Éléonore Paste Backfill Composition

Sébastien Girard, Pierre-Luc Lajoie, and Paul Germain
Éléonore Gold Mine, Goldcorp Inc., Canada

ABSTRACT

Paste backfill and uncemented rockfill are used at the Éléonore gold mine to allow pillarless recovery of the narrow gold veins. A major constraint of the Éléonore operation is to store the sulphide tailings underground. Maximizing uncemented rockfill underground is an important economic factor. A good balance of paste backfill and uncemented rockfill is critical to allow the mill to discharge the sulphide material without compromising paste quality and the continuous mill operation.

This study is part of an ongoing internal research program that aims to find an economical mix design with desired fresh and hardened properties at high sulphide content. The effects of the different mix parameters were evaluated independently using the compressive strength at different curing times. All of the mixes were batched at the same consistency. This paper covers the mix design philosophies and challenges encountered during full-scale implementation tests along with innovative techniques used at the Éléonore paste backfill plant.

INTRODUCTION

The Éléonore Project is located in the James Bay region of Quebec, Canada on the Caniapiscau Reservoir. It is one of the most important gold-bearing mining operations in Canada. Production begun during the last quarter of 2014 and is scheduled to reach 7000 tons/day in 2017. The operation uses a ramp access from the surface and two shafts of 725m and 1180m length. The orebody is sub-vertical, and is exploited using the long-hole mining method. Mining is planned to take place in two phases, with the first one occurring between the depths of 80m and 650m, and the second phase occurring between 650m and 1400m depth. The Éléonore Project is highly mechanized, and the hauling drifts and the draw points have typical cross sections of 5.5 m x 5.5 m.

Éléonore uses paste backfill and uncemented rockfill in the mining sequence. Typically, 30% of the available filling volume is rockfilled while the rest is paste backfilled. This paper presents the operational constraints of using Éléonore Mine paste backfill that include the discharge of sulphide tailings, creation of economical paste backfill mixes, and capacity to keep up with increases in mine production.

ÉLÉONORE SULPHIDE CONSTRAINT

At the Éléonore Mine, the backfill strategy is a key element to ensure continuous production and lower the mining cost. To achieve these goals the engineering team needs to balance the utilization of paste backfill and uncemented rockfill. As described, two types of tailings are generated by the mill: sulphide and non-sulphide tailings. Non-sulphide tailings are dried and can be discharged in the surface tailings pad. The sulphide tailings are accumulated in a tank, thickened and incorporated into the paste backfill mix. No discharge and storage in the environment is allowed of sulphide tailings. This is part of the environmental certificate issued by regulators for the Éléonore Mine. Another section of this certificate limits the storage of the waste rock extracted from the mine. During the life of mine period waste rock can be stored at the surface but, by the end of the mine life, all the waste material will have to be returned underground. Two solutions are used to comply with this regulation. First, the use of uncemented rockfill reduces the amount of waste material that is skipped to surface. Second, waste is incorporated into the paste backfill. The waste rock is crushed at a maximum size of 10 mm and then incorporated in the paste mix. This process helps reduce the paste binder content and balance the particle size distribution of the paste backfill.

The sulphide storage capacity is 3580 cubic meters, which represents 6 to 7 days of surface waste inventory depending of the mill production rate. Managing the sulphide tailings requires good coordination effort between the mine and the mill team. The mine planning department needs to take consideration of this rule and adapt the mining sequence to avoid any unplanned stoppages of crushed and sized waste at the mill.

The composition of the paste backfill, the tailings produced by the mill and the backfill requirements are summarised in Table 1. The numbers reported in this table represent one year's production at the maximum expected rate at the Éléonore Mine.

Table 1. Production parameters at the Éléonore Gold Mine

Description	Quantity	Comments
Total Mine Production (tons/year)	2 558 049	Maximum expected production at Eleonore
Underground Volume to Fill (m^3)	828 145	
Uncemented Rockfill (tons/year)	447 198	30% of the backfil volume
Paste Backfill (tons/year)	1 159 403	70% of the backfil volume
Sulphide Tailings (tons/year)	204 644	8% of the tailings generated
Non Sulphide Tailings (tons/year)	2 353 405	
Paste Composition		
Binder (tons/year)	25 043	Average 3% binder in the paste
Crushed Waste (tons/year)	121 459	15%
Sulphide Tailings (tons/year)	204 644	all the sulphide must be included in the paste
Non Sulphide Tailings (tons/year)	483 624	

To achieve higher gold recovery, the mill has to produce 8% sulphide tailings. All the material remaining can be considered as non-sulphide tailings. According to the geometry of the orebody and the mining sequence, approximately 30% of stopes can be filled with uncemented rockfill. Along with uncemented rockfill, Éléonore is incorporating crushed waste (aggregate) in paste backfill to increase the paste strength. With these conditions in mind, and a maximum sulphide content in paste of 30%, the team performed laboratory scale tests in order to find the most economical proportions of binder, crushed waste and sulphide tailings. The following sections describe the work performed on paste backfill optimization to economically balance sulphide material on surface.

METHODOLOGY

The material used in this program is composed of filtered cake, sulphide slurry, processed water, slag, type GU cement, and aggregates. Tailing material from ore processing is usually disposed of at a nearby mine site. It is a non-valuable material that is used in the production of paste backfill. Tailings particles are in the size range of 10 to 30 µm. The water content of the material varies from 82 to 88 percent. The sulphide slurry is made of pyrrhotite that is finely ground using an Isa mill to increase gold recovery. A typical particle size distribution is shown in Figure 1. Two types of binder were used in this project: Ground Granulated Blast Furnace Slag (GGBFS) and Type 10 Portland cement.

The two binder types are blended at a proportion of 90% slag and 10% cement. One type of coarse aggregate was used in this study. The material is produced using waste rock as a raw material and the maximum particle size is 10mm.

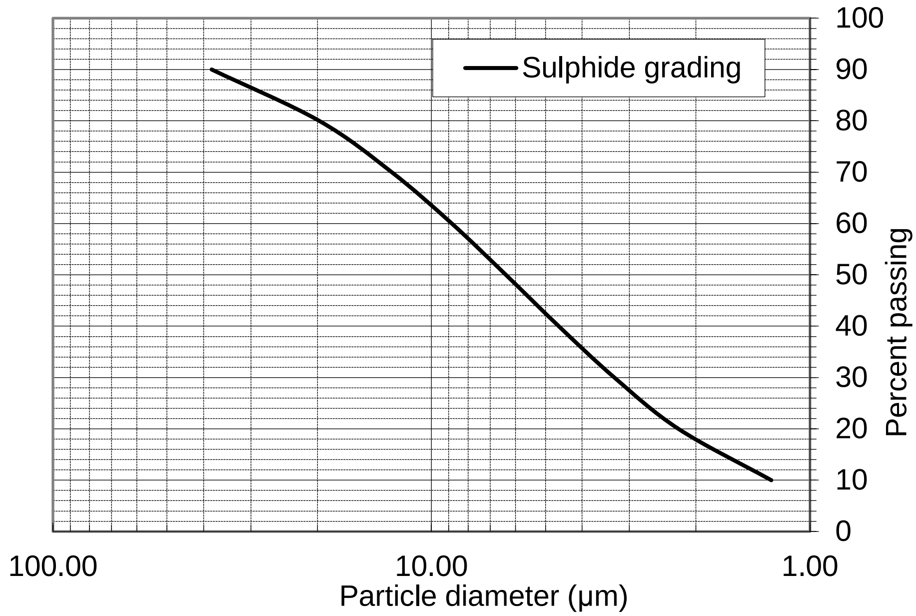

Figure 1. Particle size distribution of sulphide material

The effect of very fine particles in paste backfill is that it prevents good interaction between the cement and the filtered cake, preventing the development of a good bond. Bonding between cement and filter cake particles is essential to reach a good quality paste. As a good bond is necessary to ensure a satisfactory strength, the impact of very fine sulphide material in the binder must be taken seriously. Sulphide should not be present in excessive quantities because of its fineness and therefore its high surface area. Otherwise it leads to non-economical proportioning of binder in paste. High surface area increases the water demand to wet all the particles and directly increases the yield stress and plastic viscosity of the mix.

Figure 2 describes the particle gradation of the aggregate available at the mine site. It shows a continuous grading with a high packing density. One of the most important factors when using aggregate is good gradation. Good grading implies that the material contains all fractions of aggregates, such that the material contains minimum voids. A well-graded material containing minimum voids will require fewer fines to fill up the voids. Less quantity of fines means less quantity of water and less quantity of binder, which will further enhance economy.

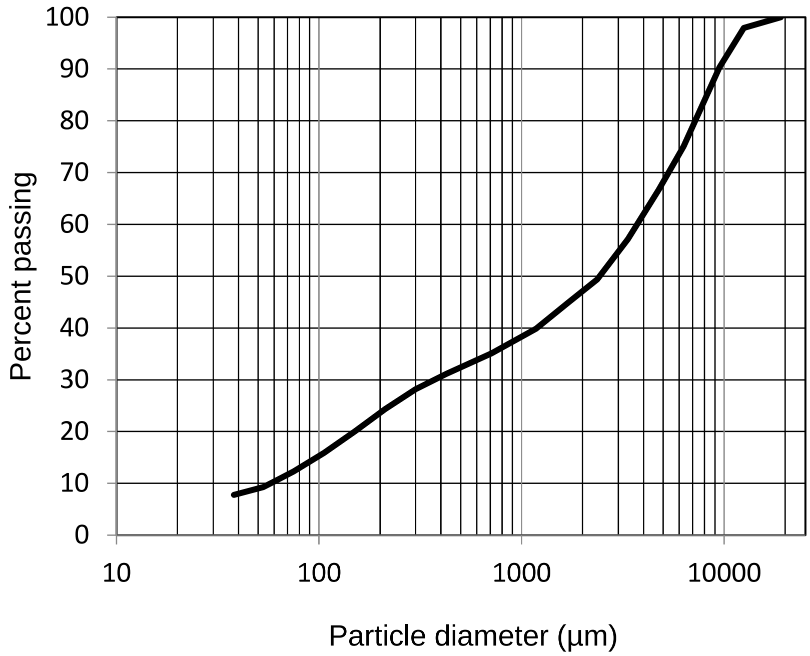

Figure 2. Particle size distribution of aggregate (ASTM, 2006)

Numerous mixes were designed using different combinations of these materials. All of the mixes were evaluated at the same workability by adjusting the mixture water content during the batching process. A set of 10 cylinder samples was prepared for each batch mixture and cured under laboratory conditions. The paste backfill unconfined strength was evaluated at 7, 14, 28 and 56 days of cure. The mixes were all designed at 4% binder of 90/10 scorie, a pre-blended material containing 90% slag and 10% Type 10 cement. Tables 2 and 3 present the various mixture specifications and physical characteristics.

Table 2. Mixture specifications with sulphide

Mix specifications						
Mix	**W/C**	**Water content (kg/m³)**	**Binder (%)**	**Sulphide (%)**	**Density (kg/m³)**	**Slump (mm)**
Reference	8,5	482,0	4,0	0	1,88	180
S10	9,7	537,0	4,0	10	1,86	200
S20	10,0	579,8	4,0	20	1,86	200
S25	9,9	578,6	4,0	25	1,87	190
S30	10,7	629,5	4,0	30	1,88	190
S35	11,1	654,5	4,0	35	1,87	200

Table 3. Mixture specifications with aggregates

Mix specifications						
Mix	**W/C**	**Water content (kg/m³)**	**Binder (%)**	**Aggregate (%)**	**Density (kg/m³)**	**Slump (mm)**
Reference	8,4	467,9	4,0	0	1,90	190
A10	7,8	429,6	4,0	10	1,93	200
A15	7,3	400,4	4,0	15	1,94	190
A20	6,7	370,5	4,0	20	2,00	200
A30	5,9	324,3	4,0	30	2,04	190
A40	5,2	285,5	4,0	40	2,11	190

RESULTS

Considerable work was needed to establish the optimal proportions of the paste backfill mixes. The investigated mixes were first evaluated under laboratory conditions. The idea was to find a paste backfill mix with low binder content containing different sulphide proportions that would allow ~~a~~ full discharge of the sulphide material in the paste backfill. The paste backfill unconfined strength was evaluated based on different requirements. The engineered strength for a plug (first 7 meters at the bottom of a stope to be filled) was fixed at 1200 kPa and at 250 kPa for a main pour. Once the mixture strength was exceeded, the strength evaluation exercise was performed for all of the mixes to find the lowest acceptable limit of binder content that would meet the minimum design requirements. The pumpability of the mix was then evaluated under full-scale conditions.

This phase of the investigation was done to evaluate the impact of a high sulphide dosage on the paste backfill strength. The different mixtures were compared based on their compressive strengths. Results show that increased sulphide contents lower the compressive strength of the paste backfill mixes at all cure ages. As shown on Figure 2, the mixes with 20% and 30% sulphide contents showed a 23% and 41% reduction in unconfined compressive strength with respect to the reference paste backfill mix, respectively. This was taken into account when designing the production mix. It can be observed in Table 2 that the increase of sulphide proportion directly increases the water demand of the mix at constant workability.

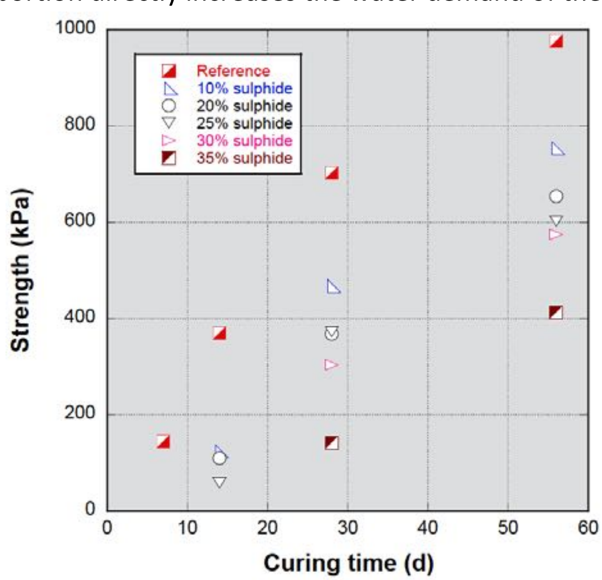

Figure 3. Mechanical properties of the mixes with sulphide (UCS)

The aggregate influences paste properties through a number of parameters. The water absorption, compressive strength, bond with cement particles, elastic modulus, and packing density are all important parameters to consider. Some of these parameters can be seen on Table 3. The results show that the use of aggregate leads to a reduction of water demand and thus, a decrease of the matrix porosity. Another parameter observed is the increase of the packing density of the mix. The density of the mix increases with the increase of the aggregate proportion. As shown on Table 3, the density of the mix increases from 1.90 to 2.11 kg/m^3 with the addition of 40% aggregate. These parameters improve directly the hardened paste properties. Higher packing density, lower water demand and better bond to cement particles increases the compressive strength. The fracture process of paste containing aggregate is also different. In conventional paste, stresses are distributed more evenly in the hardened paste material ~~phase~~. Cracks appear in high-deformed areas and propagate easily through the material. With the use of aggregate, stresses are concentrated in the lowest deformable component - the aggregate. Therefore, the stresses are concentrated in aggregate and transferred to the aggregate-paste interface. Cracks are forced to run around the surface of aggregate particles to propagate in the material, leading to higher overall strength.

From Figure 4, it can be seen that an increase in aggregate content increases the compressive strength of the mixes. Compared to the reference paste backfill mix, the unconfined strength increases by 81% with the addition of 40% aggregate. It is important to note that not all of the mixes that were tested can be produced at the paste plant. Only mixes with 10 and 15% aggregate contents can be produced at full scale due to equipment limitations. It was decided to keep the aggregate content as high as possible and to decrease the binder content accordingly. The optimization of the binder ratio content in order to reduce the binder consumption was then addressed. The depleting binder content effect on paste backfill strength had to be compensated for by increasing the use of aggregate in the paste. After numerous full-scale tests, results showed that the mix using 15% aggregate content is more suited for the Éléonore paste plant and yielded results that met strength design criteria. When paste backfill mixes were proportioned at 15% aggregate content, laboratory scale results showed that the paste strength increases by 24%.

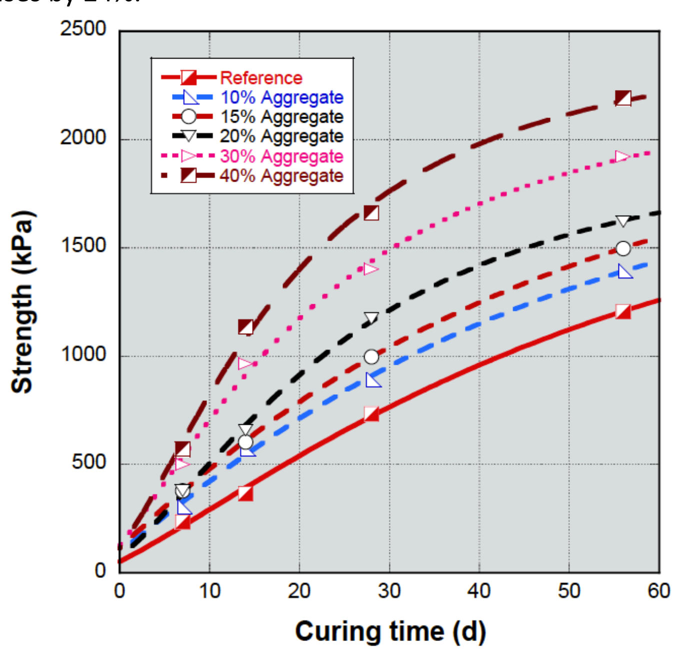

Figure 4. Mechanical properties of the mixes with aggregate (UCS)

The particle size distribution is a very important parameter for fresh and hardened paste backfill properties. The workability of fresh paste is greatly influenced by its particle size. Stiff paste is harder to pump, needing greater pumping pressures, and has a higher potential risk to block the paste fill line. The mix designs tested in laboratory conditions were also evaluated in full-scale conditions to validate their pumpability characteristics. To record the pressure exerted on the paste backfill in the line, a series of pressure gauges were placed at different locations along the length of the pumping line. Based on experience, the maximum allowed operating face pressure is 5000 kPa. It has been found that a higher sulphide content backfill mixture increases the pumping pressure under constant slump conditions. It is believed that increasing the fine particle content in the mix increases the plastic viscosity of the mix and thus increases the pumping pressure.

QUALITY CONTROL

Quality control is an essential requirement to maintain good quality paste backfill underground and to ensure that paste properties meet the design criteria. Paste samples are taken on a daily basis during production. The slump of the paste backfill ~~cone~~ is evaluated from the upper feed of the main pump, once the paste is thoroughly mixed. A series of cylinders are additionally filled and stored in a moist room at a constant temperature to cure for strength testing purposes. The unconfined compressive strength is evaluated at 14, 28 and 56 days of cure to ensure that the paste backfill strength character complies with the design criteria.

CONCLUSION

This research program brings several interesting answers to the optimization of the paste backfill mix. The main objectives were to find an economical mix design that allows the full disposal of sulphide material within the paste backfill along with the production of an economic and good quality paste. In addition to the fresh properties, the hardened properties were evaluated to fully characterize the mixtures with time. The conclusions of this research program are summarized as follow:

Hardened properties

- Higher sulphide content decreases paste strength;
- Mix with 20% sulphide content shows a 22% reduction in strength;
- It is possible to decrease binder content by 20% when incorporating 15% aggregate in paste to keep the same or higher strength characteristics

Fresh properties (pumpability)

- Pumping pressure increases with an increase of sulphide content

Although this research program gives interesting answers, more research is needed to better understand and optimize paste backfill behaviour at the Éléonore Mine.

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