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Development of a novel methodology to characterise preferential grade by size deportment and its operational significance

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ABSTRACT

Over the last 30 years the average grade of ore bodies has significantly decreased while the proportion of waste removal has in many cases more than doubled. This in turn has led to a major increase in energy consumption and decrease in productivity across mining operations.

Metal preconcentration at coarse scale (10–100 mm) by screening has the potential to reverse decreasing mining productivity trends through early rejection of uneconomic grade material prior to energy intensive comminution. Metal preconcentration of feed grades using screening exploits the propensity of certain ores to preferentially deport metal into specific size fractions during breakage. This phenomenon is referred as preferential grade by size deportment. The exploitation of preferential grade by size response involves generation of multiple streams with different metal content post screening. Streams can be engineered for different grade characteristics suitable for different processing destination (eg: as waste, leach, and mill).

Preferential grade by size data obtained by an extensive belt cut sampling campaign after primary crushing has been used to develop a method to define samples that are amenable for metal preconcentration by size. This amenability changes depending on cut-off grade, magnitude of preferential grade by size response and the proportion of mass contained in individual screen products.

Outcomes of this work will support the short term preferential grade by size operational implementation.

1. Introduction

The mining industry is facing a range of economic, technological, social, and environmental challenges all impacting on productivity and sustainability (Bearman, 2012; Prior et al., 2012). A key components of the economic and technological challenges are an ongoing decrease in feed grades of base and precious metal mining operations together with a need to process more complex ores (Mudd, 2009, 2007; Topp et al., 2008). This is partly a function of depletion of near surface, high-grade ore bodies which are not being replenished by exploration discoveries, and increasing reliance on technologies that can support larger scale material movement and mineral processing efficiency. The net result is that, for most metals, while feed grades have declined over time the annual production of metal has dramatically increased as a function of increased demand (Access Economics, 2008).

While the ability to exploit the economics of production scale have enabled profitable exploitation of increasingly lower grade ores, there is evidence suggesting economic limits to this type of exponential growth. This is coupled with constraints on associated infrastructure such as power and water, together with an increasing requirement to minimise greenhouse emissions and adopt more socially responsible practices (Prior et al., 2012; ABARES, 2011; Franks et al., 2010).

Within Australia, multifactor productivity is used as a measure of the efficiency of capital, labour, materials, services and energy that are utilised to generate a unit of product. Since 2001, according to the aforementioned measure, there has been a consistent decline in productivity in the minerals industry. For mining in Australia it now takes 40% (2000–2001 indexed as 100%) more input to generate a single unit of mineral product (Topp et al., 2008). Similar but less pronounced trends are evident for other countries (Topp et al., 2008).

A significant proportion of the drop in multifactor productivity is attributed to decreasing head grades. Removing the influence of decreasing head grades upon multifactored productivity reflected

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an overall increase of 2.5% per annum over the previous period of decline (Topp et al., 2008).

The effect of decreasing head grades is to increase energy consumption (Fig. 1) and therefore unit metal cost of production (Norgate and Haque, 2010; Norgate and Jahanshani, 2010; Norgate et al., 2007). Lower head grades requires more comminution and grinding to effectively liberate the metal contained in the rock.

More than 50% of energy consumed in a typical base and precious metal mining operation can be accounted for in crushing and grinding circuits feeding into conventional flotation recovery. As feed grades continue to decrease much of this energy is directed towards inefficient liberation of dominant gangue components at a P80 of generally <150 μm and in some cases <50 μm.

To overcome this trend, the mining industry needs to focus on finding new technologies and operational strategies to increase extraction efficiency and decrease unit metal energy intensity.

For low feed grades early coarse uneconomic material rejection (∼10–100 mm) has been identified as an important operational advance which could increase unit metal productivity and efficiency (Carrasco et al., 2014;Bowman and Bearman, 2014; Carrasco, 2013; Bearman, 2012; Logan and Krishnan, 2012; Bamber, 2008; Bamber et al., 2008b, 2006a, 2006b).

Metal preconcentration of feed grades using screening is based on the propensity of some ores to preferentially deport metal in specific size fractions. Fig. 2 depicts a belt cut sample where Au grade varies across the size fractions analysed. Although this sample is defined as waste (feed grade 0.26 ppm < cut-off 0.3 ppm) there are size fractions that could be classified as ore. This phenomenon is referred as preferential grade by size deportment. This is a function of the competence difference between the host lithology and mineralisation structure coupled with breakage energy to condition the feed material (Carrasco, 2013).

Although preferential grade by size deportment is widely recognised and accepted, there is limited published data on the nature and magnitude of preferential deportment response and its potential economic significance.

An extensive Semi-Autogenous Grinding (SAG) mill feed belt cut sampling campaign carried out at Telfer Au–Cu mine in Western Australia indicated that preferential Au–Cu deportment in primary crusher products can generate new reject waste streams by screening at coarse sizes (10–100 mm) (Bowman and Bearman, 2014; Carrasco et al., 2014; Carrasco, 2013). In some cases >90% of the Au is contained in <40% of the mass below 50 mm. This has major implications for increasing unit metal productivity and profitability due to the opportunity of rejecting low grade coarse material prior to comminution. This requires the development of a new set of enabling tools and concepts to facilitate integration of dynamic metal preconcentration by size streams into process control and mine optimisation. The current work presents a novel methodology to analyse preferential grade by size responses within an operational context and provides a framework for economic evaluation.

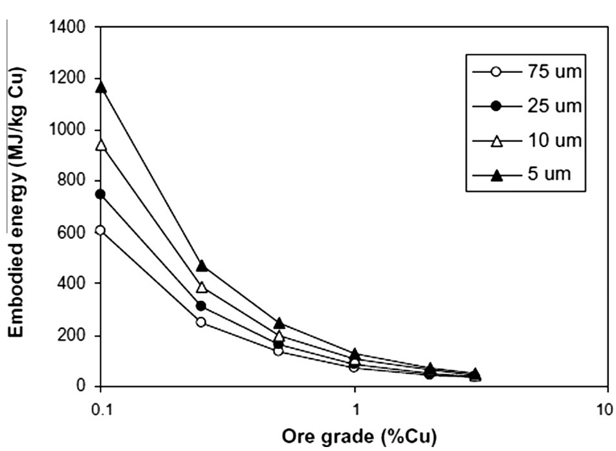

Fig. 1. Effect of ore grade and grind size on embodied energy copper production during concentrating and smelting (Norgate and Jahanshani, 2010).

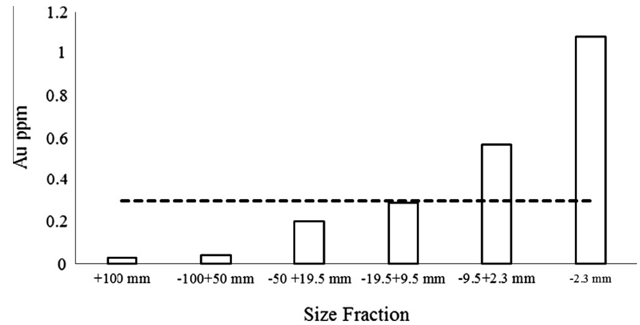

Fig. 2. Belt cut grade by size raw data in an operation with a waste-ore cut-off of 0.3 ppm. There are certain size fractions that can be classified as ore.

2. Preferential grade by size deportment ranking

As with any other metallurgical parameter, exploitation and optimisation of preferential grade by size deportment in a production environment require characterisation and quantification.

An example of relationship between particle size distribution and preferential grade by size response is illustrated in Fig. 3. 40% of the total mass stream is contained at −50 mm fraction at this defined particle size distribution (PSD) (Fig. 3a). Fig. 3b depicts the associated preferential grade by size deportment yield response. This is defined as a function that relates metal upgrade and the proportion of mass contained at specific size fractions. Metal upgrade is defined as the ratio between the grade of the size fraction retained and feed grade. For the mass pull shown in Fig. 3 (−50 mm) the accept mass fraction is 1.7 times the feed grade (1.7 metal upgrade).

The shape and the extent of this curve is used to estimate the propensity of metal to preferentially concentrate into finer particles during breakage.

Based on extensive analysis of preferential grade by size data (Carrasco, 2015) a mathematical model was employed to describe the preferential grade by size deportment curve depicted in Fig. 3b, (Eq. (1)).

$$Upg = \frac{K}{1 + W \times (K - 1)} \quad (1)$$

where Upg: Metal upgrade; W: Mass pull; and K which describes the extent of preferential grade by size deportment response. Higher K's display greater preferential grade by size response. $K = 1$ means no grade by size response, whereas $0 < K < 1$, metal is concentrated into the coarse fractions.

This model was selected given its mathematical simplicity (one parameter needs to be fitted, K) and the high degree of statistical confidence. Fig. 4 shows a normal probability plot, the low relative standard deviation (RSD) of K values using the aforementioned model (Eq. (1)) and Telfer SAG feed mill sampling campaign data as example. A similar approach is used within metallurgical testing to characterise impact hardness, $A \times b$ parameter where A and b values are obtained by fitting an exponential function that relates t10 and applied specific energy (Napier-Munn et al., 1996).