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The use of granulated blast furnace slag based binders with platinum tailings for underground support systems

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Over the past few years there has been a dramatic increase in the number of platinum mines. With this have come new challenges to remove higher volumes of ore without harm to personnel. This paper will examine two possible methods which can assist mines to achieve this by the introduction of cemented backfill and improved grout pack support.

Although historically a support system used predominantly by gold and base metal mines, some platinum mines are now considering the use of backfill as an integral part of their mine support system where ground conditions are poor or as a possible method to increase the percentage of ore extracted safely.

Standard grout packs have been used on the platinum mines for many years. Some platinum mines are now investigating grout packs which give high early strength so as to reduce waiting times before blasting onto these packs.

Minova RSA have for many years supplied binders based on Granulated Blast Furnace Slag for use in backfill. Over the past three years work has been done with various platinum tailings using these binders to create both backfill and high strength grout packs. Results using both cycloned and full plant tailings will be discussed and the potential use of these products to improve underground support.

Introduction

Every mine owner's goal would be to have an ore extraction rate of 100% without any harm to personnel while removing the orebody at the lowest possible cost. Unfortunately there are obstacles that make achieving this goal difficult, for example adverse rock conditions, geological disturbances and economic constraints. Better support systems could help in overcoming some of these obstacles and make achieving these goals easier. Two support systems used, namely backfill and grout packs and the grout design and components making up these grouts will be discussed.

Grout design

Grout packs have been used on platinum mines for a number of years, whereas backfill has been restricted to the South African gold and base metal mines. Binders are used in backfill where the stoping widths are high and the backfill must be free standing, or in areas of low closure where early stiffness of the backfill is required.

Binders used in backfill and grout packs

Currently all these binders are based on Ordinary Portland Cement (OPC) which is then blended with a cement extender being either Ground Granulated Blast Furnace Slag (GGBS) or Pulverized Fly Ash (PFA). Chemical admixtures are at times used in the grout pack plants to aid flow. In this paper, binders based on GGBS will be looked at in more detail.

GGBS, (slag), is a by-product of iron and steel production and has been used routinely in the manufacture of cements since the latter half of the nineteenth century. In a standard concrete design, those containing slag develop higher compressive strengths than concretes based on ordinary cements. This is also apparent in backfill, where similar 28-day strengths are achieved at lower more economical additions of slag-based binder compared to those based on OPC or OPC/PFA blends.

Table I shows the % by mass of the major chemical component oxides present in OPC, slag, and PFA respectively.

The higher content of calcium oxide in slag results in its being more reactive than PFA and a more effective cement extender when early strength development is required.

Table I
Comparison of the typical chemical composition of the main components of binders and extenders

	OPC %	GGBS %	PFA %
CaO	64.60	34.50	5.10
SiO_2	19.80	38.80	56.10
MgO	1.80	6.50	0.8
Al_2O_3	4.30	14.60	31.60
MnO	-	1.00	0.10
K_2O	0.40	1.10	0.60
S	-	1.00	-
SO_3	2.90	-	0.1
Fe	-	0.40	-
Fe_2O_3	2.40	-	3.40
Na_2O	0.10	0.30	0.40
Minor components	3.70	1.80	1.80

Tailings

A mine can use either full plant tailings, classified tailings (Figure 1), or a combination of both. When using full plant tailings, the mine will have the advantage of having an adequate supply of tailings and no size classification costs, but these tailings may have excessive fines content which will result in poor water drainage and inadequate backfill stiffness. With classified tailings, better water drainage occurs and hence volume loss. This volume loss can result in shrinkage and movement of the backfill away from the hanging wall.

This shrinkage problem can be overcome by adding gelling agents at the discharge nozzle, such as Fillgel, used in the Fillset system developed by Minova RSA, which will be discussed later.

The pH of the tailings is another important factor in determining the strength of the backfill. If cemented tailings are to be used and the pH is lower than 7.00, the tailings are acidic and the pH needs to be adjusted to above 7.0. This can be achieved by the addition of lime, otherwise insufficient strength development will occur. This is illustrated in tests 1 and 2 in Table II. In tests 2 and 3, the pH has been adjusted by addition of lime, and in test 3 water run-off has been eliminated by the addition of Fillgel, thereby eliminating volume loss and therefore contributing to minimal backfill shrinkage.

Water

The quality of both mixing and groundwater can have a negative effect on strength development. Water should be tested and any potential problems identified beforehand.

Admixtures

The use of chemical admixtures such as plasticizers are not uncommon in the platinum industry. This is common practice in grout pack plants where the grout mixtures are pumped from surface for many kilometres through 25 mm grout ranges at relative densities around 2.

Very few, if any, admixtures are used with backfill. Tests carried out by Minova RSA on plasticizers have allowed a reduction in binder content but it has been found that the cost saving on binder does not offset the cost of the plasticizer.

From the three tests detailed in Table III, for typical platinum tailings it can be seen that the use of plasticizer 1,

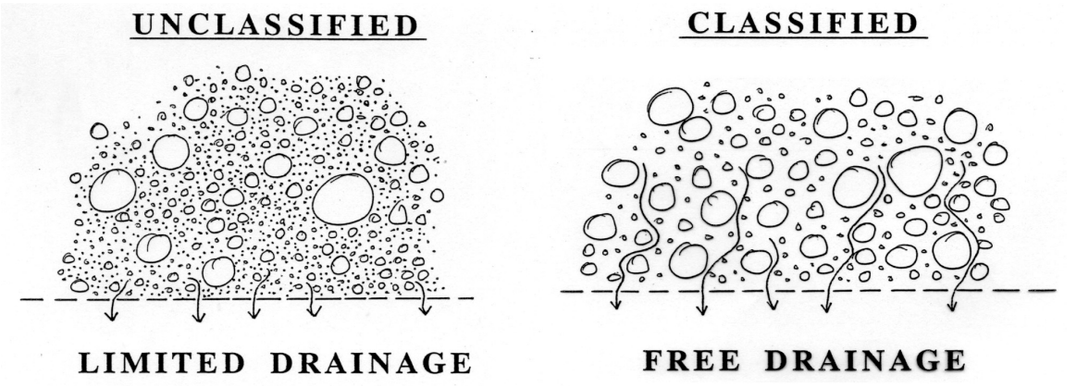

Figure 1. Classified vs unclassified tailings

Table II
Effect of pH on strength development with gold mine tailings

Test No.:	1	2	3
Starting RD	1.75	1.60	1.60
Starting pH	2.0	2.0	2.0
Wet tailings (kg)	10.00	6.10	6.10
Lime (kg)	0	0.10 (1.64%)	0.10 (1.64%)
Solids (kg)	6.807	3.533	3.533
Water (kg)	3.193	2.476	2.476
Final RD	1.73	1.60	1.59
Final pH	9.08	12.52	12.35
Fillset slurry			
Fillcem (kg)	0.500 (5%)	0.305 (5%)	0.305 (5%)
Water (kg)	0.250	0.153	0.153
Fillgel (kg)	0	0	0.61 (1%)
Water run-off (kg)	0.14 (4.38%)	0.179 (7.26 %)	0 (0%)
Volume lost (%)	2.45	4.70	0
Volume retained (%)	97.55	95.30	100
Compressive strength(MPa)			
7 days	Not set	Not set	0.16 MPa
14 days	No strength	0.13 MPa	0.22 MPa
28 days	No strength	0.28 MPa	0.34 MPa

Table III
Effect of plasticizers on backfill performance

Test No.:	**1**		**2**		**3**	
Starting RD	2.11		2.11		2.11	
Starting pH	7.84		7.84		8.58	
Wet tailings (kg)	8.00		10.00		10.00	
Solids (kg)	5.990		7.488		7.488	
Water (kg)	2.010		2.512		2.512	
Final RD	2.09		2.07		2.06	
Final pH	12.26		12.13		12.70	
Fillcem slurry		%		%		%
Fillcem (kg)	0.540	8.00	0.800	8.00	0.800	8.00
Water (kg)	0.320		0.400		0.400	
Plasticizer 1 (g)	0.00	0.00	8.0	*1.00	0.00	0.00
Plasticizer 2 (g)	0.00	0.00	0.00	0.00	4.00	*0.50
Water run-off	0.371	18.46	0.337	13.42	0.770	30.65
Volume loss (%)	9.79		7.11		16.25	
Volume retained (%)	90.21		92.89		83.75	
Compressive strength (MPa)						
7 days	0.38		0.38		0.50	
14 days	0.66		0.66		0.91	
28 days	1.31		0.94		1.66	

* % on cement content

test no. 2, results in a slightly increased retained volume which gives lower compressive strengths because of the more porous fill. Use of plasticizer 2, test no. 3, results in lower retained volume and a denser fill, giving higher compressive strengths.

Another system using admixtures is the Fillset backfill system where a sodium silicate-based additive Fillgel is used to reduce shrinkage of the fill by elimination of water run-off. Fillgel is added to the fill at additions of between 0.5% and 1.0 % at the discharge nozzle at the backfill paddock. The system is used with a slag-based binder, Fillcem, which is mixed into the fill on surface.

Figure 2 shows the results of laboratory work in which the reduction in water run-off was measured as the Fillset addition rate is increased using typical platinum full plant tailings. All tests were done using 0.50% Fillgel with increasing the addition of Fillcem to increase backfill strength.

A series of compressive tests were carried out on samples containing 5% Fillset. These results are shown in Figure 3, full plant tailings at a relative density of 1.80.

Figure 4 shows a backfill paddock 24 hours after placement of Fillset backfill with full plant platinum tailings. The absence of shrinkage away from the hanging wall can be seen. This is due to the elimination of water run-off. Although these tests were done in backfill paddocks, the same system can be used for grout packs where shrinkage is a major problem.

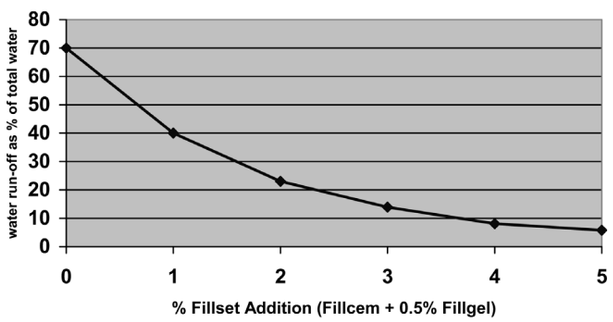

Figure 2. Water run-off vs fillset addition

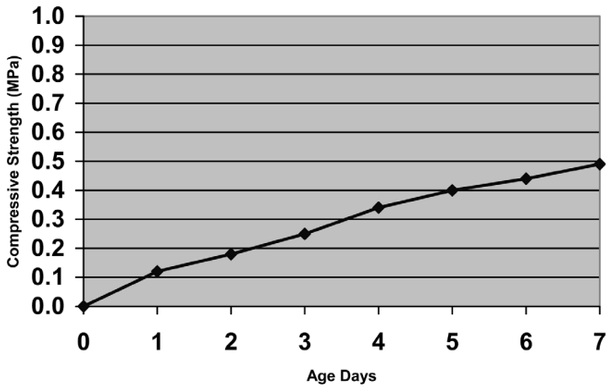

Figure 3. Compressive strengths using Fillset at 5% addition rate by mass

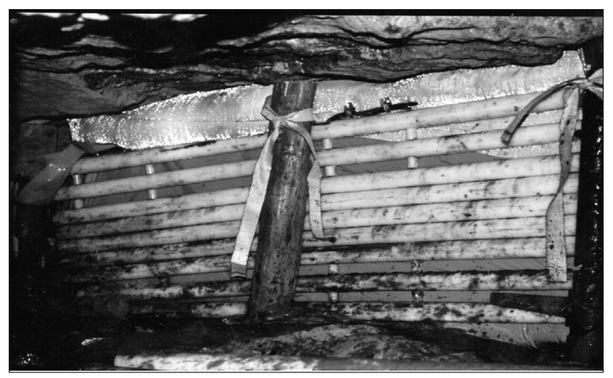

Figure 4. Backfill bag 24 hours after placing of backfill

Recent laboratory work using platinum tailings

Minova RSA continues to conduct laboratory work for the development of backfill systems based on the use of platinum tailings, for example using the Fillset backfilling system.

The results in Table IV show that Fillcem works well with both unclassified Merensky and UG2 tailings. In order to reduce shrinkage and retain volume, Fillgel can be added to the backfill as in tests 2 and 4, thereby reducing water run-off and hence backfilling shrinkage. This does, however, affect the strength as water is retained in the fill. Fillcem binder can be increased should higher strengths be required.

Cost of slag binders vs conventional binders

Backfill binders based on slag are more economical than those based on OPC/PFA or RHPC (Rapid Hardening Portland Cement)/PFA blends. Table V shows results of OPC/PFA, RHPC/PFA blends compared with a Blended Conbex (a slag-based binder). Blended Conbex is used for backfilling where volume loss is not a problem and the backfill paddocks can be topped up at a later stage. Results are for classified gold plant tailings at an initial RD of 1.75, compressive strengths measured at the time intervals shown.

Although these results are based on tests done with gold tailings, similar results will be achieved with platinum tailings. These costs are for cementitious binder only and exclude the additional cost of silos on the plant to accommodate the various binders components. From these test results it can be seen that binders based on slag are currently the most cost-effective product that can be used with backfill.

Pack grouts

Standard packs

Grout packs have for many years been used on the platinum mines as a standard part of their underground support system. At present, the binder used with tailings to fill the packs is a blend of OPC and PFA. Minova RSA has run comparative tests using Fillcem which is slag-based, with typical platinum run-of-plant tailings. Details of the results obtained are shown in Figure 5, for variable addition rates of Fillcem as shown and an OPC/PFA blend for comparison.

The results confirm that a similar addition rates, Fillcem

Table IV
Results of laboratory work using FILLSET with typical platinum full plant tailings

	Merensky		Merensky		UG2		UG2	
Test No:	1		2		3		4	
Starting RD	2.00		1.96		2.14		1.97	
Starting pH	6.96		6.95		7.98		7.99	
Total tailings (kg)	13.00		13.00		13.00		13.00	
Solids (kg)	9.542		9.542		10.40		10.40	
Water (kg)	3.458		3.458		2.600		2.600	
Final RD	1.96		1.93		2.09		1.97	
Final pH	11.78		11.79		11.88		11.89	
Fillset		%		%		%		%
Fillcem (kg)	0.910	7.0	0.910	7.0	0.910	7.0	0.910	7.0
Water (kg)	0.455	-	0.455	-	0.455	-	0.455	-
Fillgel (kg)	0.00	0.0	0.130	1.0	0.00	0.0	0.130	1.0
Water run-off (kg)	0.582	16.83	0.034	0.98	0.292	11.23	0.098	3.77
Volume loss %	8.95		0.51		4.81		1.49	
Volume retained %	91.05		99.49		95.19		98.51	
Compressive strength (MPa)								
7 days	0.56		0.50		0.28		0.28	
14 days	0.87		0.68		0.62		0.81	
28 days	1.56		0.72		0.91		1.09	
56 days	2.41		1.34		1.63		1.28	

Table V
Laboratory results on slag vs OPC-based backfill binders using gold tailings

Test no.	1	2	3	4	5	6
Conbex (slag) %	4.78	-	-	-	-	-
PFA %	-	13.50	-	9.45	9.45	10.50
Lime %	-	0.75	1.50	1.50	1.50	1.50
OPC %	-	0.75	4.05	4.05	-	-
RHPC %	-	-	-	-	4.05	3.00
Total % binder	4.78	15.00	5.55	15.00	15.00	15.00
Compressive strength (MPa)						
7 days	0.28	0.00	0.25	0.24	0.19	0.18
14 days	0.63	0.00	0.38	0.50	0.34	0.25
28 days	1.38	0.00	0.44	0.84	0.47	0.34
56 days	1.91	0.13	0.44	1.34	1.31	1.13
Binder cost/m³ of backfill placed	R55.06	R72.17	R85.32	R125.31	R149.61	R123.63

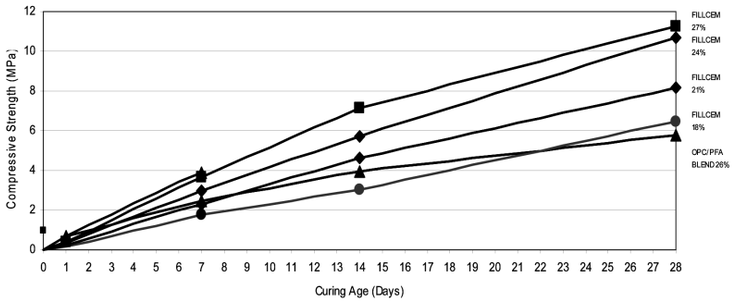

Figure 5. Strength development using Fillcem with platinum run-of-plant tailings

achieves much higher compressive strengths. These results do not take into account the contribution to pack support characteristics of the pack containment. Fillcem has therefore the potential to reduce the binder addition rate required and therefore the cost of the pack.

High early strength packs

High early strength packs may be required to allow the mine to blast earlier. The use of Fillcem as binder for the tailings in combination with strength development accelerators, perhaps added immediately before discharge of the tailings into the packs, may allow the desired more rapid rate of strength gain to be achieved. This concept is currently under development at Minova RSA together with the investigation of tailings binder systems which will offer much more rapid rate of early strength development. The results of these developments will be presented with this paper.

Conclusion

From the results discussed in this paper, it can be seen that binders based on blast furnace slag are cost-effective and can be used with full plant platinum tailings to produce backfill and pack-filling grouts with a wide range of strength performance. In addition, full plant tailings can be used thus eliminating the requirement for classification.

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