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Development and Challenges on Mining Backfill Technology

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Abstract

This paper discusses the development and challenges of mining backfill technology for the past 20 years. The traditional backfill technology such as rock backfill, hydraulic backfill and paste backfill as well as some emerging mining backfill technologies as the “High water content backfill technology”, “Total tailing backfill technology” and “Mining paste-like backfill technology” were also detailed discussed for the challenges in engineering application, and it is illustrated that they indeed have some unique characteristics in high-early strength, excellent workability, and resisting dewatering. In the mining backfill, many factors attribute to the performance of the backfill body, and it is found that the properties of the binder and the grade of the tailings as aggregate play significant role in the mechanical properties of the backfill body.

Keywords: mining, backfill, performance, challenges

1. Introduction

In China, the mining industry produces different types of waste such as tailings, waste rock, and water treatment sludge (Aubertin et al., 2002). And a lot of various techniques have been used in mining industry to dispose them, such as rock backfill, hydraulic backfill and cement paste backfill. For example, rock backfill and hydraulic backfill usually used for waste rock and sand disposal and the cemented paste backfill usually acts as an optimal solution for recycling the waste tailings. However, stockpiled industry waste is still in an accumulated trend throughout the world. In this case, clean and efficient mine backfill technology attracts the attention from the scientists and policy makers throughout the world (Benzaazoua et al., 1999). In this paper, the development of the mining backfill will be reviewed and different backfill technologies will be discussed according to specific challenges in industrial application.

2. Traditional Backfill Technologies

Backfill refers to any waste material that is placed into voids mined underground for the purpose of either disposal or to perform some engineering functions (Liu et al., 1999). According to Tony Grice from Australian Mining Consultants, there are three major traditional backfill methods: Rock backfill, hydraulic backfill and paste backfill (Grice, 1998). Rock backfill is a technology which transports backfill materials such as stone, gravel, soil, industrial solid waste through manpower, gravity or mechanical equipment in order to form compressible backfill body. The raw material usually prepared by crushing, sieving and mixing by mechanical force according to the particle size distribution pattern. Hydraulic backfill is a technology which takes water as transports medium to carry the hydraulic backfill materials, such as mountain sand, river sand, crushing sand, tailings or water quenching slag. Paste backfill is transports cemented slurry that is prepared by mixing and stirring water with aggregate materials.

3. Challenges in Traditional Backfill Technology

Although each of these backfill methods has some unique characteristics, they share some disadvantages when Ordinary Portland cement is used as binder. And the disadvantages include: 1) A large amount of cement in the slurry is carried away by water during the dewatering process, which not only causes environmental problems, but also decreases the strength of backfill body. 2) Large spaces between the backfill body and the roof of the stope cannot be fully filled due to slurry volume loss during dewatering so that multiple backfilling procedures are often required to fill up this space. 3) Only the coarse fractions of the tailings can be used as aggregate in order to create high permeability in the backfill body. The utilization efficiency of tailing is less than 40%. The large quantity of unused fine tailings has to be disposed, which causes environmental problems on mine surfaces. 4) The purchase of sands to make up aggregates is costly if the amount of tailings available is not sufficient for backfill. 5) Due to the long solidified period of the backfill body (7 - 28 days), the delay of the next mining operation will happen and the production efficiency is low.

4. Emerging of Some Modified Backfill Technologies

The scenarios discussed above which are always around the focus of improving the concentration of slurry and aimed to solve the series of problems of dehydrating and bleeding, such as underground waste water pollution and low filling body strength which is caused by low concentration tailings cemented filling. However, an innovative material "high-water contained material" as gelled material was sent the high-water consolidation filling slurry to the underground. In the early 1990s, quite a few metal mines successfully applied a high-water rapid setting and solidifying tailings cemented filling process. However, due to the high expense of high-water and high cost of filling job, the cement filling process has been limited to be applied in a more extensive field.

4.1 High Water Content Material

The "High-water content" material binder is made of two equal parts termed A and B materials (Sun et al., 1993, 1998a). And material A and material B are from bauxite and quick lime by sintering, and the chemical compositions are Al_2O_3, SiO_2, Fe_2O_3, CaO etc, in which the content of Al_2O_3 and CaO is controlled such that the alumina acid salt can be produced (Zhang et al., 1995). In backfill application, slurry A containing the A binding material and slurry B containing the B binding material are sent to the mine stope through two separate pipelines. The two slurries are then mixed together at a place close to the mine stope for backfill. After 30 minutes, the backfill slurry solidifies in the stope without losing any water. These backfill material use so-called 'High-water content' materials to replace Portland cement as binder to form low pulp density slurry with 15 - 70% pulp density (Sun et al., 1992), which is mainly used for gob-along roadside packing and metal tailing backfill, as well as gob plugging, fire retardant, and emergency repair when the material is modified (Sun et al., 1994). This is due to the some excellent properties of high water content material such as strong water-solidifying capability, fine pumpability quick setting and with early-developed strength, and high residual strength after being cracked, etc. While the material A and material B must not be mixed before use because when these two substances are mixed with 90 percent of water to form slurry, they quickly become a high-strength solid-artificial stone (Qiu et al., 1992). If the material A and material B is kept separately, they can both remain liquid without solidification for one to three days (Yang et al., 1999a; Sun et al., 1999a). This characteristic gives an excellent chance to control the reaction status in mining backfill system.

However, there are also some problems associated with this method: 1) .The ratio between A and B has to be exactly 1:1. Changing of this ratio may prevent the slurry from solidifying; 2) .The A and B slurries have to be transported through two separate pipelines. This directly increases the capital cost of the mining process; 3) .Since the two slurries have to be mixed at a place close to the backfill stope in the mine, satisfactory mixing requires that the pulp density of the slurry must be less than 70%; 4). Due to the low solids content in the slurry, more binder material is needed if high strength is required (Sun et al., 1999b; Yang et al., 1999b).

4.2 Total Tailing Backfill Technology

With the development of backfill mining in 1990s', the paste-fill backfill turned to be a tendency for backfilling (Liu et al., 1999). Any mining industry takes this method as application in backfill; however, it is challenging to control the density of the paste. If the density of the paste is in poor consistency, it will be a disaster for the mining backfill system (Zheng et al., 2000a). Unpredictable accidents often happen, such as pipe plugging and bursting because of the tiny change of paste-fill system's parameters (Duan et al., 2000). How to control the paste-fill density and procedure turned to be the biggest challenge. In Garson Mine, INCO (Sudbury, Canada), the largest nickel corporation in the world, it was found that the non –continuous flow of the paste caused huge damage to the pipeline system which was 1160 meters below the ground level (Duan et al., 2000). It is illustrated that most damage of the paste-fill pipelines were caused by the "Jet stream" which is the dispersed paste formed in the vertical pipeline. This "Jet stream" would cause two major impacts on the pipeline system: vacuum steam etching and high velocity abrasion. In order to avoid this kind of accident, it is necessary to develop a new backfill material which would be continuous and full pipe flow (Yang et al., 2000a).

Tailings paste backfill technologies are extensively used in Canada and in several other countries (Benzaazoua et al., 2002, 2004). Tailing paste backfill is a mixture of water (fresh water and/or mine process water), tailings material (often a percentage of solids between 70% and 85%) and hydraulic binders. Ordinary Portland cement is usually used alone or blended with various binders such as sulphate-resistant Portland cement, blast furnace slag, fly ash, etc (Sun et al., 2000). Continuous backfill flow is the key in backfill development, thus, the "total tailings", instead of traditional graded tailings, are used to develop the paste. In this method, around 20-35% fine tailings are added into the paste which significantly improves the consistency and flowability when compared with the graded tailing backfill paste (Pullum et al., 2007). The graded tailings backfill paste is relatively low concentrated, turbulent, water based systems, while the total tailing backfill paste is thick when it binds with particles together as a continuous flocculated suspension (Pullum et al., 2007). But sometimes, due to non-prefect homogeneity of fine tailings, the total tailing backfill material still exists some "pseudo-homogenous" phenomena, which means that the particle suspension happens due to low activity of the tailings to react with water to form solid (Hu et al., 2001). Another reason is that cement as binder used in the paste will cause dewatering and shrinkage problem. That will significantly affect the durability of the solidified backfill body. This is because the high calcium content nature of cement inevitably results in calcium hydroxide when it reacts with the water in the backfill paste and the calcium hydroxide will react with the silicate tailings surrounding the cementitious material. Thus, the crack or shrinkage in the solidified backfill body will formed. Therefore, cement is not an ideal binder for the backfill material and it is necessary to find a new binder material that has better performance.

4.3 Paste-Like Mining Backfill Material and Technology

Paste-like fill material usually has higher pulp density (72%-76%) and better mechanical properties than conventional paste fill material (Sun et al., 1999a). In this technology, silica-alumina based cementitious binder, which is usually combines fly ash, slag, gypsum, is used to improve the durability of the backfill body and "self-flowing fine tailing" is added to form the "paste-like" slurry which is able to enhance the workability of the backfill slurry (Sun et al., 2003a). For the paste-like backfill technology, there are five major features:1) Use silica alumina based cementitious as binding material 3-5%; 2) Prepare the pulp density of the backfill slurry 65-85%; 3) Use solid wastes (including mining tailing, mineral processing wastes, coal combustion wastes) as main backfill material 95-97%; 4) Shorter curing time (can be controlled from 1-7 days without dewatering); 5) High early strength (shortening mining backfill cycle significantly).

The binder-silica alumina cementitious material is a new class of high performance binder material that is produced by a low temperature activation and simple mill mixing on different pozzolanic material and cement (Sun et al., 2004, 1998b). The silica alumina cementitious material utilizes industrial solid wastes as its main raw material (such as tailing, slag, fly ash, coal refuse, waste bricks and waste glass, etc., which can make up >95% of the mass composition) (Sun et al., 2007, 2003b). Silica alumina based cementitious material, has been currently used, not only meets all the standards from different counties for ordinary Portland cement, but possesses many special excellent performances.

4.3.1 Binding Properties of Mining Cementitious Material

Silica alumina based cementitious material, as binder in backfill slurry, has strong cementing characteristics due to its ability to "weld" together many different types of aggregates. By using this, people can substitute total tailing instead of graded tailing in order to make mining backfill slurry having superior performance to traditional backfill slurry using Portland cement as binder. Table 1 and Table 2 show the physical and mechanical property of hardenite of OPC and silica-alumina binder.

4.3.2 Effect of Fine Tailing on Mining Backfill Material

Beside the new cementitious material as binder, the amount of fine tailings which added into the backfill slurry is another keystone in the mining paste-like backfill system. A proper amount of fine tailing adding into the paste not only increases the workability of the paste, also enhanced the compressive strength of the solidified backfill body.

Table 3 shows the effects of fines tailing content and curing temperature on the compressive strength of backfill body. It indicates that 20-30% of fine tailing added as aggregate sharply increase the middle-age strength. For example, when the paste curing at 20°C, the fine tailing increased from 0%-25% resulted in incensement of compressive strength from 0.48 Mpa to 1.12 Mpa. However, when the fine tailing amount kept going uphill from 25% to 45%, the compressive strength went to a slightly decrease.

Table 1. The physical property of hardenite of mining paste-like binding material

Binding material	Paste consistency	Capacity stability	Fineness(0.08mm) sieve residue %	Time of setting/(h:min)	
				Initial set	Final set
42.5 OPC	24	Accept	3.85	2:35	4:35
Silica alumina binder	23	Accept	4.25	2:30	7:00

Table 2. The mechanical property of hardenite of mining paste-like binding material

Binding Material	Bending strength (Mpa)			Compression strength (Mpa)			The ratio of bending and compressive strength		
	3 Day	7Day	28Day	3Day	7Day	28Day	3 Day	7 Day	28 Day
42.5 OPC	4.33	5.21	7.32	16.7	27.3	45.5	0.26	0.19	0.16
52.5 OPC	4.52	6.0	6.83	18.4	40.2	53.5	0.25	0.15	0.13
Silica-alumina Binder	6.6	8.3	10.7	20.3	45.6	58.6	0.33	0.18	0.18

Table 3. Effects of fines tailing content and curing temperature on the compressive strength of backfill body

Fine Tailing (%)	Compressive strength/MPa											
	Cured at 12°C			Cured at 20°**C**			Cured at 25°**C**			Cured at 30°**C**		
	1d	7d	28d	1d	7d	28d	1d	7d	28d	1d	7d	28d
0	0.1	0.22	0.4	0.10	0.34	0.48	0.2	0.46	0.52	0.22	0.53	0.6
10	0.12	0.3	0.48	0.14	0.64	1.02	0.23	0.64	0.86	0.24	0.72	0.72
15	0.15	0.34	0.52	0.20	0.68	1.08	0.26	0.72	0.92	0.26	0.84	0.80
20	0.15	0.32	0.56	0.16	0.80	1.12	0.30	0.76	1.0	0.30	0.90	0.92
25	0.12	0.3	0.60	0.19	0.82	1.12	0.25	0.76	0.94	0.26	0.82	1.02
30	0.1	0.26	0.64	0.18	0.64	1.0	0.24	0.76	0.88	0.3	0.94	1.20
35	0.1	0.24	0.62	0.20	0.74	1.10	0.16	0.72	0.88	0.3	0.92	1.10
40	0.1	0.22	0.62	0.14	0.66	1.0	0.16	0.72	0.88	0.24	0.94	1.08
45	0.1	0.2	0.58	0.16	0.70	0.94	0.18	0.72	0.82	0.22	0.86	1.12

5. Discussion and Conclusions

Since 1990s', mining backfill and technology has been developed through a great amount of scientific research, as well as through manufacturing and application practices. It has been demonstrated that mining backfill material has greater performance than traditional backfill material using OPC cement as binder. The most significant reason for this is that mining binder is silica-alumina based rather than calcium based and this binder is developed .The fine tailings added in the Mining paste-like slurry not only increase the workability and strength of the solidified body, also brought a huge environmental benefit to the environment and economy. Generally speaking, there are five major characteristics for mining paste-like backfill material as the following: 1). Lower material cost since the use of mining wastes, mineral processing wastes, coal combustion wastes as aggregates, and the use of Mining as raw material; 2). Easy transportation like hydraulic backfill, pipe system is easily to design and realize; 3). The solidified time of backfill slurry can be controlled from 1-7 days without dewater, saving dewatering cost, decreasing the onsite cleaning cost; 4). The investment of backfill system is similar to hydraulic backfill, and less than a half of the paste backfill; 5). Backfill body with high early strength decreased the mining waiting time, and shortened mining backfill cycle significantly(Yao et al., 2012a, 2012b, 2012c)

However, if people want to use mining cementitious material alone to substitute OPC in construction, there are still some challenges on its way, although it has been successfully applied in backfill industry. Due to the strict limitation on the chemical and mineral compositions of Portland cement in the Europe standard EN197-1:2000, the large amount of industry waste in Mining cementitious material makes it hard to meet this standard. For instance, sodium oxide content is limited within 0.6% by mass, and Chloride is limited within 0.1%. However, the US standard ASTM C1157 brings an excellent opportunity for Mining development and application within the States, which is a specification giving performance requirement without restrictions on the composition of the cement or its constituents. But to the backfill industry, there is still a huge free space for Mining backfill science and technology, which will bring great advantages in many aspects such as: performance, environment and economy.

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