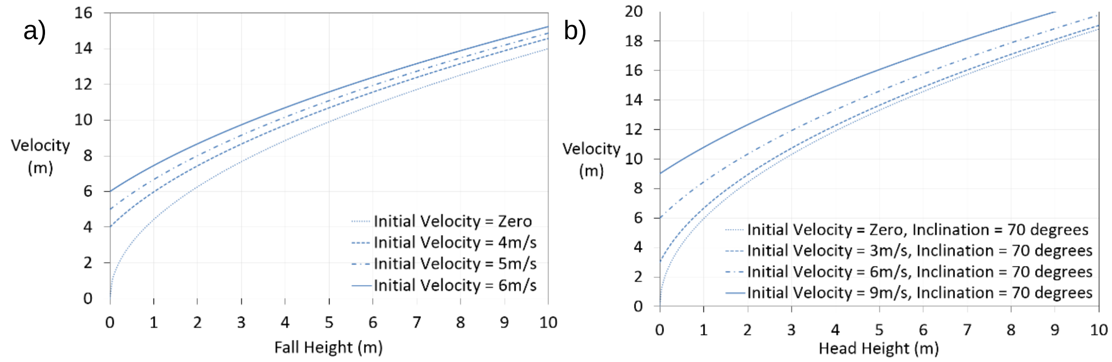

Figure 2. Free fall Velocity (left) and Sliding Velocity (right) as a Function of Head Height

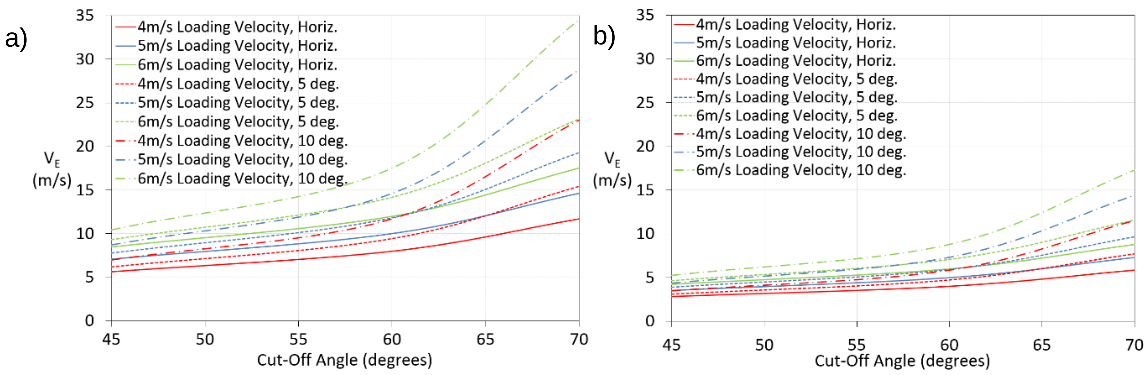

Figure 3. Chute Exit Velocity, V_E Required for Loading at a) 100% Belt Speed and b) 50% of Belt Speed with Respect to Cut-off Angle

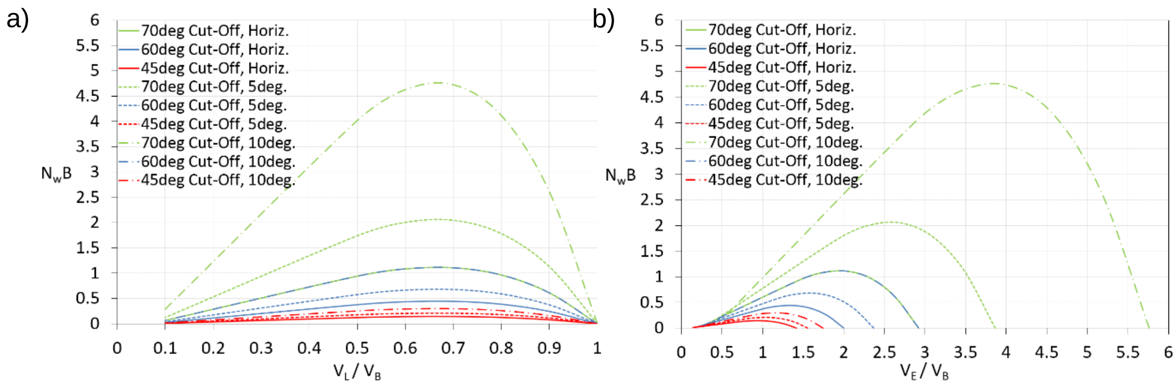

Figure 4. N_WB vs Exit and Loading Velocity as a ratio of Belt Speed

.

6 QUALITATIVE MODELLING CASE STUDY EXAMPLE

A case study example using DEM is presented to illustrate the influence of transfer design on the exhibited wear. Modelling was performed on an existing 90° transfer, with general arrangement shown in Figure 5 a). The total transfer head height of

ISSN 2176-3135

11.0m is atypical of that generally observed in the iron ore operations of Western Australia, (typical head heights are in the order of 7.0m). The existing design consisted of a curved deflector (orange) and rock-box chute inclined at 70° to the horizontal. The chute was initially installed with smooth ceramic liners throughout and was subsequently modified during commissioning with the introduction of rock-box ledges to address extremely poor chute wear life. Incoming and outgoing conveyor belts operate at 4.3m/s and 3.6m/s respectively handling screened lump material (+6.3mm – 32mm) at a throughput of 5,000t/h.

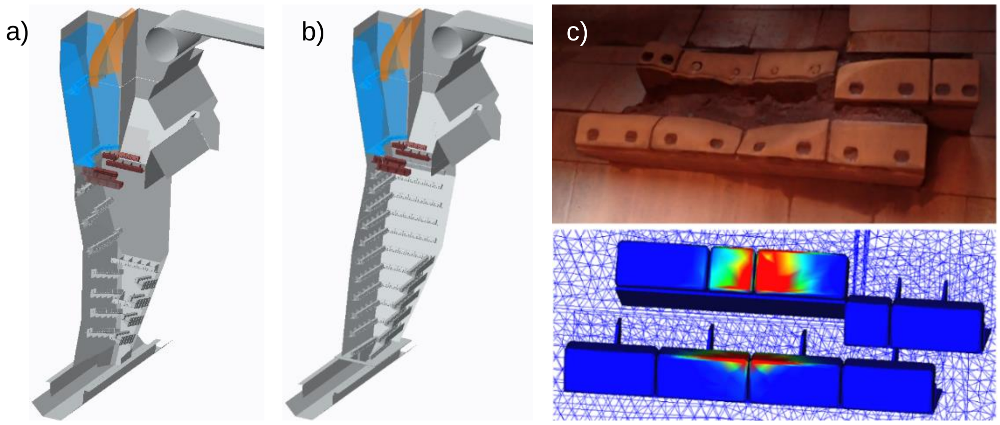

Figure 5. Transfer Designs Modelled - a) Existing, b) Revised and c) Billet Wear

Fifteen design variations were modelled in total of which six are summarised in Table 1, with the existing design and an investigated revised design incorporating a chute inclined at 60° to the horizontal. Variations included incorporating a rock-box deflector (shown in light blue in Figure 5 a) and b)) in place of the curved one, modifying the number of ledges and their spacing and also a training plate (or spoon) at the bottom, placed between the final ledge of each chute and the outgoing belt.

Table 1. Key Design Variations Investigated and Description

Design	Description
1. Existing Design	Curved Deflector, 70° Chute
2. Revised Design	Curved Deflector, 60° Chute, 45° Training Plate
3. Existing - Design A	Rock-box Deflector, 70° Chute
4. Revised - Design A	Rock-box Deflector, 60° Chute, 45° Training Plate
5. Existing - Design B	Rock-box Deflector, 70° Chute, Bottom Ledge #1
6. Revised - Design B	Rock-box Deflector, 60° Chute, Bottom Ledge #2

Note: *- Vertical distance from the bottom ledge of the chute to the top of the outgoing belt is approx. 1000mm and 750mm for the existing and revised designs respectively. The 45° training plate is a smooth straight inclined plate with sidewalls, located between the final ledge of the revised chute and the outgoing belt. The vertical distance between the 45° chute and top of outgoing belt is approx. 150mm. Bottom Ledge #1 refers to an additional ledge protruding in direction of outgoing belt travel and forming an effective inclination angle of 55° with the final chute ledge. Bottom Ledge #2 refers to an additional ledge forming an effective inclination angle of approx. 45° with the final chute ledge. The vertical distance between each Bottom Ledge and the top of outgoing belt is approx. 250mm.*

For the existing design with a curved deflector, the chute exhibited high rates of wear on the upper ledges shown in dark red Figure 5 a) and b), and the areas of limited material depth in the lower rock boxed section. The ledges comprised rows of 100 x 150 mm Ni-Hard billets bolted to shallow frames forming rock ledges. The wear pattern on the upper ledges observed is shown in Figure 5 c) with this image taken after 12 weeks of operation. Also shown is the corresponding wear contour obtained

ISSN 2176-3135

from qualitative DEM analysis, with red areas indicating highest wear. In this zone, the outer edges of the stream falling from the curved deflector are in continuous impact with the billets at velocities of 9.0 to 9.5 m/s. The area of the billets exposed to continuous contact by the individual particles here is in the order of 0.02 to 0.03 m^2.
The average and maximum peak stream velocities through the chute are presented in Figure 6. The data shows that the average peak velocity is highest immediately prior to impact with the inclined chute section, i.e. at 8.0 m and 5.5 m below the head pulley for the existing and revised designs respectively. The area of the transfer containing the ledges experiencing greatest wear and previously shown in Figure 5 is situated 4.0 to 5.0 m below the head pulley. The plot in Figure 6 b) shows continuous increase in maximum peak velocity with the existing designs whilst the revised designs all show reduction in maximum peak velocity toward the bottom of the transfer. Whilst high velocities are evident, high wear, particularly associated with continuous impact is minimised through prevention of areas of localised impact. It is noted that the revised design has higher velocities in the upper chute sections where the material is in free fall prior to impacting the rock-box deflector, the impacts of which are managed through careful placement of the billet ledges. The reduction in maximum velocity possible through the introduction of design revision is in the order of 3.0 m/s.
In Figure 6, the bottom of the curved and rock-box deflectors correspond to 2.0 m and 4.5 m below the incoming conveyor head pulley respectively. An additional observation from Figure 6 is that the average peak velocities at the bottom of the transfer are in the range of 7.0 to 8.0 m/s and maximum peak velocities are in the range of 11.0 to 14.0 m/s. Note that these are total magnitudes.
A velocity assessment of the stream centreline at the final ledge of each chute and at loading is summarised in Figure 7 a). Results indicate that incorporating a rock-box in place of the curved deflector is insufficient to be of significant influence on the loading velocity. Lowest velocity at chute exit and at loading is obtained through the incorporation of both the rock-box deflector and reduction in loading angle (Designs 4, 5 and 6).

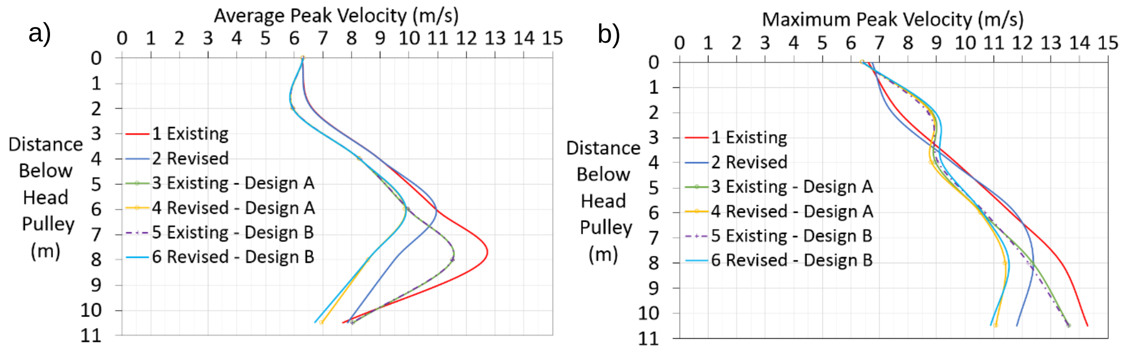

Figure 6. a) Average Peak and b) Maximum Velocities within the Transfer

Additionally, shear and impact intensity data of the outgoing conveyor belt are presented in Figure 7 b). Essentially a dot product of force at the contact (frictional in the tangential or elastic-plastic in the normal) and the relative velocity in each direction, the data is cumulative and averaged over the length of the simulation. It provides a qualitative indication of shear and impact damage of the surface analysed. Observations from the results of numerical modelling are summarised below:

ISSN 2176-3135

- Maximum velocities and impact occur during initial stages of loading over a period of a few seconds.
- Highest impact intensity is exhibited by Designs 1 and 3. These designs had the steepest loading angle of 70°.
- Lowest impact intensity is exhibited by Designs 2, 4, 5 and 6. These designs had a loading chute or bottom ledge and reduced loading angle.
- Highest shear intensity is exhibited by Design 5. This design incorporated a bottom ledge with effective loading angle of 55°. Results also indicated that this design had the highest stream velocity variation during loading. Lowest shear intensity is exhibited by Designs 2 and 4, both of which incorporate the 45° loading chute with smooth walls. These designs exhibited lowest velocity variation during loading.
- Type of deflector alone did not significantly influence belt impact or shear intensity.
- For the existing design, incorporating the bottom ledge resulted in a significant decrease in the impact intensity, however a similarly significant increase in shear intensity was observed.
- For the revised design, a decrease in both the impact and shear intensity was observed with the incorporation of the 45° loading chute or bottom ledge.
- Relative to the existing design (Design 1), reducing impact intensity may lead to an increase in shear intensity. This appears related to the uniformity of the material stream including velocity profile at loading.

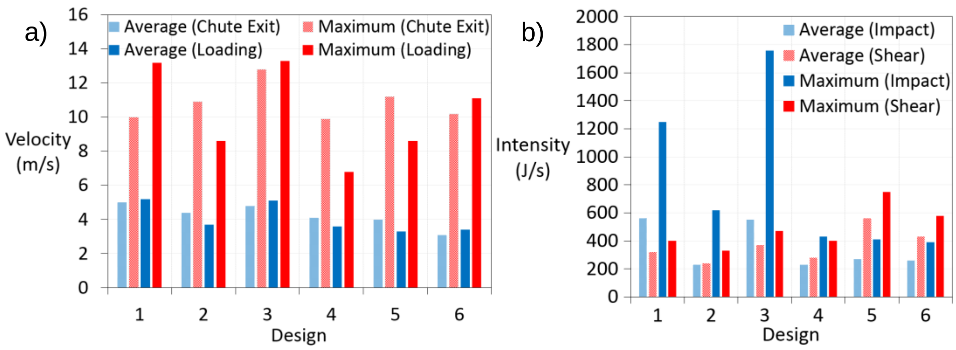

Figure 7. a) Velocity at Chute Exit and at Loading, b) Impact and Shear Intensity on Outgoing Belt
Note: *Average refers to the steady state period of each simulation.*

Whilst it is difficult to develop absolutes from the qualitative analysis with respect to the performance, it is predicted that the design modifications would yield improvements in both chute and belt wear life. This is shown in Table 2.

Table 2. Indicative Effect on Chute and Belt Wear Performance

Design	Chute Life	Belt Life
1. Existing Design	Base	Base
2. Revised Design	113 %	135 %
3. Existing - Design A	112 %	90 %
4. Revised - Design A	128 %	127 %
5. Existing - Design B	112 %	61 %
6. Revised - Design B	128 %	92 %

The indicative values presented in Table 2 are for illustrative purposes only and were calculated based on the following assumptions:

ISSN 2176-3135

- Chute life is related to the cumulative difference in the square of average peak velocities presented in Figure 6 a), in line with the underlying assumption based on the classical approach of Archard in which wear is proportional to V^2;
- Belt life is based on a linear relationship between average energy and wear, in which it is arbitrarily assumed that shear energy contributes 80% of the total wear exhibited, with the remainder caused by impact.

It is clear that each of the designs investigated will affect the performance of both the chute and the belt. In this instance, Design 4 exhibits the best balance of improved belt and chute life. Knowledge of the wear behaviour of the chute and belt allows the designer to develop a transfer arrangement which best meets the specified requirements. This could for example include prioritisation of chute over belt wear, in applications where the belt has a short cycle period.

7 CONCLUSIONS

Transfer chutes in the iron ore industry are typically designed to handle a broad range of materials, including highly cohesive materials with steep internal angles of friction, and are not necessarily defined by characteristics of the actual product handled. They are generally specified by rules of thumb developed through previous experience and highly influenced by geometric constraints such as steep angle of inclination in the order of 70° or other fixed plant components. The effect of this type of specification is a transfer in which the main ore stream flow may be compromised resulting in sub-optimal performance. The analyses presented within this paper demonstrates that this can result in high chute and belt wear, which can be significantly reduced. Furthermore, with an appreciation of the chute performance characteristics, and plant duty, an opportunity exists to influence design outcomes during the project planning and scoping phases to achieve performance criteria (an example may include specification of minimising shear energy on short high cycle belts to maximise belt life at the expense of chute wall liners). It is proposed that transfer design specifications must be developed exclusively for their intended application, are clearly defined in view of the operational requirements and are based on the material characteristics of the ore handled. The criteria should be introduced at the earliest stage of the project possible, and in addition to the existing functional requirements include specification regarding:

- Material flow properties, or minimum flow property test work requirements;
- Minimum and maximum bulk material stream velocities through the chute;
- Minimum chute angles specific to each location based on the characteristics of the ore handled;
- Maximum impact pressures or energy densities for the chute and belt;
- Maximum shear energy densities for the chute and belt;
- The bulk material stream at loading should have a uniform direction defined by the loading angle and minimised variation in velocity profile.
- Design hold points for acceptance of the arrangement, including minimum technical supporting evaluation (Scale modelling, DEM, Continuum method);

It is suggested that the owner of the intended application should introduce specification for transfer chute designs during the preliminary stage of plant layout design. This should be performed in parallel with other integral components such as conveyor head and tail pulleys, inclinations, take-up and other structural components.

ISSN 2176-3135

REFERENCES

1 Villaggio, P, Wear of an Elastic Block, Meccanica, 2001; 36, pp243-249.

2 Winer WO, Peterson MB.(Eds.), Archard JF, Wear Theory and Mechanisms, Wear Control Handbook, New York, NY, ASME, 1980; pp35-80.

3 Donohue, TJ, Ilic, D, Krull, T, Modelling of Iron Ore in Materials Handling Applications with a Focus on Wear, Proceedings, Iron Ore 2013, The Australasian Institute of Mining and Metallurgy, Melbourne, Australia, 2013; pp355-362.

4 Hutchings I. M., Wear by Particulates, Chemical Engineering Science, 1987; 42(4): pp869-878.

5 Roberts AW, Chute design considerations for feeding and transfer, Proceedings BELTCON 11, International Materials Handling Conference, Johannesburg, 2001.

6 Ilic, D, Transfer Chute Analysis Techniques Including Continuum Modelling and the Discrete Element Method (DEM), Proceedings, Bulk 2014, Materials Handling Engineers Association (MHEA), 2014, North Lincolnshire, England.